Agriculture and Food Development Authority

Teagasc Technology Updates 2007–2012

A collection of 100 Technology Updates highlighting the findings and key technologies from research projects within Teagasc

Animal and Grassland Research & Innovation Programme

Crops Environment & Land Use Programme

Rural Economy & Development Programme

Agriculture and Food Development Authority

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Compiled by Jane Kavanagh

For more Technology Updates see **www.teagasc.ie/publications**

Foreword

Professor Gerry Boyle
Director, Teagasc

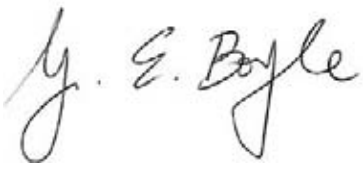
Teagasc is the leading organisation in the fields of agriculture and food research in Ireland. Our mission is to support science-based innovation in the agri-food sector and wider bio-economy that will underpin profitability, competitiveness and sustainability. This is achieved through the close coupling of research and knowledge transfer in four programme areas:

- Animal and Grassland Research and Innovation
- Crops, Environment and Land Use
- Food
- Rural Economy and Development

Our annual research portfolio comprises some 300 research projects, carried out by 500 scientific, technical and support staff in our research centres throughout Ireland. We are committed to transferring the latest discoveries from these research projects to end users to ensure that our research has an impact and delivers a benefit to our stakeholders and the Irish economy. We publish **Technology Updates** in respect of all completed research projects. These reports are designed to ensure a more effective transfer of new research information to the advisory and training services and to the end-user and to provide an easily accessible record of the main research findings.

This collection of Technology Updates from agriculture and rural development focussed research projects completed since 2007 represents a significant body of information on state of the art technologies and up to data analysis of the sector. It will be of great interest and use to advisers, teachers, farmers, policy makers, scientists and others interested in agricultural issues.

I wish to commend all the researchers involved in conducting these research projects, as well as the support staff in our research centres who make this work possible. I would also like to thank the many staff who assisted in the writing, review and collation of this collection of Technology Updates, as well as those staff who provided the design, layout, format and inspiration for an easy to read report on research project outcomes.



Professor Gerry Boyle
Director, Teagasc

Agriculture and Food Development Authority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Teagasc Research

Teagasc conducts research across four programme areas to lead the development of a competitive, sustainable agri-food sector, and to promote rural development:

- Animal and Grassland Research and Innovation
- Crops, Environment and Land Use
- Food
- Rural Economy and Development

Teagasc engages extensively with stakeholders to ensure the research addresses strategic priorities with a strong focus on impact, that it is high quality and efficiently conducted. Knowledge Transfer Departments are integrated into each of these programme areas and ensure the research results are interpreted in the context of existing systems, and information from other sources, and then effectively disseminated to advisers, teachers and farmers/industry.

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Animal and Grassland Research & Innovation Programme

Animal and Grassland Research & Innovation Programme Technology Updates

Animal and Bioscience Department

Year	Author	Title	RMIS No.	Page
2012	McParland, S	Innovative and practical breeding tools for improved dairy products from more robust dairy cattle	5791	9
2012	Waters, S	Examination of the molecular control of muscle growth and development in cattle	5759	12
2011	Berry, D	Genomic selection in dairy cattle	5883	16
2011	Butler, S	Effects of genetic merit for fertility traits on phenotypic performance of lactating Holstein cows	5672	19
2011	Butler, S	Use of synchronisation in dairy cows to maximise submission rates	5672	23
2011	Diskin, M	The effect of negative energy balance on gene expression in cattle	5756	27
2011	Earley, B	Examination of the effect of weaning stress on physiological, immune and behavioural responses of beef calves	5742	32
2011	Morris, D	The effect of stage of cycle and steroid environment on the uterine proteome of the cow and differences from plasma	5677	35
2010	Berry, D	Localisation of milk production and tuberculosis resistance genes in cattle	5665	38
2010	Butler, S	Relationships among maternal environment, fetal development, follicle numbers and fertility in cattle	5667	40
2010	Earley, B	European Ruminant Infrastructure Network (ERIN)	5905	43
2009	Berry, D	Genetics of predisposition to tuberculosis in Irish dairy cattle	5499	46
2009	Diskin, M	Repeatability and heritability of metabolic hormones in the cow	5546	49
2009	Waters, S	Dietary omega-3 polyunsaturated fatty acids alter the expression of fertility related genes in the cow	5679	53

Grassland Science Department

Year	Author	Title	RMIS No.	Page
2012	O'Kiely, P	Manipulating the ensilage of maize whole-crop, cob and stover	5769	56
2011	Horan, B	The influence of animal genetic potential across a variety of futuristic pasture-based systems of milk production	5501	60
2011	Keady, T	Effects of grass silage and maize silage feed value, and concentrate feed level on ewe and lamb performance	5657	63
2011	Kennedy, E	Strategies to increase the length of the grazing season for spring and autumn calving cows	5798	68
2011	McEvoy, M	Development of a grass economic index for ranking perennial ryegrass cultivars	5663	73
2011	O'Kiely, P	Reducing enteric methane production by finishing beef cattle	5628	76
2011	O'Kiely, P	*In vitro* rumen methane output of feeds consumed by housed cattle	5631	80
2010	Hennessy, D	Effect of grazing season length and stocking rate on nitrate leaching	5498	84

Grassland Science Department *(continued)*

Year	Author	Title	RMIS No.	Page
2010	Horan, B	Participative on-farm research for the Border Midland West (BMW) region	5396	88
2010	O'Donovan, M	Strategies to increase dairy cow performance at pasture	5664	90
2009	Horan, B	Evaluating alternate pasture based milk production systems for the Border Midland West region	5500	93
2007	Keady, T	Prime lamb production from ewes offered grazed grass, as the sole forage, throughout the year	4925	96

Livestock Systems Department

Year	Author	Title	RMIS No.	Page
2012	Humphreys, J	Productivity of clover-based grassland under organic management and nitrate losses to ground water	5782	101
2012	Humphreys, J	Quantification of the potential of white clover to lower GHG emissions from Irish grassland-based dairy production	5783	105
2011	Gleeson, D	Milk quality as influenced by cow and machine	5896	109
2011	Humphreys, J	Post-grazing height and productivity of white clover based systems of dairy production	5676	112
2011	O'Brien, B	Optimum milk quality focusing particularly on chemical residues	5895	115
2011	O'Brien, B	Efficient milking systems	5897	119
2010	Shalloo, L	Development of farming systems for the future	5668	123
2010	Shalloo, L	Development of a benchmarking system to increase the sustainability of Irish Dairy Farmers	5799	126
2009	Patton, J	The role of total mixed ration (TMR) feeding in pasture-based dairy systems	5673	129

Pig Development Department

Year	Author	Title	RMIS No.	Page
2012	Lawlor, P	Solid-liquid separation of pig manure and manure management	5565	132
2012	Lawlor, P	Effect of low phosphorus diets on pig health and welfare	5603	136
2010	Boyle, L	Impact of the social environment on the welfare and meat quality of pigs in entire male production systems	5825	139
2007	Lawlor, P	Feeding and management of high performing sows in pregnancy and lactation	5366	143

Crops, Environment & Land Use Programme Technology Updates

Crop Science Department

Year	Author	Title	RMIS No.	Page
2012	Hackett, R	Agronomy of oilseed rape in Ireland	5542	155
2012	Mullins, E	Identifying challenges to the coexistence of GM and non-GM potatoes	5772	158
2011	Finnan, J	Nitrogen value and greenhouse gas footprint of digestate from anaerobic digestors	5819	161
2011	Milbourne, D	Developing biotechnology-based resources for white clover	5762	165
2010	Forristal, D	Managing bumblebee imports to maintain pollinator diversity	5633	168
2010	Frohlich, A	Field trials of the oilseed crop camelina sativa and properties of the obtained oil	5771	172
2010	Hackett, R	Weed control with herbicides in forage maize in Ireland	5618	175
2010	Milbourne, D	Sequencing the potato genome and exploiting the results to produce better potato cultivars	5545	179
2010	Milbourne, D	The genetics of selfincompatibility in white clover	5761	182
2010	Mullins, E	Assessing the relevance and impact of GM crop management on the Irish landscape	5621	186
2010	Mullins, E	A novel method for the genetic transformation of plant cells	5630	189
2009	Finnan, J	The role of energy crops in effluent disposal, energy supply and soil remediation	5543	193
2009	Finnan, J	Feasibility of production and combustion of pellets from straw and energy crops	5613	197
2009	Milbourne, D	Basic genetic characterization of *Adonis* spp. germplasm for breeding and domestication	5544	201
2009	Mullins, E	Towards the development of an Irish coexistence strategy for GM and non-GM oilseed rape	5629	204
2008	Finnan, J	Cereal grains and crop residues as feedstocks for combustion	5377	207
2008	Griffin, D	Strategies for the control of Potato late blight caused by *Phytophthora infestans* (Mont.) de Bary	5373	211
2008	Hackett, R	An assessment of the potential of cultivar mixtures in Ireland	5375	214
2007	Forristal, D	Cereal production systems	5249	216
2007	Hackett, R	Agronomy of triticale under Irish conditions	5376	220

Environment and Land Use Department

Year	Author	Title	RMIS No.	Page
2012	Lanigan, G	Assessing the greenhouse gas budget of biomass and biofuel crops	5801	223
2012	Lanigan, G	Assessing the greenhouse gas budget of tillage mitigation options for arable systems	5802	227
2010	Finn, J	Benefits of agronomic plant diversity in forage mixtures	5583	231
2010	Finn, J	Monitoring the environmental impacts of the Rural Environmental Protection Scheme: a scoping study	5757	234
2010	Lalor, S	Efficient and reliable utilisation of nutrients in animal manures	5512	237
2010	Lalor, S	Survey of fertilizer use in Ireland from 2004- 2008 for grassland and arable crops	5943	240
2010	Lanigan, G	Greenhouse gases mitigation and agriculture	5800	244
2010	O hUallachain, D	Creating and enhancing farmland habitats: a review of options and evidence	5768	248
2010	Richards, K	Landspread Pathogen Survival and Transport in Irish Soils	5728 & 5191	252
2009	Finn, J	Novel experimental designs and models for measuring agronomic effects of multi-species grassland swards	5658	255
2009	Finn, J	Surveying and modelling of seminatural habitat cover on farmland	5729	258
2009	Lanigan, G	An evaluation of strategies to control ammonia emissions from the land – spreading of cattle slurry and cattle wintering facilities	5509	262

Forestry Development Department

Year	Author	Title	RMIS No.	Page
2012	Farrelly, N	The objectives and harvesting plans of Irelands forest owners	5504	265
2011	Douglas, G	Co-ordination of tree breeding in Europe	5519	268
2011	O'Connor, E	Birch and Alder – the development of a tree breeding programme and a seed supply for Irish forestry	5086	272
2010	Douglas, G	Characterising 'brown bud' – hybrid ash	5699	275
2010	Short, I	Broadleaf silviculture	5701	279
2009	Douglas, G	Characterisation and conservation of veteran hardwood trees	5461	283
2009	Farrelly, N	A Cluster based approach for identifying farm forest resources to maximize potential markets	5700	288

Horticulture Development Department

Year	Author	Title	RMIS No.	Page
2010	Grogan, H	Detecting dry bubble disease on mushroom farms	5695	291
2010	Grogan, H	Understanding Mushroom Virus X disease	5850	294

Rural Economy & Development Programme Technology Updates

Agricultural Economics and Farm Surveys Department

Year	Author	Title	RMIS No.	Page
2011	Donnellan, T	Market and non-market based strategies to reduce greehouse gas emissions on farms	5816	305
2011	Donnellan, T	Environmental economic model for agriculture	5724	308
2011	Donnellan, T	Meeting national targets for organic farming in Ireland	5934	310
2011	Hanrahan, K	Economic analysis of the impact of policy on Irish agriculture using the FAPRI-Ireland model	5935	312
2010	Hanrahan, K	Extension of the AGMEMOD model to Turkey	6039	315
2010	Hennessy, T	The impact of climate change on Irish farming	5623	318
2010	Thorne, F	Modelling the effect of policy reform at the farm-level: the FAPRI-Ireland farm-level model	5496	321
2010	O'Donoghue	Evaluation of direct aid in the beef and veal sector	6050	336
2009	Thorne, F	The relative competitivenes of Irish agriculture	5652	339
2008	Hanrahan, K	Agricultural member state modelling for the EU and Eastern European countries – AGMEMOD 2020	5529	353
2007	Finn, J	Estimating the environmental performance of agri-environment schemes	5260	356

Agri-Food Business and Spatial Analysis Department

Year	Author	Title	RMIS No.	Page
2010	Green, S	The Irish hedge map – version 1.0	5690	324
2010	Heanue, K	Audit of housing in rural areas	5577	327
2010	Howley, P	Traditional farm landscapes	5737	330
2010	Meredith, D	European development options for rural areas	5913	333
2009	Feally, R	A novel GIS-based approach for catchment selection in Irish Agricultural Catchments Programme	5866	342
2009	Green, S	Mapping the National Farm Survey	5838	345
2009	O'Donoghue, C	Accurate income measurement for the assessment of public policies	5562	347
2008	Meredith, D	Assessing rural potential in the Western Balkans	5223	353

Animal and Grassland Research & Innovation Programme

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Animal and Grassland Research & Innovation Programme

The objectives of the Animal and Grassland Research and Innovation Programme are to:

- Increase the profitability and competitiveness of Irish animal production systems
- Improve the environmental sustainability of Irish animal production systems in terms of nutrient use efficiency and greenhouse gas emissions
- Enhance the quality and safety of Irish meat and milk products
- Assist in the delivery of new technology to key stakeholders
- Become a leading international science authority on technologies for pasture-based animal production
- Become a leading international science authority of improved animals (cattle and sheep) through breeding, genetics and genomics
- Contribute to the achievement of the targets set out in *Food Harvest 2020*

The AGRI programme consists of three research departments; Grassland Science, Animal and Bioscience; Livestock Systems; two knowledge transfer departments; Dairy and Drystock; and the Pig Development Department spread across three main locations, Athenry, Grange and Moorepark with grass and clover breeding situated at the Crops Research Centre in Oak Park.

1. Grassland Science Research Department

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The objective of the Grassland Science research programme is to develop an efficient grass based ruminant production sector which focuses on high levels of grass utilisation.

To achieve this objective research is focused on:

- Grass breeding and evaluation
- Grazing management
- Rumen digestion and supplementation
- Grass growth and intake modelling
- Nutrient use efficiency

Grass Breeding and Evaluation

The focus of this research is to improve the performance of the sward and consequently animal performance through the application of plant breeding technologies. This will be achieved by selecting grass and clover cultivars with improved DM production, canopy structure, quality characteristics and persistence. The development of the Grass Breeding Index to ranked grass cultivars based on their total economic merit within a grass-based production system has been a significant development.

Grazing Management

This research focuses on improving the growth and utilisation of the grazed grass through improved grazing management practices. Factors included are pre-grazing herbage mass, post grazing residual, pasture allowance, sward digestibility and grass and clover physiology. Grazing management strategies have been developed to maximise grass growth and utilisation/ha through manipulating grazing rotation length, pre-grazing herbage mass and post-grazing residuals.

Rumen Digestion and Supplementation

Grazing nutrition models are being developed to better align the feeding value of grazed pasture with the nutrition requirement of the modern high genetic merit dairy, sheep and beef cattle.

Grass Growth and Intake Modelling

This area of research focuses on developing a grass growth and a grass intake animal performance for predicting grass DM intake and animal performance under Irish grazing conditions. This includes using the model to improve grazing management decisions on farms, to improve grass growth prediction, particularly in early spring and late autumn and to predict the trend in grass growth for up to two weeks ahead.

Nutrient Use Efficiency

There is a continued requirement to increase nutrient use efficiency and reduce green house gas emissions of pasture-based systems. This research focuses on improving the efficiency of the use of P and N on-farm and by defining the net global reduction in GHG per unit of milk production that can be achieved with grass based systems.

The key challenge for the future will be to further increase animal production/ha from pasture by improving pasture growth and quality, intake characteristics and feed conversion efficiency. This will require a multi-disciplinary research approach, bringing together grass physiologists, agronomists, plant breeders, animal nutritionists and environmental expertise. This should further increase Ireland's competitive advantage in animal production from pasture.

2. Livestock Systems Research Department

Animal production from pasture based systems is unique in that the animal interacts with the feed supply and small animal management changes such as calving or lambing date or stocking rate have significant impact on grass production and utilisation as well as animal product output and quality. The focus of the Livestock Systems Research Department is to achieve maximum performance of the whole farm system by optimising the interaction between pasture utilisation, supplementary feeding strategy and animal performance. These complex interactions can only be understood and exploited through farm system research.

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Profitable Sustainable Production Systems

Research encompasses the development of highly profitable sustainable production systems, farm bio-economic and biophysical modelling, development of precision farming systems encompassing increases in energy and labour efficiency plus the production of meat and milk of high safety/quality. Additionally it encompasses using demonstrations farms and decision support tools to assist the adoption of key technologies.

Research includes:

- Investigating the potential for alternative animal genotypes and alternative feed demand strategies (such as stocking rate and calving date combinations) to deliver increased animal production from available pasture supply.
- Bio-economic and bio-physical modelling is used to understand the impacts of technology changes on product output and quality, environmental sustainability and interaction with the product processing and pricing.
- Labour research is focused on optimisation of capital (parlour type and automation), people (work routines) and farm system (grass based seasonal calving) to reduce the labour input per unit of output.
- Developing technologies and management strategies to underpin the highest standards of quality and safety of Irish food products. This includes benchmarking both energy and water use efficiency on grassland farms.

Demonstration Farms

The Kilkenny Greenfield demonstration farm was developed to demonstrate the conversion of a greenfield farm into a fully functional profitable dairy farm using best technologies from research. Both the BETTER beef and sheep programmes are joint projects with the KT Drystock Department which aim to develop a road map for profitable beef and sheep production through improving technical efficiency within the farm gate. Numerous decision support tools have been developed that supports farmers in decision-making activities.

3. Animal and Bioscience Department

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The department was established in 2010 by integrating existing animal science staff at Athenry (sheep), Grange (beef) and Moorepark (dairy) into a single department, in combination with an internationally focussed recruitment drive to employ additional senior researchers, particularly in molecular and computational biology, nutrition physiology and immunology. Currently the department has 18 researchers, 6 postdoctoral fellows and 35 postgraduate students.

Research encompasses nutrition, fertility, breeding, health and welfare, focussing on producing profitable animals and the corresponding management strategies to deliver the productivity, sustainability and product quality targets set out in Ireland's *Food Harvest 2020* vision. Our close links with the national animal breeding programmes is used to exploit results from genetic and genomic research. Additional research is directed to the development of management blueprints or novel therapies.

We are developing a powerful combination of established animal science techniques and cutting-edge molecular and computational biology tools, to answer relevant industry research questions. Our focus is on ruminant livestock, working across scales from small groups of animals to the national herds and flocks. We have developed animal models that are divergent for a range of economically important traits (fertility, feed efficiency, growth and carcass traits, parasite resistance).

There has been significant investment in state of the art equipment, with construction of high-tech laboratories, offices and ancillary facilities just being completed at Grange. A new animal facility will be constructed at Grange over the coming months. This investment complements Teagasc's existing farm and laboratory resources for studies on nutrition, physiology and animal health.

4. Pig Development Department

The pig development department provides integrated research advice and education services to the pig industry. The challenges for the pig research programme are feed costs, sow productivity, welfare regulations and welfare problems, environmental legislation and food safety.

Pig research focuses on:

- **Feed costs**

Developing near infra-red spectrophotometery (NIRS) calibrations for predicting the DE/NE value of cereals. Evaluation of feeding systems- long trough vs ad-libitum liquid feeding.

- **Sow productivity**

Gilt Development/sow longevity (Teagasc/AFBI/ University of Leeds).

- **Pig Health and Welfare**

Facilities and management to enable producers to improve pig welfare and comply with welfare regulations including issues relating to pig health such as carcass condemnations and lameness.

- **Meat Quality and Food Safety**

Identification of methods to reduce Salmonella prevalence in herds.

- **Environmental Management**

Solutions are required to minimise the cost to producers of complying with environmental regulations post 2012 and especially post 2016.

Pig Knowledge Transfer

The pig knowledge transfer programme includes training in pig production and is conducted by Pig Development Officers. This team works closely with the pig researchers and Walsh Fellows. These KT team members are located at centres throughout the country, Ballyhaise, Tullamore, Oak Park, Moorepark and Athenry. There are 317 pig herds in Ireland classified as commercial (more than about 30 sows or 200 pig finishing places). The Pig KT staff provide a Business and Technology service with the primary emphasis being on the business management aspect and the use of technology to improve profitability.

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Objectives

- Improve the international competitiveness of Irish pig production
- Improve the standard of record-keeping on pig units to allow effective benchmarking of herd performance
- Improve technical competence of staff on pig units
- Deliver a structured FETAC accredited training programme for operatives on pig units
- Help secure the financial viability of the maximum number of pig units
- Assist pig producers to change sow housing systems to comply with pig welfare regulations from 2013
- Promote the efficient use of pig manure as a crop fertiliser while complying with the environmental regulations as set down in 2011 Nitrates Action Plan.

Activities

- Herd performance analysis using PigSys
- Farm visits by the Pig Development Officer to provide advice on herd performance, prepare financial plans and assists in the preparation of development plans such as changes to housing systems, compliance with environmental regulations, meeting food safety and pig meat quality assurance standards.
- National and regional events
- Training courses
- Monthly technical newsletter
- Monthly monitoring of feed and pig prices

5. Dairy KT Department

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The objectives of the Dairy KT Programme are aligned with those of the overall AGRI Programme area. Given our particular focus on knowledge transfer, our primary objective is 'to assist in the delivery of new technologies to key stakeholders'; these key stakeholders are both internal (advisers, colleagues in other Programme Areas) and external to Teagasc.

We see our key roles as the:

- Interpretation of the key messages coming from research for delivery to advisers, farmers and the wider industry and
- Provision of feedback to researchers to allow for the development of relevant research programmes.

The Dairy KT team is responsible for formulating and reviewing the annual Dairy Advisory Programme. Objectives are agreed on an annual basis following consultation with key internal and external stakeholders; formally through the Dairy Stakeholders Consultation Group and the Dairy Programme Development Group and informally through contacts with key internal and external stakeholders.

Activities

Our activities are delivered through the six KT Specialists in the dairy KT Department, 75 Business and Technology (B&T) Dairy Advisers located around the country in the KT Directorate, private consultants and other industry stakeholders with whom we have contact. Our activities include:

- In-service training
- Ongoing adviser support and mentoring
- Joint Programmes with industry partners including milk processors, Glanbia, Kerry Agribusiness, Dairygold, Connacht Gold, Arrabawn, Tipperary and Carbery, seed merchants, Germinal Seeds, and ICBF
- Delivery of industry training
- Leadership of the Heavy Soils and Liquid Milk BETTER Farm projects.
- Leadership of the KT element of the Teagasc New Milk/ Greenfield Dairy programme
- Organisation of national events – National Dairy Conferences, Liquid Milk Conferences.
- Organisation of national competitions – EBI, Heifer Rearing competition
- Dairy Efficiency Programme – collaboration with Department of Agriculture, Marine and Food (DAMF) in the delivery of this initiative including the training and assessment of Teagasc and private facilitators
- Membership of internal and external working groups
- Development of decision support tools

6. Drystock KT Department

The principle role of the drystock specialist team is to provide leadership in developing technologies and decision support tools in planning and delivering of the Teagasc national extension programme to cattle and sheep producers.

Our vision of the Teagasc drystock advisory service is to provide independent analysis and advice to farm business's and to promote the most appropriate technology transfer to ensure the sustainable development of drystock farming and the food industry that will ensure profitable production systems to meet the most demanding consumer requirements.

Increasing the production efficiency from grazed grass combined with improved breeding efficiency and accelerating the rate of genetic gain are the principle drivers of improving output and profitability levels on cattle and sheep farms. Adoption of best practice in relation to animal health and developing/modifying production systems can also contribute to increased profitability. Enhanced knowledge transfer incorporating BETTER Farm programmes in beef and sheep are key in achieving improvements in farm efficiency.

Teagasc Farmers Journal BETTER Beef Programme

The Teagasc Farmers Journal BETTER beef programme aims to develop a road map for profitable beef production through improving technical efficiency within the farm gate. The programme focuses on boosting profitability on farms by reducing production costs and increasing farm output and has set a target of €1,000 gross margin/ha to be achieved over a period of three years. Key areas of focus are to increase the genetic quality of the breeding herds and developing practical grassland management systems to deliver high liveweight gain at optimal stocking rates.

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BETTER Sheep Programme

Similar to the Teagasc Farmers Journal BETTER beef programme the objective is to establish focal points for the on-farm implementation, development and evaluation of technology that is relevant to the sheep sector. The programme, implemented on the collaborating farms, is used to support the wider adoption of grassland management, breeding and production methods. The central concept is that the programme is built upon active collaboration between the farmer and Teagasc research and advisory staff in the application and development of appropriate technology. A very close linkage with discussion groups and other advisory initiatives is an integral part of the process and this revolves around the farmer sharing experiences and performance results with visiting groups.

Innovative and practical breeding tools for improved dairy products from more robust dairy cattle

Project number:
5791
Date:
Sept 2012
Funding source:
FP7 KBBE
Project dates:
April 2008–Jan 2012

Key external stakeholders:

- The Irish Cattle Breeding Federation (ICBF)
- International breeding industry
- Milk processors and national dairy boards
- Dairy farmers
- International genetic evaluation bodies
- International geneticists, nutritionists and other scientists

Practical implications for stakeholders:

This study

- Developed an international database among 4 countries for the storage of, in particular, difficult to measure traits such as feed intake, to facilitate international genetic and genomic evaluations which would not be possible using individual research institute databases.
- Clearly demonstrated that the saturated fatty acid content in milk can be very accurately predicted using infrared spectroscopy, the routine method currently used to analyse the composition of milk samples from Irish (and international) milk recorded cows and bulk milk tank samples.
- Demonstrated the ability of infrared spectroscopy of milk to predict body energy status.
- Demonstrated that both predicted milk quality and energy status exhibit exploitable genetic variation.
- Developed sophisticated statistical models for the analysis of udder health to better reflect the underlying biology.
- Identified regions of the bovine genome associated with a range of performance traits included in milk production, the feed intake complex, fertility and milk quality.
- Improved genomic selection algorithms to facilitate the joint inclusion of both cow and sire DNA information and field data.

Collaborating Institutions:
Wageningen University
Scottish Agricultural College
University of Liege,
Swedish University of Agricultural Sciences
Irish Cattle Breeding Federation

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Technology

Main results:

- Milk fatty acid content can be accurately predicted from milk samples using mid-infrared spectroscopy thereby incurring no additional operation costs over and above the current cost of milk recording and bulk tank testing.
- Energy balance can also be predicted from milk mid-infrared spectroscopy and exhibits heritable genetic variation thereby providing the necessary resources for inclusion in a national breeding programme.
- Including cow genotypes in genomic selection increases the accuracy of prediction.

Opportunity/Benefit:

To improve the accuracy of selection for difficult to measure traits, in particular milk quality and robustness thereby increasing overall herd profitability through a more balanced breeding scheme.

1. Project background:

Dairy cattle have been selected primarily for increased production for over 20 years in many EU countries. This has been mostly as a result of importation of genetic material from North America followed by within – country selection policies specific to each country's local circumstances. In the majority of countries, selection has favoured milk or protein yield whilst in a few countries the focus has been more balanced for improved milk production without compromising health and fertility. Focussed selection for milk production has resulted in impressive improvement in milk production but has also resulted in dairy cows that lose lots of body energy reserves to meet milk production demands, and are in varying degrees of negative energy balance for some parts of the lactation. Consequently, dairy cows are considered less 'robust' than they once were. More recently, as a result of a general public interest in milk production practices and the environment, selection pressure in many (if not most) countries has shifted more towards non-production traits. These non-production traits are mostly those associated with cow health but increasingly, human health is of interest.

2. Questions addressed by the project:

The objective of ROBUSTMILK is to develop new useful and practical technologies to allow dairy farmers and the dairy industry to refocus their selection decisions to include additional traits such as milk quality and dairy cow robustness. It is of utmost importance that farmers can evaluate the consequences of selection for these novel and additional traits within their own milk production systems. Likewise, it is important that the inclusion of traits such as milk quality in selection indices does not compromise health, fertility or "robustness" of the cow. We seek the win-win situation where dairy cow milk is healthy for humans and is also healthy for the cow.

3. The experimental studies:

- The initial task involved the collation of data from research herds in Ireland, the UK, the Netherlands and Sweden as well as milk spectral data from Walloon region in Belgium.
- Fatty acid composition and lactoferrin composition of several thousand milk samples from Ireland, the UK, Belgium and the Netherlands were determined using gas chromatography and ELISA laboratory methods, respectively. The true fatty acid and lactoferrin composition were subsequently related to the mid infrared spectrum of those samples using multivariable approaches. Genetic variation was estimated using data from participating countries.
- The mid infrared spectrum of milk samples was also related to energy balance information in Irish and UK dairy cows using multivariable regression techniques and the genetic variation in the predicted equations estimated. The prediction equations were also applied to spectral data generated from the Walloon region of Belgium and phenotypic and genetic parameters were estimated.
- Alternative statistical approaches accounting for the genetics of residual variation in somatic cell count was estimated using Irish national data.
- A total of 1,500 Holstein-Friesian dairy cows from Ireland, the UK, Sweden and the Netherlands were genotyped for over 50,000 genetic markers and their genotypes related to a range of performance variables derived from the international database of research phenotypes.

4. Main results:

- Milk fatty acid content can be predicted from milk samples using mid-infrared spectroscopy thereby incurring no additional operational costs over and above the current cost of milk recording and bulk tank testing.

- Energy balance can also be predicted from milk mid-infrared spectroscopy and exhibits heritable genetic variation thereby providing the necessary resources for inclusion in an national breeding programme.
- Including cow genotypes in genomic selection increases the accuracy of prediction Somatic cell count is not the same genetic trait in seasonal and year-round calving herds, meaning that the same bulls were not the best in both systems. Models were developed that can estimate if the offspring from some sires are more variable than the offspring from other sires, and the developed algorithms were much faster than those previously used.
- Regions of the bovine genome putatively associated with several performance traits, particularly on difficult to measure traits, were identified.

5. Opportunity/Benefit:

- The mid-infrared spectrum is routinely generated for all individual and bulk milk samples, thus milk fatty acid content can be predicted for all milk samples at no additional cost to milk recording. And since milk fatty acid exhibits genetic variation, the milk fatty acid profile of Irish dairy cows can be altered through animal breeding.
- Energy balance status can also be predicted from the routinely available milk mid-infrared spectrum and because it also exhibits genetic variation, energy status can also be improved through animal breeding. However, to date, the predictions can also be used as a management tool. Additional research is required to quantify the benefit of including predicted energy status in multi-trait genetic evaluations for health and fertility.
- There is an increase in the quantity of genomic information (with phenotypes) available in Ireland and the tools for combining with sire genotype and phenotype data is now available.

6. Dissemination:

(http://www.robustmilk.eu)

International conferences: Several invited and contributed presentations at international conferences, including the European Association of Animal Production, INTERBULL, International Committee of Animal Recording, International Society of Animal genetics, Symposium on Applied Biological Science, International Conference on Quantitative Genetics, British Society of Animal Science, British Cattle Breeders Club, NCCC204: The Interface of Molecular and Quantitative Genetics in Plant and Animal Breeding, International Symposium on Animal Functional Genomics, International Cattle Breeders Round Table, American Dairy Science Association Annual meeting, European Society for Domestic Animal Reproduction, and the World Congress on Genetic Applied to Livestock Production.

National Conferences and seminars: Presented at the annual Agricultural Research Forum throughout the duration of the project and at national farmer conferences (e.g., Irish Grassland Association Conference, Teagasc National Dairy Farmers Conference) including G€N€ IR€LAND® user days.

Open Day: Presented at all Moorepark open days.

Industry consultation days: Presented and discussed at several industry meeting days with representatives from the different AI organisations, breed societies, Teagasc extension service, farmer groups and farmers. Also presented to several milk processors and the Irish dairy board.

Farmer discussion groups: Discussed at many farmer discussion groups and seminars.

Press: Results regularly presented in the Irish Farmers Journal, Farming independent, Today's Farm, TResearch, and Moorepark News as well as on radio and television.

Main publications:

Berry, D.P., Bastiaansen, J.W.M., Veerkamp, R.F., Wijga, S., Wall, E., Berglund, B. and Calus, M.P.L. 2012. Genome-wide associations for fertility traits in Holstein-Friesian dairy cows using data from experimental research herds in four European countries. Animal, doi:10.1017/S1751731112000067

Mc Parland, S., Banos, G., Wall, E., Coffey, M.P., Soyeurt, H., Veerkamp, R.F. and Berry, D.P. 2011. The use of mid-infrared spectrometry to predict body energy status of Holstein cows. J. Dairy Sci., 94:3651:3661. Soyeurt H., Dehareng, F., Gengler, N., McParland, S., Wall, E., Berry, D.P., Coffey, M. and Dardenne, P. 2011. Mid-infrared prediction of bovine milk fatty acids across multiple breeds, production systems and countries. J. Dairy Sci., 93:1657–1667.

Animal and Grassland Research & Innovation Programme

Project number:
5759

Date:
August, 2012

Funding source:
Teagasc

Project dates:
Sept 2008–Aug 2012

Examination of the molecular control of muscle growth and development in cattle

Key external stakeholders:

Livestock farmers, Universities, Meat Processors, Animal Feed Industry, AI industry, Department of Agriculture, Food and the Marine, Irish Cattle Breeding Federation.

Practical implications for stakeholders:

- A panel of genes has been identified which may serve as potential molecular markers for muscle growth and development in cattle.
- Farmers exploit the compensatory growth phenomenon in order to reduce the cost of feeding cattle over the winter. We have shown that muscle tissue has the ability to grow rapidly during feed realimentation, following a period of restricted feed intake.
- Animals subjected to nutritional restriction exhibit higher feed efficiency when subsequently offered *ad libitum* access to feed.
- While compensatory growth had little residual effect on meat quality characteristics, there was a trend for meat flavour and tenderness to be lower in animals that experienced compensatory growth compared to animals on a continual plane of nutrition.
- Despite its potential importance, compensatory growth ability is not a trait that will be measured routinely and thus in the absence of easily measured, accurate molecular markers, will not be selected for.

Collaborating Institutions:
National University of Ireland Maynooth
University College Dublin
University of Bristol

Teagasc project team:
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Technology

Main results:

- We found significant effects of breed (Aberdeen Angus vs Belgian Blue) and sire genetic merit for carcass weight (EPD_{cwt}) on the expression of genes in the somatotrophic axis (a major regulator of skeletal muscle growth and development in cattle). Furthermore, enzymes involved in glycolysis and the citric acid cycle were increased in Aberdeen Angus compared to Belgian Blue sired-animals, and in animals of high-compared to low-genetic merit for growth rate potential.
- Muscle tissue has the potential to recover completely following a period of compensatory growth. Compensatory growth had little residual effects on meat quality characteristics.
- Many genes, particularly those of the TGF-β pathway, were differentially regulated in muscle tissue during the compensatory growth period.

Opportunity/Benefit:

- Key genes have been identified which may serve as molecular markers for muscle growth rate. Following appropriate validation, these markers could be incorporated into future cattle breeding programs to improve the accuracy of selection for muscle growth.
- This information will also aid in the understanding of genetic influences controlling muscle growth and fat accumulation, and could contribute to breeding programmes to increase lean tissue gain of beef cattle.
- Muscle tissue has the ability to fully compensate following a period of restricted growth demonstrating that feed restriction followed by a period of compensatory growth can be implemented on farm without knock on effects for carcass meat yield.
- A further advantage is that animals which underwent nutritional restriction exhibited greater feed efficiency when offered *ad libitum* access to feed.

1. Project background:

Bovine skeletal muscle is a tissue of significant economic importance worldwide. In Europe and the USA approximately 17 and 37 kg of beef, respectively, is consumed per capita annually with worldwide beef production projected to increase at a rate of 0.9 to 1.4% annually over the next decade. The Irish Cattle Breeding Federation undertakes genetic evaluations for a range of performance traits across all of the main cattle breeds. Breeding value for carcass weight, an important trait reflecting lifetime growth, is estimated using a multi-trait animal model and is expressed as the EPD for carcass weight (EPD_{cwt}). Both sire breed type and EPD_{cwt} influence carcass characteristics including yield and quality of saleable meat from cattle. Previously, data from Teagasc Grange reported that muscle area were greater for Belgian Blue × Holstein Friesian compared to Aberdeen Angus × Holstein Friesian sired steers and also for Aberdeen Angus animals sired by bulls with high compared to low EPD_{cwt}. In beef cattle production, feed accounts for up to 80% of total variable costs. Thus, strategies to reduce feed costs without compromising overall animal performance are of particular interest. Compensatory growth is the ability of an animal to undergo accelerated growth after a period of restricted feeding. The exploitation of this biological phenomenon facilitates redistribution of feed supply from a time when feed is expensive (e.g. winter) to when it is cheap and plentiful (e.g. pasture in spring/summer) while maintaining overall production targets. Animals can undergo compensatory growth when offered unrestricted access to high quality feed, following a period of undernutrition. Due to its potential benefits to the economic efficiency of cattle production, the trait has been the subject of numerous studies worldwide. Many of these studies have investigated the effect of feed restriction, followed by compensatory growth, on body weight, carcass composition, meat quality, blood metabolites and hormones and metabolic organ size. Metabolic and blood hormone profiles have offered revealing insights into the physiological changes taking place in the animals body during feed restriction and compensatory growth. However, further research in now required to simultaneously elucidate all aspects of this growth phenomenon, including performance traits, feed intake, blood metabolites and hormones, and carcass characteristics together with possible interactions with maturity genotype.

2. Questions addressed by the project:

- Does sire breed (Aberdeen Angus vs. Belgian Blue) and sire EPD_{cwt} (High vs Low for carcass growth potential) affect the expression of genes and proteins in muscle tissue?
- How do crossbred steers from Aberdeen Angus and Belgian Blue sires respond to differential feeding treatments with a view to examining the potential of these two genotypes to exhibit compensatory growth following feed realimentation?
- Does compensatory growth have an effect on meat quality and sensory analysis?

- What are the key genes and pathways controlling accelerated muscle growth during feed restriction and compensatory growth?

3. The experimental studies:

The focus of this project was to investigate how skeletal muscle growth, a trait of major economic importance to beef cattle production, is controlled at a molecular level with a view to better understanding the key mechanisms involved. The approach taken was to combine key physiological and molecular analyses regulating the growth and development of muscle in an attempt to elucidate key genes, proteins and pathways that influence muscle growth in animals differing in genetic merit for growth potential as well in animals undergoing compensatory growth.

Study 1:

Animals of either high or low EPD_{cwt} were allocated to one of four groups, in a 2 (sire breed) x 2 (sire EPD_{cwt}) factorial design with 9 animals per group. Blood plasma was collected throughout the animals' lifetime for the analysis of IGF–1 and insulin concentrations. Muscle tissue was collected at slaughter and RT-qPCR analysis was carried out to determine the effect of sire breed and sire EPD_{cwt} on the mRNA expression of genes of the somatotropic axis. Using the same tissue, the effect of sire breed and sire EPD_{cwt} on the expression of proteins in muscle of Aberdeen Angus and Belgian Blue sired cattle was examined using 2D gel difference electrophoresis and mass spectrometry.

Study 2:

Crossbred Aberdeen Angus × Holstein Friesian (n = 22) or Belgian Blue (n = 24) × Holstein Friesian steers were assigned to one of two treatment groups in a 2 (genotypes) x 2 (feeding treatments) factorial design. The Aberdeen Angus and Belgian Blue genotypes were selected because of their well documented differences in carcass conformation, muscle composition and maturation rates. Over a 99 day differential feeding period, half of the animals in each group were offered a high energy control diet whereas the other half group was offered an energy restricted diet. At the end of the differential feeding period, both groups were offered a TMR with a grass silage:concentrate ratio of 80:20, with the concentrate proportion increasing gradually over a 3 week period to the *ad libitum* high energy ration. This period, which lasted 200 d, was termed the realimentation period, and all animals were slaughtered on d 299 of the study. Muscle biopsies were collected at 2 different time points, *viz* end of the differential feeding period (d 99) and during the realimentation period (d 131), for transcriptomic analysis. This study measured the response to a period restriction and compensatory growth in a large number of performance and physiological traits across the two genotypes. We also aimed to clarify the effect of a compensatory growth feeding regime on meat tenderness and intramuscular fat content, as the literature has been equivocal on these issues. Therefore the effect of compensatory growth on meat quality and sensory analysis in meat (including temperature and pH of carcasses post slaughter, chemical composition, muscle drip loss and cooking loss, muscle and fat colour, shear force, sensory and flavour characteristics) from Aberdeen Angus and Belgian Blue sired steers was analysed. Furthermore, the transcriptional regulation of key genes and pathways controlling muscle growth during feed restriction and compensatory growth in Aberdeen Angus sired steers was examined using a novel molecular approach called RNAseq to measure global gene expression.

4. Main results:

Gene expression of *IGF-1R* and *IGFBP3* was up-regulated in Aberdeen Angus compared to Belgian Blue sired steers whereas *IGF-1* was up-regulated in high compared to low EPD_{cwt} animals. Greater gene expression of *IGF-1* and reduced transcript levels of *IGFBP3* in muscle may play a role in increased muscle growth potential in steers during the finishing period.

The analysis of muscle showed higher protein and moisture, and lower lipid concentrations for Belgian Blue compared to Aberdeen Angus sired steers. Enzymes involved in glycolysis (glycogen phosphorylase, phosphoglycerate mutase) and the citric acid cycle (aconitase–2, oxoglutarate dehydrogenase) were increased in Aberdeen Angus sired steers. Protein abundance of glucose–6–phosphate isomerase, enolase–3 and pyruvate kinase was higher in Aberdeen Angus sired steers of high compared to low EPD_{cwt}.

In the compensatory growth study, at the end of the differential feeding period (99 d), there was an average difference in weight of 82 kg between animals in the restricted and the *ad libitum* groups with average daily gains of 1.55 vs 0.63 kg for the *ad libitum* and restricted animals, respectively. During feed restriction, animals that were restricted consumed less DM, had a poorer feed conversion ratio and lower concentrations of plasma hormone and metabolites compared to steers on the *ad libitum* diet.

Restricted steers had lower muscle and fat development, as assessed ultrasonically, compared to steers on the *ad libitum* diet. During feed realimentation, there was no difference in DM intakes between feeding treatments; however, steers which had been restricted had greater live weight gain compared to steers on the *ad libitum* diet. Overall, unrestricted steers consumed more feed and had a better feed conversion ratio compared to restricted steers. Carcass weight was affected by feeding treatment with *ad libitum* animals having heavier carcasses. At slaughter, there was no difference in plasma metabolite or hormone concentrations, linear body measurements, ultrasonically scanned fat depth, carcass conformation or dressing percentage between the two groups. Furthermore, ultrasonically scanned muscle tissue was shown to recover completely.

Compensatory growth had no effect on carcass pH and temperature decline, chemical composition, drip loss, fat colour, or juiciness. However, Warner-Bratzler shear force increased and tenderness and overall flavour decreased as a result of this compensatory growth feeding strategy. For Belgian Blue sired steers, cooking loss percentage was greater in animals that experienced compensatory growth; however, this was not observed for Aberdeen Angus sired animals. Meat from Aberdeen Angus sired steers had better sensory flavour characteristics compared to Belgian Blue sired steers. Live weight gain prior to slaughter (d 195 to d 299) was not correlated with the meat quality characteristics measured. Overall, genotype has larger effects of meat quality than feeding treatment. These data suggest that the compensatory growth-based feeding regime applied here had little lasting effect on meat quality characteristics.

During the realimentation period, 65 differentially expressed genes were identified. TGF-βR1, a key receptor in the TGF-β signaling pathway, which plays an important role in muscle tissue growth, was down-regulated in previously restricted animals during compensatory growth. It is hypothesised that the signaling effects of the TGF-β pathway are reduced thereby promoting accelerated cell growth and proliferation in muscle tissue of animals experiencing compensatory growth.

5. Opportunity/Benefit:

- Key genes have been identified which may serve as molecular markers for muscle growth rate. Following appropriate validation, these markers could be incorporated into future cattle breeding programs to improve the accuracy of selection for muscle growth.
- This information will also aid in the understanding of genetic influences controlling muscle growth and fat accumulation, and could contribute to breeding programmes to increase lean tissue gain of beef cattle.
- Muscle tissue has the ability to fully compensate following a period of restricted growth demonstrating that feed restriction followed by a period of compensatory growth can be implemented on farm without knock on effects for carcass meat yield.
- A further advantage is that animals which underwent nutritional restriction exhibited greater feed efficiency when offered *ad libitum* access to feed.

6. Dissemination:

Keady, S. (2011) 'Examination of the expression of genes and proteins controlling *M. longissimus thoracis et lumborum* growth in steers'. Thesis. National University of Ireland, Maynooth, Ireland.

Keady, S.M., Kenny, D.A., Keane, M.G. and Waters, S.M. (2011) 'Effect of sire breed and genetic merit for carcass weight on the transcriptional regulation of the somatotropic axis in *M. longissimus dorsi* of crossbred steers.' *Journal of Animal Science,* 89(12):4007–4016.

Keady, S.M., Ohlendieck, K., Doyle, S., Kenny, D.A., Keane, M.G., Owens, R. and Waters, S.M. (2011)

'Effect of breed and sire genetic merit for growth on the expression of growth related genes in muscle of steers.' *Proceedings from the International Symposium for Animal Genomics*, Dublin, Ireland, 7th October, pp29.

Keady, S.M., Kenny, D.A., Keane, M.G. and Waters, S.M. (2011) 'Effect of sire breed and genetic merit for carcass weight on the transcriptional regulation of the somatotropic axis in *M. longissimus dorsi* of crossbred steers.' 62nd *Annual Meeting of the European Association of Animal Production*, Stavanger, Norway, 29th August, pp30.

Keady, S.M., Ohlendieck, K., Kenny, D.A., Doyle, S., Keane, M.G. and Waters, S.M. (2011) 'Proteomic profiling of bovine *skeletal muscle* from Aberdeen Angus and Belgian Blue steers differing in sire expected progeny difference for carcass weight.' *Proceedings of the Agricultural Research Forum*, Tullamore, Ireland, 13th March, pp114.

Animal and Grassland Research & Innovation Programme

Project number:
5883
Date:
June 2012
Funding source:
Teagasc
Project dates:
July 2008–Nov 2011

Genomic selection in dairy cattle

Key external stakeholders:

The Irish Cattle Breeding Federation (ICBF), breeding industry, dairy farmers, AI technicians, international genetic evaluation bodies, international geneticists.

Practical implications for stakeholders:

This study

- Identified the optimal algorithm for genomic selection in Irish Holstein-Friesian dairy cattle across over 30 traits thereby increasing the accuracy of selection and thus genetic gain.
- Provided industry with an immediately implementable pipeline for genomic selection in Irish Holstein-Friesian cattle and undertook the first national genomic evaluation in Irish Holstein-Friesian cattle.
- Passed the international quality control on national genomic evaluations.
- Generated the pipelines for imputing from lower density genotype platforms to higher density genotype platforms thereby reducing the cost of genomic selection.
- Determined the optimal national breeding scheme for genomic selection in Irish Holstein-Friesian dairy cattle.
- Initiated an international initiative for the exchange of genotypes thereby improving the accuracy of genomic predictions.
- Disseminated the benefits and approaches to optimally exploit genomic selection on farm as well as by breeding companies.

Collaborating Institutions:
ICBF

Teagasc project team:
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Dr. Sinead McParland
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Mr. T. Baker (Eurogene)

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Technology

Main results:

- The accuracy of genetic evaluations can be augmented considerably (i.e., from ~32% reliability to ~55% reliability) by exploiting genomic information in national two-step genetic evaluations.
- The cost of genomic selection can be reduced by 66% by using a lower density genotyping platform and imputing to a higher density.
- Genetic gain in Irish Holstein-Friesian cattle can be increased >50% by optimising the national breeding scheme to exploit genomic selection.

Opportunity/Benefit:

Greater accuracy of genetic selection and thus genetic gain for profitability as well as international market share by Irish indigenous breeding companies.

1. Project background:

Genetic gain is a function of how accurately the genetically elite animals within a population can be identified; the greater the accuracy, all else being equal the greater will be genetic gain. However, being able to accurately identify genetically elite animals at a younger age, without the requirement for a supervised progeny testing scheme can not only increase annual genetic gain further but can also reduce the cost of a breeding program for a given number of animals. Because DNA is 1) responsible for some of the variation in performance among animals, 2) remains the same throughout an individual's lifetime, and 3) is available for birth, being able to optimally exploit DNA information in the national breeding schemes can be very beneficial. Individual differ at millions of sites along their DNA resulting in differences in characteristics and performance; one type of variation in DNA among individuals is called a single nucleotide polymorphism (SNP). Differences in single sites along DNA generally result in only tiny differences among animals but when all the DNA differences between individuals are summed the differences in performance can be substantial. The basis of genomic selection is to quantify the impact of variations in thousands of SNPs in dairy cattle for a range of production traits. Once known, the DNA profile of selection candidate (e.g., young test bulls) can be generated and the sum of all DNA variants for that individual obtained resulting in an estimate of the genetic merit of that individual – this can be available at a very young age.

2. Questions addressed by the project:

- Can low-cost, accurate genomic selection be implemented for a range of performance measures in Irish dairy cattle?
- What is the optimal breeding program to exploit genomic selection in Ireland?

3. The experimental studies:

- This was a desktop study.
- Genotypes (54,001 genetic markers per animal) on several thousand Holstein-Friesian bulls were used to develop the accurate genomic predictions.
- The same genotypes, with a large proportion of genotypes masked to mimic lower density genotypes, were used to test the accuracy of imputation from lower to higher density genotype panels.
- A simulation study, including a cost benefit analysis, was used, based on Irish dairy cattle population parameters, to define the optimal breeding program exploiting genomic selection.

4. Main results:

- The accuracy of national genetic evaluations was augmented through the incorporation of genome-wide genetic marker information; the improvement in accuracy varied by trait which was primarily a function of the effective number of animals used to estimate the genetic marker effects and their relatedness to the candidate animals.
- Genomic predictions were estimated using a genomic relationship matrix commonly referred to as GBLUP.
- Retrospective analysis comparing original genomic proofs of bulls at the time of sale compared to current daughter derived traditional genetic evaluations clearly show an improvement in accuracy of selection of up to 21%.
- The accuracy of imputing (i.e., predicting) the 54,001 genetic markers used in the national genomic evaluations from 3,000 and 6,000 genetic markers was 98 to 99% with a similar effect on genomic predictions.
- Inclusion of female phenotypic and genomic information can lead to a 3–fold increase in the rate of genetic gain compared with a traditional BLUP breeding program and decrease the generation interval of the males by 3.8 years, while maintaining a reasonable rate of inbreeding.

5. Opportunity/Benefit:

- The accuracy of selection increased with genomic selection and was implemented in the national dairy cattle genetic evaluations for all traits in the national breeding objective, the EBI, in Spring 2009; genomic evaluations for linear type traits followed in 2012.
- In 2009, 34% of semen used was to genomically selected sires which increased to 47% in 2011.
- Simulations clearly show that a 50% increase in genetic gain is achievable with genomic selection; this is worth €8 million annually which is cumulative and permanent; greater genetic gain has been observed since the implementation of genomic evaluations.

6. Dissemination:

International conferences: Presented at many international conferences, invited and contributed, such as the European Association of Animal Production, British Society of Animal Science, British Cattle Breeders Conference, INTERBULL, ICAR, American Dairy Science Association Annual meeting, New Zealand Society of Animal Production, International Society of Animal Genetics, Recent Advances in Animal Nutrition Annual Conference (Nottingham), and the World Congress on Genetic Applied to Livestock Production.

International workshops and seminars: Presented at several international workshops and seminars including the University of Pretoria, South Africa, and Massey University, New Zealand, Lincoln University, Nebraska National Conferences and seminars: Presented at the Agricultural Research Forums through the duration of the project and at national farmer conferences (e.g., Irish Grassland Conference) including G€N€ IR€LAND® days.

Open Day: Presented at all Moorepark open days.

Breeding industry consultation days: Presented and discussed at several industry meeting days with representatives from the different AI organisations, breed societies, Teagasc extension service, farmer groups and farmers.

Farmer discussion groups: Discussed at many farmer discussion groups and seminars.

Press: Results regularly presented in the Irish Farmers Journal, Farming independent, Today's Farm, TResearch, and Moorepark News as well as on radio and television.

Main publications:

Berry, D.P. and Kearney, J.F. (2011) 'Imputation of genotypes from low-to high-density genotyping platforms and implications for genomic selection.' *Animal*, 5 (8): 1162–1169.

McHugh, N., Meuwissen, T.H.E., Cromie, A.R and A. K. Sonesson (2011) 'Use of female information in dairy cattle genomic breeding programs.' *Journal of Dairy Science,* 94: 4109–4018.

Wickham, B.W., Amer, P.R., Berry, D.P., Burke, M., Coughlan, S., Cromie, A., Kearney, J.F., McHugh, N., McParland, S. and O'Connell, K. (2012) 'Industrial perspective:capturing the benefits of genomics to Irish cattle breeding.' *Animal Production Science,* 52: 172–179.

Popular publications:

Berry, D.P., Cromie, A., McHugh, N. and Kearney, F. (2010) 'Genomic selection in Ireland – from zero to hero in one year.' In: *British Cattle Conference*, BCBC, p46–50.

Berry, D.P., Howard, D., Waters, S. and Kearney, F. (2008) 'Genomic selection to increase EBI.' In: *National Dairy Conference,* Rochestown Park Hotel, Cork, 4 pages.

Berry, D.P., Kearney, F. and Harris, B. (2009) 'Genomic selection in Ireland.' In: *Proceedings of the Interbull International Workshop: Genomic Information in Genetic Evaluations*, Uppsala, Sweden, Bulletin No. 39, 29–34.

Effects of genetic merit for fertility traits on phenotypic performance of lactating Holstein cows

Project number:
5672 A
Date:
Aug, 2012
Funding source:
Teagasc
Project dates:
Jan 2007–Dec 2011

Key external stakeholders:

Dairy farmers, Irish Cattle Breeding Federation, AI companies, reproductive biologists.

Practical implications for stakeholders:

This study developed and validated a novel genetic model of fertility in lactating dairy cows.

- The results clearly highlighted the benefits of selecting for improved genetic merit for fertility on the phenotypic reproductive performance of lactating Holstein cows. Of note, excellent fertility performance was achieved without a detrimental effect on phenotypic milk production.
- Cows with poor genetic merit for fertility traits displayed multiple physiological defects that collectively explain the main areas of reproductive loss.

Main results:

A lactating Holstein cow genetic model of fertility was generated by selecting animals with similar proportions of Holstein genetics and similar genetic merit for milk production traits, but with extremes of good (Fert+) or poor (Fert-) genetic merit for fertility traits. The main results were:

- Phenotypic milk production was similar in both genotypes, but fertility performance was markedly superior in the Fert+ cows compared with the Fert-cows. This was verified by also examining the milk production and fertility performance of a large number of Fert+ and Fert-animals in the national database.

Collaborating Institutions:
Teagasc
UCD

Teagasc project team:
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Dr. Sean Cummins
Dr. Donagh Berry

External collaborators:
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Dr. Ross Evans (ICBF)

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Technology

- The Fert+ cows maintained greater body condition score (BCS) throughout lactation, in agreement with the observation that they also maintained greater circulating concentrations of the key metabolic hormones insulin and IGF-I.
- The incidence of both 'silent heats' and ovulation failure after displaying heat was greater in Fert-cows. This likely represents a substantial area of reproductive loss.
- Fert+ cows had a larger dominant follicle at ovulation, and during the luteal phase had a larger corpus luteum and greater concentrations of progesterone.

Opportunity/Benefit:

The immediate benefit of this research is the clear indication that selecting for improved genetic merit for fertility traits will result in improved phenotypic fertility performance. This has positive implications for Irish dairy farmers, the current national breeding programme, and Irish AI companies. In the longer term, this unique animal model will allow us to improve our understanding of the basic physiological mechanisms responsible for fertility failure in lactating Holstein cows.

1. Project background:

Despite the crucial role fertility plays in maximizing economic output, reproductive efficiency in dairy cows has decreased during the past half century both in Ireland and internationally. In Ireland, some of this decrease has been attributed to the intense selection for milk production traits and the associated introduction of North American Holstein genes.

To address the problem of decreasing fertility, the Irish national breeding program moved from being predominantly focused on milk production traits to a more holistic multi-trait index called the Economic Breeding Index (EBI). Introduced in 2001, the EBI included production and non-production traits, thus identifying animals of superior genetic merit for delivering on-farm profit. Since its introduction, the EBI has evolved to include 6 sub-indexes. Of these, milk production (38.1%) and fertility and survival (34.8%) have the greatest weighting (weighting indicated in parentheses).The fertility sub-index itself is composed of two traits: calving interval (23.2%) and survival (11.5%). Good genetic merit for fertility traits requires negative estimated breeding values (EBV) for calving interval and positive EBV for survival.

In previous studies comparing models of good and poor fertility, observed differences in phenotypic fertility performance were generally confounded with genetic merit for milk yield and phenotypic milk production. Therefore, the aim of this study was to characterize the phenotypic performance of cows with similar genetic merit for milk production traits and similar proportions of Holstein genes, but with either good (Fert+) or poor (Fert-) genetic merit for fertility traits.

2. Questions addressed by the project:

- Would differences exist between Fert+ and Fert-cows in fertility performance, milk production, body reserve mobilization and circulating concentrations of metabolic hormones and metabolites?
- Does genetic merit for fertility traits impact follicular and corpus luteum development, reproductive hormone profiles and oestrous behaviour during the oestrous cycle?
- Are there detectable differences in oocyte and embryo morphology and the abundance of key genes associated with oocyte and embryo developmental competence?
- Are there temporal differences in the pattern of somatotropic axis gene expression in liver tissue?

3. The experimental studies:

Using the official dairy evaluations published by the Irish Cattle Breeding Federation (ICBF, Bandon, Co. Cork, Ireland), the national dairy cattle database was screened for heifers due to calve for the first time in Spring 2008 and again in spring 2009. Restrictions were placed on the EBV for milk production (between +200 and +900 kg) and proportion of Holstein genetics (>75%). Within this population, heifers with extreme positive (i.e., poor fertility) and negative (i.e., good fertility) EBV for calving interval were identified. Poor-fertility (**Fert–**) heifers were restricted to animals where both the sire and maternal grand-sire had positive EBV for calving interval. Conversely, good-fertility (**Fert+**) heifers were restricted to animals where both the sire and maternal grand sire had negative EBV for calving interval. Heifers identified as being available for purchase were screened for infectious diseases. A total of 26 nulliparous Fert– and 26 nulliparous Fert+ cows were purchased and moved to the Animal & Grassland Research and Innovation Centre, Moorepark. Within the Irish national herd,

these animals were representative of the top quartile in genetic merit for milk production, whereas the Fert+ and Fert– groups represented the top 20% and bottom 5% for calving interval, respectively.

The animals were run as a single herd, with identical general husbandry and nutritional management. Milk production, BCS, and bodyweight measurements were recorded routinely, and blood samples were collected at frequent intervals to assess hormonal and metabolite indicators of bioenergetic status. In 2008 (all first lactation animals), the heifers were bred as normal, and reproductive performance was recorded. In 2009 (mix of first and second lactation), breeding was delayed to allow detailed measurements to be collected during early and mid lactation. These measurements included:

- Collection of immature cumulus-oocyte complexes using transvaginal ovum pick-up for assessment of morphology and expression of key genes associated with competence; Collection of embryos following superovulation treatment by non-surgical flushing of the uterine horns on day 7 after AI for assessment of morphology and expression of key genes associated with competence;
- Collection of daily blood samples and daily transrectal ultrasound measurements of ovarian follicular and corpus luteum dynamics for one full oestrous cycle;
- Collection of liver tissue by percutaneous punch biopsy at weeks–3, 1, 8, 20 and 34 relative to parturition to assess the expression of genes involved in the somatotropic axis.

4. Main results:

- The Fert+ cows had greater daily milk yield (19.5 vs. 18.7 kg/d), shorter interval from calving to conception (85.6 vs. 113.8 d), and fewer services per cow (1.78 vs. 2.83). No difference between groups in grass dry matter intake, energy balance, or body weight was observed. The Fert+ cows maintained greater BCS during mid (2.84 vs. 2.74 units) and late lactation (2.82 vs. 2.73 units). Circulating concentrations of insulin-like growth factor-I were greater throughout the gestation-lactation cycle in Fert+ cows (148.3 vs. 128.2 ng/mL). The Fert+ cows also had greater circulating concentrations of insulin during the first 4 wk of lactation (1.71 vs. 1.24 µIU/mL). Analysis of records from national herd data verified the association between genetic merit for fertility traits and phenotypic reproductive performance; Fert+ cows (n = 2,436) required 11.1 d less to re-calve than did Fert– cows (n = 1,388), and the percentage of cows that successfully calved for the second time within 365 and 400 d of the first calving was 8 and 13% greater for Fert+ compared with Fert– cows, respectively.
- There was no substantial difference between Fert+ and Fert-cows in either oocyte or embryo morphology, or in the abundance of transcripts associated with oocyte or embryo developmental competence.
- The Fert+ cows tended to have fewer follicular waves (2.2 vs. 2.7) and had a shorter oestrous cycle (21.0 vs. 25.1 d) than Fert– cows. During the first 13 d of the cycle, Fert+ cows developed a corpus luteum that was 16% larger than that in Fert– cows. Circulating progesterone concentrations were 34% greater in Fert+ than in Fert– cows (5.15 vs. 3.84 ng/mL, respectively) from d 5 to 13. During the final follicular wave, maximum preovulatory follicle diameter was larger in Fert+ than Fert– cows (17.9 vs. 16.8 mm, respectively), but circulating concentrations of oestradiol were not different between genotypes. A greater proportion of Fert– cows ovulated to a 'silent heat' than Fert+ cows (22 vs. 2%, respectively). Of cows that showed behavioural oestrus, a greater proportion ($P = 0.04$) of Fert– cows failed to ovulate a DF (0 vs. 14% for Fert+ and Fert–, respectively). Amongst the cows that showed behavioural oestrus, Fert+ cows had 41% greater mean activity count; however, no difference was seen in mounting behaviour between genotypes.
- The Fert+ cows had increased mean expression of *IGF-I* mRNA during the study; however, the difference in *IGF-I* mRNA abundance between Fert+ and Fert– cows was most pronounced at week 20 and 35 of lactation. The abundance of *IGFBP3* and *ALS* transcripts was similar in Fert+ and Fert– cows for the duration of the study, but Fert– cows, had greater expression of low molecular mass binding proteins (*IGFBP2–6*). This has important implications for the half-life of IGF-I in circulation. Genetic merit for fertility traits affects hepatic expression of key genes of the somatotropic axis regulating the synthesis, bioavailability, and stability of circulating IGF-I.

5. Opportunity/Benefit:

The results clearly highlight the importance of selecting for improved fertility traits in dairy cattle, which will provide long-term benefits to Irish dairy farmers. There is an opportunity for AI organisations to improve the marketing of Irish bulls with a strong fertility sub-index, both nationally and internationally.

6. Dissemination:

Main publications:

Cummins, S. B., Lonergan, P., Evans, A.C.O., Berry, D.P., Evans, R.D. and Butler, S.T. (2012) 'Genetic merit for fertility traits in Holstein cows: I. Production characteristics and reproductive efficiency in a pasture-based system.' *Journal of Dairy Science* 95:1310–1322.

Cummins, S. B., Lonergan, P., Evans, A.C. and Butler, S.T. (2012) 'Genetic merit for fertility traits in Holstein cows: II. Ovarian follicular and corpus luteum dynamics, reproductive hormones, and estrus behavior.' *Journal of Dairy Science* 95:3698–3710.

Cummins, S. B., Waters, S.M., Evans, A.C., Lonergan, P. and Butler, S.T. (2012) 'Genetic merit for fertility traits in Holstein cows: III. Hepatic expression of somatotropic axis genes during pregnancy and lactation.' *Journal of Dairy Science* 95:3711–3721.

Conferences and Open Days:

Cummins, S.B. and Butler, S.T. (2009) 'The effect of genetic merit for fertility on cow performance.' Pages 57–59 in Moorepark '09 Open Day 'Irish Dairying: new thinking for challenging times', 18th June 2009, Moorepark, Fermoy, Co. Cork. www.agresearch.teagasc.ie/moorepark/Publications/pdfs/Open%20Day%20Moorepark%202009.pdf

Berry, D.P., Buckley, F., Butler, S.T., Cummins, S.B. and Cromie, A. (2012) 'Breeding for fertility in Irish dairy cows.' Pages 30–38 in conference proceedings 'Dairy cow fertility: reproductive performance for efficient pasture-based systems', 11th and 12th April 2012, Cork. www.agresearch.teagasc.ie/moorepark/publications/pdfs/DairyCowFertilityConference.pdf

Popular publications:

Cummins, S.B. and Butler, S.T. (2011) High and low fertility in dairy cows. TResearch 6(1): 26–27.

Use of synchronisation in dairy cows to maximise submission rates

Project number:
5672 B
Date:
Aug, 2012
Funding source:
Teagasc
Project dates:
Jan 2007–Dec 2011

Key external stakeholders:

Dairy farmers, farm advisors, veterinary practitioners, pharmaceutical companies, AI companies, reproductive biologists.

Practical implications for stakeholders:

This study developed and compared different controlled breeding programmes for cows in seasonal calving dairy production systems with the primary goal of maximising submission rates.

- Fixed-time AI synchronisation protocols can be successfully used to achieve 100% submission rate in treated animals while maintaining similar conception rates to non-synchronised cows.
- The interval from mating start date to first insemination can be shortened by using synchronisation. Use of synchrony treatments should be targeted at anoestrous cows and late-calving cows to advance the time of re-breeding after calving. Beneficial effects on subsequent calving pattern will be maximised through early intervention.

Main results:

- Ovulation synchronisation protocols tightly synchronise timing of ovulation, which may or may not have been preceded by behavioural oestrus. These protocols facilitate insemination at a pre-determined time, and hence are also called 'fixed-time AI' protocols.
- Treatments that synchronise the timing of ovulation facilitate 100% submission rate in treated animals.
- Ovulation synchronisation protocols that provide supplemental progesterone (CIDR, PRID) result in superior reproductive performance in anoestrous cows compared with ovulation synchronisation protocols that do not include supplemental progesterone.

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Technology

Opportunity/Benefit:

Dairy farmers should identify anoestrous cows before and during the breeding season, and utilize synchrony to improve the reproductive performance of these cows. Similarly, oestrous and ovulation synchronisation treatments are useful tools to shorten the interval from calving to first AI in late-calving cows.

1. Project background:

Achieving a highly concentrated period of calving in the spring requires a high conception rate within a short period following the planned start of mating during the previous breeding season. Maximizing the proportion of cows that establish pregnancy within the first 6 weeks of the breeding season decreases the incidence of extended calving patterns. Cows with an extended postpartum anoestrous interval and late-calving cows in the herd can disrupt the seasonal calving pattern and result in extended calving patterns. Low submission rates decrease the proportion of animals becoming pregnant within the pre-defined 6 week period, thus negatively affecting the profitability of seasonal calving systems. Decreased profitability arises from mean calving date (**MCD**) occurring later in the year than optimal, and consequently, results in a less compact calving pattern, poor utilisation of feed, shorter lactation lengths, increased breeding costs and fewer calf sales.

Traditional oestrous synchronisation programmes using GnRH, progesterone (**P4**) and PGF2α were previously demonstrated to successfully synchronise oestrus and resulted in earlier conception in seasonal calving systems. Ovulation synchronisation protocols using timed AI (**TAI**) ensure that a cow is submitted for AI without the requirement to observe for signs of oestrus. Successful use of TAI protocols requires (i) synchronising the growth of a new follicular wave; (ii) synchronising luteal regression; and (iii) synchronising the time of ovulation. This project was undertaken to evaluate the role of oestrous and ovulation synchronisation protocols in Irish seasonal-calving systems.

2. Questions addressed by the project:

- What is the effect of different synchronisation protocols on ovarian follicular and luteal dynamics, reproductive hormone profiles and the timing of ovulation?
- To examine the potential effect on calving pattern and MCD through aggressive whole-herd intervention with protocols to synchronise oestrus or ovulation?
- What animal factors affect the responsiveness to different synchrony protocols?

3. The experimental studies:

Study 1: Lactating autumn-calving dairy cows (n = 64) were managed as a single herd at Moorepark.

Cows were stratified by parity and days in milk and randomly assigned to 1 of the 3 synchronisation treatments (CIDR_OBS, CIDR_TAI or Ovsynch) illustrated in Figure 1 (lower panel). The CIDR_OBS treatment was an oestrous-synchronisation protocol, whereas CIDR_TAI and Ovsynch were ovulation-synchronisation protocols. All cows were ≥35 DIM (mean = 58; range 35 to 82 DIM) at the initiation of synchrony treatments, resulting in synchronised oestrus/ovulation at ≥45 DIM (mean = 68; range = 45 to 92 DIM). Blood samples were collected and ovarian structures were examined by transrectal ultrasonography at frequent intervals to monitor responses to hormonal treatments, to determine time of ovulation, and to monitor corpus luteum formation after ovulation. Cows assigned to CIDR_ OBS were inseminated using the am/pm rule following detection of oestrus with the aid of tail paint. All cows on the CIDR_TAI and Ovsynch treatments received TAI 18 hours after the second GnRH injection, which was administered 60 hours after PGF injection. To enhance expression of oestrous behaviour, all cows were moved to a clean stand-off woodchip pad 3 days before the presumptive day of oestrus until ovulation was confirmed.

Study 2: A study was conducted using 1,538 cows in 8 Irish commercial spring-calving dairy herds between April and June 2008. Within each herd, cows were divided into 3 groups: early, mid, and late calving based on days in milk (DIM) at the farm mating start date (MSD). Early calving cows (n = 1,301) were 42 DIM at MSD, mid-calving cows (n = 212) were 21 to 41 DIM at MSD, and late-calving cows (n = 126) were 0 to 20 DIM at MSD. Synchronisation treatments commenced 10 days before MSD for the early calving cows, facilitating oestrus or TAI at MSD (planned breeding 1; PB1) as illustrated in Figure 1 (upper panel). All early calving cows were _42 DIM at AI (range in DIM of 42 to 105). Synchronisation treatments commenced on day 11 and 32 after MSD for the mid-and late-calving cows, respectively. The treatments facilitated oestrus or TAI 21 days after

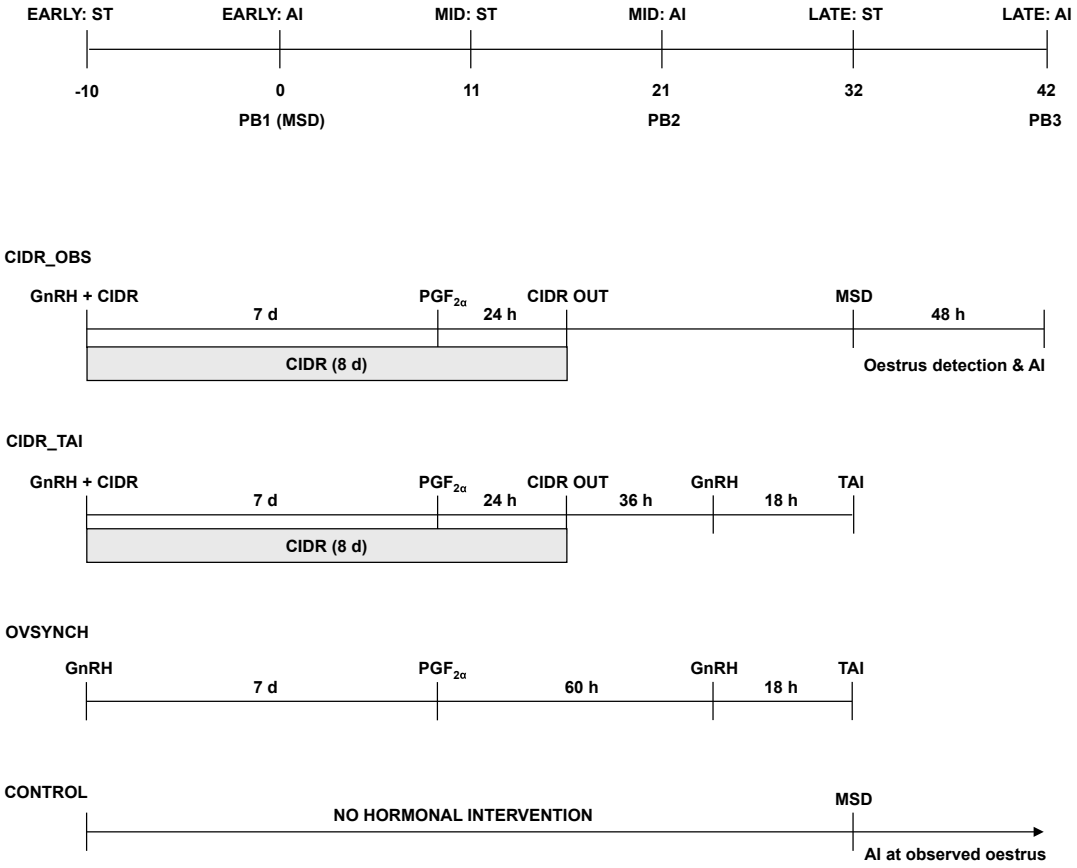

Figure 1: Schematic diagram of experimental design used to evaluate synchronisation treatments (ST) (upper panel) and treatment protocols to synchronise oestrus and ovulation (lower panel). ST = Start or synchrony treatment; AI = Artificial Insemination; PB = Planned breeding date; MSD = Mating start date.

MSD (PB2) and 42 days after MSD (PB3) for the mid-and late-calving cows, respectively. All mid-and late-calving cows were between 42 and 62 DIM at AI. Thus, the experimental treatments were imposed on all cows that had calved up to and including MSD. Within each calving group, cows were stratified by parity and days in milk and randomly assigned to 1 of the 4 treatments illustrated in Figure 1 (lower panel). Cows assigned to the control (CTRL) treatment received no hormonal interventions.

Study 3: Additional statistical analysis of the data generated in the large-scale on-farm study was used to identify animal factors associated with fertility outcomes in cows treated with protocols to synchronise oestrus and ovulation.

4. Main results:

Study 1: Circulating concentrations of P4 were greater for CIDR_OBS and CIDR_TAI compared with Ovsynch during the synchronisation treatment. Peak circulating concentrations of oestradiol were greater for CIDR_OBS compared with Ovsynch, but CIDR_TAI did not differ from either CIDR_OBS or Ovsynch. The interval from PGF injection to peak circulating oestradiol did not differ between CIDR_TAI and Ovsynch, but both of these treatments had shorter intervals from PGF injection to peak circulating oestradiol concentrations compared with CIDR_OBS. The diameter of the dominant follicle before ovulation was greater for CIDR_OBS compared with Ovsynch, but CIDR_TAI did not differ from either of the other treatments. The mean interval from PGF to ovulation was longer for CIDR_OBS (100.0 hours) compared with CIDR_TAI and Ovsynch (84.4 and 83.2 hours, respectively). All of the cows on the CIDR_TAI and Ovsynch treatments had ovulated by 92 hours after PGF, whereas 53% of the cows on the CIDR_OBS treatment had ovulated at this time. Use of CIDR_OBS resulted in increased preovulatory follicle size and greater circulating concentrations of oestradiol due to a longer period of preovulatory follicle growth. Progesterone supplementation during synchronisation and GnRH on the day before TAI affected ovulatory follicle size, and periovulatory circulating concentrations of P4 and oestradiol. No differences, however, in postovulatory P4 or luteal volume profiles were observed.

Study 2: The likelihood of successful conception per AI was greater for CIDR_OBS (59%), CIDR_TAI (54%) and CTRL (53%) compared with Ovsynch (45%). Both CIDR_TAI and Ovsynch had an increased likelihood of earlier conception compared with the CTRL. A greater proportion of cows on the CIDR_TAI treatment successfully established pregnancy in the first 42 days of the breeding season compared with the CTRL (75% vs. 67% 42–day pregnancy rate, respectively). Protocols to synchronise oestrus and ovulation were effective at achieving earlier first service and conception in pasture-based seasonal calving dairy herds. However, animals that conceived following insemination at observed oestrus (CTRL and CIDR_OBS) had a decreased likelihood of embryo loss to first service compared with animals bred with TAI (CIDR_TAI and Ovsynch). Use of TAI protocols resulted in shorter intervals from calving to first service and from mating start date to conception. Progesterone supplementation as part of a TAI protocol resulted in a greater proportion of these animals successfully establishing pregnancy during the first 42 days of the breeding season.

Study 3: Use of a CIDR-based ovulation synchronisation protocol (i.e., CIDR_TAI) increased synchronisation rates in anovular cows (i.e., a greater proportion of cows successfully responded to the synchronisation protocol). Both CIDR_OBS and CIDR_TAI animals without a corpus luteum (CL) had increased likelihood of conception at first service compared with Ovsynch animals without a CL. Low body condition score (BCS) animals treated with CIDR_OBS had increased likelihood of

conceiving at first service compared with low BCS animals treated with CIDR_TAI, Ovsynch, and CTRL. Animals < 60 days in milk (DIM) treated with CIDR_OBS and CIDR_TAI had increased likelihood of conceiving at first service compared with Ovsynch. Treatment with CIDR_TAI increased synchronisation rate in cows categorised as low BCS, anovulatory, and < 60 DIM compared with both CIDR_OBS and Ovsynch, and increased submission rate compared with CIDR_OBS. Conception rate in cows within these categories, however, was greatest for CIDR_OBS, resulting in minimal differences in actual pregnancy rates between CIDR_OBS and CIDR_TAI treatments, both of which were superior to Ovsynch. Treatment differences in the response variables investigated were minimal in cows categorised as medium or high BCS, ovulatory and > 60 DIM, indicating that CIDR-based protocols could be targeted at particular cows, and all other cows could be synchronised using Ovsynch.

5. Opportunity/Benefit:

The results of this research are of immediate practical relevance to dairy farmers. Cow fertility during the breeding season and subsequent calving pattern the following spring can be improved through targeted use of oestrous and/or ovulation synchronisation protocols. Early treatment of anoestrous cows and late-calving cows will have a beneficial impact on herd calving pattern.

6. Dissemination:

Main publications:

Herlihy, M.M., Berry, D.P., Crowe, M.A., Diskin, M.G. and Butler, S.T. (2011) 'Evaluation of protocols to synchronize oestrus and ovulation in seasonal calving pasture-based dairy production systems.' *Journal of Dairy Science* 94:4488–4501.

Herlihy, M.M., Crowe, M.A., Diskin, M.G. and Butler, S.T. (2012) 'Effects of synchronization treatments on ovarian follicular dynamics, corpus luteum growth, and circulating steroid hormone concentrations in lactating dairy cows.' *Journal of Dairy Science* 95:743–754.

Conferences and Open Days:

Butler, S.T. and Herlihy, M.M. (2012) 'Use of controlled breeding programs in seasonal calving systems'. Pages 95–98 in conference proceedings 'Dairy cow fertility: reproductive performance for efficient pasture-based systems', 11th and 12th April 2012, Cork. www.agresearch.teagasc.ie/moorepark/publications/pdfs/DairyCowFertilityConference.pdf

Herlihy, M.M. and Butler, S.T. (2009) 'Increasing submission rates on dairy farms'. Pages 60–62 in Moorepark '09 Open Day 'Irish Dairying: new thinking for challenging times', 18th June 2009, Moorepark, Fermoy, Co. Cork. www.agresearch.teagasc.ie/moorepark/Publications/pdfs/Open%20Day%20Moorepark%202009.pdf

Popular publications:

Butler, S.T. Turning up the heat: alternative detection aids. Irish farmers Journal, 10/5/2008, pages 24–25. Butler, S.T and Herlihy, M.M. (2008) Fancy an extra €170 profit from each cow? Today's Farm, 19:20–21. Does cow synchronisation have a role? *Today's Farm* March–April 2012, 23(2):20–21.

The Effect of Negative Energy Balance on Gene Expression in cattle

Project number:
5756
Date:
Sept 2012
Funding source:
Teagasc
Project dates:
Jan 2008–Dec 2011

Key external stakeholders:

Dairy and beef farmers, Irish Cattle Breeding Federation (ICBF), nutrition, physiology and genetic scientists.

Practical implications for stakeholders: This study

- The study provided new insights into the effects of short-term negative energy balance (NEB) on gene expression in the hypothalamic-pituitary-ovarian axis and on immune function in cattle.
- Some cattle are very sensitive to short term periods of NEB and rapidly become anoestrus.
- Systemic concentrations of insulin-like growth factor–1 (IGF–1) appear to be centrally involved in mediating the reproductive effects of NEB, and would appear to be a good predictor of the reproductive response to NEB.
- NEB alters the expression of genes involved in mediating an immune response.
- NEB does not cause a stress response in heifers if adequate concentrations of IGF–1 and insulin are present. Heifers that became anoestrus appear to experience a certain degree of stress and altered immune function but the response is less marked than that observed for other husbandry practices.
- Periods of severe negative energy balance must be avoided otherwise reproductive and immune competencies will be compromised.

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Technology

Main results:

- Almost a third of heifers became anoestrous following a short period of NEB. Heifers with low systemic concentrations of IGF–1 were more likely to become anoestrus.
- In hypothalamic tissue over one thousand genes were shown to be differentially expressed (DE) in heifers that became anoestrous compared with heifers that remained cyclic.
- Pathway analysis showed that these genes were associated with pathways involving neuroactive ligand-receptor, homeostasis and immune response.
- These data suggest that heifers became anoestrus following increased expression of molecules within the hypothalamus that provide GnRH neurons with information that body reserves are not adequate to continue oestrous cyclicity. The catabolic environment induced by negative energy balance may ultimately cause anoestrus by reducing oestradiol synthesis, FSH-responsiveness and IGF signaling in granulosa, and LH-responsiveness in theca cells of dominant follicles.
- After 18 days of alterations in eosinophil and monocyte numbers and altered expression of *IL8*, *IL2* and *TNFα* could be attributed to NEB.
- This study also suggests that negative energy balance does not cause a stress response in heifers if adequate concentrations of IGF–1 and insulin are present. Heifers that became anovulatory appear to experience a certain degree of stress and altered immune function but the response is less marked than that observed for other husbandry practices.

Opportunity/Benefit:

Provides an opportunity to identify heifers sensitive or tolerant to the effects of NEB at a young age. This could be invaluable in selecting cows with greater reproductive efficiency. Because of the central role of reproductive performance in determine productive and economic efficiency in Irish seasonal calving milk and beef herds this would be of immediate practical relevance to beef and dairy farmers.

1. Project background:

Nutrition plays a fundamental role in the modulation of reproduction in cattle. It is likely that this is mediated through effects on the functioning of the hypothalamic-pituitary-ovarian axis. However, the underlying biological mechanisms are poorly understood. Previous work from our laboratory has clearly shown that following short term severe dietary restriction, some heifers will become anoestrus within approximately two weeks, whereas others will continue normal oestrous cyclicity. Studies of both short term and long term feed restriction in beef heifers have provided evidence that NEB, induced by dietary restriction, causes decreased growth rate and maximum diameter of dominant follicles (DF) and often results in anovulation due to reduced LH pulse frequency. During periods of metabolic stress, animals typically channel energy toward survival and away from processes such as reproduction. The reproductive axis, therefore, has the capacity to respond to changing systemic concentrations of metabolic cues. GnRH neurons, present in the hypothalamus, represent the final output pathway of the neural network that integrates a multitude of internal and environmental cues to regulate the secretion of LH and FSH from the anterior pituitary gland. However, little is known of the molecular regulation of the secretion of GnRH due mainly to the difficulty and expense of obtaining hypothalamic tissues in cattle.

Numerous molecules are believed to communicate with the GnRH neuron and are the primary focus of this study. Therefore, real-time RT-qPCR assays were designed to examine the effect of acute severe NEB on the expression of a number of genes with known direct or indirect effects on the secretion of GnRH in the hypothalamus. Given the critical importance of hypothalamic-pituitary signalling to the occurrence of ovulation, the expression of candidate genes in the anterior pituitary were also investigated.

The objective of this study was to investigate possible reasons for a differential reproductive response to short term diet restriction, specifically investigating systemic metabolites and metabolic hormone concentrations and gene expression in the hypothalamus and anterior pituitary glands of heifers.

The molecular basis for an apparent differential response among cattle to dietary restriction and energy balance has not been established. Thus the objective of this study was to compare differences

in transcriptional profiles in hypothalamic tissue between two groups of animals in energy deficit and a third control group on a higher level of feed all with divergent reproductive performance using RNAseq technology and pathway analysis.

Our hypothesis was that gene expression profiles within these cells, along with the endocrine changes in response to brain activation, may provide biomarkers of NEB. In order to gain new insights into the effects of nutrition induced NEB on the stress-immune system our objectives were to characterise the effects of dietary restriction on haematological responses and leukocyte gene expression and 2), to investigate if heifers less tolerant of NEB experience a greater degree of stress.

2. Questions addressed by the project:

- What is the molecular biological basis for the differential reproductive response to short term diet restriction?
- What are the systemic metabolite, metabolic hormone and gene expression changes in the hypothalamus and anterior pituitary glands of heifers to short term diet restriction?
- Does acute nutritional restriction influences the expression of genes regulating gonadotrophin and IGF response in ovarian follicles, thereby reducing their functional capacity for differentiation and ovulation?
- What are the effects of dietary restriction on haematological responses and leukocyte gene expression?
- Do heifers that are less tolerant to NEB experience a greater degree of physiological stress?

3. The experimental studies:

A total of 4 studies were carried out.

Study 1. A total of 40 heifers were used to determine the effect of severe short term dietary restriction on systemic metabolites, metabolic hormones and provide tissues for subsequent gene expression of candidate genes in the hypothalamus and anterior pituitary of beef heifers. To facilitate the study, the oestrous cycles of all heifers were synchronised using an 8 day combined controlled internal drug-releasing device Ten days after CIDR withdrawal luteolysis was induced using PGF2α to allow ovulation of the DF of the subsequent oestrous cycle (2nd DF). During the oestrous synchronisation period heifers were individually offered a grass silage and concentrate diet (fed 1:1 on an energy content basis) supplying the energy for 1.2 times maintenance (1.2 Mn). One day before CIDR removal (day 0), heifers were allocated randomly to either a restricted diet supplying 0.4 Mn (n=28) or retained on 1.2 Mn as control (n=12). Ovarian follicular growth and incidence of ovulation were monitored by daily transrectal ultrasonography. Blood samples were collected twice daily (0900 and 2100 h) prior to feeding all heifers from the day of diet allocation (day 0) until the day of slaughter for reproductive (progesterone, FSH and oestradiol) and metaboloic (IGF–1, insulin and leptin) hormones and metabolite (glucose, urea, and β-hydroxybutyrate) analyses. Heifers were slaughtered on day 18 and hypothalamic, anterior pituitary and ovarian tissues collected, snap frozen and stored at–80°C. The relative expression of 18 genes in the hypothalamus, and 11 genes in anterior pituitary was measured by RT-qPCR, in a subset of 21 heifers (7 Control (C)), seven Restricted Ovulatory (RO) and seven Restricted Anovulatory (RA)).

Study 2. The effect of severe short term dietary restriction on gene expression in the bovine hypothalamus using next generation RNA sequencing technology was investigated.

Study 3. Haematological variables known to be reliable biomarkers of husbandry stressors and gene expression of seven leukocyte cytokine genes and five immunological biomarkers were investigated. Heifers were blood sampled on selected days during the period of dietary restriction and total leukocyte, neutrophil, lymphocyte, eosinophil and monocyte number, red blood cell number, haemoglobin, mean corpuscular haemoglobin concentration, haematocrit percentage and platelet number were measured. The relative expression of 12 genes were then measured on days 0,5 9, 13 and 18.

Study 4. Following slaughter, each pair of ovaries were removed, follicles were dissected from the stroma, follicular fluid was aspirated from both the dominant and the largest subordinate follicle and snap frozen for subsequent assay of oestradiol, progesterone and IGF–1. Theca and granulosa cells were isolated from the follicle wall. Follicle total cholesterol, β-hydroxy butyrate, and glucose were analysed using commercial biochemical assay kits. Total RNA was extracted from theca and granulosa cells using Trizol® reagent. Complementary DNA was synthesised from 1 µg of total RNA using random primers and the High Capacity cDNA reverse transcriptase kit. Quantitative real-time PCR (Q-RT-PCR) was carried out on the 7500 Fast

Real-Time PCR System. All primers were designed using PrimerBLAST and manufactured by Eurofins MWG (Ebersberg, Germany). Primer sequences for genes within the IGF family were those previously validated for bovine endometrial gene expression analyses.

4. Main results:

Study 1

- Nine of 28 heifers became anoestrous due to diet restriction.
- Follicular growth rate and maximum diameter were reduced by dietary restriction,
- Systemic concentrations of IGF–1 were positively associated with the probability of ovulation on days–2, 0, 5 and 9, relative to diet allocation. The results indicate that IGF–1 concentrations define if a heifer is capable of ovulating during an energy deficit.
- The expression of 18 candidate genes in the hypothalamus and 11 candidate genes in the anterior pituitary of heifers was also measured. Of these (*GHSR*) was highest in the anterior pituitary of RA heifers.

Study 2

- A total of 15,295 genes were expressed in hypothalamic tissue.
- The largest number of differentially expressed genes was observed between RO and RA heifers, with 1094 genes shown to be differentially expressed (DE).
- Innatedb pathway analysis showed that these DE genes were associated with 6 canonical pathways ($P < 0.01$), of which neuroactive ligand-receptor interaction was the most significant.
- Pathways regulating homeostasis and immune response were significantly altered between restricted anovulatory and restricted ovulatory heifers.
- We conclude that heifers became anovulatory following increased expression of molecules within the hypothalamus that provide GnRH neurons with information that body reserves are not adequate to continue oestrous cyclicity.

Study 3

- After 18 days of differential feeding alterations in eosinophil and monocyte numbers and altered expression of *IL8*, *IL2* and *TNFα* could be attributed to diet restriction.
- More specifically, effects on these five variables occurred in animals that became anovulatory. It has previously been described that heifers that become anovulatory have lower circulating concentrations of IGF–1 and insulin. Therefore, we conclude that diet restriction does not cause a stress response in heifers if adequate concentrations of IGF–1 and insulin are present. Heifers that became anovulatory appear to experience a certain degree of stress and altered immune function but the response is less marked than that observed for other husbandry practices.

Study 4

- Acute dietary restriction decreased oestradiol ($P<0.01$) and IGF–1 ($P<0.01$) in follicular fluid and mRNA for follicle stimulating hormone receptor FSHR ($P<0.01$) in granulosa cells but increased mRNA for IGFBP2 ($P<0.05$) in theca cells of the newly selected dominant follicle.
- This only led to anovulation when dietary restriction also decreased mRNA for CYP19A1 ($P<0.05$), IGF2 ($P<0.01$) and IGF1R ($P<0.05$) in granulosa cells and LHCGR ($P<0.05$) in theca cells of ovarian follicles.
- These results suggest that the catabolic environment induced by dietary restriction may ultimately cause anovulation by reducing oestradiol synthesis, FSH-responsiveness and IGF signalling in granulosa, and LH-responsiveness in theca cells of dominant follicles.

5. Opportunity/Benefit:

The results of this research have significantly extended our understanding of nutritional effects on reproduction, particularly of the underlying biological mechanisms, by which negative energy balance modulate reproductive function. It indicates that some animals have the biological capacity to be more tolerant or sensitive to an energy deficit. The identification, through genetic selection possibly using systemic IGF–1 measurements, of such tolerant animals could be used as a strategy to counteract the detrimental effects of NEB, and increase overall reproductive performance in cattle. Because of the central role of reproductive performance in determine productive and economic efficiency in Irish seasonal calving dairy and beef herds, the results of this study are of immediate and practical relevance to beef and dairy farmers.

6. Dissemination:

National Conferences and seminars
Presented at the Agricultural Research Forum.
Open Day Farmer Discussion Groups

The results of these studies have informed the presentations at Beef Open in Grange and have been incorporated into presentations at Discussion Group and Farmer and industry seminars.

Main publications:

Walsh, S.W., Matthews, D., Browne, J.A., Forde, N., Crowe, M.A., Mihm, M., Diskin, M., Evans, A.C. (2012). Acute dietary restriction in heifers alters expression of genes regulating exposure and response to gonadotrophins and IGF in dominant follicles. *Anim Reprod Sci*.133:43–51.

Walsh, S.W., Mehta, J.P., McGettigan, P.A., Browne, J.A., Forde, N., Alibrahim, R.M., Mulligan, F.J., Loftus, B., Crowe, M.A., Matthews, D., Diskin, M., Mihm, M., Evans, A.C. (2012) Effect of the metabolic environment at key stages of follicle development in cattle: focus on steroid biosynthesis. *Physiol Genomics*, 44:504–17.

Matthews, D. (2012). Investigating variation in reproductive responses to diet restriction in heifers. Ph.D. Thesis University, College Dublin.

Matthews, D., Kenny, D.A., Morris, D.G., Waters, S., Wylie, A.R.G. and Diskin, M.G. (2011). Effect of short term diet restriction on follicle wave dynamics, incidence of anovulation, metabolic hormones and metabilite profiles. In: Agricultural Research Forum, Tullamore, Co. Offally, 14–Mar, p. 170.

Popular publications:

Kenny, D.A. and Diskin, M.G. (2010). Factors affecting the reproductive efficiency of beef cow herds. Irish Charolais News 50–52.

Animal and Grassland Research & Innovation Programme

Project number:
5742

Date:
Dec, 2011

Funding source:
Teagasc

Project dates:
Oct 2007–Dec 2011

Examination of the effect of weaning stress on physiological, immune and behavioural responses of beef calves

Key external stakeholders:

Suckler beef farmers, beef industry, Department of Agriculture, Food and the Marine (DAFM).

Practical implications for stakeholders:

- Weaning is a multifaceted stress that results in a transitory weakening of the immune system and this can result in increased susceptibility to diseases, such as respiratory infections.
- Implementing pre-weaning practices, such as feeding supplementary concentrates, and post-weaning practices, such as deferring housing and dietary changes and, weaning calves next to the dam, resulted in a less marked stress response, as indicated by physiological, immunological and/or behavioural responses, in suckler beef calves.
- The findings of this project, substantiated and contributed to the "Animal Welfare, Recording and Breeding Scheme for Suckler Herds" as outlined by the Department of Agriculture, Food and the Marine. http://www.agriculture.gov.ie/farmerschemespayments/sucklerherdswelfarescheme2008–2012/awrbs2010/.

Main results:

- Abrupt weaning is a stressful event for calves and cows and results in transient alterations to the immune system that can be measured at both the physiological and molecular level.
- Reducing simultaneous stressors at weaning, such as deferring housing and dietary changes, leaving weaned calves in close proximity to the cow for a period of time or preparing the calf for subsequent dietary changes by feeding supplementary concentrates pre-weaning, reduced physiological, immunological and/or behavioural stress responses in weaned beef calves.

Collaborating Institutions:
NUI (Maynooth)

Teagasc project team:
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Dr. Aran O'Loughlin

External collaborators:
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Compiled by:
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Technology

Opportunity/Benefit:

The results of this research have

- Demonstrated that, as a result of transitory alterations in the immune system, abrupt weaning can increase susceptibility to disease in beef calves.
- Identified strategies pre-and post-weaning that help reduce the magnitude of the stress response in beef calves and alleviate alterations to the immune system attributed to the weaning process.

1. Project background:

Within seasonal, grassland-based suckler beef production systems in Ireland, calves are generally spring-born and reared with their dam at pasture for approximately 8 months until the end of the grazing season in autumn when they are weaned. In addition to separation from the dam and removal of milk from the diet, the weaning procedure is generally compounded by other stressors/practices occurring around the same time, e.g. change of environment (outdoors to indoors), change of forage diet (grazed grass to conserved forage with or without concentrates), and transport/marketing. Weaning therefore can be a multi-factorial stressor, in which, nutritional, social, physical, and psychological stress are combined. Physical and nutritional stressors are often present through the introduction and adaptation to a new diet and new environment, whereas, psychological stress is present in the form of maternal separation and social disruption. Bovine respiratory disease (BRD) is a major animal welfare and economic concern for the beef cattle industry. For the recently-weaned suckler bred calf, susceptibility to BRD can be a serious problem, with negative knock-on implications for markets, in particular, live export markets. There is little published information on the effects of weaning and associated practices on the physiological and immunological responses in the beef calf. This project set about addressing the knowledge gaps.

2. Questions addressed by the project:

- What are the physiological and immunological consequences of weaning and associated weaning practices for suckled beef calves and their dams?
- Can post-weaning management practices (i.e. deferring housing and dietary changes and, weaning calves next to the dam) alleviate the stress response in weaned beef calves?
- Can pre-weaning management practices (i.e. offering supplementary concentrates) alleviate the stress response in weaned beef calves?

3. The experimental studies:

1. Characterised the physiological and immunological response in beef calves and cows to abrupt weaning and subsequent housing.
2. Studied the effects of abrupt weaning at housing on peripheral leukocyte distribution, functional activity of neutrophils, immune response genes, and the acute phase response of beef calves.
3. Examined the effects of post-weaning management practices; (i) abruptly weaned and housed and, offered grass silage *ad libitum* plus concentrates *versus* abruptly weaned and returned to pasture with no concentrates offered and subsequently housed and (ii) weaned and housed in the presence of the dam *versus* weaned and housed away from the dam, on physiological and immunological responses of beef calves.
4. Examined the effects of offering concentrate supplementation pre-weaning on the peripheral leukocyte distribution, functional activity of neutrophils and the acute phase protein response of abruptly weaned beef calves.

4. Main results:

- Using conventional blood indicators of stress (i.e physiological, haematological and immunological variables), abrupt weaning (vs. not weaning) was shown to be stressful to the suckler calf with alterations in immune function and hormonal mediators of stress still evident 7 days post-weaning.
- Similarly, abrupt weaning is a stressful event for the beef cow. However, it appears that the stress response is activated to a lesser degree and for a shorter period in the cow than in the calf.
- Through the use of molecular techniques (i.e. real-time (RT)-qPCR), the expression of a number of key genes regulating immune function in the calf are impaired up to 7 days after abrupt weaning. Impairment in the function of these genes could have a profound impact on the health of calves in terms of susceptibility to infection during this time and response to vaccination.
- Beef calves that were abruptly weaned and returned to familiar pasture had a less marked stress response compared to calves that were abruptly weaned, housed indoors and offered a

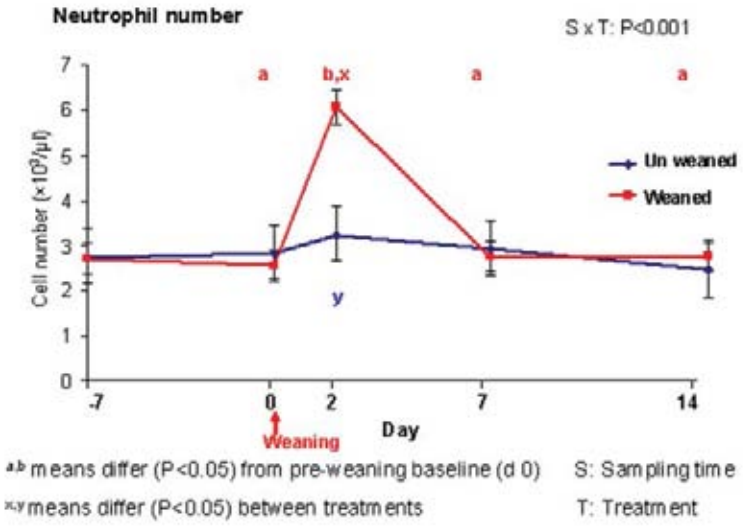


Figure 1: Neutrophil distribution in Weaned and Un-weaned beef calves. (A neutrophil is an immune blood cell that increases in response to stress).

new diet of grass silage plus supplementary concentrates. As housing was also shown to be a stressful event for beef calves, delaying this practice until after weaning reduces the magnitude of the stress response.

- Suckler calves, particularly bulls, may benefit from a weaning strategy where they are allowed visual, oral and olfactory contact with the dam but are prevented from suckling for a number of days prior to total separation.
- Single-suckled beef calves supplemented with concentrates prior to weaning had a lesser reduction in some immune cells (i.e. gamma delta T lymphocytes), started consuming meal faster when housed indoors and spent more time lying down (rather than standing and walking) post-weaning compared with non-supplemented calves.
- Reducing the cumulative effect of multiple stressors around weaning time results in a less marked stress response in the calf.

5. Opportunity/Benefit:

The results of this research have; 1), demonstrated that, due to transitory alterations in the immune system, abrupt weaning can increase susceptibility to disease in beef calves; and 2), identified strategies pre-and post-weaning that help reduce the magnitude of the stress response in beef calves and alleviate alterations to the immune system attributed to the weaning process.

6. Dissemination:

Main publications:

Lynch, E.M., Earley, B., McGee, M., Doyle, S. (2010) Effect of abrupt weaning at housing on leukocyte distribution, functional activity of neutrophils, and acute phase protein response of beef calves. *BMC Veterinary Research* 6:39 doi:10.1186/1746–6148–6–39.

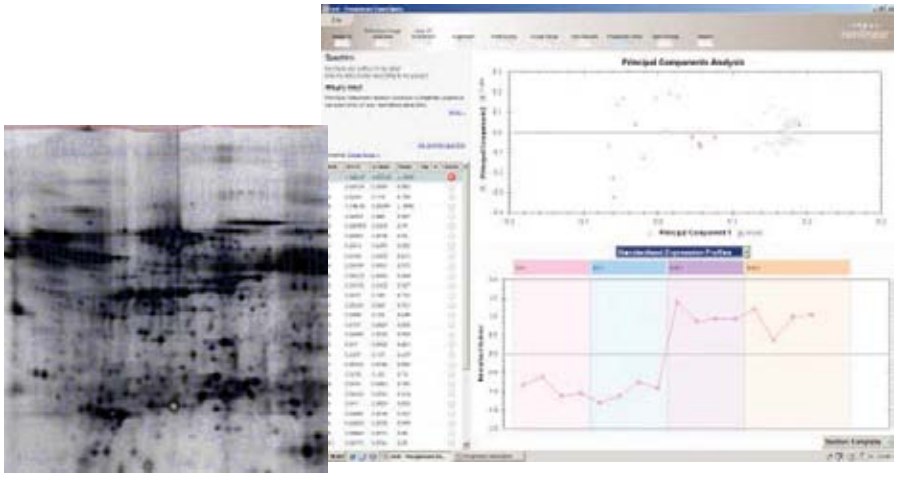
Lynch, E.M., McGee, M., Doyle, S., Earley, B. (2012) Effect of pre-weaning concentrate supplementation on the peripheral distribution of leukocytes, functional activity of neutrophils, the acute phase protein response and the metabolic responses in abruptly weaned beef calves. *BMC Veterinary Research* 8:1.

O'Loughlin, A., McGee, M., Waters, S.M., Doyle, S., Earley, B. (2011) Examination of the bovine leukocyte environment using immunogenetic biomarkers to assess immunocompetence following exposure to weaning stress. *BMC Veterinary Research* 7:45.

Popular publications:

Earley, B., McGee, M., Lynch, E. (2011) Management of suckler beef calves at weaning. *Irish Farmers Monthly* 40–41.

The effect of stage of cycle and steroid environment on the uterine proteome of the cow and differences from plasma



Project number:
5677
Date:
April, 2012
Funding source:
Teagasc
Project dates:
Sept 2008–Dec 2011

Key external stakeholders:

Dairy and beef cattle breeders, ICBF, veterinary diagnostic companies, scientific community.

Practical implications for stakeholders:

The main findings from this research show that the uterus is a dynamic organ capable of regulating the proteomic composition of the histotroph or uterine milieu and that this is in turn affected by the systemic concentration of progesterone the key hormone of reproduction.

- The protein composition of uterine fluid changes throughout the oestrous cycle consistent with the demands of the rapidly growing embryo.
- The concentrations of many uterine proteins 7 to 15 days after oestrus (the period of greatest embryonic loss) are directly related to the concentration of systemic progesterone as early as 3 days after oestrus.
- Adequate progesterone very early in the oestrous cycle is indicated for a uterine proteomic environment conductive to optimal embryo growth and subsequent survival.
- The concentrations of many uterine proteins are very different from plasma a further indication of the dynamic nature of the uterine proteome.

Main results:

- The protein composition of uterine fluid changes throughout the cycle consistent with the demands of the rapidly growing embryo.
- The concentrations of many uterine proteins 7 to 15 days after oestrus (the period of greatest embryonic loss) are directly related to the concentration or changes in the concentration of systemic progesterone as early as 3 days after oestrus and the response is greatest to changes in progesterone on day 3.

Collaborating Institutions:
UCD

Teagasc project team:
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imon Faulkner
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Technology

- This study indicates that the uterus is responsive to changes in progesterone very early in the oestrous cycle and that an adequate supply of progesterone is indicated for a uterine environment conducive to optimal embryo growth and survival.
- The uterine proteome is in some cases very different to that of plasma and this has implications for the composition of synthetic *in vitro* culture media in particular those using serum as an additive.

Opportunity/Benefit:

Knowledge gained from this study will guide researchers in defining the critical window for adequate progesterone and the development of strategies designed to increase the concentration of systemic and uterine concentrations of progesterone, particularly in dairy cows where systemic progesterone concentrations during the early part of the cycle are known to be inadequate in a high proportion of cows.

1. Project background:

Embryo loss is the single greatest factor affecting fertility in both the dairy and beef herds with over 40% of embryos lost before term. Early embryo loss occurring in the first two weeks after fertilization accounts for over 70% of that loss. Although there are many potential factors that contribute to embryo death, it is the physiology of the maternal reproductive system and principally the uterus, however, that has the greatest potential to affect embryo viability until implantation. Prior to implantation the embryo is metabolically most active and grows at an exponential rate between days 8–16 after fertilization a period which also coincides with the time of greatest embryo loss. The embryo maintains a free floating existence in the uterus from day 4 to commencement of implantation at around day 20 and the role of the uterus is to supply nutrients and growth factors necessary for development. Therefore inadequacies in the regulation of this environment are detrimental to a successful pregnancy. The hormonal mediated regulation of uterine secretions can indirectly influence the growth of the embryo and an increase in embryonic loss is observed when the physiological regulation of uterine function is sub-optimal. For example, low circulating concentrations of progesterone in the first few days after AI is associated with a low probability of embryo survival in dairy cows and heifers. Furthermore, uterine gene expression is sensitive to changes in systemic concentrations of progesterone. Many of these genes are essential for normal embryo growth, survival and implantation.

The objectives of this study were to identify bovine uterine proteins that are sensitive to changes in the systemic concentration of progesterone and how this varies throughout the oestrous cycle. The ultimate aim was to improve our understanding of the dynamics of uterine protein expression and identify the critical period affecting embryo growth and development.

2. Questions addressed by the project:

- Does the uterine proteome differ from plasma or is it essentially a transudate of plasma?
- Does the uterine proteome change throughout the oestrous cycle?
- Is the uterine proteome affected by changes in the concentration of systemic progesterone?

3. The experimental studies:

Sample collection was carried out under license in accordance with European Community Directive 86/609/EEC. Uterine flushings (UF) were collected non-surgically from the ipsi-and contralateral uterine horns of cross-bred beef heifers on day 7 or day 15 of the oestrous cycle. The protein was fractionated and subjected to strong cation exchange chromatography followed by mass spectrometric analysis. Bioinformatics was used to identify and classify proteins and to assign biological functions.

4. Main results:

The findings of this study indicate that there are many proteins in uterine fluid whose concentrations differ significantly from plasma. Many proteins were found to be present at much higher (or lower) concentrations in uterine fluid when compared to plasma indicating the dynamic nature of the uterus in maintaining an environment different to that of the peripheral circulation and this is the first study to demonstrate this.

The proteome of the uterus changes significantly between the two stages of the cycle examined and this is consistent with an exponential increase in embryo size during this period and with the period of greatest embryo loss.

In addition, this is the first study to demonstrate a linear positive relationship between the concentrations of uterine proteins and the concentration or the rate of increase in the concentration of systemic progesterone in the days prior to uterine fluid collection. Changes in the concentrations of systemic progesterone as early as day 3 after oestrus were seen to affect the subsequent concentrations of uterine proteins recovered on day 7 or day 15 after oestrus. The magnitude of the effect of progesterone was also greatest on day 3 and decreased with increasing days after oestrus.

The progesterone regulated proteins identified in this study are involved in a variety of functions critical to ensuring embryo survival including energy substrate availability, regulation of prostaglandin synthesis and moderation of immune response and reduction of oxidative stress. The concentrations of these proteins appear to be regulated by the uterine endometrium through either selective mechanisms or synthesis and are likely influenced by environmental factors including the local steroidal milieu.

5. Opportunity/Benefit:

This study has led to an increased understanding of the dynamic nature of the uterus and its proteome. The results indicate that changes in the composition of the uterine proteome are consistent with the requirements of the embryo and with the provision of a receptive environment for the embryo.

The most significant and unexpected finding was that the uterine proteome in the mid to late luteal phase (day 7 to day 15) of the cycle is responsive to changes in the steroidal environment in the early luteal phase (as early as day 3) of the cycle and that the effect of progesterone is more pronounced at this early stage.

This study changes the way we now think about the relationship between systemic concentrations of progesterone and embryo loss and ways in which we might develop strategies to reduce the embryonic loss associated with inadequate progesterone in the first week after AI in dairy and beef cow herds.

6. Dissemination:

The outputs from this research have been and continue to be disseminated to stakeholders through seminars, research forums and presentations at national and international scientific meeting including an EU COST action FA1002 on Farm Animal Proteomics. To date one peer reviewed publication has been published, one accepted for publication and one is in preparation for submission to the journal *Proteomics*. A review of uterine proteomic and technological advances is also in preparation.

Main publications:

Faulkner, S., Elia, G., Hillard, M., O'Boyle, P., Dunn, M. and Morris, D. (2011) 'Immunodepletion of albumin and immunoglobulin G from bovine plasma'. *Proteomics* 11: 2329–2335 doi: 10.1002/pmic.201000364.

Faulkner, S., Elia, G., Mullen, M.P., O'Boyle, P., Dunn, M. and Morris, D. (2012) 'A comparison of the bovine uterine and plasma proteome using ITRAQ proteomics'. *Proteomics* 12, 2014–2023.

Faulkner, S., Elia, G., Hillard, M., O'Boyle, P., Dunn, M. and Morris, D. (2011) 'An efficient and reproducible method for the depletion of albumin and immunoglobulin G from bovine plasma'. *EU COST ACTION FA1002; Farm Animal Proteomics* Spring Meeting, Glasgow, p65.

Popular publications:

Faulkner, S., Dunn, M. and Morris, D.G. (2009) 'Evaluation of an immunospecific technique for the depletion of albumin from bovine plasma'. *Agricultural Research Forum*, Tullamore, Offaly, p62.

Faulkner, S., Elia, G., Mullen, M., O'Boyle, P., Dunn, M. and Morris, D. (2011) 'The effect of stage of cycle on the bovine uterine proteome'. 4th *International Symposium on Animal Functional Genomics*, Dublin, p255.

Faulkner, S., Elia, G., Mullen, M., O'Boyle, P., Dunn, M. and Morris, D. (2011) 'Differences in the bovine uterine and plasma proteome'. *BSPR-EBI* Meeting, Cambridge, p49.

Project number:
5665
Date:
December, 2010
Funding source:
DAFF (RSF 06/0409)
Project dates:
Sept 2006–Dec 2010

Localisation of milk production and tuberculosis resistance genes in cattle

Key external stakeholders:

Scientific community

Practical implications for stakeholders:

This study has identified potential regions of the genome associated with milk production and susceptibility to bovine tuberculosis in Holstein-Friesian dairy cattle which can be used to help in identifying the mutations in the genome that are actually causing the differences in production and disease susceptibility among animals.

Main results:

- Regions of the genome were identified to be associated with milk production, corroborating previous international results on genome wide association studies as well as research on candidate genes undertaken by Teagasc.
- Regions of the genome were found to be associated with susceptibility to bovine tuberculosis.

Opportunity/Benefit:

Preliminary knowledge on the regions of the dairy cow genome associated with milk production and bovine tuberculosis. This information can be used in the search for the causative mutations affecting milk production and disease susceptibility

Collaborating Institutions:
Trinity College Dublin
University College Dublin
Department of Agriculture Food & Fisheries
Irish Cattle Breeding Federation

Teagasc project team:
Dr. D. P. Berry

External collaborators:
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Dr. Margaret Good, DAFF
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Technology

1. Project background:

There is currently a lack of information about the genomic regions that affect susceptibility to bovine tuberculosis (TB). Herd-and animal-level incidence of TB is approximately 5.0 and 0.2% in Ireland, respectively with an estimated control cost of €80 million per annum – this is unsustainable. Reduced genetic susceptibility of TB in Irish cattle will increase our competitiveness internationally. Increasing our knowledge on genomic regions associated with milk production, especially in grass based systems of milk production, will also be useful for scientists to help understand the biological mechanism underpinning genetic differences in milk production.

2. Questions addressed by the project:

Are there regions of the genome associated with milk production and bovine tuberculosis?

3. The experimental studies:

- The data used to determine if regions of the genome were associated with milk production came from 914 Holstein-Friesian AI bulls with progeny in Ireland and genotyped using the Illumina Bovine50 Beadchip. The variable of interest was milk production.
- The data used to identify possible regions of the genome associated with bovine tuberculosis were estimated breeding values for tuberculosis on 323 Holstein-Friesian AI sires with progeny that underwent a tuberculin test in Ireland. These estimated breeding values were generated in a previous project.
- Genome wide associations were undertaken on all data using genotype data on up to 50,000 genetic markers and different statistical approaches.

4. Main results:

- Regions of the genome were identified to be associated with milk production, corroborating previous international results on genome wide association studies as well as research on candidate genes undertaken by Teagasc.
- Regions of the genome were found to be associated with susceptibility to bovine tuberculosis.

5. Opportunity/Benefit:

Preliminary knowledge on the regions of the dairy cow genome associated with milk production and bovine tuberculosis. This information can be used in the search for the causative mutations affecting milk production and disease susceptibility.

6. Dissemination:

No technology transfer occurred during this project because of the potential intellectual property associated with the results.

Main publications:

Finlay, E.K., D.P. Berry, B.R. Wickham, E.P. Gormley, and D.G. Bradley. 2011. A Genome Wide Association Scan of Bovine Tuberculosis Susceptibility in Holstein-Friesian Dairy Cattle. *PLos One*. (Submitted).

Animal and Grassland Research & Innovation Programme

Project number:
5667
Date:
August, 2012
Funding source:
DAFF RSF 06 328
Project dates:
Nov 2006–Feb 2010

Relationships among maternal environment, fetal development, follicle numbers and fertility in cattle

Key external stakeholders:

Reproductive biologists, geneticists, animal breeding organisations, dairy farmers.

Practical implications for stakeholders:

- Improved understanding of the links between in utero development, ovarian organogenesis, postnatal follicle numbers and fertility performance in lactating dairy cows.

Main results:

The key results were:

- Greater milk yield (after accounting for differences in genetic merit) around the time of conception and during gestation was associated with reduced survival and milk yield and greater SCC in the progeny.
- Restricting maternal nutrition during the first 110 days of gestation results in the birth of calves with reduced numbers of ovarian follicles.
- The number of follicles on the ovaries was positively associated with fertility in dairy cattle.

Opportunity/Benefit:

The number of ovarian follicles may be a useful index of fertility in lactating dairy cows. An opportunity exists to develop a rapid low-cost screening test to assess ovarian follicle numbers. Subsequent research would be necessary to validate the relationship with phenotypic fertility performance, determine heritability, and assess whether there is value in incorporating the trait into the national breeding objective.

Collaborating Institutions:
Teagasc
UCD
Michigan State University

Teagasc project team:
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Dr. Donagh Berry

External collaborators:
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Prof James Ireland (MSU)

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Technology

1. Project background:

An emerging area of developmental biology is the study of the foetal origins of adult disease. The hypothesis proposes that some diseases originate through adaptations that the foetus makes when it is undernourished, which permanently alter the structure and function of the body. This hypothesis is frequently referred to as the 'Barker hypothesis' after David Barker who first suggested it.

Dairy cows have been selected for an increase in milk production, but there has been a concomitant decrease in fertility and increased susceptibility to some diseases. In order to have a 365 day calving interval, cows must conceive during the period of their peak lactation. This period of peak metabolic burden is coincident with follicle growth, ovulation, fertilization, early embryonic development and early fetal development. According to the Barker Hypothesis, animals conceived and developing in this nutritionally stressed maternal environment have compromised development that could affect them for the rest of their lives.

Previous research established that peak numbers of follicles in ovarian follicular waves of the oestrous cycle are highly variable amongst animals but very highly repeatable within individuals. Also, cows that consistently have relatively high numbers of follicles during waves have higher serum inhibin-A concentrations, but lower serum FSH and similar oestradiol concentrations during the first follicular wave compared with cows with low numbers of follicles during waves. While the link between follicle numbers and fertility had not been studied, we had recently found differences in superovulatory response (quality and number of embryos) and also noted that progesterone concentrations were greater in animals with high numbers of follicles.

The focus of the research reported here was to further our understanding of the links between the environment in which cattle embryos/foetuses develop, the numbers of ovarian follicles, and reproduction and fertility in cattle. We proposed to test an overarching hypothesis that a major factor contributing to fertility in cattle is the numbers of follicles in the ovaries and that this is regulated by the conditions present during foetal development.

2. Questions addressed by the project:

- Is the number of follicles per wave linked to ovarian size, number of oocytes (eggs), and circulating concentrations of reproductive hormones?
- Is ovarian development in offspring affected by maternal nutritional status in early gestation?
- Is the number of follicles present on the ovary linked to reproductive performance?

3. The experimental studies:

The research used complex statistical analyses of large data sets (national database containing several million records), animal models to examine foetal development, oocyte quality and follicle development, and cellular and molecular techniques to understand the development of tissues in the ovaries. This wide range of methods was chosen as they each probed the issues being studied in a slightly different way to increase our knowledge of the relationship between foetal development, the numbers of ovarian follicles and fertility in cattle.

4. Main results:

Analysis of the national data set on Irish Holstein-Friesian dairy cows indicated that, after accounting for genetic merit of the cow, greater milk yield prior to conception and during gestation was associated with reduced survival and milk yield and greater SCC in the progeny. This suggests that offspring survival and performance is affected by conditions that they experience in utero — as an oocyte, embryo or foetus — mediated through factors related to milk production of the dam.

Restricting maternal nutrition (to simulate the metabolic stress of high milk production) during the first 100 days of gestation (period encompassing ovarian organogenesis and oogenesis) resulted in the birth of calves with altered numbers of ovarian follicles. This finding supports our initial hypothesis that maternal nutritional status during in utero development impacts postnatal ovarian function.

We showed for the first time in a single-ovulating species that the inherently high variation in follicle numbers during follicular waves is also associated with significant alterations in intra-follicular oestradiol production, which is the hallmark of follicular function. Expression of key genes

important for differentiation, function and survival of follicular cells were also different in animals with high versus low numbers of ovarian follicles. Hence, there are functional differences between follicles from animals with high versus low numbers of ovarian follicles.

Finally, we tested the hypothesis that the numbers of follicles in the ovaries is associated with fertility in dairy cattle. The results suggest a positive association between the numbers of follicles in the ovaries and fertility in post partum dairy cows. Additional analysis of the data indicated that the number of ovarian follicles and the fertility of the adult offspring may be affected by dam parity, and that follicle numbers are moderately heritable. These effects warrant further investigation.

5. Opportunity/Benefit:

This research has improved our understanding of the links between maternal status at the time of conception and subsequent ovarian function and fertility performance. Further work is necessary to determine if direct or indirect measures of ovarian follicle numbers could be incorporated into the national breeding objective.

6. Dissemination:

Main publications:

Berry, D. P., Lonergan, P., Butler, S.T., Cromie, A.R., Fair, T., Mossa, F. and Evans, A.C. (2008) 'Negative influence of high maternal milk production before and after conception on offspring survival and milk production in dairy cattle.' *Journal of Dairy Science* 91:329–337.

Evans, A. C., Mossa, F., Fair, T., Lonergan, P., Butler, S.T., Zielak-Steciwko, A.E., Smith, G.W., Jimenez-Krassel, F., Folger, J.K., Ireland, J.L. and Ireland, J.J. (2010) 'Causes and consequences of the variation in the number of ovarian follicles in cattle.' *Society of Reproduction and Fertility supplement* 67:421–429.

Mossa, F., Jimenez-Krassel, F., Walsh, S., Berry, D.P., Butler, S.T., Folger, J., Smith, G.W., Ireland, J.L.H., Lonergan, P., Ireland, J.J. and Evans, A.C.O. (2010) 'Inherent capacity of the pituitary gland to produce gonadotropins is not influenced by the number of ovarian follicles _3 mm in diameter in cattle.' *Reproduction, Fertility and Development* 22:550–557.

Mossa, F., Walsh, S.W., Butler, S.T., Berry, D.P., Carter, F., Lonergan, P., Smith, G.W., Ireland, J.J. and Evans, A.C.O. (2012). 'Low numbers of ovarian follicles ≥3 mm in diameter are associated with low fertility in dairy cows.' *Journal of Dairy Science* 95:2355–2361.

European Ruminant Infrastructure Network (ERIN)

Project number:
5905
Date:
November, 2010
Funding source:
EU FP7, Project No.227750
Project dates:
Nov 2008–Dec 2010

Key external stakeholders:

European Union and Irish Agri-Food research institutes; European & Irish research funders.

Practical implications for stakeholders:

ERIN stems from the acknowledgment that farm animals are nowadays used in research to produce knowledge applicable to many areas including sustainable agriculture, global warming, human food and human health. These issues need to be considered at the European level since they are shared by many, if not all, EU countries. Experimental facilities where such research is carried out are distributed throughout Europe and require specific resources and management.

A European shared infrastructure, in the form of a network of facilities in Europe, would largely benefit an integrated approach to global issues (such as the need to decrease the environmental impact of farming while increasing consumer confidence), to the efficiency of research on animals in Europe (less animals, avoidance of duplication, access to animal models), and to research expertise in Europe (through exchanges of procedures and training of personnel).

Main results:

- More than 3,000 scientific articles are published per year on ruminant research. In Europe, 400 European institutes or universities carry out research on ruminants. Research groups are small, with half of them having less than 10 researchers.

Collaborating Institutions:
INRA
MTT
LMU
INIA
NRIAP

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- The five specialised fields that represent current research interests of research managers and how they may change in the future are: animal nutrition (present 45.7%; future 54.3%), dairy science (present 44.3%; future 50.0%), biology of reproduction (present 38.6%; future 48.6%), molecular biology (present 28.6%; future 58.6%) and metabolism (present 27.1%; future 37.1%). In addition, the specialised fields representing biotechnology, animal welfare, metabolism, microbiology, herd management, endocrinology, production systems, molecular genetics, and modelling were considered important by 30 to 40% of research managers and the trends showed an increase compared with present research interests.

Opportunity/Benefit:

A network of research facilities dedicated to research on large animals is thus crucial for coordinating research efforts to match future, increasingly sophisticated scientific developments and to stimulate synergies. It will attract the best scientists and encourage joint experiments, and wider dissemination of the results

1. Project background:

Science-based innovation support requires excellence in knowledge generation and procurement (research); knowledge transfer (dissemination activity) and knowledge absorption (education and training). This is particularly relevant to the future needs for research on ruminants in view of ongoing developments in specialized techniques and methodologies. Exploiting new research opportunities on ruminants will depend on access to expertise, facilities, techniques, and equipment through collaborative initiatives. One objective of the ERIN project was to collect quantitative information on present needs, future needs (in 3–10 years) of experimental animals, equipment, rearing or investigation methods and infrastructures for research on ruminants across Europe. Research managers from all European research organisations were questioned using an internet-based questionnaire.

2. Questions addressed by the project:

- What are the estimated needs for ruminant research in relation to future research areas, and in terms of expertise, animals and equipment?
- What are the future potential of research facilities dedicated to ruminants?
- What are the prospective needs and the supply of facilities with a view to creating an integrated organisation of research facilities likely to match future scientific developments and stimulate synergies in order for European research on farm animals and farming systems to play a leading role?

3. The experimental studies:

ERIN conducted bibliometric analyses from the Web-of-Science, reviewed vision papers and foresight studies, interviewed 70 research managers and members of funding bodies, surveyed research groups and experimental facilities, ran a scenario exercise on possible organisations of the research infrastructure in Europe, and organised a stakeholder conference to discuss the findings of the project.

4. Main results:

More than 3,000 scientific articles are published per year on ruminant research. In Europe, 400 European institutes or universities carry out research on ruminants. Research groups are small, with half of them having less than 10 researchers. The overall collaborations within Europe, and between European groups and partners outside Europe, are extensive; collaborations with Eastern European groups remain limited.

Cattle have been and remain the predominant ruminant species studied, followed by sheep and goats, both in terms of number of publications and number of experimental facilities for ruminants. The published articles concern mainly veterinary sciences, agriculture, dairy and animal science, food science and technology.

A quantitative analysis of the interviews with research managers showed that ruminant research is given a high priority at present, and will be in the next 3–10 years, within all organisations. The five specialised fields that represent the present research interests of research managers and how they may change in the future are: animal nutrition (present 45.7%; future 54.3%), dairy science (present 44.3%; future 50.0%), biology of reproduction (present 38.6%; future 48.6%), molecular biology (present 28.6%; future 58.6%) and metabolism (present 27.1%; future 37.1%). In addition, the specialised fields representing biotechnology, animal welfare, metabolism, microbiology, herd management, endocrinology, production systems, molecular genetics, and modelling were considered important by 30 to 40% of research managers and the trends showed an increase compared with present research interests. The two major constraints associated with ruminant research are the cost (present 62.9%; future 68.6%) and the associated funding (present 55.7%; future 62.9%), which were highlighted by the majority of research managers.

The changes that may be made regarding future research objectives for performing research on ruminants, in the next three to ten years, in order of priority are: increased focus on "omics" (74.3%), animal health (61.4%), in-depth analysis of biological processes (57.1%), molecular genetics (55.7%), production efficiency (51.4%), environmental impact (51.4%), animal well-being (50.0%), food quality (47.1%), economically viable agricultural production (45.7%), food safety (44.3%), support biomedical research (42.9%), advanced imaging tracer techniques (38.6%), genetics and breeding of farm animals (37.1%), economic modelling (32.9%), quality and utilisation of agricultural products (31.4%), metabolic studies (metabolic chambers) (24.3%) and phenomics (21.4%).

The services expected from a shared European infrastructure are knowledge transfer, specific expertise in ruminant research; training of technical staff, students or research staff; definition of procedures for specific measurements or techniques including for the collection of samples; contributing to science-society dialogue; professional management of research projects; collecting and processing samples and data; the use of defined Intellectual Property policies; specific expertise in functional genomics and bioinformatics; "technology watch" on techniques etc. Research managers considered that a European network of ruminant facilities would be beneficial at a Regional, National, European, and International level.

5. Opportunity/Benefit:

A network of research facilities dedicated to research on large animals is crucial for coordinating research efforts to match future, increasingly sophisticated scientific developments and to stimulate synergies. It will attract the best scientists and encourage joint experiments, and wider dissemination of the results.

6. Dissemination:

A stakeholder conference to discuss the findings of the project www.erinetwork.eu/erin/conference.

Main publications:

Earley, B. 2010. Future needs for research on ruminants www.erinetwork.eu/erin/conference.

Earley, B. 2010. European Ruminant Infrastructure Network (2010) Tresearch, Winter 2010.

Earley, B. 2010. ERIN, presentation in Brussels April 2010 to Dr. Christos Profilis at DG Research.

Animal and Grassland Research & Innovation Programme

Project number:
5499

Date:
November, 2010

Funding source:
Teagasc, ERAD

Project dates:
Sept 2006–Dec 2009

Genetics of predisposition to tuberculosis in Irish dairy cattle

Key external stakeholders:

The Irish Cattle Breeding Federation (ICBF); breeding industry; dairy farmers

Practical implications for stakeholders:

The results show that susceptibility to bovine tuberculosis (TB) is under genetic control. Twelve to eighteen percent of the variation in susceptibility to TB among animals is due to their genetic makeup which is passed on from one generation to the next. Therefore breeding for resistance to TB is feasible if sufficient information is available to accurately identify genetic differences among animals.

The results suggest that selection for improved survival may indirectly reduce susceptibility to TB infection, while selection for reduced somatic cell count and increased fat production and body condition score may increase susceptibility to TB infection.

Main results:

- Twelve to eighteen percent of the differences among animals in susceptibility to TB due to differences in their genetic makeup which are passed on from one generation to the next. This means that breeding for TB resistance is possible.

Opportunity/Benefit:

- Breeding for resistance to TB is possible.
- Estimates of genetic merit for TB derived that could be used in subsequent genomic research.

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1. Project background:

Mycobacterium bovis, the causal organism of bovine tuberculosis (TB), remains an important infection of cattle in many countries. A TB eradication programme has been operating in the Irish cattle herd since the 1950s, with control costs being borne by both government and industry. There is a large gap in knowledge on genetic predisposition to TB and how current breeding programs may be affecting this. There are several large animal-and herd-level datasets (animal breeding, disease control) in Ireland which represent an opportunity, unique internationally, to address some of these gaps in knowledge. Results from this study will provide an initial understanding of the genetics behind susceptibility to TB, and has the potential to identify Irish and foreign animals with relatives in Ireland that are genetically predisposed to infection with TB. An outcome of this study will also be measures of genetic merit for TB that can be used by other scientists in the discovery of regions of an animal's genome (i.e., DNA) associated with TB susceptibility/resistance.

2. Questions addressed by the project:

Can we alter susceptibility to TB using animal breeding and if so what is the impact of current breeding goals on genetic susceptibility in the national herd?

3. The experimental studies:

Data from the national tuberculosis database (held at CVERA, dating back to the early 1990s) was used along with performance and pedigree data from the ICBF. Only data from herds that experienced some degree of infection were included in the analysis. Within the CVERA database, individual animal records on the result of the tuberculin test as well as a lesion score were available for herds that had a positive case of TB. Different statistical approaches were undertaken to quantify the contribution of genetics to TB susceptibility.

4. Main results:

- The heritability of responsiveness to the tuberculin test was 0.14 in cows and 0.12 in heifers; the heritability of confirmed TB infection based on carcass lesions in cows was 0.18. This means that 12% to 18% of the differences among animals in susceptibility to TB was due to differences in their genetic makeup which are passed on from one generation to the next. It also implies that breeding for TB resistance will be fruitful.
- A very strong positive genetic correlation (r_g=0.999; SE=0.0024) was estimated between responsiveness to the tuberculin test and confirmed *M. bovis* infection in cows, indicating that they are genetically very similar traits, and that genetic selection to reduced responsiveness to the tuberculin test will also reduce genetic susceptibility to TB.
- Responsiveness to the tuberculin test was significantly positively genetically correlated with fat production (0.39) and body condition score (0.36), and negatively correlated with somatic cell score (–0.34) and survival (–0.62). Hence, these results suggest selection for increased survival may indirectly reduce susceptibility to TB infection, while selection for reduced somatic cell count and increased fat production and body condition score may increase susceptibility to TB infection.
- Large emphasis on TB within breeding goals needed to increase resistance to TB infection.

5. Opportunity/Benefit:

- We now know that breeding for resistance for TB could form an integral part of a national strategy against TB infection in cattle.
- Estimates of genetic merit derived using the statistical methodology developed in this study should be used to identify regions of the genome associated with TB to help understand the genetic architecture of the trait and develop the necessary tools to help eradicate TB.

6. Dissemination:

Papers were presented at the European Association of Animal Production; British Society of Animal Science and the World Congress on Genetic Applied to Livestock Production. Papers were also presented at the Agricultural Research Forum and results presented at the Moorepark Open Day 2009.

Main publications:

Bermingham, M.L., S.J. More, M. Good, A.R. Cromie and D.P. Berry (2009) Genetics of tuberculosis in Irish Holstein-Friesian dairy herds. *Journal of Dairy Science* 92, 3447–3456.

Bermingham, M.L., S.J. More, M. Good, A.R. Cromie and D.P. Berry (2010) Genetic correlations between measures of *Mycobacterium bovis* infection and economically important traits in Irish Holstein-Friesian dairy cows. *Journal of Dairy Science* 93, 5413–5422

Bermingham, M.L., S. Brotherstone, D.P. Berry, S.J. More, M. Good, A.R. Cromie, I.M.S. White, I.M. Higgens, M.P. Coffey, S.H. Downs, E.J. Glass, S.C. Bishop, A.P. Mitchell, R.S. Clifton-Hadley, and J.A. Woolliams. (2011) Evidence of genetic variance in resistance to tuberculosis in Great Britain and Irish Holstein-Friesian populations. BMC Proceedings. 5: 515

Repeatability and heritability of metabolic hormones in the cow

Project number:
5546
Date:
Sept 2012
Funding source:
Teagasc
Project dates:
Jan 2006–Dec 2009

Key external stakeholders:

Dairy and beef farmers, Irish Cattle Breeding Federation (ICBF), nutrition, physiology, genetic and molecular scientists.

Practical implications for stakeholders:

This study showed that IGF–1 has potential as a predictor of cow fertility due to its moderate repeatability and well documented association with a number of reproductive processes. Sampling cows between 2 and 4 weeks postpartum for IGF–1 could help identify cows that are more resilient to the effects of negative energy balance, thereby providing valuable additional information for breeding programmes and assisting selection for improved productive and reproductive potential. We also identified potential causative polymorphisms which, if augmented with functional genomic studies and validated in independent populations of cattle, would yield greater insight into the influence of variants of *IGF-1* and *GH1* on cow performance. While there is considerable variability between animals in the duration of heat and time of ovulation, neither were related to subsequent embryo survival. Furthermore, the study showed that successful pregnancy was possible even when ovulation occurred 31.5 h after AI. This suggests that there would be no detrimental effect of herds adopting once-daily AI, provided that oestrus detection is accurate.

Main results:

This study shows clearly that key metabolic changes that occur in the GH/IGF axis during the early postpartum period are associated with fertility traits. Circulating concentrations of IGF–1, insulin and glucose, indicators of energetic status, have direct and indirect effects on reproductive function. Of all the variables measured, IGF–1 has most potential as a predictor of cow fertility due to its moderate repeatability and well documented association with a number of

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reproductive processes. Increased circulating concentrations of IGF–1 during the early post partum period had concurrent and latent effects on reproductive events, leading to a shorter interval to first ovulation and conception, improved first service conception rate and overall pregnancy rate.

Two *IGF-1* SNPs, *IGFi1* and *IGFi2* were associated ($P<0.05$) with body condition score at calving while a single *IGF-1* SNP, *IGFi3*, was associated ($P<0.05$) with milk production including milk yield (± 751 kg), fat yield (± 21.3 kg) and protein yield (± 16.5 kg) per lactation. Only one *GH1* SNP, *GH33*, was associated ($P<0.05$) with milk protein yield in the second lactation (allele substitution effect of 9.8 kg). Several *GH1* SNPs were associated ($P<0.05$) with fertility, including *GH32*, *GH35* and *GH38* with calving to third parity (± 22.4 days) (*GH32* and *GH38*), pregnancy rate to first service (± 0.1 %) and overall pregnancy rate (± 0.05 %).

There was no effect of the intervals from the onset of heat to AI or ovulation or from AI to ovulation on embryo survival ($P > 0.10$). There was a tendency ($P = 0.09$) for an inverse relationship between preovulatory follicle size and embryo survival that was unrelated to concentrations of oestradiol or IGF–1 during the periovulatory period ($P > 0.05$). There was evidence ($P = 0.08$) of a positive association between embryo survival and concentrations of progesterone on Day 7, though this relationship was independent ($P < 0.05$) of hormonal and follicular measurements during the periovulatory period. This study shows that heifers could be inseminated up to 31.5 h before ovulation without compromising the probability of embryo survival.

Opportunity/Benefit:

Provides an opportunity to identify animals at a young age that are likely to have subsequently superior reproductive performance. This could be invaluable in selecting cows with greater reproductive efficiency. This is of immediate practical relevance to Irish dairy and beef herds because of the central role of reproductive performance in determining productive and economic efficiency in Irish seasonal calving systems.

1. Project background:

Reproductive efficiency in both dairy and beef cow herds is a major factor affecting the economic and biological efficiency of milk and beef production, particularly in seasonal calving herds. In dairy cows the decline in conception rate to a single service is the single most important contributor to the decline in overall herd reproductive efficiency. This decline in conception rate has been ongoing for the past three decades, with an average annual decline of 0.5 to 1 percentage points recorded over the past decade; it is currently estimated to cost the Irish cattle industry in excess of €400 million annually. Most discussion about the decline in dairy cow fertility has focused on the possible effects of lactation and or nutrition. Changes in metabolic hormones are dynamic in the post-partum dairy cow and largely reflect the shifting metabolic status of the cow at this time. Blood concentrations of insulin-like growth factor (IGF-I) and insulin decrease immediately after calving and then gradually increase as lactation progresses. These hormones are under metabolic regulation and can influence GnRH secretion by impacting on the neuronal pathways controlling its release. This in turn may alter LH and FSH secretion, the regulators of ovarian follicular dynamics and ovulation. Increased duration of anovulation was associated with decreased concentrations of IGF-I and IGFBP–3 in the follicular fluid of beef cows. There was also evidence that both insulin and IGF-I directly increase the sensitivity of the ovary to gonadotrophins. At the cellular level, physiological concentrations of insulin and IGF-I interact to stimulate oestradiol production by granulosa cells. Irrespective of which pathways insulin and IGF-I operate, there is some evidence that low blood concentrations of both are associated with prolonged postpartum anoestrous intervals in both beef and dairy cows. As well as the roles of IGF-I and insulin in regulating ovarian function and onset of oestrous cycles post-partum, there is emerging evidence of an association between blood concentration of these hormones and conception rate. Both Teagasc and UK studies have recorded a positive association between blood concentration of IGF-I during the early post-partum period and subsequent conception rate. Similarly, in beef heifers, positive association between blood concentrations of IGF-I and embryo survival rate has been reported. The appropriate incorporation of such easily measurable traits as blood insulin and IGF–1 into breeding programmes has the potential to increase the accuracy of selection, provide more accurate breeding values for fertility traits, and at younger ages. This will shorten generation interval or allow more animals to be evaluated, thereby increasing selection intensity. However, further studies are required to clarify the genetic control of IGF-I and determine how best to use systemic insulin and or IGF-I as potential indicator traits to improve reproductive efficiency.

2. Questions addressed by the project:

- What is the relationship between metabolic hormones, metabolites and milk production variables during early lactation and subsequent fertility in lactating dairy cows managed at pasture?
- What are the repeatability values for these hormones and metabolites during this early post-partum period?
- What are the associations of SNPs in bovine growth hormone (GH1), insulin-like growth factor I (IGF–1) genes with direct performance trait measurements of lactation and fertility in Holstein-Friesian cows?
- What are the relationships between periovulatory endocrine events, ovarian activity, and embryo survival after AI in cattle?

3. The experimental studies:

A total of 3 studies were carried out.

Study 1. A total of 371 spring calving multiparous Holstein-Friesian dairy cows, in 7 dairy herds were blood sampled within 8 days of calving and at weekly intervals thereafter, until 4 weeks post calving. Cows were body condition scored (BCS) on a scale of 0–5 on Week 1 and Week 4. Cows were bred by AI at a spontaneous oestrus and scanned for pregnancy at 30–60 days post AI. Milk production and composition was determined from on farm milk recording. Blood concentrations of total IGF-!, insulin glucose, NEFA, BHB and urea were determined. The repeatability of all metabolic hormones and metabolites across the four-week sampling period was calculated as the ratio of the within group variance to the sum of the within and between group variances. From the on-farm insemination records and detailed pregnancy scans, it was possible to determine the result of each insemination for all cows and this was subsequently confirmed by calving records in the following year. From these data, the following reproductive variables were calculated: postpartum interval to first service (PPSERV1) and days from calving to conception interval (CCI), conception rate to 1st service (PD1) and pregnancy rate (PDFINAL) for all services combined. The relationships between the dependant binary variables and the continuous independent variables IGF1, insulin, glucose NEFA, BHB, urea, BCS and all milk related variables were evaluated using logistic regression.

Study 2. A total of 16 SNPs in both the IGF–1 and GH1 genes were genotyped across 610 cows and association analyses carried out with traits of economic importance including: calving interval, pregnancy rate to first service and 305–day milk production using mixed animal linear models accounting for additive genetic effects (ASREML).

Study 3. A total of 84 beef heifers were oestrus synchronized using a prostaglandin-based regimen. AI was performed between 5 and 21 h after heat onset. Ultrasonic examination of ovarian structures began 12 h after the onset of heat and continued every 6 h until confirmed ovulation. Blood samples were collected for measurement of oestradiol, progesterone, and IGF–1. Pregnancy diagnosis was conducted on Days 30 and 100 after AI. Embryo survival was defined as the presence of an embryo with a detectable heartbeat in a clear amniotic sac at Day 30 post AI.

4. Main results:

Study 1

- Plasma concentrations of IGF–1 in weeks 2, 3, 4 (and the mean of weeks 1 to 4 post calving), and concentrations of glucose (weeks 1, 2, 3 and the mean weeks of 1 to 4 post calving) and urea (week 3 post calving) were positively related to with first service conception rate. Conception rate to first service was also positively related to yields of milk, fat, protein and lactose, as well as energy output during the 3rd month of lactation. Concentrations of IGF–1 were negatively associated with commencement of oestrous cycles. Calving to first service and calving to pregnancy intervals were negatively associated with concentrations of IGF–1 (weeks 1 to 4 and mean of weeks 1 to 4). Conversely, there was a negative association with concentrations of urea (week 3 and 4). Body condition score was negatively association with calving to first service and calving to pregnancy intervals (week 1 and 4).
- IGF–1 during the early post partum period had a moderate repeatability (0.63); repeatability estimates for the other analytes were lower (0.34 to 0.47).
- Systemic concentrations of IGF–1 in early lactation may be a useful metabolic indicator of the subsequent reproductive performance potential of dairy cows.

Study 2

- Two IGF–1 SNPs, IGFi1 and IGFi2 were associated (P<0.05) with body condition score at calving while a single IGF–1 SNP, IGFi3, was associated (P<0.05) with milk production including milk yield (± 751 kg), fat yield (± 21.3 kg) and protein yield (± 16.5 kg) per lactation.
- One GH1 SNP, GH33, was associated (P<0.05) with milk protein yield in the second lactation (allele substitution effect of 9.8 kg).
- Several GH1 SNPs were associated (P<0.05) with fertility, including GH32, GH35 and GH38 with calving to third parity (± 22.4 days) (GH32 and GH38 only), pregnancy rate to first service (± 0.1 %) and overall pregnancy rate (± 0.05 %).
- Results of this study demonstrate the direct effects of variants of the somatotrophic axis on milk production and fertility traits in commercial dairy cattle.

Study 3

- There was no effect of the intervals from the onset of heat to AI or ovulation or from AI to ovulation on embryo survival (P > 0.10). There was a tendency (P = 0.09) for an inverse relationship between preovulatory follicle size and embryo survival that was unrelated to concentrations of oestradiol or IGF–1 during the periovulatory period (P > 0.05).
- There was evidence (P= 0.08) of a positive association between embryo survival and concentrations of progesterone on Day 7; however, this relationship was independent (P < 0.05) of hormonal and follicular measurements during the periovulatory period.
- This study shows that heifers could be inseminated up to 31.5 h before ovulation without compromising the probability of embryo survival.

5. Opportunity/Benefit:

The results of this research have significantly extended our understanding of relationships between metabolic hormones, metabolites and milk production variables during early lactation and subsequent fertility in lactating dairy cows. It indicates that IGF–1 measurements during early lactation is moderately repeatable and is a useful predictor of subsequent reproductive performance. The study identified the effects of single nucleotide polymorphisms (SNPs) of the somatotrophic axis on milk production and fertility traits in commercial dairy cattle and these following further examination could be incorporated into breeding programmes. While considerable variability exists between individual animals in the duration of heat and time of ovulation, neither affects subsequent embryo survival. Furthermore, it was possible to establish a pregnancy when ovulation occurred 31.5 h after AI. This suggests that there would be no detrimental effect of herds adopting once-daily AI, provided that oestrus detection is accurate. This is of immediate practical relevance to Irish dairy and beef herds because of the central role of reproductive performance in determining productive and economic efficiency in Irish seasonal calving systems.

6. Dissemination:

National Conferences and seminars

Presented at the Agricultural Research Forum and International conferences such as the World Buiatrics Conference.

Open Day Farmer Discussion Groups

The results of these studies have informed the presentations at Beef Open in Grange and have been incorporated into presentations at Discussion Group and Farmer and industry seminars.

Main Publications:

Mullen, M.P., Lynch, C.O., Waters, S.M., Howard, D.J., O'Boyle P., Kenny, D.A., Buckley, F., Horan, B., Diskin M,G. (2011). Single nucleotide polymorphisms in the growth hormone and insulin-like growth factor–1 genes are associated with milk production, body condition score and fertility traits in dairy cows. *Genetics and Molecular Research*, 10:1819–1830.

Lynch, C.O., Kenny, D.A., Childs, S. and Diskin, M.G. (2010). The relationship between periovulatory endocrine and follicular activity on corpus luteum size, function, and subsequent embryo survival. *Theriogenology*, 73:190–198.

Diskin, M.G. and Morris, D.G. (2008). Embryonic and early foetal losses in cattle and other ruminants. *Reproduction Domestic Animals*, 43 (Suppl. 2): 260–267.

Technical publications:

Diskin, M.G. (2011) Reproductive Management of Dairy Cows. Dairy Encyclopaedia Page 475–484

Diskin, M.G. (2008). Reproductive management of dairy cows: A review (part I). *Irish Veterinary Journal*, 61: 233–239.

Diskin, M.G. (2008). Reproductive management of dairy cows: A review (part II). *Irish Veterinary Journal*, 61: 375–383. 7.

Dietary omega–3 polyunsaturated fatty acids alter the expression of fertility related genes in the cow

Project number:
5679
Date:
January, 2011
Funding source:
DAFF (RSF 06/412)
Project dates:
Sept 2006–Dec 2009

Key external stakeholders:

Scientists, animal nutrition companies; AI industry, Irish Cattle Breeding Federation (ICBF), beef and dairy farmers.

Practical implications for stakeholders:

Nutrition plays a fundamental role in reproduction and there is emerging evidence that dietary omega–3 polyunsaturated fatty acids (n–3 PUFA) supplementation may increase cow fertility independent of their role as energy substrates.

- Results from this research shows that some of the positive effects of n–3 PUFA on reproductive performance may be mediated by changes in gene expression in the uterus of the cow.
- The research results taken together with that of other studies, indicate that n–3 PUFA mediated modification of uterine function in cattle is worthy of further investigation.

Main results:

Dietary supplementation with n–3 PUFA altered the expression of genes which regulate implantation and pregnancy such as prostaglandin (PG) biosynthesis and the insulin like growth factor (IGF) system in the uterus of the cow. The results indicate an alteration in the cellular concentrations of the enzymes controlling the synthesis of key PGs and components of the IGF system in a manner which may positively influence uterine function and embryo survival.

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Opportunity/Benefit:

The implications of this research for the broader animal science community and livestock industry are that enriching cattle diets with n–3 PUFA evokes significant alterations in the expression of uterine genes.

However, it is only when the magnitude and timing of these effects are elucidated that appropriate supplementation regimens may be accurately and cost-effectively developed.

1. Project background:

Nutrition plays a critical role in the regulation of cow fertility. There is emerging evidence that dietary long chain n–3 PUFA may act as specific regulators of some reproductive processes. A number of studies where dairy cow diets were supplemented with a source of n–3 PUFA, mainly in the form of fish-oil or fishmeal, have reported beneficial effects on reproductive performance independent of their role as energy substrates.

Therefore this nutritional strategy has potential for amelioration of the decline in bovine fertility.

The hormone PG is released by the uterus at about 16 days following insemination when an embryo is sufficiently well developed. This hormone will cause the cessation of pregnancy and the return to normal cycling. When an embryo is sufficiently well developed it produces a protein (interferon tau) which helps to counteract the negative effect of PG and aids the continuation of pregnancy. It is thought that feeding n–3 PUFA to cows in early pregnancy can help to suppress PG production, thus potentially increasing pregnancy rate. In addition, it has been demonstrated by colleagues at Teagasc and internationally that increases in IGF–1 in blood have been positively associated with improved fertility.

Gene expression is the process by which information from a gene (found in DNA) is used in the synthesis of a functional gene product which is generally a protein. Proteins carry out the main functions of a cell. The synthesis of IGF–1 occurs mainly in the liver however it is locally produced in other tissues such as the uterus. In the current study we were interested in genes in the uterus that regulate the synthesis of PG, IGF–1 and important hormones that influence fertility and how these are affected through feeding supplementary n–3 PUFA in the diet.

2. Questions addressed by the project:

What are the effects of dietary supplementation of n–3 PUFA on uterine gene expression in cattle and how any changes in expression could potentially impact on fertility in cattle?

3. The experimental studies:

Beef heifers (n = 7) were supplemented with a rumen protected source of either a saturated fatty acid (control) or high n–3 PUFA (275g) (High PUFA) diet per animal per day for 45 days. These animals were slaughtered and uterine endometrial tissue was recovered. Tissue and blood samples were analysed to confirm that the diets offered had evoked different concentrations of n–3 PUFA in both systemic circulation as well as the uterus of the supplemented and control animals. The effect of dietary n–3 PUFA on uterine gene expression was then examined, with particular focus on three components:

- We investigated if feeding n–3 PUFA altered the expression of specific genes involved in the prostaglandin biosynthesis pathway in uterine tissue.
- Synthesis of IGF–1 mainly occurs in the liver however it is also locally produced in the uterus. We therefore examined if feeding n–3 PUFA altered expression of the genes that synthesize IGF–1 in liver and locally in the uterus.
- In an effort to gain a broader understanding of the role of n–3 PUFA in cattle, we conducted a study to analyse simultaneously the expression of 23,000 genes in the uterus of cows fed either control or high PUFA diets.

4. Main results:

5. Dietary supplementation with n–3 PUFA altered the expression of genes necessary for PG biosynthesis in the uterus. The results indicate an alteration in the cellular concentrations of the enzymes controlling the biosynthesis of PGs in a manner which may positively influence uterine function and embryo survival.
6. Dietary supplementation with n–3 PUFA altered the gene expression of components of the IGF system in both the uterus and liver of cattle; however, the changes occurred in a tissue dependent fashion. The pattern of expression of IGF–1 and IGF–2 in the uterus of animals fed the n–3 PUFA diet was similar to that previously observed in pregnant cows and may indicate a more suitable environment for embryo survival.

7. Dietary supplementation with n–3 PUFA can change gene expression in numerous biological processes which potentially have important roles in the establishment of early pregnancy, including prostaglandin biosynthesis, steroidogenesis, transcription factor regulation, immune response and tissue remodelling. An amendment to any of these processes has the potential to influence a variety of reproductive events and thus warrant further investigation into the possible regulatory mechanisms and effects.

5. Opportunity/Benefit:

The opportunities of this research for the broader animal science community and livestock industry are that enriching cattle diets with n–3 PUFA evokes significant alterations in the expression of uterine genes, particularly in those regulating the PG and IGF–1 biosynthesis and action, the pattern of which suggests a potential beneficial effect on fertility. It is only when the magnitude and timing of these effects are elucidated that appropriate supplementation regimens may be accurately and cost-effectively developed.

6. Dissemination:

Data from this study has been transferred through national and international conferences, scientific publication in international peer reviewed articles and in technical papers and magazines.

Main publications:

Coyne GS, Kenny DA, Childs S, Sreenan JM, Waters SM. (2008) 'Dietary n–3 polyunsaturated fatty acids alter the expression of genes involved in prostaglandin biosynthesis in the bovine uterus'. Theriogenology 70: 772–782.

Coyne, G.S., Morris, D.G., Childs, S., Kenny, DA, Waters, S.M. (2008) 'Effect of dietary n–3 polyunsaturated fatty acids on gene expression in the bovine uterus using microarray technology'. Proceedings from the 3rd international symposium on Animal Functional Genomics. 7–9th April, Edinburgh. P36.

Coyne GS, Kenny DA, Waters SW. (2011) 'Effect of dietary n–3 polyunsaturated fatty acid supplementation on bovine uterine endometrial and hepatic gene expression of the insulin-like growth factor system'. Theriogenology 75: 500–512.

Popular publications:

Waters, S.M. Dietary polyunsaturated fatty acid supplementation modifies the expression of key uterine genes involved in cow fertility. TResearch Issue 2–February 2007. Waters, S.M. Diets for fertility. Farm today. November 2006.

Animal and Grassland Research & Innovation Programme

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Project dates:
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Manipulating the ensilage of maize whole-crop, cob and stover

Collaborating Institutions:
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Key external stakeholders:

Livestock farmers, contract tillage farmers, commercial companies, ruminant nutritionists, anaerobic digestion biogas producers, Dept. Agriculture, Food and the Marine.

Practical implications for stakeholders:

Maize silage can be an expensive feed to produce, and variation in yield, quality and some conservation traits remains a limitation to the attractiveness of this crop.

- The optimal harvest date for whole-crop maize varies with the hybrid sown, the weather pattern of that year and the particular balance required between crop yield and quality.
- Circumstances exist where some farmers can reduce fertiliser nitrogen (N) input without lowering the yield or quality of maize silage.
- Maize cobs and stover can be successfully ensiled separately.
- An indigenous 'wild type' lactic acid bacteria can be present on a crop and prevail over added lactic acid bacteria added to maize at ensiling.
- Upgrading stover digestibility, to increase whole-crop nutritive value, remains an unfulfilled goal.

Main results:

- The higher whole-crop yields achieved with high biomass later-maturing hybrids of forage maize result from higher yields of stover compared to more conventional early-maturing hybrids.
- The digestibility of whole-crop maize can increase and then decline during September-October, and this profile differs among hybrids. There is therefore a unique optimal time at which to harvest each hybrid.

Technology

- Similar yields, nutritive value, ensiling characteristics and aerobic stability occurred when maize was grown with either a high permitted input of organic N or of organic N plus inorganic N fertiliser.
- Inoculation with added lactic acid bacteria did not improve silage aerobic stability because of the activity of an indigenous 'wild type' lactic acid bacteria.
- Two types of white-rot fungi reduced rather than improved the digestibility of conserved stover.

Opportunity/Benefit:

- Greater precision can now be exercised during the production and harvest of forage maize, or of cob and stover, to produce ensiled feed of a particular quality.
- Costs can be reduced in some circumstances by using less N fertiliser, without any negative implications for maize yield or quality traits.
- Limitations were identified to improving the aerobic stability of maize silage and to upgrading stover nutritive value. These limitations remain to be solved. However, an indigenous lactic acid bacteria with potential to improve aerobic stability was discovered.

1. Project background:

Forage maize has the potential to produce a very high yield of biomass, of high digestible energy content and ensilability, in a single harvest. These yield and quality traits can be altered by the hybrid and N fertiliser input used. Whereas well developed crops should not produce effluent during ensilage, whole-crop maize silages do tend to be aerobically unstable during feedout, and the resultant aerobic deterioration can diminish the quantity and quality of feed used.

The cob (high digestibility and starch content) and stover (high fibre and buffering capacity; relatively low digestibility) components of whole-crop maize provide contrasting energy and ensilability characteristics, and both of these components undergo considerable changes during the maturing phase of the crop in September-October. Although forage maize is normally ensiled as a whole-crop and fed to ruminants, the potential exists to ensile cob and stover separately. These components can be recombined in optimal combinations prior to feeding, or they can be fed separately to different categories of livestock. In addition, the separate ensilage of these two quite different substrates provides the opportunity to differentially manipulate their fermentation during ensilage. This has potential to improve the efficiency of conservation or improve the nutritive value of the conserved products. It also provides the opportunity to exploit non-agricultural uses of maize cob, stover or whole-crop.

2. Questions addressed by the project:

- How do high biomass hybrids of forage maize compare to more conventional early-maturing hybrids (those currently used to provide feed for ruminants in Ireland) in terms of the relative contributions of cob and stover to the whole-crop during the maturing phase of the crop in September-October? What are the subsequent effects of hybrid and harvest date on the conservation characteristics of whole-crop silage, and how differentially do the cob and stover affect these conservation characteristics?
- How does a high biomass hybrid of forage maize compare to more conventional hybrids, when grown with high permitted rates of organic or total N input, in terms of the relative contributions of cob and stover to the whole-crop during the maturing phase of the crop in September-October? What are the subsequent effects of N application rate, hybrid and harvest date on the conservation characteristics of whole-crop silage, and how differentially do the cob and stover affect these conservation characteristics?
- What are the effects of three lactic acid bacteria, thought to differ in their effects on silage aerobic stability, on the temporal profile of fermentation and subsequent aerobic stability of silages made from the chemically contrasting cob and stover components of forage maize?
- Can either of two white-rot fungi (Pleurotus ostreatus or Trametes versicolor), known to be capable of upgrading low digestibility lignocellulosic substrate, improve the digestibility of maize stover? Is the response affected by the part of the stover digested or by its physiological state at harvest?

3. The experimental studies:

- Using a split-plot design with three replicate blocks, six hybrids of forage maize (four conventional [FAO 190–230] and two high biomass [FAO 260–280]) were harvested on three dates between mid-September and late October. In each case, (a) the yield and chemical

composition of the whole-crop, and of the cob and stover components, was assessed, and (b) samples of each of these entities were ensiled in laboratory silos, and silage chemical composition, yeast numbers and aerobic stability were quantified.

- Using a split-plot design with three replicate blocks, three hybrids of forage maize (two conventional and one high biomass), grown under two nitrogen input regimes (33 vs. 168kg available N/ha), were harvested on three dates between mid-September and late October. In each case, (a) the yield and chemical composition of the whole-crop, and of the cob and stover components, was assessed, and (b) samples of each of these entities were ensiled in laboratory silos, and silage chemical composition, lactic acid bacteria and yeast numbers, and aerobic stability were quantified.
- Maize cobs and stover were ensiled in laboratory silos following treatment with no additive, Lactobacillus plantarum MTD–1, Lactobacillus plantarum 30114 or Lactobacillus buchneri 11A44. Triplicate silos were opened after 3, 10, 35 or 130 days ensilage, and silage chemical and microbiological (using both traditional and molecular biology techniques) composition, and aerobic stability characteristics, were determined.
- Three components of maize stover (leaf, upper stem and lower stem) were harvested on each of three dates (early September, early October and early November) and digested with each of two white-rot fungi (Pleurotus ostreatus and Trametes versicolor) for one of four digestion durations (1–4 months). A split-plot design was used, with three replicate blocks.

4. Main results:

- High biomass hybrids had a lower content of cobs, and these in turn were less mature, compared to conventional hybrids. The higher whole-crop dry matter (DM) yield for the high biomass hybrids reflected their higher yield of stover DM. Across all hybrids, whole-crop DM digestibility increased until 7 October (due to the increasing starch content of the cobs and the increasing cob proportion in the whole-crop) and declined thereafter (due to the increasing fibre content in the stover, and probably a simultaneous decline in fibre digestibility). Whole-crop silages had more restricted and heterolactic fermentations at later harvest dates, and this was more pronounced with conventional hybrids. Overall, the fermentation characteristics of the whole-crop reflected the different contributions of the cob and stover components.
- Increasing the rate of applying N fertiliser had no effect on the DM yield, nutritive value, ensiling characteristics or silage aerobic stability associated with the whole-crop under the prevailing conditions (soil had relatively high organic N content; accumulated ambient heat units during crop growth were low). Although the water-soluble carbohydrate (g/litre aqueous content) and buffering capacity results indicated that whole-crop maize was readily ensilable, the ensilability characteristics of the stover were more challenging than for the cobs.
- The nutritive value, aerobic stability and DM recovery of cob and stover silages were not improved by inoculation with Lactobacillus plantarum MTD–1, Lactobacillus plantarum 30114 or Lactobacillus buchneri 11A44. This was due to the highly heterolactic secondary fermentation that dominated the later stages of the 130 day ensilage process. The latter was most likely promoted by an indigenous epiphytic Lactobacillus buchneri.
- Both white-rot fungi reduced rather than increased herbage DM and neutral detergent fibre digestibility after a four month digestion. This may reflect the rapid utilisation of readily digestible cell wall carbohydrate by the fungi substantially reducing the opportunity for lignin degradation to improve digestibility. While Pleurotus ostreatus showed the ability to degrade acid detergent lignin after more than 1 month of digestion had elapsed (this effect was most evident with leaf and upper stem), leading to a partial recovery in DM digestibility, the Trametes versicolor showed no such effect.

5. Opportunity/Benefit:

- Greater precision can now be exercised during the production and harvest of forage maize, or of cob and stover, to produce ensiled feed of a particular quality.
- Costs can be reduced in some circumstances by using less N fertiliser, without any negative implications for maize yield or quality traits.
- Limitations were identified to improving the aerobic stability of maize silage or to upgrade stover nutritive value. These limitations remain to be solved. However, an indigenous lactic acid bacteria with potential to improve aerobic stability was discovered.

6. Dissemination:

Main publications:

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2012). 'Yield, nutritive value and ensilage characteristics of whole-crop maize, and of the separated cob and stover components – nitrogen, harvest date and cultivar effects.' *Journal of Agricultural Science (Cambridge)*, [doi:10.1017/S0021859612000342].

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2012). 'Yield, quality and ensilage characteristics of whole-crop maize and of the cob and stover components: harvest date and hybrid effects.' *Grass and Forage Science*, [doi: 10.1111/j.1365–2494.2012.00868.x].

Lynch, J.P., O'Kiely, P., Murphy, R. and Doyle, E.M. (2012). 'Changes in chemical composition of three maize stover components harvested at sequential maturities and digested by white rot fungi. *Journal of the Science of Food and Agriculture* (under review).

Lynch, J.P., O'Kiely, P., Waters, S.M. and Doyle, E.M. (2012). 'Conservation characteristics of corn ears and stover ensiled with the addition of Lactobacillus plantarum MTD–1, L. plantarum 30114, or Lactobacillus buchneri 11A44.' *Journal of Dairy Science*, 95: 2070–2080.

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2010). 'Conservation characteristics of maize cultivars ensiled as whole-crop, cob or stover at sequential stages of maturity.' In: (eds. H. Schnyder, J. Isselstein, F. Taube, K. Auerswald, J. Schellberg, M. Wachendorf, M. Hermann, M. Gierus, N. Wrage and A. Hopkins) *Proceedings of 23rd General Meeting of the European Grassland Federation*, Kiel, Germany (29 August – 2 September, 2010). *Grassland Science in Europe*, 15: 356–358.

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2010). 'Yield and chemical composition of contrasting maize cultivars at sequential stages of maturity.' *Proceedings of a joint meeting of the Agricultural Research Forum and the British Society of Animal Science* (Cambridge University Press), Belfast, 12–14 April, p322.

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2010). 'Yield and agronomy of contrasting cultivars of maize harvested at sequential stages of maturity in 2008 and 2009.' *Proceedings of the Irish Plant Scientists Association meeting*, University College Dublin, 2–4 June, 2010. Paper S3–1.

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2011). 'Conservation characteristics of ensiled maize whole-crop, cob and stover – harvest date, cultivar and N application rate effects.' *Proceedings of the British Grassland Society* 10th Research Meeting, 20–21 Sept. 2011, Belfast. Published by British Grassland Society. p55–56.

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2011). 'Dry matter recovery and aerobic stability of maize whole-crop, cob and stover silages – harvest date and cultivar effects.' *Eucarpia – 29th Fodder Crops and Amenity Section meeting*, Dublin, 4–8 September 2011. *Book of Abstracts* – p66.

Lynch, J.P., O'Kiely, P. and Doyle, E.M. (2011). 'Yield and chemical composition of whole-crop maize and its components – harvest date, cultivar and N application rate effects.' *Proceedings of the Agricultural Research Forum*, Tullamore, 14 & 15 March, p95.

Lynch, J.P., O'Kiely, P., Murphy, R. and Doyle, E.M. (2012). 'Changes in chemical composition of three maize stover components harvested at sequential maturities and digested by white rot fungi.' *Proceedings of the Agricultural Research Forum*, Tullamore, 12 & 13 March, p114.

Lynch, J.P., O'Kiely, P., Murphy, R. and Doyle, E.M. (2012). 'White-rot fungal digestion of maize stover components harvested at sequential maturities.' In (Editors K. Kuoppala, M. Rinne and A. Vanhatalo) *Proceedings of the XVI International Silage Conference*. Hameenlinna, Finland, 2–4 July 2012, p220–221.

Lynch, J.P., O'Kiely, P., Waters, S.M. and Doyle, E.M. (2012). 'Conservation characteristics of maize stover ensiled with the addition of *Lactobacillus plantarum* MTD–1, *L. plantarum* 30114 or *L. buchneri* 11A44.' In (Editors K. Kuoppala, M. Rinne and A. Vanhatalo) *Proceedings of the XVI International Silage Conference*. Hameenlinna, Finland, 2–4 July 2012, p372–373.

Lynch, J.P., O'Kiely, P., Waters, S.M. and Doyle, E.M. (2012). 'Conservation characteristics of maize cob ensiled with the addition of *Lactobacillus plantarum* MTD–1, *L. plantarum* 30114 or *L. buchneri* 11A44.' In: (eds. P. Golinski, M. Wanda & P. Stypinski) *Proceedings of 24th General Meeting of the European Grassland Federation*, Lublin, Poland (4–7 June, 2012). *Grassland Science in Europe*, 17:373–375.

Popular publications:

Lynch, J., O'Kiely, P. and Doyle, E. (2012). 'Improving forage maize production in Ireland.' *T.Research*, Spring 2012, Vol. 7 (No. 1): p17.

Animal and Grassland Research & Innovation Programme

Project number:
5501

Date:
March, 2011

Funding source:
Teagasc & Dairy Levy

Project dates:
Jan 2006–Dec 2010

The influence of animal genetic potential across a variety of futuristic pasture-based systems of milk production

Key external stakeholders:

Grass based dairy farmers; milk processors; ICBF & AI companies; consultancy agencies; education agencies.

Practical implications for stakeholders:

With land availability the likely longer term limitation to increased productivity, the objective of Irish production systems will be to increase productivity per unit of available feed through increased grass production and utilisation.

The findings of this research project indicate that:

- High Economic Breeding Index (EBI) genotypes produced greater volumes of milk solids, maintained superior body condition score (BCS) during lactation, achieved improved reproductive performance and were more feed efficient when compared to lower EBI animals.
- Selection for increased genetic merit for milk and fertility related traits using the Irish EBI will result in substantial improvements in economic performance and increased tolerance to fluctuating milk prices when compared to average genetic potential genotypes.

Main results:

Selection for increased genetic merit for milk and fertility related traits using the Irish EBI will result in substantial improvements in economic performance and increased tolerance to fluctuating milk prices when compared to average genetic potential genotypes

Collaborating Institutions:
University College Dublin
FBD Trust

Teagasc project team:
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Technology

Opportunity/Benefit:

Irish dairy farmers should use high EBI AI sires to increase the future productivity and profitability of their dairy herds.

1. Project background:

Irish milk production systems are characterized by a pasture based diet incorporating lower production costs within a European Union (EU) context. With the proposed abolition of EU milk quotas by 2015, milk production within the EU will move to areas of competitive advantage such as Ireland. With land availability the likely longer term limitation to increased productivity, the objective of Irish production systems will be to increase productivity per unit of available feed through increased grass production and utilization. Such adaptations have occurred in other pasture-based countries and are characterized by increased stocking densities and adjustments to breeding objectives to increase production efficiency.

2. Questions addressed by the project:

- What is the impact of genetic improvement using the Irish total merit index, the economic breeding index (EBI), on overall biological and economic performance of two likely post quota pasture-based systems of milk production?
- What is the profile dry matter (DM) intake across the entire lactation within intensive pasture based systems?
- Can we establish the profile of feed efficiency over the lactation?

3. The experimental studies:

Three genotypes of Holstein-Friesian dairy cattle were established from within the Moorepark dairy research herd: LowNA, indicative of the Irish national average genetic merit North American Holstein-Friesian at the time of the study; HighNA, high genetic merit North American Holstein-Friesian; HighNZ, high genetic merit New Zealand Holstein-Friesian. Animals from within each genotype were randomly allocated to one of two possible post European Union milk quota pasture-based feeding systems (FS): 1) The Moorepark pasture (MP) system (2.64 cows/ha and 344 kg concentrate supplement per cow per lactation) and 2) a high output per hectare (HC) system (2.85 cows/ha and 1,056 kg concentrate supplement per cow per lactation). Pasture was allocated to achieve a similar post grazing residual sward height for both treatments. A total of 126, 128 and 140 spring calving dairy cows were used during the years 2006, 2007 and 2008, respectively. Each group had an individual farmlet of 17 paddocks and all groups were managed similarly throughout the study.

4. Main results:

The current body of research investigated the effects a total merit index derived under Irish conditions for increased farm profitability on potential future performance of Irish production systems. A thorough examination of phenotypic performance was undertaken on three genotypes of HF to determine the potential milk production, fertility performance, DM intake capacity across lactation, feed efficiency and overall economic performance when managed under two intensive pasture based FS for a post milk quota scenario.

The results clearly illustrate the potential benefits that may be achieved from increased EBI through increased genetic merit for increased MS production and improved fertility performance. The results also show the benefits of intensive pasture based systems of milk production in terms of increased pasture growth and utilisation and increased stock carrying capacity resulting in increased output per unit of land. Specifically, the main findings include:

- High EBI genotypes produced more milk solids per cow and per hectare, maintained a higher body condition score and had improved reproductive performance compared to the LowNA genotype.
- Selection using the Irish EBI had no effect on DMI across lactation.
- The ranking of genotypes for feed efficiency differed depending on the definition of feed efficiency used and that while differences in feed efficiency exist between strains of Holstein-Friesian, variation also exists within genotypes so that improvements in feed efficiency can be achieved.
- Selection for increased genetic merit for milk and fertility related traits using the Irish EBI will result in substantial improvements in economic performance and increased tolerance to fluctuating milk prices when compared to average genetic potential genotypes

5. Opportunity/Benefit:

Irish dairy farmers should use High EBI AI sires to increase the future profitability of their dairy herds

6. Dissemination:

During each week of the grazing season, a web update of the research activities was published on the Teagasc website to allow stakeholders to follow the project. The update was used by research and advisory staff to disseminate research findings to the wider industry. The research results from the web also featured in the mainstream agricultural media. (http://www.agresearch.teagasc.ie/moorepark/CurtinsFarm/curtins.asp)

In addition to open day events, individual discussion groups frequently visited the experiment during the project. Topics covered at these events by research and advisory staff included grassland management best practice advice, animal breeding and health recommendations and economic implications of research results.

Main publications:

Coleman, J., Berry, D.P., Pierce, K.M., Brennan, A. and Horan, B. (2010). Dry matter intake and feed efficiency profiles of 3 genotypes of Holstein-Friesian within pasture-based systems of milk production. Journal of Dairy Science 93:4318–4331

Coleman, J., Pierce, K.M., Berry, D.P., Brennan, A. and Horan, B. (2010). Increasing milk solids production across lactation through genetic selection and intensive pasture-based feed system. Journal of Dairy Science 93:4302–4317

Coleman, J., Pierce, K.M., Berry, D.P., Brennan, A. and Horan, B. (2009). The influence of genetic selection and feed system on the reproductive performance of spring-calving dairy cows within future pasture-based production systems. Journal of Dairy Science 92:5258–5269

Effects of grass silage and maize silage feed value, and concentrate feed level on ewe and lamb performance

Project number:
5657
Date:
September 2012
Funding source:
Teagasc
Project dates:
Nov 2006–Nov 2011

Key external stakeholders:

Sheep producers, ruminant nutritionists, agricultural consultants, extension officers, Department of Agriculture, Food and the Marine

Practical implications for stakeholders:

- The feed value of grass silage offered to ewes during pregnancy influences subsequent lamb birth and weaning weights by up to 0.6 and 1.3 kg respectively.
- Grass silage feed value is affected by harvest system and has an impact on subsequent lamb performance.
- Maize can replace grass silage in the diet of pregnant ewes and finishing lambs.
- Whilst maize silage is characterized as having low crude protein concentrations, additional dietary protein supplementation is not required by ewes until late pregnancy.
- Response to concentrate supplementation is dependent on forage feed value but not forage type.
- High feed value forage reduces concentrate requirements for ewes in late pregnancy by up to 80%.
- High feed value forage increases finishing lamb performance even when it accounts for as low as 37% of food DM intake.
- High levels of finishing lamb performance (267g/day) are achievable from *ad libitum* concentrate feeding.

Collaborating Institutions:
N/A

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External collaborators:
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Technology

Main results:

- Relative to growing maize in the open use of the complete cover plastic mulch (CCPM) system increased forage yield by up to 42% and dry matter concentration at harvest by up to 98g/kg.
- Increasing grass silage feed value offered to pregnant ewes increased lamb birth and weaning weights and reduced concentrate requirement in late pregnancy by up to 80%.
- Whilst silage harvest system had no affect on lamb performance or lamb birth weight, lambs from animals which had been offered big bale silage during pregnancy were 1.8kg lighter at weaning.
- Increasing maturity of maize at harvest, when offered to pregnant ewes tended to increase lamb weaning weight by 1kg and when offered to finish lambs tended to increase slaughter weight by 1.4kg.
- Ewes offered maize silage do not require protein supplementation until late (final 7 weeks) pregnancy.
- Ad-libitum concentrate supplementation resulted in high levels of performance (live weight gain of 267g/day) of finishing lambs.
- The response to concentrate feed level offered to finishing lambs depends on forage feed value, but not forage type.

Opportunity/Benefit:

The results of this project demonstrate the benefit of producing high feed value silages for offering to pregnant ewes and to finishing lambs. The benefits for pregnant ewes include improvements in ewe weight and condition at lambing, increased lamb birth weight, and lamb growth rate to weaning consequently increasing weaning weight which reduced age at drafting by up to 2 weeks. Furthermore, increasing forage feed value reduces concentrate requirements in late pregnancy by up to 80%. For finishing lambs the benefits to high feed value silages, which are high growth rate and dressing proportion are still apparent when concentrate accounts for up to 63% of total dry matter intake. Maize silage can replace high feed value grass silage in the diet of pregnant ewes. For finishing lambs *ad-libitum* concentrate feeding results in high levels of lamb performance.

1. Project background:

Grass growth in Ireland is seasonal, peaking in May and June with little daily production between December and March. Consequently, on many farms ewes are housed during the winter feeding period to enable a higher stocking rate to be achieved. During the indoor period ewes are normally offered silage, which can differ in forage type and feed value which is influenced by harvest system. The level of concentrate supplementation required by ewes in late pregnancy is dependent on forage feed value and litter size. Whilst many lambs are finished by the end of the grazing season approximately 20% are slaughtered between January and March thus providing a continuous supply of lamb to the market. During finishing use of high feed value ensiled forages many enable a reduction in the costs of production.

2. Questions addressed by the project:

- What is the impact of silage feed value on ewe and subsequent lamb performance?
- What is the potential concentrate spring effect of high feed value forages?
- What is the effect of the big bale silage system on silage feed value when offered to pregnant ewes?
- What is the feed value of maize silage for pregnant ewes and finishing lambs?
- Is additional, protein supplementation required by ewes and lambs offered maize silage base diets?
- Does stage of maturity at harvest influence maize silage feeding value?
- Is the response to concentrate supplementation influenced by forage type and feed value?
- What level of performance is achievable from finishing lambs offered *ad-libitum* concentrate diets?

3. The experimental studies:

Experiment 1.

The effects of grass silage harvest system, concentrate feed level and maize silage maturity and soyabean supplementation on ewe and subsequent lamb performance. Ewes (n=180) were allocated at random to 12 treatments from day 58 of pregnancy until lambing in early March. The 12 treatments were 2 maize silages (low DM, high DM) x 2 protein levels (0 and 200g soya/ewe daily) and 2 grass silage harvest system (precion chop, big bale) x 2 harvests (29th

May, 18th July) x 2 concentrate feed levels (18 and 27 kg/ewe during late pregnancy). Post lambing all ewes rearing singles and twins were grazed as one flock until weaning without concentrate supplementation. Ewes rearing triplets received 0.5kg concentrate for 5 weeks post lambing whilst their lambs had access to up to 300g concentrate per lamb daily until weaning.

Experiment 2.

The effects of maturity of maize at harvest and soyabean supplementation, grass silage feed value and concentrate feed level on ewe and subsequent lamb performance. Nine dietary treatments were offered to 160 ewes during mid and late pregnancy. The 9 treatments were 2 maize silages (low and high DM) x 2 levels of protein supplementation (0 or 200 g soyabean meal/ewe daily) and 2 grass silages (high or medium feed value) x 2 concentrate feed levels (15 or 25 kg/ewe in late pregnancy) and high feed value grass silage supplemented with 5kg concentrate per ewe in late pregnancy. The ewes offered the maize silage based diets received 15kg concentrate per ewe during late pregnancy. Post lambing the ewes and their lambs were managed as described in experiment 1.

Experiment 3.

The effects of supplementation of maize silage diets during pregnancy on ewe and subsequent lamb performance. Three dietary treatments were offered to ewes during mid and late pregnancy. The diets consisted of maize silage (DM 33g/kg, starch 236g/kg DM) supplemented with either 200g soyabean meal daily during mid and late pregnancy plus 15 kg concentrate in late pregnancy (SC); 10kg soyabean meal during late pregnancy (10S) or 5kg soyabean meal during late pregnancy (5S).

Experiment 4.

The effect of grass silage and concentrate feed level on ewe and subsequent progeny performance and on potential concentrate sparing effect. High and medium feed value grass silages were ensiled precision chopped treated with a bacterial inoculant following a 24 hour wilt on 12th May and 14th June respectively. Seven treatments consisting of medium feed value grass silage supplemented with either 15, 25, 35 or 45kg concentrate and high feed value grass silage supplemented with either 5, 15 or 25kg concentrate in late pregnancy were offered to 112 ewes during mid and late pregnancy respectively.

Experiment 5.

The effects of maturity of maize at harvest, grass silage feed value and concentrate feed level on finishing lamb performance. High and medium feed value grass silages were ensiled on 11th May and 8th June precision chopped and treated with a bacterial inoculant. Two maize silages were produced either grown in the open (sown 8th May) or under the CCPM system (sown 16th April). Thirteen dietary treatments were offered to 260 Suffolk-X lambs for 76 days prior to slaughter. The 13 treatments were as follows: 2 grass silages (high and medium feed value) and 2 maize silages (low and high DM) x 3 concentrate feed levels (0.2, 0.5 or 0.8kg/lamb daily) plus ad-libitum concentrate plus with 0.5kg high feed value grass silage.

Experiment 6.

The effects of forage type and feed value, concentrate feed level and protein concentration, and shearing on lamb performance. Maize was grown under the CCPM system and ensiled on 29th September. High and medium feed value grass silages were ensiled on 24th May and 17th June respectively. Eleven dietary treatments were offered to 264 castrated male Suffolk-X lambs for 54 days prior to slaughter. The eleven dietary treatments were as follows: 2 grass silages (high and medium feed value) and maize silage x 3 concentrate feed levels (0.4, 0.8 or 1.2kg/d) plus *ad-libitum* concentrate supplemented with 0.5kg high feed value grass silage plus maize silage supplement with 0.4kg of low protein concentrate.

4. Main results:

Experiment 1.

- Silage harvest system did not alter forage intake or ewe performance. However, lambs born from ewes effected the precision chopped silage were heavier at weaning.
- Increasing concentrate by 9 kg to ewes offered the grass silage increased lamb birth weight by 0.3 kg.
- Protein supplementation of maize silage during pregnancy did not alter ewe or lamb performance.
- Increasing maturity (DM) of maize at harvest increased forage intake and ewe condition at lambing and improved lamb weaning weight by 1.05kg.

Experiment 2.

- The DMD of the medium and high feed value grass silages were 730 and 790 g/kg respectively. The DM and starch concentrations of the low and high DM maize silages were 215 and 339 g/kg and 110 and 236 g/kg DM respectively.
- Use of the CCPM system increased forage yield by 42% and forage DM at ensiled by 98g/kg, compared to maize grown in the open.
- Increasing grass silage feed value increased ewe condition and weight at lambing, and lamb weight at birth (+0.5kg) and weaning (+1.8kg) and reduced lamb age at slaughter by 13.5 days.
- Increasing concentrate feed level in late pregnancy had no effect on ewe or lamb performance.
- High feed value grass silage can reduce concentrate supplementation in late pregnancy by up to 80%.
- Increasing maize maturity at harvest increased ewe weight and condition at lambing and tended to improve lamb weaning weight by 1.1kg.
- Protein supplementation of maize silage based diets during mid and late pregnancy increased ewe condition and weight at lambing and lamb birth weight (+ 0.25kg) but did not affect lamb weaning weight.

Experiment 3

- Soyabean supplementation during mid-pregnancy did not improve ewe or lamb performance.
- Ewes offered the 5S treatment had lower condition at lambing and tended to produce lambs with lower weigh at birth.
- With maize-silage based diets concentrate supplementation can be reduced to approximately 10kg soya per ewe during late pregnancy.

Experiment 4.

- Increasing silage feed value increased ewe weight and condition at lambing.
- Increasing concentrate feed level with the medium feed value grass silage linearly increased ewe condition and weight post lambing and lamb birth weight.
- Concentrate level offered with the high feed value silage did not alter lamb birth or weaning weights.
- Each 1 kg increase in concentrate feed level for ewes offered the medium and high feed value grass silages increased lamb birth weight by 0.015 and 0.019kg respectively.
- In terms of lamb birth weight the potential concentrate sparing effect of the high feed value grass silage supplemented with either 5, 15 or 25kg concentrate was 9, 7 and 5kg respectively.

Experiment 5.

- Dietary treatment had a large effect on lamb performance (daily live weight gain varied from 46 to 267g/d).
- Use of the CCPM system increased forage DM yield by 36% and forage DM concentration at ensiling by 65g/kg.
- Increasing grass silage feed value increased lamb daily live weight (71g) and carcass (37g) gain.
- Increasing concentrate feed level increased lamb performance.
- Increasing maturity of maize at harvest tended to increase lamb performance.
- There was a greater response to concentrate supplementation from lambs offered medium feed value maize and grass silages (+ 33 and 62g live weight gain per lamb daily) relative to those offered the high feed value maize and grass silage respectively.
- Forage type had no effect on the response to concentrate feed level.
- Relative to the medium feed value grass silage supplemented with 0.2kg concentrate/lamb daily the potential concentrate sparing effect of the high feed value grass silage and the medium and high feed value maize silages were 0.41, 0.10 and 0.25 kg per lamb daily respectively.

Experiment 6.

- Maize silage based diets resulted in the highest levels of lamb performance.
- Response to concentrate depended on forage feed value. The response was linear for lambs offered the high feed value grass and maize silages and quadratic when offered the medium feed value grass silage.
- Whilst the response to forage feed value declined as concentrate feed level increased. There was still a benefit to high feed value forage when it accounted for as low as 37% of total feed intake.
- Reducing concentrate protein concentration to 144g/kg DM did not alter lamb performance.

5. Opportunity/Benefit:

- Greater precision can be exercised when formulating winter diets for pregnant ewes and finishing lambs.
- A number of options are developed that enable the same levels of ewe and lamb performance to be achieved, therefore the least cost option can be implemented to improved individual farm profitability.

6. Dissemination:

Main publications:

Keady, T.W.J. and Hanrahan, J.P. (2008). 'The effects of grass silage harvest system, concentrate feed level and maize silage maturity and soyabean supplementation on ewe and subsequent lamb performance'. *Proceedings of the British Society of Animal Science* p125.

Keady, T.W.J. and Hanrahan, J.P. (2009). 'An evaluation of the effects of maturity of maize at harvest and soyabean supplementation, grass silage feed value and concentrate feed level on ewe and subsequent lamb performance'. *Proceedings of the Agricultural Research Forum* p16.

Keady, T.W.J. and Hanrahan, J.P. (2009) 'The effects of maturity of maize at harvest and soyabean supplementation, grass silage feed value and concentrate feed level on ewe and subsequent lamb performance'. *Proceedings of the XVth International Silage Conference* pp. 133–134.

Keady, T.W.J. and Hanrahan, J.P. (2009). 'The effects of supplementation of maize silage diets during pregnancy on ewe and subsequent lamb performance'. *Proceedings of the British Society of Animal Science* p51.

Keady, T.W.J. and Hanrahan, J.P. (2010). 'An evaluation of the effect of grass silage and concentrate feed level on ewe and subsequent progeny performance and on the potential concentrate sparing effects'. *Proceedings of the British Society of Animal Science* p38.

Keady, T.W.J. and Hanrahan, J.P. (2011). 'An evaluation of the effects of maturity of maize at harvest, grass silage feed value and concentrate feed level on finishing lamb performance'. *Proceedings of the Agricultural Research Forum* p63.

Keady, T.W.J. and Hanrahan, J.P. (2012) 'An evaluation of the effects of forage type and feed value, concentrate feed level and protein concentration and shearing on lamb performance'. *Proceedings of the XVI International Silage Conference, Hameenlinna, Finland* pp168–169.

Keady, T.W.J. and Hanrahan, J.P. (2012). 'Effects of forage type and feed value, concentrate feed level and protein concentration, and shearing on lamb performance'. *Animal* (under review).

Keady, T.W.J. Marley, C.L. and Scollan, N.D. (2012). 'Grass and alternative forage silages for beef and sheep: effects on animal performance'. *Proceedings of the XVI International Silage Conference, Hameenlinna, Finland* pp152–165 (invited paper).

Keady, T.W.J. and Hanrahan, J.P. Marley, C.L. and Scollan, N.D. (2012). 'Silage production – factors affecting the utilization of ensiled forages by beef cattle, dairy cows, pregnant ewes and finishing lambs'. A review. *Agricultural and Food Sciences (under review)*.

Popular publications:

Keady, T.W.J. (2010) 'Finishing store lambs: what diet to offer'. *Irish Farmers Journal* 63, (49): 28–29.

Keady, T.W.J. (2011) 'Late pregnancy nutrition – the key to flock profitability'. *Irish Farmers Journal* 64, (4): 28–29.

Animal and Grassland Research & Innovation Programme

Project number:
5798

Date:
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Nov 2007 to Oct 2011

Strategies to increase the length of the grazing season for spring and autumn calving cows

Key external stakeholders:

Dairy farmers, extension officers, dairy processors

Practical implications for stakeholders:

- Cows can be retained at pasture during periods of heavy rainfall without any poaching damage occurring due to the development of on/off grazing technologies which will lead to an increase in the number of days at grass.
- On/off grazing can also be used as a strategy to allow an earlier turnout date on farms with heavy soil.
- Grazed grass in conjunction with low levels of concentrate can be incorporated into the diet of early lactation autumn calving dairy cows for a 6 week period and cumulative milk production levels similar to TMR fed cows can be achieved.

Main results:

- No reduction in milk yield, milk solids yield, bodyweight or body condition score was observed when animals were allocated two three hour periods of access to grass compared to cows grazing full-time.
- By adjusting their grazing behaviour (i.e. grazing bites per minute and grass dry matter intake per bite) cows given two three hour periods of access to grass grazed for 5.9 hours (98% of their time at pasture) resulting in no difference in grass dry matter intake.
- By allocating autumn calving cows herbage and a low level of concentrate (1kg DM) during the first 6 weeks of lactation there was a significant reduction in immediate milk production compared to cows offered herbage and either 4 or 8 kg DM concentrate or a TMR. However, when all cows were treated similarly after the initial 6–week period there was no difference in cumulative milk production performance.

Collaborating Institutions:
UCD
INRA
Teagasc Knowledge Transfer

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Technology

Opportunity/Benefit:

This research caters for both spring and autumn calving herds and provides valuable information on how the grazing season can be extended and the proportion of grass in the diet of the dairy cow increased. Increasing the proportion of grass in the dairy cow's diet will reduce feed costs aiding overall farm profitability.

1. Project background:

Soil conditions and inclement weather are two of the biggest limitations affecting the extension of the grazing season on Irish dairy farms. Over 50% of soils in the Republic of Ireland are classified as Podzols, Gleysols or Histosols. These soils are slow draining and practically impervious thereby preventing full-time turnout to pasture in early spring and late autumn, due to a high risk of poaching damage.

Furthermore, due to frequently unfavourable climatic conditions, deteriorating herbage quality and availability, Irish winter milk producers tend to favour retaining autumn calving dairy cows indoors post-partum and offering concentrate based diets.

Currently, farm gate prices are volatile and subjected to fluctuations on world markets thus more low-cost sustainable systems of production for spring and winter milk producers are required. Grazed grass is the cheapest feed available and it has previously been shown that as the proportion of grazed grass in the diet increases costs of production decrease.

2. Questions addressed by the project:

- What is the effect of restricting pasture access time on milk production and composition, bodyweight (BW), body condition score (BCS), dry matter intake (DMI) and grazing behavior of autumn calving dairy cows in early and mid-lactation.
- What is the effect of supplementing dairy cows in early lactation with grass silage when they return indoors after a limited period of access to pasture on animal production performance and grazing behaviour.
- What is the effect of offering three levels of concentrate at pasture to autumn calving dairy cows in early lactation and to compare the milk production performance of these cows to those offered a TMR diet indoors. The study also aimed to evaluate the effect of offering ad-lib TMR during the carryover period on production performance and also total lactation performance.

3. The experimental studies:

Experiment 1 – Effect of restricted access to pasture on production performance of mid-lactation cows

Fifty-two (19 primiparous and 33 pluriparous) Holstein-Friesian dairy cows (mean calving date – 17 August) were balanced and randomly assigned to a four treatment (n = 13) study. The four treatments were: full-time access to pasture (22; control); 9 hours pasture access after a.m. milking (9); three hours pasture access after both milkings (2×3); four-and-a-half hours pasture access after both milkings (2×4.5). All treatments were offered a daily herbage allowance of 15.5 kg DM (dry matter)/cow/day (> 4cm) and supplemented with 3 kg DM/cow/day. Fresh herbage was allocated daily. Additional feed was not offered when animals returned indoors. Treatment groups grazed separately for the duration of the study.

Experiment 2 – Effect of restricted access to pasture on production performance of early lactation dairy cows

Fifty-two (20 primiparous and 32 pluriparous) Holstein-Friesian spring calving dairy cows (mean calving date – 31 January) were balanced in a randomised block design. The animals were randomly assigned to a four treatment (n = 13) study. The four treatments were: full-time access to pasture (22; control); four-and-a-half hours pasture access after both milkings (2×4.5); three hours pasture access after both milkings (2×3); three hours pasture access after both milkings with silage supplementation by night (2×3S). All treatments were offered a daily herbage allowance of 15 kg DM (dry matter)/cow/day (> 4cm) and supplemented with 3 kg DM/cow/day of concentrate. The 2×3S treatment was offered an additional 3 kg DM of grass silage by night. Fresh herbage was allocated twice daily. Treatment groups grazed separate farmlets for the duration of the study so that effects on subsequent grass re-growth could be established. Pre-and post-grazing sward heights were measured daily. Effect of poaching on re-growth was measured by comparing the DM yield of paddocks grazed fulltime to those where pasture access was restricted.

Experiment 3 – Comparison of grazed grass and a TMR diet on early lactation milk production performance

Forty eight (18 primiparous and 30 pluriparous) autumn calving Holstein-Friesian dairy cows (mean calving date – 12 September; s.d. 15 days), were balanced and randomly assigned to a four treatment study (n = 12) at 10 days in milk. The four treatments were: outdoors full-time offered fresh herbage + 1 kg DM concentrate (G1); outdoors full-time offered fresh herbage + 4 kg DM concentrate (G4); outdoors full-time offered fresh herbage + 8 kg DM concentrate (G8); indoors full-time offered a total mixed ration (TMR). Fresh herbage was allocated daily to the G1, G4 and G8 treatments. Treatment groups grazed separately for the duration of the study yet were offered similar swards. Each animal was assigned to her respective treatment for a 6– week period; following this 6–week experimental period, cows were housed on a full-time basis and offered *ad-lib* TMR for 13 weeks to monitor carryover effects. The composition of the TMR was on average 4.1 (s.d. 0.55) kg DM/cow/day grass silage, 8.2 (s.d. 0.98) kg DM/cow/day maize silage, 0.7 (s.d. 0.07) kg DM/cow/day straw, 10.4 (s.d. 0.99) kg DM/cow/day concentrate and 1.5 (s.d. 0.133) kg DM/cow/day molasses.

4. Main results:

Experiment 1

The pre-grazing herbage mass of swards offered to all treatments was 1282 kg DM/ha and sward organic matter digestibility was 864 g/kg, indicating high quality swards conducive to high DMI. Swards where animals had 22 hours and 2×4.5 hours access to pasture had the lowest post-grazing sward heights (3.6 cm) reflecting greatest levels of sward utilisation. During the experimental period there were no differences in most milk production parameters (Table 1). However reducing access time to 2×3 hour periods significantly reduced milk protein concentration (–1.3 g/kg) compared to the 22 hour treatment. Furthermore, restricting pasture access time to one period of 9 hours reduced DMI compared to the control treatment. Restricting pasture access time resulted in much greater grazing efficiency as animals from the 9, 2×3 and 2×4.5 treatments spent a greater proportion of their time at pasture grazing (80, 97 and 78%, respectively) than control animals (41%).

Table 1. Effect of restricting access time to pasture for 31–days on milk yield, milk composition, bodyweight change, dry matter intake and grazing time

Treatments (pasture access time)	22	9	2×3	2×4.5	SED	Sig
Milk yield (kg/cow)	22.0	22.6	21.4	21.7	0.30	NS
Milk fat content (g/kg)	41.2	41.8	41.8	40.4	0.61	NS
Milk protein content (g/kg)	35.5a	34.2ab	33.2b	34.3ab	0.29	*
TDMI (kg/cow/day)	17.4a	15.7b	16.6ab	16.3b	0.20	*
Grazing time (mins/day)	540a	431b	349c	425b	8.7	***

NS= Non significant, ***=P<0.001, *=P<0.05. abc values in the same row not sharing a common superscript are significantly different

TDMI – Total Dry Matter Intake

Experiment 2

The pre-grazing herbage mass of swards offered to all treatments was 1739 kg DM/ha. Supplementing cows with silage significantly increased (+0.7 cm) post grazing height compared to the 3 other treatments (4.1 cm) which will impact on sward quality in subsequent grazing rotations. Full-time access to pasture during inclement weather results in poaching damage. Results from this study show that subsequent re-growth is reduced by 20% (250 kg DM/ha) compared to paddocks where animals grazed for a restricted period of time. During the experimental period there were no differences in most milk production variables (Table 2).

However, supplementing cows with silage reduced milk protein content (1.6 g/kg) compared to cows offered full-time access to pasture (33.7 g/kg). The 2×3S treatment had a higher BW due to gut fill. However, there was no difference in BCS between treatments. Restricting pasture access time results in much greater grazing efficiency as animals from the 2×3 treatment grazed for 98% of their time at pasture compared to the animals given fulltime access to pasture (37%). Allocating silage reduced grazing time (56 mins) in comparison to the 2×3 treatment (353 mins).

Experiment 3

There was no significant difference in pre-grazing height (12.5 cm) or pre-grazing yield (1,708 kg/DM/ha) between grazing treatments and all grazed to a common post-grazing height of 6 cm. There were differences in the daily herbage allowance of the G1, G4 and G8 treatments (19, 14 and 12 kg DM/cow/day, respectively). Sward utilisation was similar for all treatments (0.77). The grass dry matter intake (GDMI) of the G1, G4 treatments was similar (14 kg DM/cow/day) yet higher than the G8 treatment cows (12.1 kg DM/cow/day). As all concentrate was utilised this resulted in a total DMI of 14.7, 18.2 and 20.1 kg DM/cow/day. When DMI was measured by weighing back refusals it was determined that the TMR cows were consuming 21 kg DM/cow/day. All treatments differed from each other in terms of milk yield (Table 3) – the TMR treatment had the highest milk yield (26.9 kg/cow/day) while the G1 cows had the lowest milk yield and milk solids yield (20.7 and 1.50 kg/cow/day, respectively). However milk solids yield was similar for the G8 and TMR treatments (1.80 kg/cow/day) due to the higher ($P<0.01$) protein content of the G8 milk. There was no difference in body condition score during the experimental period. There was no significant difference between the four treatments in the

Table 2. Effect of restricting access time to pasture for 30–days on milk yield, milk composition, bodyweight change, dry matter intake and grazing time

Treatments (pasture access time)	22	2×3S	2×3	2×4.5	SE	Sig
Milk yield (kg/cow)	28.1	29.0	28.5	28.0	0.55	NS
Milk fat content (g/kg)	42.1	43.3	42.6	42.9	0.99	NS
Milk protein content (g/kg)	33.7^{a}	32.1^{b}	32.7^{ab}	32.5^{b}	0.43	0.04
End body weight (kg)	488^{a}	508^{b}	481^{a}	479^{a}	4.4	0.001
Eating time (mins/day)	483^{a}	297^{d}	353^{c}	410^{b}	19.9	0.001

SE = Standard Error ; NS= Non significant, abc values in the same row not sharing a common superscript are significantly different

Table 3. Milk production performance of autumn calving cows assigned to one of four early lactation experimental treatments

	G1	G4	G8	TMR	SE	Sig
Milk Yield (kg/day)	20.7b	23.4c	25.0d	26.9a	0.48	0.001
Milk Fat Content (g/kg)	39.9^{b}	37.5^{a}	36.0^{a}	37.1^{a}	0.019	0.001
Milk Protein Content (g/kg)	32.1^{a}	32.3^{a}	33.2^{b}	32.4^{a}	0.025	0.01
Milk Solids Yield (kg/day)	1.50^{a}	1.63^{b}	1.72^{c}	1.87^{c}	0.037	0.001
End Bodyweight (kg)	498^{b}	505^{ab}	524^{a}	525^{a}	3.6	0.01
End Body Condition Score	2.52	2.66	2.56	2.68	0.049	0.529

abc values in the same row not sharing a common superscript are significantly different

carryover period in terms of milk yield (23.9 kg/cow/day). However, milk solids yield was highest for the TMR treatment. The G1 treatment had higher milk solids yield (1.68 kg/cow/day) than the G4 and G8 treatments (1.64 kg/cow/day) during the carryover period. Even though the bodyweight of the G1 treatment was lower by the end of the experimental period this difference disappeared after the cows were offered a TMR diet during the carryover period. There was no difference in body condition score during the experimental or carryover period.

5. Opportunity/Benefit:

The information generated from this project has been disseminated by knowledge transfer personnel and is currently being integrated into grazing management practices during the spring and autumn to help extend the grazing season thereby reducing feed costs and helping to improve overall farm profitability.

6. Dissemination:

Main publications:

Kennedy, E., McEvoy, M., Murphy, J.P. and O'Donovan, M. (2009). Effect of restricted access time to pasture on dairy cow milk production grazing behaviour, and dry matter intake. *Journal of Dairy Science* 92:168–176

Kennedy E., Lewis E., Murphy J.P. and O'Donovan M. (2010) Comparison of grazed grass and a TMR diet on early lactation milk production performance. In EGF 2010 Grassland in a changing world, Kiel, Germany 29 Aug – 2 Sept. 2010. p. 75

Kennedy, E., Curran, J., Mayes, B., McEvoy, M., Murphy, J.P. and O'Donovan, M. (2011). Restricting dairy cow access time to pasture in early lactation: the effects on milk production, grazing behaviour and dry matter intake. Animal 5 (11) 1805–1813

Kennedy, E., Lewis, E., Murphy, J.P. and O'Donovan, M. (2011). Effects of Level of Grass Inclusion in the Diet of Early Lactation Autumn Calving Dairy Cows on Milk Production Performance. In: British Grassland Society, Belfast, Northern Ireland, 20–Sep–2011, p. 107

Popular publications:

Kennedy, E. and Dunwoody, T. (2011). Grazing management in autumn – extending the grazing season. Ballyhaise Agricultural College Open Day 6/10/11. Teagasc IE p. 25–27

Moorepark 09 and Moorepark 11 National Dairy Conference 2009 7.

Development of a grass economic index for ranking perennial ryegrass cultivars

Project number:
5663
Date:
June 2012
Funding source:
Teagasc
Project dates:
Jan 2006 to Dec 2011

Key external stakeholders:

Grassland farmers, dairy industry, grass seed industry, grass breeders, grass evaluators, advisors

Practical implications for stakeholders:

The development of this index has identified key traits which influence the economic performance of a grass based dairy farm and quantified the effect each trait will have on the overall profitability of the system

- Rank cultivars based on their economic performance.
- Assist farmers in the selection of cultivars.
- Farmers can easily identify cultivars which are performing well in a particular trait and can select cultivars to meet their farm requirements accordingly.

Main results:

- The grass economic index was published in 2010.
- Cultivars ranked according to their performance with a grazing system.
- Cultivars with highest economic contribution to the system can be identified.
- Scenario analysis identified that economic ranking is stable regardless of system, farming intensity or milk price.

Opportunity/Benefit:

- This information will assist farmers in the selection of perennial ryegrass cultivars by highlighting the advantages and shortcomings of a cultivar in economic terms.
- Key traits identified which grass breeders should incorporate into their breeding program in order to ensure the best cultivars are being selected for grazing systems.

Collaborating Institutions:
DAFM AFBI UCD

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Technology

1. Project background:

Perennial ryegrass is the most important forage grass species used in temperate agriculture for ruminant animal production. In Ireland, 80% of the agricultural area is devoted to pasture, hay and grass silage. The economic merit of an individual grass cultivar across a full production year has not been quantified previously. In cattle breeding, the development of a total merit index to assist farmers in identifying the most profitable bulls and cows (Veerkamp et al., 2002) has been successfully adopted and accepted in many countries including Ireland (Economic Breeding Index; ICBF, 2008). The development of a similar approach to rank grass cultivars would be a significant advancement in grass selection to guide grass breeders, research scientists, advisors and farmers in identifying grass cultivars that would deliver the highest increases in profitability at farm level. The identification and application of economic values to each trait of economic importance (DM yield, silage yield, quality and persistency) and the presentation of grass cultivar ranking based on their total economic merit will provide the industry with information on the optimum cultivars for a system.

2. Questions addressed by the project:

- What are the key grass production traits influencing farm profitability?
- What is the economic value of a change in each trait?
- Is cultivar ranking stable in economic terms if farming system, intensity or product price is altered?

3. The experimental studies:

The economically important traits were identified based on their importance in influencing the profitability of a farm system. The key traits were spring, mid-season and autumn grass dry matter (DM) yield (€ per kg DM per ha), grass quality (€ per unit DMD), first and second cut silage DM yield (€ per kg per ha) and sward persistency (€ per % change in persistency per year). The economic value for each trait was calculated by changing the trait of interest while keeping all other traits constant using the Moorepark Dairy Systems Model (MDSM). Herd parameters (including cow numbers and calving pattern), milk production, energy demand, supplementary feeds and land area were readjusted to calculate the economic value for the trait of interest. The base scenario assumed fixed cow numbers with 40 ha of land available, with full costs included. Sensitivity of the economic values to changes in milk price and scenarios were tested. The economic values were applied to experimental production data collected over three years for 20 perennial ryegrass cultivars to establish the total economic merit for each cultivar and then to rank each cultivar based on their economic performance. Rank correlations between the base and alternative scenarios ranged from 0.90 to unity. This indicates that the economic values are reliable regardless of system, intensity or price. The total merit index will identify the cultivars that can make the greatest economic contribution to a grass-based production system.

4. Main results:

The key traits influencing farm profitability are: Seasonal DM yield (spring, mid-season and autumn), 1st and 2nd cut silage DM yield, quality (April to September inclusive) and sward persistency. The economic value of a trait can be described as follows:

$$\text{Economic value} = \frac{\Delta \text{ net margin per hectare}}{\Delta \text{ in trait of interest}}$$

Economic values calculated per unit change in each trait were as follows: Spring DM yield (€0.15 per kg DM), Mid-season DM yield (€0.03 per kg DM), Autumn DM yield (€0.10 per kg DM), 1st cut silage (€0.03 per kg DM), 2nd cut silage (€0.02 per kg DM), quality was €0.001, €0.008 and €0.010, €0.009, €0.008 and €0.006 per unit change in DMD per kg DM yield for the months of April, May, June, July, August and September, respectively, and -€4.961 per 1% decrease in persistency/ha/year.

The scenario analysis identified that rank correlations between the base and alternative scenarios ranged from 0.90 to unity. This indicates that the economic values are reliable regardless of system, intensity or price. The total merit index will identify the cultivars that can make the greatest economic contribution to a grass-based production system.

5. Opportunity/Benefit:

The grass economic index will assist in the selection of grass cultivars by ranking them based on their economic performance. It will simplify the selection process of a cultivar for the farmer, while also highlighting the key traits which a grass breeder must select for.

6. Dissemination:

Economic values will be applied to data generated within the Recommended List Trials to present the economic merit of individual cultivars to farmers. Farmers will then be able to select cultivars which best meet their needs. In addition farmers will be easily able to recognise the most appropriate cultivars for grazing systems or silage systems depending on their requirements.

Main publications:

McEvoy, M., O'Donovan M., and Shalloo L. (2011). 'Development and application of an economic ranking index for perennial ryegrass cultivars' *Journal of Dairy Science* 94:1627–1639.

McEvoy, M., O'Donovan M., and Shalloo L. (2011). 'Capturing the economic benefit of Lolium perenne cultivar performance' *Irish Journal of Agriculture and Food Research* 50: 83–98.

McEvoy, M., O'Donovan M., and Shalloo L. (2010). 'Capturing the economic benefit of cultivar performance'. *Proceedings of the Grasses in a Changing World Conference*. Cork. 14–15 October 2010. Teagasc.

McEvoy, M., O'Donovan M., and Shalloo L. (2011) 'Economic index for ranking perennial ryegrass cultivars.' *Proceedings of the Agricultural Research Forum 2011*. Tullamore. 14–15 March. p143.

McEvoy, M., O'Donovan M., and Shalloo L. (2009). 'Evaluating the economic performance of grass varieties.' *Proceedings of a joint meeting of the Agricultural Research Forum and the British Society of Animal Science* (Cambridge University Press), Belfast. p328.

Popular publications:

McEvoy, M. Variety Selection. *Todays Farm*. March/ April 2011.

McEvoy, M. and O'Donovan, M. (2011). Evaluation of perennial ryegrass cultivars. *Irish Dairying Planning for 2015*, Moorepark'11 Open Day (29/6/11). Teagasc IE p. 68–70 ISBN 24964 B3

Animal and Grassland Research & Innovation Programme

Project number:
5628

Date:
Nov, 2011

Funding source:
DAFF (RSF 05/R&D/224)

Project dates:
Oct 2006–May 2011

Reducing enteric methane production by finishing beef cattle

Key external stakeholders:

Dept. Agriculture, Food and the Marine, beef farmers, beef industry, policy-makers.

Practical implications for stakeholders:

Greenhouse gas (GHG) emissions from finishing cattle systems reflect the dietary ingredients fed. Diets high in cereal grains increase growth rate and reduce enteric methane emissions compared to forage-based diets. A life-cycle analysis accounting for (a) direct and indirect GHG emissions (carbon dioxide, methane and nitrous oxide) from the cattle production system, (b) carbon sequestration under permanent grassland, and (c) carbon loss where grassland is replaced by cereals or maize, indicates that the beef from cattle finished on a grass silage-based diet had a lower emissions intensity (a.k.a. carbon footprint; kg CO_2e/kg carcass gain) than from a diet based on maize silage, whole-crop cereal silage or *ad libitum* concentrates. The results of this project provide:

- **Farmers** with dietary and management strategies for simultaneously increasing profitability and reducing the emissions intensity of the beef they produce.
- **Policy makers** with the evidence that national GHG inventory systems must account for land use and land use change (LULUC) in addition to the more obvious direct and indirect emissions of GHG.
- **Beef exporters** with a marketing advantage for Irish beef produced from permanent grassland.

Collaborating Institutions:
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Technology

Main results:

- Increasing the growth rate of finishing cattle by feeding diets of higher grain content reduced the output of enteric methane.
- A final decision on the efficacy of any strategy for reducing GHG emissions must account for all GHG emitted and for associated changes in the carbon status of the soil. Thus, when soil carbon is assumed to be in equilibrium, cattle finishing systems based on high grain diets have a lower emissions intensity than finishing systems with grass silage-based diets. However, when account is taken of carbon sequestration under permanent grassland and carbon loss where permanent grassland is tilled (to sow small-grain cereals or maize), the estimated GHG emissions intensity of beef is significantly altered such that finishing cattle on grass silage-based diets have a lower emissions intensity.

Opportunity/Benefit:

The results show

- **Farmers** that increasing animal productivity increases profits and reduces GHG emissions intensity.
- **Policy makers** the importance of ensuring that national inventory systems account for changes in soil carbon status in addition to the more standard emissions of GHG.
- **Beef exporters** the opportunity to market Irish beef as generally having a low emissions intensity arising from the permanent grassland based production systems that dominate the Irish cattle sector.

1. Project background:

Increases in atmospheric concentrations of GHG are considered a likely cause of global warming. In Ireland, 29% of our national emissions derive from agriculture, a much higher proportion than occurs in other northern European countries. Since enteric methane produced by ruminants (predominantly cattle) contributes about half of the GHG output from Irish agriculture, mitigating methane output has been the focus of considerable research.

Diets that provide cattle with an increasing proportion of starch (e.g. maize silage harvested at a more advanced growth stage, whole-crop wheat silage of higher grain content, barley grain fed to appetite) are predicted to reduce methane emissions and increase animal growth rate, thereby reducing emission intensity (i.e. kg CO_2e/kg carcass gain; CO_2e is the amount of carbon dioxide that has an equivalent global warming potential as the net amount of carbon dioxide, methane and nitrous oxide released as part of the beef production system). What is unclear is the extent of these effects, the relativity between contrasting feeds and what the overall outcome might be as assessed by a life-cycle assessment.

2. Questions addressed by the project:

- What effect does delaying the harvest date of forage maize (thereby allowing its starch content to increase) have on both the carcass gain and enteric methane output of finishing beef cattle, and how does this compare to a diet based on cereal grain concentrates fed *ad libitum*?
- What effect does increasing the grain content of whole-crop wheat silage (thereby allowing starch content to increase) have on both the carcass gain and enteric methane output of finishing beef cattle, and how does this compare to a diet based on grass silage or cereal grain concentrates fed *ad libitum*?
- What are the relative outputs of methane from these and other comparable feeds when assessed in an *in vitro* rumen digestion system?
- What are the effects on profitability and total GHG emissions intensity of beef produced when the above diets are fed to finishing cattle?

3. The experimental studies:

- Forage maize was harvested and ensiled on four occasions between early September and late October. Groups of 12 beef steers were offered one of these silages (plus 3 kg concentrates per head daily) or concentrates *ad libitum* for 110 days. Feed composition, intake and digestion characteristics were measured together with animal performance, methane production (using the sulphur hexafluoride (SF_6) based technique), and carcass and blood plasma traits.
- Whole-crop wheat silage was separated into grain and straw + chaff fractions and recombined in four ratios – 11:89, 21:79, 31:69 and 47:53. Groups of 15 beef steers were offered one of these mixtures or grass silage (plus 3 kg concentrates per head daily) or concentrates *ad libitum* for 154 days. Feed composition, intake and digestion characteristics were measured together with animal performance, methane production (using the SF_6 based technique), rumen fermentation characteristics, and carcass and blood plasma traits.

- The *in vitro* rumen total gas production technique was used as a rapid screening tool to quantify fermentation characteristics, methane output and dry matter disappearance for a range of feeds including grass, maize and whole crop cereal silages, and wheat, barley and triticale grains stored dry or moist (stored anaerobically).
- A hybrid modelling approach was used to evaluate the physical and financial performance of the production systems corresponding to the finishing diets under investigation and their associated GHG emissions. A bioeconomic model (Grange Beef Systems Model) specified the animal production profile, the inputs to and the outputs from the assumed systems, and the associated financial performance. A beef systems greenhouse gas emissions model (BEEFGEM) then calculated (a) direct emissions including those arising from enteric fermentation, agricultural soils and manure management, (b) indirect emissions from ammonia volatilization, nitrate leaching and from the production of inputs utilised in beef production, and (c) GHG emissions or sequestration associated with land use and land use change (LULUC; i.e. permanent pasture vs. tilling). The estimates of carbon sequestration and loss from soils entailed a degree of uncertainty in their calculation.

4. Main results:

- The relatively narrow range achieved in maize maturities meant that that animal performance response to the harvest date of maize was quite small. Nevertheless, the intensity of methane emissions (methane per kg carcass gain) declined with maize silages made from crops harvested at more advanced stages of maturity. In addition, higher performance and lower methane emission intensity occurred when animals consumed concentrates *ad libitum*.
- The wide range achieved in whole-crop wheat silage grain content meant that increasing its grain content increased animal performance and reduced methane emission intensity. Grass silage supported similar performance and methane emission as the 21:79 and 31:69 ratio whole-crop wheat silages, but the highest performance and lowest methane emission intensity occurred when animals consumed concentrates *ad libitum*.
- The methane responses observed in the *in vitro* study contradicted expected *in vivo* trends in methane output, thus challenging the reliability of the *in vitro* technique to usefully determine methane output of feeds differing widely in fibre and starch contents.
- Based on the assumptions made (including accounting for LULUC) in the whole-farm systems modelling exercise, the finishing system based on grass silage supported the highest net financial margin and the lowest GHG emissions intensity.

5. Opportunity/Benefit:

The results show;

Farmers that increasing animal productivity can increase profits and reduce GHG emissions intensity.

Policy makers the importance of ensuring that national inventory systems account for changes in soil carbon status in addition to the more standard emissions of GHG.

Beef exporters the opportunity to market Irish beef as generally having a low emissions intensity arising from the permanent grassland based production systems that dominate the Irish cattle sector.

6. Dissemination:

Main publications:

McGeough, E.J., Crosson, P., Kenny, D.A. and O'Kiely, P. (2012). 'Greenhouse gas emissions from integrated crop – beef finishing systems.' *Journal of Animal Science* (in preparation).

McGeough, E.J., O'Kiely, P., Foley, P.A., Hart, K.J., Boland, T.M. and Kenny, D.A. (2010). 'Methane emissions, feed intake, and performance of finishing beef cattle offered maize silages harvested at 4 different stages of maturity.' *Journal of Animal Science*, 88: 1479–1491.

McGeough, E.J., O'Kiely, P., Hart, K.J., Moloney, A.P., Boland, T.M. and Kenny, D.A. (2010). 'Methane emissions, feed intake, performance, digestibility, and rumen fermentation of finishing beef cattle offered whole-crop wheat silages differing in grain content.' *Journal of Animal Science*, 88: 2703–2716.

Popular publications:

O'Kiely, P., O'Brien, M., McGeough, E., Navarro-Villa, A. and Purcell, P. (2010). 'Reducing methane emissions from cattle.' *TResearch*, 5 (1) Spring :38–39. http://www.teagasc.ie/publications/2010/6/6_TResearch_201002.pdf

The Investigators (popular science TV documentary series) – Padraig O'Kiely appeared in Programme 2 entitled "Climate Change". http://www.rte.ie/tv/theinvestigators/prog2.html

Public lecture organized by UCD Earth Sciences Institute, TCD TrinityHaus and Dublin City Council, under the TCD-UCD Innovation Alliance and in collaboration with Business in the Community and the main agencies involved involved in delivering policy (Comhar Sustainable Development Council, Enterprise Ireland, EPA, Geological Survey of Ireland, Marine Institute, Met Éireann, Sustainable Energy Authority of Ireland and Teagasc). The lecture ('Future opportunities to reduce bovine greenhouse gas emissions') given by Padraig O'Kiely can be accessed at http://www.ucd.ie/earth/newsevents/transformingirelandseminarseries2010/seminar1160310/

Animal and Grassland Research & Innovation Programme

Project number:
5631

Date:
November, 2011

Funding source:
DAFF (RSF 06/R&D/361)

Project dates:
Oct 2007–Dec 2011

In vitro rumen methane output of feeds consumed by housed cattle

Key external stakeholders:

Dept. Agriculture, Food and the Marine; rumen function and animal nutrition researchers; policy-makers; livestock industry; livestock farmers

Practical implications for stakeholders:

Methane is a potent greenhouse gas, and manipulating the diet consumed by ruminant livestock can reduce enteric methane output. The *in vitro* rumen gas production technique (GPT) is a rapid screening tool to quickly estimate the methane output (and related characteristics) for a range of feeds, under standard conditions. It involves incubating a dried, milled sample of feed with rumen micro-organisms and artificial saliva (*i.e.* buffer) at body temperature and air-free conditions for 24 hours.

- Practices such as the use of red clover, the application of inorganic N fertiliser to perennial ryegrass and the ensilage of herbage can reduce enteric methane output.
- Modifications made to the GPT and expressing methane output relative to dry matter (DM) apparently digested provided more meaningful rankings of the methane output of forages *vs.* high starch feeds. The GPT can help identify worthwhile treatments to include in *in vivo* experiments that have the objective of formulating diets to reduce methane output per unit meat or milk produced.

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Technology

Main results:

- Red clover produced less methane than perennial ryegrass, but applying inorganic N fertiliser to the ryegrass reduced methane output to the level achieved with red clover.
- Silage produced less methane than the grass from which it was made, and this effect was larger when silage fermentation was more extensive.
- The GPT was modified to allow the pH of the *in vitro* rumen medium to change in response to the digestion of a feed. This altered the digestion characteristics to produce more meaningful methane output values (when expressed relative to the DM apparently digested) for forages *vs.* high starch feeds.

Opportunity/Benefit:

- These experiments using the GPT have identified factors such as red clover, inorganic N fertilisation of ryegrass, autumn regrowth, herbage nitrate concentration and the ensilage of herbage (especially an extensive silage fermentation) that result in lower outputs of methane. This information can help identify treatments to include in *in vivo* methane output studies, with an objective of formulating diets that produce less methane per unit meat or milk produced.
- The modified GPT will allow more meaningful *in vitro* comparisons of feeds that contrast widely in chemical composition. These comparisons can be undertaken in experiments in Ireland or elsewhere.

1. Project background:

Since enteric methane accounts for about half of the greenhouse gas (GHG) emissions from Irish agriculture and the diet consumed by ruminants has a major impact on enteric methane output, much effort has been invested in measuring the methane output associated with diets consumed by grazing and indoor-fed animals. However, the high cost, large resource requirement, long duration of experiments and considerable variability in methane output estimates (made using sulphur hexafluoride as a marker) associated with *in vivo* studies present a range of considerable challenges. In this context, *in vitro* techniques have been developed to partially simulate rumen conditions and thus provide a standardised methane output index for feeds. They involve incubating a dried, milled sample of feed with rumen micro-organisms and artificial saliva (*i.e.* buffer) at body temperature and air-free conditions for 24 hours. These relatively rapid and low cost methods also permit the use of adequate experimental replication. This single *in vitro* trait of a feed provides useful information about its propensity to produce methane, but this value must be interpreted carefully since methane output by cattle consuming a diet to appetite will also be influenced by the actual intake achieved and by the dynamic activities that occur during rumen digestion. Since at least one-third of the lifetime intake of most Irish cattle occurs when they are accommodated indoors, a ranking of the propensity of conserved feeds to produce enteric methane could help in the formulation of 'low-methane' diets. However, any treatments investigated need to be ultimately submitted to a full life cycle assessment to account for all direct and indirect GHG emissions (and also sequestration).

The *in vitro* rumen gas production technique (GPT) was operated to allow a ranking of the methane output of feeds rather than describing their temporal kinetics of digestion.

2. Questions addressed by the project:

- What is the *in vitro* rumen methane output of perennial ryegrass and red clover when harvested at a silage production growth stage? How is this influenced by harvesting the primary growth in late May or mid June, or by harvesting an autumn regrowth? Does the variety of red clover alter the outcome and what is the impact of applying inorganic nitrogen fertiliser to the perennial ryegrass?
- What is the effect of ensiling grass on *in vitro* rumen methane output? How is this influenced by the extent and direction of silage fermentation?
- What is the relative *in vitro* rumen methane output of a range of ingredients commonly included in concentrate feeds and how do these compare to the values expected from some forages?
- Following on from concerns about the methane output of the above concentrate feeds, could the GPT be modified so it would provide results more similar to those expected in *in vivo* experiments?

3. The experimental studies:

Herbage samples were obtained from a randomised complete block field plot experiment where, in each of two successive years, two varieties of red clover (Merviot & Ruttinova) were harvested at two stages of the primary growth (late May & mid-June) or in an autumn regrowth. Comparable plots of perennial ryegrass (Greengold – tetraploid, intermediate-heading date) that received 0 or 150 kg fertiliser N/ha/growth were also harvested. Samples were incubated using the GPT and methane output was expressed relative to total gas or volatile fatty acids (VFA) produced, to dry matter (DM) incubated or to DM apparently digested.

Herbage samples from replicated field plots of three grass crops differing in ensilability (likely to undergo (a) extensive but undesirable fermentation, (b) extensive but desirable fermentation, and (c) restricted fermentation) were assessed for methane output using the GPT both pre-and post-ensilage. In each case the direction and/or extent of silage fermentation was further manipulated by chemical and biological additives in order to broaden the range of silage fermentation characteristics being assessed. Samples of 30 feeds (for which some *in vivo* digestion/metabolism data were available) were assessed for methane output using the GPT. These ranged from high starch feeds (*e.g.* barley, wheat, tapioca) to degradable fibre/high sugar feeds (*e.g.* locust beans, beet pulp, citrus pulp), high fibre feeds (*e.g.* grain screenings, rice bran, grass meal, grass silage, lucerne, pollard, malt sprouts, palm kernel) and high protein feeds (*e.g.* maize gluten feed, maize distillers, rolled beans, cottonseed meal, rapeseed meal, sunflower meal, soyabean meal).

A combination of a weaker buffer solution and a higher feed to buffer ratio were used with three contrasting feeds (barley grain, grass silage and barley straw), and the effects on methane output during the GPT were expressed relative to DM incubated and digested, and VFA and total gas produced. A range of associated fermentation characteristics were also monitored.

4. Main results:

- Red clover variety had no impact on methane output. Red clover produced less methane per unit feed DM incubated (CH_4i) than perennial ryegrass that received no inorganic N fertiliser, but when the ryegrass had 150 kg N applied/ha/growth then CH_4i declined to a similar value as red clover (this effect was due to the hydrogen-scavenging by the nitrate in the N fertilised ryegrass). In contrast, methane output per unit feed DM apparently digested (CH_4d) during the incubation was similar for these four feeds. Delaying the harvest date of the primary growth reduced CH_4i but not CH_4d, whereas herbage from the autumn regrowth supported lower CH_4i and CH_4d than herbage from the early primary growth (due to high nitrate concentrations in the autumn grass).
- Ensilage reduced *in vitro* rumen methane output (whether expressed as CH_4i or CH_4d), reflecting a reduction in the proportion of acetic acid and an increase in the proportion of propionic acid in the *in vitro* rumen VFA. The magnitude of this decrease in methane output increased as the extent of silage fermentation increased, reflecting the greater change in herbage chemical composition during an extensive silage fermentation (it was related mainly to the higher concentration of lactic acid). However, among silages with a similar extent of fermentation, methane output was positively related to the proportion of lactic acid in fermentation products.
- Mean methane output values (CH_4i) were 47.1, 41.1, 28.6 and 33.2 ml/g DM for high starch, degradable fibre/high sugar, high fibre and high protein feed categories, respectively (corresponding CH_4d values were 53.9, 56.4, 51.4 and 45.3 ml/g DM). This outcome contrasts with values expected from *in vivo* experiments. Thus, the GPT as originally operated may not be appropriate for ranking methane output of feeds that range from forages to high starch feeds.
- The modified GPT permitted a shift in the pH of the *in vitro* medium to occur in response to the extent of *in vitro* fermentation associated with a feed. This resulted in a more *in vivo*-like ranking of methane output among feed types when expressed as CH_4d.

5. Opportunity/Benefit:

- These experiments using the GPT have identified factors such as red clover, inorganic N fertilisation of ryegrass, autumn regrowth, herbage nitrate concentration and the ensilage of herbage (especially an extensive silage fermentation) that result in lower outputs of methane. This information can help identify treatments to include in *in vivo* methane output studies, with an objective of formulating diets that produce less methane per unit meat or milk produced.
- The modified GPT will allow more meaningful *in vitro* comparisons of feeds that contrast widely in chemical composition. These comparisons can be undertaken in experiments in Ireland or elsewhere.

6. Dissemination:

Main publications:

Navarro-Villa, A., O'Brien, M., Lopez, S., Boland, T.M. and O'Kiely, P. (2011). 'Modifications of a gas production technique for assessing *in vitro* rumen methane production from feedstuffs.' *Animal Feed Science and Technology*, 166–167: 163–174.

Navarro-Villa, A.. O'Brien, M., Lopez, S., Boland, T.M. and O'Kiely, P. (2011). '*In vitro* rumen methane output of red clover and perennial ryegrass assayed using the gas production technique (GPT).' *Animal Feed Science and Technology*. 168: 152–164.

Navarro-Villa, A.. O'Brien, M., Lopez, S., Boland, T.M. and O'Kiely, P. (2012). '*In vitro* rumen methane output of grasses and grass silages differing in fermentation characteristics using the gas production technique (GPT).' *Grass and Forage Science* (under review).

Popular publications:

O'Kiely, P., O'Brien, M., McGeough, E., Navarro-Villa, A. and Purcell, P. (2010). 'Reducing methane emissions from cattle.' *TResearch*, 5 (1) Spring :38–39. http://www.teagasc.ie/publications/2010/6/6_TResearch_201002.pdf

The Investigators (popular science TV documentary series) – Padraig O'Kiely appeared in Programme 2 entitled "Climate Change". http://www.rte.ie/tv/theinvestigators/prog2.html

Public lecture organized by UCD Earth Sciences Institute, TCD TrinityHaus and Dublin City Council, under the TCD-UCD Innovation Alliance and in collaboration with Business in the Community and the main agencies involved involved in delivering policy (Comhar Sustainable Development Council, Enterprise Ireland, EPA, Geological Survey of Ireland, Marine Institute, Met Éireann, Sustainable Energy Authority of Ireland and Teagasc). The lecture ('Future opportunities to reduce bovine greenhouse gas emissions') given by Padraig O'Kiely can be accessed at http://www.ucd.ie/earth/newsevents/transformingirelandseminarseries2010/seminar1160310/

Animal and Grassland Research & Innovation Programme

Project number:
5498

Date:
December, 2011

Funding source:
DAFF, Dairy Levy & Teagasc

Project dates:
Jan 2006–Sept 2010

Effect of grazing season length and stocking rate on nitrate leaching

Key external stakeholders:

Research scientists, dairy industry, policy makers

Practical implications for stakeholders:

This project examined the effect of stocking rate and grazing season length on nitrate (NO_3) leaching to 1 m depth in the soil. Nitrate leaching was measured using ceramic cups.

- As stocking rate and fertiliser N application rate increased there was a trend for nitrate (NO_3) leached to 1 m depth in soil to increase.
- Early spring turnout (1st February) tended to have lower quantities of NO_3 leached to 1 m depth in soil than later turnout in spring; early autumn housing (21st October) had slightly lower quantities of NO_3 leached to 1 m depth in soil than later housing.
- Land use management affects NO_3 leaching – including one or two cuts of silage to grazed grassland reduces nitrate leaching to 1 m depth in soil compared to grazing only.
- Bulk density increased as stocking rate increased, and was not affected by grazing season length.
- Increasing stocking rate and grazing season length increases profit per ha.
- Increasing stocking rate and grazing season length increased farm profit.
- The N balance model developed in this project can be used to assess the N use efficiency of grass based milk production systems.

Collaborating Institutions:
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Technology

Main results:

The key results are:

- As stocking rate and fertiliser N application rate increased there was a trend for NO_3 leached to increase.
- Increasing stocking rate while maintaining N fertiliser application rate at a given level increases N use efficiency.
- There was a trend for the 1st February turnout date to have lower quantities of NO leached than the 21st February or 15th March turnout dates; while the 21st of October had slightly lower (but not significantly) quantities of NO_3 leached than the 10th November or 25th November housing dates.
- Increasing stocking rate increased farm profit from €578/ha for 2.0 LU/ha to €914/ha for 2.47 LU/ha and €1097/ha for 2.94 LU/ha. Profit per ha also increased as fertiliser application rate increased.

Opportunity/Benefit:

This project shows that increasing grazing season length does not increase NO_3 leached to 1 m. Increasing stocking rate within a given level of N fertilizer application can increase N use efficiency and farm profitability. Information on herbage production over winter helps farmers understand the requirement for an autumn closing strategy. The N balance model can be used by researchers to assess the N use efficiency of grass based production systems.

1. Project background:

Along with increasing environmental pressures Irish agriculture is also under increasing economic pressure due to falling incomes, decoupling and increasing costs of production. Producers are increasingly looking towards adopting low cost production systems. Grazed grass is the cheapest feed source for milk production in Ireland. The two main components of grass based milk production systems are grazing season length and stocking rate (SR). Both of these components can affect nitrate (NO_3) leaching losses. Nitrate leaching losses can increase with increasing SR due to increased nitrogen (N) fertiliser usage and higher manure production, combined with decreasing N use efficiency at high N fertilizer application rates. Nitrate leaching is greatest in late autumn, winter and early spring when surplus rainfall washes residual N accumulated in the soil during the summer period down through the soil profile, and so extended grazing seasons may have a negative impact on NO_3 leaching. Utilisation of nutrients from animal excreta (urine and faeces) during the late autumn period is also low due do low grass growth rates. The Nitrates Action Plan imposes an upper SR limit of 2 LU/ha (170 kg organic N/ha), however, with a derogation SRs of up to 2.94 LU/ha (250 kg organic N/ha) are permitted. Thus, it is important to determine the relationship between NO_3 leaching and this range of SRs. The Nitrates Action Plan also limits N fertilizer application.

2. Questions addressed by the project:

- Does stocking rate and N fertilizer application level affect NO_3 leaching to 1 m on a free draining soil?
- Will increasing grazing season length increase NO_3 leaching to 1 m on a free draining soil?
- Can a N balance model be developed to examine N use efficiency in grass based milk production systems?
- What effect do stocking rate and grazing season length have on soil bulk density?

3. The experimental studies:

Two main experiments were undertaken. The first examined the effect of SR and N fertilizer application level on NO_3 leaching on a free draining soil type and the second examined the effect of grazing season length on NO_3 leaching on a free draining soil type. Both experiments had 9 treatments. The treatments in the SR experiment were 2, 2.47 and 2.94 LU/ha with three fertilizer N application rates per SR (165, 205 and 245 kg N/ha at 2 LU/ha; 205, 245 and 285 kg N/ha at 2.47 LU/ha; 245, 285 and 325 kg N/ha at 2.94 LU/ha). The grazing season length experiment was a 3 x 3 factorial design with three spring turnout dates (1st Feb., 21st Feb, 15th Mar.) and three autumn housing dates (25th Oct. 10th Nov., 25th Nov.). A strict set of management rules governing fertilizer and slurry application, grazing management and concentrate feeding were devised for each treatment. There were 5 cows per treatment (18 herds of cows). Each group of cows had its own distinctive area which was divided into 3 blocks – a grazing only block, a grazing and first and second cut silage and a third block which was also grazed and had silage harvested from it. In blocks 1 and 2, 16 ceramic cups were inserted in the paddock to a depth of 1 m, and there were four control paddocks which were not grazed and had no fertilizer N or slurry applied;

these also had 16 ceramic cups. Altogether there were 352 ceramic cups per experiment. The ceramic cups were sampled every second week for each experiment between September and April and every month for the remainder of the year. Sampling took place from January 2007 to June 2010. A composite sample of water extracted from the cups in each paddock was analysed for NO_3, TN, NH_4 content. Other measurements included pre grazing herbage mass, pre and post grazing heights, silage production, milk production, soil bulk density (to give an indication of soil compaction). An economic analysis was undertaken to examine the profitability of each treatment in both experiments using the Moorepark Dairy Systems Model (MDSM) (Shalloo *et al*., 2004). A N Balance Model was developed to determine N use efficiency, N surpluses and N losses from grass based milk production systems.

4. Main results:

- Nitrate leaching on all treatments in both experiments was very high at the beginning of the experimental period (average 32.25 mg NO_3–N/l), likely due to soil disturbance during ceramic cup installation, and possible previous land use management effects. Thereafter, the largest differences in NO_3 leaching occurred between the management systems in place in the experiments, rather than between the treatments. Nitrate leaching was lowest on the control paddocks, and greatest on the grazing only paddocks (average 2008–2010 was 5.38 mg NO_3–N/l). The differences between the grazing only paddocks (average 2008–2010 was 33.47 mg NO_3–N/l) and the silage and grazing paddocks (average 2008–2010 was 21.79 mg NO_3–N/l) were due to the fact that animals were present on the grazing only paddocks for a greater number of days. As paddocks were closed for a number of weeks for first and second cut silage the number of grazing days and hence number of urine depositions were reduced, with the opposite occurring on the grazing only area (increased grazing days and increased urine deposition). The grazing only area was also grazed last in the final rotation and so urine was deposited at a time which is more susceptible to NO_3 leaching (grass growth rates are low and high rainfall).
- As SR and fertiliser N application rate increased there was a trend for NO_3 leached to increase.
- There was a trend for the 1st February turnout date to have lower quantities of NO leached than the 21st February or 15th March turnout dates; while the 21st of October had slightly lower (but not significantly) quantities of NO_3 leached than the 10th November or 25th November housing dates.
- Milk production per ha increased as SR increased (782 kg MS/ha at 2 LU/ha; 971 kg MS/ha at 2.47 LU/ha; 1127 kg MS/cow at 2.94 LU/ha). Milk production was similar for all treatments on the grazing season length experiment (approx. 352 kg MS/cow).
- Bulk density was higher in treatment paddocks than in control paddocks. Bulk density increased as SR increases, however, herbage production was not reduced as bulk density increased; therefore this suggests that compaction is not closely correlated with herbage production in a grazing situation. Bulk density was similar across treatments in the grazing season length experiment.
- An economic analysis of the three year average production (2007–2009) of each treatment in the two experiments was undertaken using the MDSM (Shalloo *et al*., 2004). Due to the small numbers of animals involved, there was a lot of variation between individual animals. Turning cows out on the 1st February compared to the 15th March increased profit/ha by €311. Delaying autumn housing date from 25th October to 25th November increased profit by €50/ha. Increasing SR increased farm profit from €578/ha for 2.0 LU/ha to €914/ha for 2.47 LU/ha to €1097/ha for 2.94 LU/ha.

5. Opportunity/Benefit:

Strategic management of dairy production systems is required to ensure that they are both profitable and reduce NO_3 losses to 1 m in the soil. A long grazing season does not result in greater NO_3 leaching compared to a short grazing season. Increasing grazing season length increases milk production from grazed grass, the cheapest feed source available for milk production, and therefore can increase farm profitability. There is an effect of increasing stocking rate and fertiliser application on NO_3 leaching to 1 m. However, the quantity of NO_3 leached to 1 m is not always significantly increased by increasing stocking rate. Increasing stocking rate while maintaining N fertiliser rate at a given level can improve N use efficiency by increasing N output. Mitigation strategies to minimise NO_3 leaching to 1 m should be investigated. These include the effects of restricted access time to grazing in periods of wet weather. This management strategy does not have a negative

impact on grass DM intake or milk production but will remove animals from the paddock and therefore reduce the amount of N available for leaching from urine patches. Cows that are more efficient at converting grass to milk will also contribute to reducing NO_3 leaching. If possible, the silage area should be moved around the farm to help reduce NO_3 leaching, but this will only be possible where the silage block is accessible to milking cows. Grass based milk production is profitable, and high stocking rates combined with long grazing seasons have positive effects on farm profit. Modelling of the data can be used to determine the most profitable and the most N efficient treatments.

6. Dissemination:

Six monthly progress reports were forwarded to DAFF as required by the Research Stimulus Fund. An overview of the project was given at the Moorepark Open Day in 2007 and 2009. Visitors to Moorepark, both national and international, visited the experimental site on a number of occasions in each year of the experiment. Poster and oral presentations were made at the Agricultural Research Forum, BSAS Conference, BGS research Conference and EGF Conference. Three papers have been published from this project, one more is accepted to Journal of Agricultural Science, another is submitted for peer review to Agriculture, Ecosystems and Environment, and two more are in preparation.

Main publications:

Herbin, T., Hennessy, D., Richards, K.G., Piwowarczyk, Murphy, J.J. Holden, N.M. (2011) The effects of dairy cow weight on selected soil physical properties indicative of compaction. *Soil Use and Management* 27: 36–44.

Ryan, W., Hennessy, D., Murphy, J.J., Boland, T.M., Shalloo, L. (2011) A model of nitrogen efficiency in contrasting grass-based dairy systems. *Journal of Dairy Science* 94: 1032–1044.

Ryan, W., Hennessy, D., Murphy, J.J., Boland, T.M. (2010) The effects of autumn closing date on sward leaf area index and herbage mass during the winter period. *Grass and Forage Science* 65: 200–211.

Popular publications:

Hennessy, D. and Ryan, W. (2009) Winter grass growth. *TResearch*, Vol. 4, No. 3, pp 16–17. http://www.teagasc.ie/publications/2009/14/14_tresearch200908.pdf

Animal and Grassland Research & Innovation Programme

Project number:
5396

Date:
August, 2010

Funding source:
Teagasc & Dairy Levy

Project dates:
Jan 2005–Dec 2009

Participative on-farm research for the Border Midland West (BMW) region

Key external stakeholders:

BMW region dairy farmers; local milk processors – Lakeland Dairies, Town of Monaghan, Donegal and Connacht Gold; AI companies; consultancy agencies

Practical implications for stakeholders:

Highest profitability was achieved with high EBI animals, higher milk protein percentage, a more fertile herd with a compact breeding period, lower concentrate supplementation and higher stocking rates on the grazing platform.

Main results:

- Average milk production was 5,976 kg/cow with concentrate supplementation of 1,148 kg/cow at a stocking rate 2.32 cows/ha and a calving date of March 8th.
- Reproductive performance was highly variable on the study farms with the average breeding period length of 18 weeks, a 42–day pregnancy rate of 53% (range 28 to 85%) and calving interval of 401 days (372 to 432 days).
- The economic performance data collected shows average profit of €1,051 per hectare (and ranging from €71 to €2,111). Average gross output and common costs in cent per litre (c/l) for the study farms were 27.2 and 15.9, respectfully while average common profit was 11.4 c/l. The range in profitability within the study farms over the three year project was considerable as average common costs ranged from 10.4 to 23.2 c/l and average common profit from 3.5 to 18.2 c/l.

Collaborating Institutions:
UCD
Lakeland Dairies
Donegal Co-operative Society
Town of Monaghan Co-operative Society
Connacht Gold Co-operative Society

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Technology

Opportunity/Benefit:

The range in profitability within the study farms over the three year project was considerable and this variability in both productive and economic performance indicates that high profit dairy production can be achieved within the BMW region.

1. Project background:

The phased abolition of EU milk quotas is now well advanced and will require Irish dairy farmers to revisit the very fundamentals of their production systems to remain competitive on world markets. In future years, more variable farm gate milk prices will necessitate the development of lower cost production systems so that Irish farmers can remain profitable in low milk price years. While grazed grass will continue to be the cheapest feed available on most dairy farms, its utilization is reduced in the West, Northwest and Northeast regions of Ireland due to such limitations as shorter grass-growing season, impeded land drainage, topography, high rainfall and northerly aspect. The objectives of this project were to observe the variation in farm financial performance on 16 commercial dairy farms in the BMW region.

2. Questions addressed by the project:

What is the variation in farm financial performance on 16 commercial dairy farms in the BMW region?

3. The experimental studies:

Data recording was conducted on 16 commercial dairy farms during 2005, 2006 and 2007 to assess the animal and grassland management practices in the region. Each farm in the study completed detailed financial accounts using the Teagasc profit monitor during the years 2005, 2006 and 2007 and this data was merged to a biological database on farm biological performance (including details on milk production, stocking density, feed supplementation, herd genetics and fertility).

4. Main results:

- Average milk production was 5,976 kg/cow with concentrate supplementation of 1,148 kg/cow at a stocking rate 2.32 cows/ha and a calving date of March 8th.
- Reproductive performance was highly variable on the study farms with the average breeding period length of 18 weeks, a 42–day pregnancy rate of 53% (range 28 to 85%) and calving interval of 401 days (372 to 432 days).
- The economic performance data collected shows average profit of €1,051 per hectare (and ranging from €71 to €2,111). Average gross output and common costs in cent per litre (c/l) for the study farms were 27.2 and 15.9, respectively, while average common profit was 11.4 c/l. The range in profitability within the study farms over the three year project was considerable as average common costs ranged from 10.4 to 23.2 c/l and average common profit from 3.5 to 18.2 c/l.

5. Opportunity/Benefit:

- The variability in both productive and economic performance indicates that high profit dairy production can be achieved within the region and large potential exists to substantially increase profitability on the dairy farms analysed.
- Higher profitability was achieved through higher EBI animals, a higher milk protein percentage, a more fertile and compact breeding period, reduced concentrate supplementation and increased stocking rates.

6. Dissemination:

Three open day events were held during the project (April 6th, 2006; April 19th, 2007 and March 5th 2009) to provide local dairy farmers and industry representatives in the region with locally generated research information and system development technology. At these events research technologies to increase farm profitability post milk quotas by instigating management practices that grow and utilise higher quantities of superior quality grass and achieve high animal performance over a long grazing season were highlighted. (http://www.agresearch.teagasc.ie/moorepark/Publications/pdfs/MPK%20Dairy%20Levy%20Update%20Series%2010.pdf)

In addition to open day events, individual discussion groups frequently visited the experiment during the project. Topics covered at these events by research and advisory staff included grassland management best practice advice, animal breeding and health recommendations and economic implications of research results.

Main publications:

B. Horan 2006. In: National Dairy Conference, Belturbet, Co. Cavan, 17– Nov–2006

Animal and Grassland Research & Innovation Programme

Project number:
5664
Date:
Nov. 2011
Funding source:
Teagasc
Project dates:
Dec 2006–Dec 2010

Strategies to increase dairy cow performance at pasture

Key external stakeholders:

Dairy farmers, advisors, agricultural consultants, researchers, grassland industry.

Practical implications for stakeholders:

The research investigated the effect of different pre-grazing herbage mass swards and their impacts on animal, sward and system performance. Key results found:

- Maintaining a medium pre-grazing yield of between 1300 to 1600 kg DM/ha can achieve high cow performance at pasture.
- Grazing swards with low pre-grazing herbage mass will reduce overall annual farm growth rate by >1t DM/ha.
- Grazing heavy pre-grazing yields (>1800 kg) during the main grazing season will reduce cow performance and grass utilisation.
- Optimising pre-grazing herbage mass provides the opportunity to increase the profitability of the farm system by adjusting grassland management practices.

Main results:

Maintaining pre-grazing herbage masses in the range of 1300 to 1600 kg DM/ha (8–9cm) can maintain high levels of milk production performance and grass utilisation during the main grazing season.

Maintaining lower herbage masses (<1000 kg DM/ha) will result in reduced grass production, lower grass dry matter intakes and more frequent intervention with supplementary feed. While increasing the herbage mass (> 2200 kg DM/ha) will reduce sward quality and grass utilisation and hence lower animal performance.

Collaborating Institutions:
UCD
INRA (France)

Teagasc project team:
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Dr. Mary McEvoy

External collaborators:
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Technology

Opportunity/Benefit:

The results of this project provide clear guidelines as to the optimum level of pre-grazing yield for rotational grazing systems which will optimise the quality of the grass available and the dry matter intake and milk performance of grazing dairy cows. In addition grazing management can be simplified as results suggest that maintaining low pre-grazing yields (900 kg DM/ha) can result in insufficient grass production at farm level and therefore require a greater amount of supplementary inputs in the system.

1. Project background:

With the upcoming removal of quotas, the future expectations of the Irish dairy industry are to increase milk production with greater focus on increased grass utilisation. In order to remain competitive at an international level maximising milk production from a grass-based system is a key objective on many Irish dairy farms. Results of previous research projects have highlighted the benefits of early turnout to grass in spring in terms of improved animal performance and subsequent sward quality. Information on the optimum level of pre-grazing herbage mass which should be offered is limited. Previous research has shown that as pre-grazing yield increases the proportion of stem in the sward will also increase and this will reduce sward nutritive value. Low herbage mass swards have been shown to limit the intake of the animal as the cow must spend a larger proportion of the time grazing to meet their energy requirements, as a result animals offered high pre-grazing yield swards tend to have greater intakes than those offered low pre-grazing yield swards. As feed intake and nutritive value are key drivers of milk production, factors influencing milk performance in swards of different herbage masses must be fully investigated.

The objective of this project was to investigate the effect of different levels of pre-grazing yield on grass supply and quantify the effect on cow performance and sward structural changes. In the first grazing rotation, grass supply is generally limited, however in mid-April, grass supply begins to exceed herd demand. This project aimed to impose different levels of pre-grazing yields from the beginning of the second rotation through to the end of the grazing season to quantify the resulting effect on farm output throughout the grazing season.

2. Questions addressed by the project:

- What is the optimum pre-grazing yield to offer grazing dairy cows in rotational grazing systems?
- Will very low or high pre-grazing yield swards affect nutritive quality and animal performance?
- What key sward structural factors influence the performance of the grazing dairy cow?
- Does sward quality affect methane emissions from grazing dairy cows?

3. The experimental studies:

In order to answer the research questions posed a number of experimental studies were completed. All experiments examined the performance of grazing spring calving dairy cows. The first study investigated the effect of grazing a medium (1600) and high (2200) kg DM/ha pre-grazing yields on grass dry matter intake and performance from April, through to the end of the grazing season at two levels of daily herbage allowance (DHA). The second study compared the dry matter intake, performance and sward characteristics of 900 (low), 1400 (medium) or 2400 (high) kg DM/ha for the entire grazing season. Each study monitored sward structural changes and attempted to relate these to differences in intake, milk yield and milk composition.

4. Main results:

Results from the first study showed that grazing swards at a medium pre-grazing yields resulted in increased milk solids output (+ 6%/ ha) and grazing days (+40 days/ ha) compared to high pre-grazing yield swards. Adapting the concept of grazing medium pre-grazing mass swards resulted in increased pasture quality after the reproductive growth phase this in turn resulted in increased dry matter intake and as a result milk yield was improved compared to the high pre-grazing yield swards. Leaf proportion in the medium pre-grazing yield sward was greater than that in the high mass swards. In the second study, cows grazing the low mass swards required substantially more supplement during the grazing season to overcome grass deficits. Within the high mass treatment, sward quality and grass utilization was lower than the other treatments and milk production performance tended to decline from July onwards. A reduction in grass DM production (–1.15 t DM/ha) and grass silage conserved for winter feeding (- 180

kg DM/cow) was recorded on the low mass treatment. It was concluded that maintaining low pre-grazing yields results in reduced grass DM production and a reduced level of grass silage conserved for winter feeding while offering no benefit in terms of animal performance.

Within this study methane emissions were measured on two occasions (June and July), it was found that grazing high pre-grazing yield swards increased methane production per cow/day (+42g), per kilogram of milk yield (+3.5g/kg of milk), per kilogram of milk solids (+47g/kg of milk solids) and per kilogram of grass dry matter intake (+3.1g/kg of GDMI) in the July period. In summary cows grazing high pre-grazing yield swards lost a greater proportion of their gross energy intake as methane during both measurement periods (+0.9% and +1%). This indicates that grazing swards of high grass quality (high leaf content) can reduce methane emissions from grazing dairy cows.

Targeting pre-grazing yields in the range of 1300–1600 kg DM/ha is a suitable criterion for determining when a pasture is ready to graze as it considers both pasture and animal performance related factors. Maintaining pre-grazing yields in the range of 1300–1600 kg DM/ha will ensure high pasture growth rates coupled with high levels of herbage utilization with no adverse affect on pasture quality or animal performance.

5. Opportunity/Benefit:

This project has highlighted the optimum level of pre-grazing yield which should be maintained within rotational grazing systems. This will result in increased milk solids output per ha and a greater number of grazing days per ha in comparison to very low or high levels of pre-grazing DM yields. It provides grassland farmers with an understanding of the benefits to be achieved through targeting specific pre-grazing herbage masses. This information will also benefit advisors as it provides them with the knowledge of what is the optimum level of pre-grazing DM yield and what drives animal performance as a result of this. It also provides an understanding as to why animal performance may be suffering on particular pastures or through particular grazing management practises.

6. Dissemination:

This information has already been widely disseminated to grassland farmers via discussion groups, open days, farm walks, popular press and Teagasc publications. It will continue to be disseminated through Teagasc advisors at discussion groups. Results have also been published in a number of peer reviewed international journals.

Main publications:

McEvoy, M., Delaby, L., Murphy, J.P., Boland, T.M. and O'Donovan, M. (2010). Effect of herbage mass and allowance on sward characteristics, milk production, intake and rumen volatile fatty acid concentration. Grass and Forage Science 65 : 335–347

McEvoy, M., O'Donovan, M., Murphy, J.P., O'Mara, F., Rath, M. and Delaby, L. (2009). Effect of pre-grazing herbage mass and daily herbage allowance on the lactation performance of Holstein-Friesian dairy cows. Journal of Dairy Science 92:414–422

Palladino, R.A., O'Donovan, M., McEvoy, M. , Callan, J., Boland, T.M. and Kenny, D.A. (2009). Fatty acid intake and milk fatty acid composition of Holstein dairy cows under different grazing strategies: herbage mass and daily herbage allowance. Journal of Dairy Science 92 :

Curran, J., Delaby, L., Kennedy, E., Murphy, J.P., Boland, T.M. and O'Donovan, M. (2010). Sward characteristics, grass dry matter intake and milk production performance are affected by pre-grazing herbage mass and pasture allowance. Livestock Science 127 : 144–154

Wims, C., Deighton, M., Lewis, E., O'Loughlin, B., Delaby, L., Boland, T. and O'Donovan, M. (2010). Effect of pregrazing herbage mass on methane production, dry matter intake, and milk production of grazing dairy cows during the mid-season period. Journal of Dairy Science 93: 4976–4985. 2 PhD and 1 Masters Thesis

Popular publications:

Farmers Journal Farming Independent New Thinking in Challenging Times booklet distributed at Teagasc Moorepark open day 2009

Winning on a World Stage, booklet distributed at Teagasc Moorepark open day 2007

Several discussion groups visited the research campus Moorepark open days (2007, 2008, 2009, 2010, 2011) Farm walks (2006 to 2011 and ongoing)

Evaluating alternate pasture based milk production systems for the Border Midland West region

Project number:
5500
Date:
August, 2010
Funding source:
Teagasc & Dairy Levy
Project dates:
Jan 2005–Dec 2009

Key external stakeholders:

BMW region dairy farmers; local milk processors – Lakeland Dairies, Town of Monaghan, Donegal and Connacht Gold; AI companies; consultancy agencies.

Practical implications for stakeholders:

The success of grazing systems as determined by the ability to achieve high levels of grass utilisation is influenced by climatic and soil conditions. While many studies have investigated the effects of temperature, little is known of the biological and financial implications of wetter soil types on pasture system performance. The implications of this research project findings, undertaken at Ballyhaise Agricultural College, indicate that

- Considerable potential exists to increase animal productivity from pasture in the Border Midland and Western (BMW) region by increasing sward productivity in combination with an appropriate stocking rate and a compact calving high economic breeding index (EBI) herd.
- The economically optimum system of milk production will depend on milk price. The results suggest that at low milk prices increased concentrate supplementation will result in reduced profitability relative to systems based on a greater reliance on high quality grazed pasture.

Collaborating Institutions:
Lakeland Dairies
Donegal Co-operative Society
Town of Monaghan Co-operative Society
Connacht Gold Co-operative Society

Teagasc project team:
Dr. B. Horan
D. Patton
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External collaborators:
Dr. Pat Shields and Alan Hurst, Lakeland Dairies
Norman Witherow, Donegal Co-operative Society
Aidan McCabe, Town of Monaghan Co-operative Society
Phillip Doonan, Connacht Gold Co-operative Society

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Technology

Main results:

- Total herbage production at Ballyhaise Agricultural College averaged 12,483 kg DM / ha during the study over a 270 day growing season with high peak growth rate.
- Higher yields of milk and fat plus protein (6,049 and 458kg/ cow) were produced in the HC system compared to the HG system (5,606 and 427 kg/cow, respectively).
- High productivity systems of milk production for the BMW region will depend on milk price. At low milk prices, systems of production based on increased concentrate supplementation will result in reduced profitability relative to systems based on a greater reliance on grazed pasture.

Opportunity/Benefit:

High productivity systems of milk production can be successfully realized in the BMW region and will allow dairy farmers to maintain farm profitability when milk prices decline.

1. Project background:

The challenge for Irish dairy farmers in the years ahead is to increase the competitiveness of their business through innovation, productivity gain and increased operational scale.. With revenue from milk production projected to fall, national farm statistics show that costs of milk production are increasing by 0.15c/ litre per year while the variation between the highest cost and lowest cost producers is in excess of 9.2 c/l. This data suggests that producers must focus on achieving cost efficient milk production through more efficient use of pasture. In the Border Midlands Western (BMW) region of Ireland, the potential from pasture-based systems is reduced due to limitations such as a shorter grass-growing season, impeded land drainage and high rainfall. These factors have the effect of shortening the grazing season and poor ground conditions reduce the potential of farms in the region to utilize grass efficiently.

2. Questions addressed by the project:

What is the potential of grass and grass based dairy production systems in the BMW region?

3. The experimental studies:

This study compared he biological and financial efficiency of two likely pasture-based production systems for the BMW region over a three year period (2005–2007 incl.). The two systems compared were: a high grass allowance system (HG) and a high concentrate feeding system (HC). The HG system (stocking rate of 2.45 cows/ha feeding 578kg of concentrate/cow) was created to reflect the performance potential of a low cost grazing system with minimal external feed input. In comparison, the HC system (stocking rate of 2.92 cows/ha feeding 1,365kg of concentrate/cow) was created to reflect the performance potential of a high output per hectare system based on increased stocking intensity in combination with increased concentrate supplementation.

4. Main results:

- Total herbage production at Ballyhaise Agricultural College averaged 12,483 kg DM / ha during the study over a 270 day growing season with high peak growth rate.
- Higher yields of milk and fat plus protein (6,049 and 458kg/ cow) were produced in the HC system compared to the HG system (5,606 and 427 kg/cow, respectively).
- Milk fat and protein content were unaffected by production system.
- The combination of increased supplementation per cow and increased cow numbers per hectare resulted in a systems response of 1.41 kg of milk per 1 kg of additional supplement fed in the HC system.
- There was no significant influence of production system on reproductive performance.
- The optimum system of production was influenced by milk price. At a low milk price, highest profit was generated by the HG system where costs of production were minimised, whereas at a high milk price the HC system realised higher overall farm profitability.

5. Opportunity/Benefit:

This study demonstrates that high productivity grass based systems can be realised in the BMW region while the financial optimum system of production will depend on milk price. The results suggest that at low milk prices increased concentrate supplementation will result in reduced profitability relative to systems based on a greater reliance on high quality grazed pasture.

6. Dissemination:

Three open day events were held during the project (April 6th, 2006; April 19th, 2007 and March 5th 2009) to provide local dairy farmers and industry representatives in the BMW region with locally generated research information and system development technology. The objective of these events was to highlight research technologies that will increase farm profitability post milk quotas by instigating management practices that grow and utilise higher quantities of superior quality grass and achieve high animal performance over a long grazing season. (http://www.agresearch.teagasc.ie/moorepark/Publications/pdfs/MPK%20Dairy%20Levy%20Update%20Series%2010.pdf)

In addition to open day events, individual discussion groups frequently visited the experiment during the project. Topics covered at these events by research and advisory staff included grassland management best practice advice, animal breeding and health recommendations and economic implications of research results. In addition, the experimental farms provided a teaching platform for young dairy farmers attending the college.

Main publications:

B. Horan 2006. In: National Dairy Conference, Belturbet, Co. Cavan, 17– Nov–2006 http://www.agresearchforum.com/publicationsarf/2008/proceedings2008.pdf

Animal and Grassland Research & Innovation Programme

Project number:
4925
Date:
August, 2012
Funding source:
Teagasc
Project dates:
Oct 2000–Nov 2007

Prime lamb production from ewes offered grazed grass, as the sole forage, throughout the year

Teagasc project team:
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External collaborators:
N/A

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Key external stakeholders:

Sheep producers, ruminant nutritionists, agricultural consultants, extension officers, Department of Agriculture, Food and the Marine

Practical implications for stakeholders:

A mid-season prime lamb production system producing a lamb carcass output of 364 kg/ha, without winter housing or forage conservation, is sustainable.

- Stocking rate is limited to around 10 ewes/ha, consequently reducing potential lamb carcass output by 26%.
- Deferred (extended) grazing is an inefficient system for utilising herbage. Up to 28% of accumulated herbage for winter grazing may be lost due to senescence, and the utilisation of the remaining herbage can be as low as 35%.
- Deferred grazing impacts negatively on sward botanical composition by reducing the proportion of perennial ryegrass.
- Herbage requirement peaks in September due to the need to close approximately 50% of the grazing area in order to accumulate herbage for deferred grazing whilst at the same time providing herbage to prepare ewes for mating and to finish lambs.
- Lambs born from ewes on deferred grazing during pregnancy are heavier at birth and weaning relative to lambs from ewes that are housed unshorn. However, these benefits in lamb performance from deferred grazing can be obtained indoors by shearing the ewes at housing.

Technology

Main results:

- Lamb carcass output of up to 501 kg/ha was achieved from a mid-season prime lamb production system receiving 85 kg N per hectare, stocked at 14.4 prolific ewes/ha (Belclare) and involving winter housing and forage conservation.
- Deferred grazing ewes during pregnancy increased lamb birth weight probably due to reduced heat stress associated with the outdoor environment.
- Deferred grazing is an inefficient system of utilizing herbage and reduces the proportion of *L. perenne* in the sward.
- Allocating herbage twice weekly rather than daily did not influence animal performance whilst reducing labour requirement.
- Each 1 day delay in grazing herbage under deferred grazing reduced herbage DM yield the following spring by up to 54.2 kg/ha.

Opportunity/Benefit:

The project results demonstrate that a year-round grazing system of mid season prime lamb production is capable of producing up to 365 kg of lamb carcass per hectare. Further component studies provided greater precision as to the quantity of herbage required per ewe during mid and late pregnancy. Labour input can be reduced by allocating herbage during deferred grazing twice weekly rather than once daily. Limitations of the system include the potential stocking rate, risks from adverse prevailing weather conditions, poor herbage utilization, herbage demand variation throughout the year and deteriorating sward botanical composition. Whilst deferred grazing increased lamb birth and weaning weights, this can be achieved indoors by shearing the ewes at housing.

1. Project background:

Prime lamb production in Ireland is seasonal and grass based; lambing is normally targeted to coincide with grass growth in spring. Grass growth is seasonal, consequently, during the winter period pregnant ewes are either housed and offered predominantly grass-silage-based diets or kept outdoors often on deferred grazed paddocks. The main factors that affect the cost of grass production are herbage DM yield and utilisation rate. Low herbage production and/or poor utilisation increase the cost of grass production to a level similar to or greater than that of grass silage when expressed per kilogram of DM consumed by grazing animals.

Year-round grazing, which involves deferred grazing during the winter period, reduces fixed costs (absence of ewe housing facilities). Year-round grazing limits stocking rate. As many sheep units currently operate at a low stocking rate (average stocking rate of lowland sheep farms being 9.0 ewes/ha) opportunities exist to extend the grazing season without impacting negatively on overall farm stocking rate.

2. Questions addressed in the project:

- Can a system of mid season prime lamb production be developed involving year-round grazing?
- What is the effect of ewe prolificacy on lamb carcass output in contrasting production systems?
- What is the feed value of deferred grazed herbage?
- What is the impact of deferred grazing on ewe performance and on lamb birth and weaning weights?
- What is the effect of deferred herbage allowance in mid and late pregnancy on subsequent performance?
- Does frequency of deferred herbage allocation affect ewe performance?
- Is the response in terms of increased lamb birth weight related to when deferred grazing occurs?
- Can concentrate feeding in late pregnancy be omitted in a deferred-grazing system?
- What is the effect of deferred grazing on rearing ewe replacements?
- What is the impact of deferred grazing management on subsequent herbage yield?
- What is the impact of deferred grazing on botanical composition of the sward?

3. The experimental studies:

Experiment 1. *An evaluation of two-grassland-based systems of mid season prime lamb production using prolific ewes of two genotypes.* A 4-year systems study was undertaken to evaluate the effects of two contrasting management systems [year-round grazing (YRG) – stocking rate of 10.5 ewes/ha, N application of 92 kg/ha; normal seasonal grazing followed by indoor feeding during winter (GWF) – stocking rate 14.4 ewes/ha, N application 85 kg/ha] on the performance of mid-season lambing ewes.

Experiment 2. *Effects of deferred grazing during mid, late or throughout pregnancy, and winter shearing of housed ewes, on ewe and lamb performance.* Ewes (n=265) were allocated at random to five treatments: housed shorn (HS), housed unshorn (HU), grazing throughout pregnancy (EG), grazing to 20 January followed by housing (EGH), housed to 20 January followed by grazing (HEG). Ewes on the EG and HEG treatments lambed outdoors.

Experiment 3. *Effects of shearing at housing, grass silage feed value and deferred grazing herbage allowance on ewe and subsequent lamb performance.* Ewes (n=120) were assigned to one of 6 treatments from day 63 of pregnancy to lambing in March: two shearing treatments (shorn, unshorn) X two silage feed values (low, medium) and two deferred grazed herbage DM allowances (1.0 and 1.8 kg/day)

Experiment 4. *The effects of allowance and frequency of allocation of deferred herbage, and grass silage feed value, when offered to ewes in mid-gestation, on ewe and lamb performance.* From day 63 to 120 of gestation ewes (n=120) were assigned to a factorial study consisting of 2 herbage DM allowances (1.0, 1.8 kg/day) X 2 frequencies of herbage allocation (daily, twice weekly) and 2 grass silage feed values (low, medium). From day 120 of gestation to lambing all ewes were housed and offered the same diet

Experiment 5. *The effects of allowance and frequency of allocation of autumn-saved pasture, when offered to spring lambing ewes in mid pregnancy, on ewe and lamb performance.* From day 41 to 104 of gestation 72 ewes were assigned to a factorial study consisting of 2 herbage DM allowances (1.0 or 1.8 kg/day) X 2 frequencies of allocation (daily, twice weekly). The ewes were housed from day 105 of gestation until lambing and offered grass silage ad libitum plus concentrate supplement (total of 19 kg/ewe).

Experiment 6. *Effects of system of herbage allocation for single-and twin-bearing ewes during late pregnancy on ewe and subsequent lamb performance.* This study was undertaken in a commercial flock of 152 ewes (which had been housed in mid pregnancy) during the last 6 weeks prior to lambing. The four treatments were (i) fresh herbage offered daily to single-bearing ewes, (ii) fresh herbage offered daily to twin-bearing ewes, (iii) fresh herbage offered daily to twin-bearing ewes as leaders in a leader-follower system, (iv) pasture offered daily to single-bearing ewes as followers in the leader-follower system.

Experiment 7. *Effects of herbage allocation and concentrate supplementation on the performance of ewe lambs on deferred grazing during the winter.* This study was undertaken in a commercial flock of 248 ewe lambs that were allocated to 4 treatments: deferred grazed herbage at three DM allowances (0.75, 1.25 and 1.75 kg/head daily) and deferred grazed herbage (DM allowance of 0.75 kg/head daily) supplemented with 0.5 kg concentrate per head daily. The ewe lambs were on the treatments from 16 December to 3 March and residual effects were measured during the subsequent grazing season (4 March to 11 August). Experiment 8. *Effects of sward grazing date and management of autumn pasture on subsequent herbage yield.* A split-plot design study (72 plots) was undertaken to evaluate the effects of deferred herbage DM allowance (1.0 and 1.8 kg/ewe/d), frequency of allocation (daily, twice weekly) and grazing date (6–12 Dec, 27 Dec to 3 January or 17–23 January) on herbage yield at two harvest dates (27 April or 25 May). Experiment 9. *Effects of grazing date and system of autumn pasture management on herbage yield and composition in spring.* A split-plot study (128 plots) was undertaken to evaluate the effects of herbage DM allowance (1.0, 1.8 kg/ewe), frequency of allocation (daily, twice weekly), grazing date (28 Nov to 4 Dec, 12 to 18 Dec, 2 to 8 Jan or 23 to 29 Jan) and harvest date (4 Apr, 18 Apr, 2 May or 25 May) on herbage yield. Experiment 10. *Effects of deferred grazing pasture with ewe lambs on sward botanical composition.* A split-plot study was undertaken to evaluate the effects of date of herbage removal (early December or at grazing), daily herbage DM allowance (0.75 and 1.75 kg/lamb) and date of grazing (12–18 December, 16–22 January or 20–26 February) on sward botanical composition.

4. Main results:

Experiment 1

- A YRG system of prime lamb production was sustainable but at a reduced stocking rate (–26%) and had greater lamb mortality relative to the GWF system.
- Ewe genotypes with a mean litter size of up to 2.34 lambs were suitable for both systems.
- Lamb carcass output of 501 kg/ha was achieved from a primarily grass-based system using prolific ewes (Belclare) and involving winter housing and forage conservation.

Experiment 2

- Deferred grazing in mid and late pregnancy yielded 35% and 65%, respectively, of the increase in lamb birth weight associated with deferred grazing throughout pregnancy.
- Treatment effects on lamb birth weight were associated with those of weaning weight.
- Shearing ewes at housing gave the same increase in lamb birth and weaning weight as deferred grazing.
- The increased lamb birth weight from deferred grazing in mid pregnancy was probably due to improved utilization of protein from the grazed herbage whilst the increased lamb birth weight from grazing in late and throughout pregnancy, and shearing at housing was probably due to reduced heat stress associated with the outdoor environment and removal of the fleece, respectively.

Experiment 3

- Herbage allowance in mid-pregnancy did not alter lamb birth weight or subsequent growth rate.
- Based on the difference in lamb weight at weaning, 0.8 kg of grass silage DM intake had the same feed value as a daily deferred herbage DM allowance of 1.8 kg/ewe throughout the study.

Experiment 4

- Increasing herbage allowance in mid gestation increased lamb birth and weaning weights and reduced herbage utilisation to as low as 34%.
- Frequency of herbage allocation did not alter ewe or subsequent lamb performance.
- Based on lamb weaning weight, 1.3 kg of deferred grazed herbage DM allowance had the same feed value as 1.0 kg of low feed-value grass silage DM.

Experiment 5

- Reducing the frequency of herbage allocation increased lamb birth weight.
- To reduce labour requirement and increase stock carrying capacity a daily allowance of 1 kg of herbage DM, allocated twice weekly, is sufficient for ewes on deferred-grazed pasture in mid pregnancy. Experiment 6.
- System of herbage allocation to ewes in late pregnancy did not alter subsequent lamb performance.
- The leader-follower system increased herbage utilisation, which could increase stock-carrying capacity whilst reducing labour requirement for moving fences, without altering subsequent lamb performance Experiment 7.
- Increasing herbage allowance increased herbage intake and lamb live weight.
- The high plane of nutrition offered during deferred grazing still maintained up to 57% of the performance benefit after 155 days grazing during the subsequent grazing season.
- Each 1 kg concentrate DM had the same feed value as 2.4 kg DM of deferred grazed herbage allocation. Experiment 8.
- Frequency of herbage allocation did not alter herbage yield.
- Each 1–day delay in grazing date reduced herbage DM yield by 54.2 kg/ha. Experiment 9.
- Frequency of herbage allocation did not alter herbage yield during the subsequent grazing season.
- Increasing herbage allocation increased subsequent herbage yield and reduced bare ground.
- Delaying grazing date reduced herbage yield and increased herbage feed value.
- Delaying harvest date increased herbage yield and the proportion of bare ground. Experiment 10.
- Delaying defoliation either by clipping or grazing reduced the proportion of *L. perenne* in the sward, primarily due to the effect of herbage mass rather than poaching during deferred grazing.

5. Opportunity/Benefit:

- Greater precision can now be exercised during year-round grazing in relation to grassland management, herbage build up for deferred grazing, herbage allowance, and deferred grazing management.
- The benefits obtained from deferred grazing ewes, in terms of lamb birth and weaning weights can be gained indoors by shearing the ewes at housing.
- A year-round grazing system was developed. Potential limitations were identified including stock rate and deterioration in sward botanical composition due to heavy sward covers during the winter months.

6. Dissemination:

Main publications:

Keady, T.W.J. and Hanrahan, J.P. (2006) 'Efficient sheep production in a subsidy free environment – Research from Athenry.' *Irish Grassland Association Journal* 40: 15–27.

Keady, T.W.J. and Hanrahan, J.P. (2007) 'Extended grazing – its potentials and limitations.' *Irish Grassland Association Journal* 41: 81–96.

Keady, T.W.J., Hanrahan, J.P. (2009) 'Effects of shearing at housing, grass silage feed value and extended grazing herbage allowance on ewe and subsequent lamb performance.' *Animal* 3: 143–151.

Keady, T.W.J. and Hanrahan, J.P. (2009) 'The effects of allowance and frequency of allocation of deferred herbage and grass silage feed value, when offered to ewes in mid gestation on ewe and lamb performance and subsequent herbage yield.' *Animal* 3: 879–890.

Keady, T.W.J. and Hanrahan, J.P. (2010) 'The effects of allowance of deferred herbage and concentrate supplementation when offered to ewes in late gestation, on animal performance.' *Grass and Forage Science* 65: 227–236.

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Keady, T.W.J., Moran, J. and Hanrahan, J.P. (2010) 'An evaluation of the effects of extended grazing pasture with ewe lambs on sward botanical composition.' *Proceedings of the British Society of Animal Science* p211.

Popular publications:

Keady, T.W.J. (2011) 'Grassland management for high lamb performance.' *Irish Independent, Farming, 7 June, pp 18–19.*

Keady, T.W.J. and Hanrahan, J.P. (2008) 'Extended grazing of the ewe flock – the current thinking.' *TResearch* 3(1): 16–18.

Keady, T.W.J. and Hanrahan J.P. (2010) 'Optimising lamb performance during the grazing season.' *Irish Farmers Journal* 10 June, pp26–27.

Productivity of clover-based grassland under organic management and nitrate losses to ground water

Project number:
5782
Date:
September 2012
Funding source:
RSF07–511
Project dates:
Dec 2007–April 2012

Key external stakeholders:

Organic dairy farmers, grassland farmers, advisors, organic milk processors

Practical implications for stakeholders:

It is possible to substantially lower the cost of producing organic milk during the winter by grazing cows throughout the winter on grass/white clover swards. This practice had no impact on milk yields per cow, the processing characteristics of the milk or on N losses to ground water.

Main results:

- Producing milk by grazing cows over the winter at low stocking density (1.2 cows/ha) had no effect on milk output per cow, milk composition and the processing characteristics of the milk but substantially lowered the cost offering Irish dairy producers a viable option to produce organic milk during the winter months when a premium price is paid for the milk.
- Trampling in winter resulted in less of a reduction in pre-grazing herbage yield than trampling in spring due to lower soil surface deformation and longer recovery periods. Grazing during the winter resulted in significant increases in clover content, herbage production and N-fixation estimates. The results show that grazing during the winter can increase clover content, BNF and herbage production and is therefore a useful management tool for maintaining or increasing clover contents of swards.
- A 42–day rotation with a low defoliation height (2.7 to 3.5 cm) during the autumn and early winter gave the most desirable results in terms of herbage yield and white clover stolon mass in the following spring/ summer.

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Technology

- Grazing over the winter period on this site had no effect on N losses to groundwater due to high natural buffering capacity of the soils associated with heavy texture, high SOC, high soil pH, anaerobic conditions and presence of shallow groundwater. Mean concentrations of DON, NH_4–N, NO_2–N and NO_3–N were 2.16, 0.35, 0.01 and 0.37 mg L^{-1} respectively.

Opportunity/Benefit:

- It is possible to substantially lower the cost of producing organic milk during the winter by grazing cows throughout the winter on grass/white clover swards. This practice had no impact on milk yields per cow, the processing characteristics of the milk or on N losses to ground water.

1. Project background:

- Ireland is a net importer of organic dairy products at processing and retail levels. This contrasts sharply with conventional dairy production where approximately 80% of Irish products are exported. In Ireland, a premium price is paid for milk produced on organic dairy farms if 50% of the milk is supplied during the autumn and winter (September to March). Grazing cows on clover-based grassland is a key component of profitable organic milk production. Ireland's climate is conducive to production from clover swards over a long growing season. Organic systems of production operate at low stocking densities compared with conventional systems. Low stocking rates offer the potential to extend the grazing season throughout the autumn, winter and early spring with the potential to substantially lower the cost of feed for organic winter milk production. This project aimed at substantially lowering the cost of feed for organic winter milk production by supplying a large proportion (>50%) of the diet from grazed grass-clover during autumn and winter.

2. Questions addressed by the project:

- The objective of task 1 was to investigate the productivity of white clover-based grassland under different management regimes for dairy production including a system where a large proportion (>50%) of the diet during the autumn and winter was grazed grass-clover swards.
- The objective of task 2 was to investigate the effects of grazing interval and post-grazing height during the autumn on herbage accumulation during the autumn, winter and following spring and to investigate trampling by dairy cows on soil properties and herbage production within this winter-grazing system on a soil with impeded drainage.
- Grazing during the winter, albeit at low stocking rates, carries the risk of losses of nitrate to groundwater. The objective of task 3 was to measure the impacts of this dairy production system involving grazing over the winter on nitrate losses to groundwater compared with more conventional systems on a poorly drained clay-loam soil with a high natural attenuation capacity.

3. The experimental studies:

- Fifty four primi-and multi-parous Holstein-Friesian dairy cows were used in a one factor experiment with 3 systems and repeated over two lactations (2008/09 and 2009/10). The three systems compared had: (i) a mean calving date of 17 February, stocking density of 2.15 dairy cows ha^{-1}, receiving 90 kg ha^{-1} of annual fertilizer N input; (ii) a mean calving date of 17 February, stocking density of 1.6 dairy cows ha^{-1}, receiving no fertilizer N input and (iii) a mean calving date of 16 April, stocking density of 1.6 dairy cows ha^{-1} between calving and 1 September and stocking density of 1.2 dairy cows ha^{-1} between 1 September until dry-off in early February, receiving no fertilizer N input.
- The effects of defoliation interval (INT: 21, 42, 56 or 84–days), defoliation height (DH: 2.7, 3.6, 5.3 or 6.0 cm) and final defoliation (closing) date (FIN: 23 September, 4 November or 16 December) on herbage production in a grass-clover sward were studied. Treatments were only imposed between July and December 2008, with all plots under a common management in the following March to June 2009.
- A dense network of shallow groundwater piezometers was installed to determine groundwater flow direction and N spatial and temporal variation. Estimated vertical travel times through the unsaturated zone allowed the correlation of management with groundwater N within a short space of time.

4. Main results:

- Producing milk by grazing cows over the winter at low stocking density (1.2 cows/ha) had no effect on milk output per cow, milk composition and the processing characteristics of the milk but substantially lowered the cost offering Irish dairy producers a viable option to produce organic milk during the winter months when a

premium price is paid for the milk.

- Trampling in winter resulted in less of a reduction in pre-grazing herbage yield than trampling in spring due to lower soil surface deformation and longer recovery periods. Grazing during the winter resulted in significant increases in clover content, herbage production and N-fixation estimates. The results show that grazing during the winter can increase clover content, BNF and herbage production and is therefore a useful management tool for maintaining or increasing clover contents of swards.
- A 42–day rotation with a low defoliation height (2.7 to 3.5 cm) during the autumn and early winter gave the most desirable results in terms of herbage yield and white clover stolon mass in the following spring/summer.
- Grazing over the winter period on this site had no effect on N losses to groundwater due to high natural buffering capacity of the soils associated with heavy texture, high SOC, high soil pH, anaerobic conditions and presence of shallow groundwater. Mean concentrations of DON, NH_4–N, NO_2–N and NO_3–N were 2.16, 0.35, 0.01 and 0.37 mg L^{-1} respectively.

5. Opportunity/Benefit:

It is possible to substantially lower the cost of producing organic milk during the winter by grazing cows throughout the winter on grass/white clover swards. This practice had no impact on milk yields per cow, the processing characteristics of the milk or on N losses to ground water.

6. Dissemination:

Main publications:

Necpalova M., Fenton O., Casey I.A. and Humphreys J. (2012) N leaching to groundwater from dairy production involving grazing over the winter on a clay-loam soil. *Science of the Total Environment* 432, 159–172.

Phelan P., Keogh B., Casey I.A., Necpalova M. and Humphreys J. (2012) The effects of treading by dairy cows on soil properties and herbage production in white clover based grazing systems on a clay loam soil. *Grass and Forage Science,* (in press)

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Phelan P., Casey I.A. and Humphreys J. (2012) The effect of target post-grazing height treatment on herbage yields and dairy production from grass-white clover swards. *Journal of Dairy Science,* (accepted subject to changes)

Necpalova M., Li D., Lanigan G., Casey I.A., Burchill W. and Humphreys, J. (2012) Changes in soil organic carbon in clay-loam soil following ploughing and reseeding of permanent grassland under temperate moist climatic conditions. *Grass and Forage Science,* (submitted and under review).

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Necpalova M., Phelan P., Casey I.A., Humphreys J. (2012) Effect of non-fertilized winter grazing dairy production on soil N balances and soil N dynamics. In: Proceedings of the 63rd annual meeting of European Federation of Animal Science, Bratislava, 27–31 August 2012, p. 150.

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Necpalova M., Fenton O., Casey I.A., Humphreys J. (2012) Effect of non-fertilized winter grazing dairy production system based on clay-loam soil on N leaching to groundwater. In: *Proceedings from 17th international Nitrogen Workshop*, 26–29 June 2012, 311–312.

Necpalova M., Casey I.A., Humphreys J. (2012) Effect of ploughing and reseeding of permanent grassland on N leaching to groundwater and nitrous oxide emissions from a clay-loam soil. In: *Proceedings from 17th international Nitrogen Workshop*, 26–29 June 2012, 313–314.

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Phelan, P. Keogh, B. Casey I.A. Fitzgerald E. and Humphreys J. (2010) Cutting height and interval in autumn and annual herbage production in a white clover-grass sward. Nordic Association of Agricultural Scientists Seminar 432, Hvanneyri, Iceland, 20–22 June, 125–128.

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Quantification of the potential of white clover to lower GHG emissions from Irish grassland-based dairy production

Project number:
5783
Date:
September 2012
Funding source:
RSF07–516
Project dates:
Dec 2007–Feb 2012

Key external stakeholders:

Policy makers, milk processors, such as Carbery group, and the research community. This project was closely linked to international collaborative projects: Interreg IVB Dairyman and FP7 Legume Futures and FP7 Cantogether. The project entitled 'Carbery Greener Dairy Farms' funded by Carbery group was also initiated as a consequence of the present project.

Practical implications for stakeholders:

The inclusion of white clover in grassland can maintain high productivity and profitability while substantially lowering greenhouse gas emissions from pasture-based dairy production.

Main results:

- N_2O emissions due to biological N fixation (BNF) in permanent ryegrass/white clover grassland were negligible indicating that BNF is not an important source of N_2O. These results support the exclusion of BNF as a direct source of N_2O from the IPCC methodology.
- Annual N_2O emissions from the two clover based systems were much lower (20 to 23%) than from the fertilized N system.
- The process-based DNDC model simulated N_2O fluxes reasonably well when compared with the measured values.
- The results of the LCA of systems at Solohead Research Farm showed that the white clover-based systems (WC) had 11 to 26% lower carbon footprint (CF) compared with the fertilizer N-based systems (FN) (average CF was 0.86 to 0.89 and 1.00 to 1.16 kg CO_2 eq/kg Energy Corrected Milk (ECM).

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Technology

- In the study of 18 commercial dairy farms, large variation was found in farm attributes and management tactics. The overall CF of the milk production from the 18 dairy farms was 1.23 ± 0.16 kg CO_2 eq/kg ECM. Effective sward management of clover within a few farms lowered the CF.

Opportunity/Benefit:

- The inclusion of white clover in grassland can maintain high productivity and profitability while substantially lowering greenhouse gas emissions from pasture-based dairy production. Both the measured and simulated results supported that there was a clear reduction of greenhouse gas emissions when fertilizer N was replaced by biological N fixation.

1. Project background:

- Agriculture is the single largest contributor to greenhouse gas (GHG) emissions in Ireland accounting for nearly 27% of national emissions. Emissions are primarily determined by livestock numbers and mineral fertilizer N (FN) use on farms. Ireland, as a member of the European Union (EU), is committed to a 20% reduction in emissions by 2020 relative to 1990 and achieving this target poses a substantial challenge.
- Rhizobia bacteria in association with white clover have the capacity to produce plant-available N in the soil via biological N fixation (BNF), which can replace FN in grassland resulting in lower direct and indirect emissions of nitrous oxide from grassland and thus GHG emissions from pasture-based dairy production. However, there is uncertainty about the potential reduction of soil N_2O emission when FN is partially or completely replaced by BNF in temperate grassland. Furthermore, there is uncertainty about the impact of replacement of FN by BNF on overall GHG emissions from pasture-based dairy production, both on farm and pre-farm (associated with the manufacture of fertilizer N, for example).

2. Questions addressed by the project:

- Quantify changes in N_2O emissions when BNF is used to replace FN in permanent grassland and evaluate the applicability of the process-based model DNDC to simulate N_2O emissions from Irish grasslands.
- To determine, using LCA, the difference in GHG emissions between BNF and FN-based systems of dairy production on the clay loam soil at Solohead.
- To determine, using LCA, the change in GHG associated converting from FN-based to white clover-BNF-based grassland on commercial dairy farms in Ireland.

3. The experimental studies:

- The experiment to quantify changes in N_2O emissions when BNF is used to replace FN in permanent grassland was a randomised block design with five treatments and three replicates. The treatments were: 1) grazed perennial ryegrass (*Lolium perenne*) paddocks receiving 226 kg FN ha^{-1} yr^{-1} (GG+FN), 2) grazed ryegrass/white clover (*Trifolium repens*) paddocks receiving 58 kg FN ha^{-1} yr^{-1} (GWC+FN), 3) grazed ryegrass/white clover paddocks receiving no FN (GWC-FN), 4) perennial ryegrass plots (G-B) and 5) ryegrass/white clover plots (WC-B). G-B and WC-B were not grazed and did not receive slurry or FN and herbage was harvested by mowing. The area of these paddocks ranged from 0.32 to 1.63 ha. The dimension of each plot was 10m × 10m. Paddocks were rotationally grazed by dairy cows with stocking densities of 2.1 cows ha^{-1} for GG+FN and GWC+FN, and 1.6 cows ha^{-1} for GWC-FN. N_2O fluxes were measured weekly using the static chamber method between October 2009 and September 2010. In addition to measurements, the DNDC model was used to simulate N_2O emissions (DNDC 9.3).
- Life-Cycle Assessment (LCA) was used to determine the difference in GHG emissions between BNF and FN-based systems of dairy production on the clay loam soil at Solohead Research Farm. Data were sourced from two system-scale studies conducted at Solohead Research Farm in Ireland between 2001 and 2006. Ten FN stocked between 2.0 and 2.5 livestock units (LU) ha^{-1} with fertilizer N input between 173 and 353 kg ha^{-1} were compared with six WC stocked between 1.75 and 2.2 LU ha^{-1} with fertilizer N input between 79 and 105 kg ha^{-1}.
- Life-Cycle Assessment (LCA) was used to determine the contribution of white clover-BNF and other tactical management on 18 commercial dairy farms in Ireland to GHG emissions. This study was based on foreground data from a twelve month survey capturing management tactics and background data from literature.

4. Main results:

- N_2O emissions due to biological N fixation (BNF) in permanent ryegrass/white clover grassland were negligible indicating that BNF is not an important source of N_2O. These results support the exclusion of BNF as a direct source of N_2O from the IPCC methodology.
- Annual N_2O emissions from the two clover based systems were much lower (20 to 23%) than from the fertilized N system.
- The process-based DNDC model simulated N_2O fluxes reasonably well when compared with the measured values.
- The results of the LCA of systems at Solohead Research Farm showed that the white clover-based systems (WC) had 11 to 26% lower carbon footprint (CF) compared with the fertilizer N-based systems (FN) (average CF was 0.86 to 0.89 and 1.00 to 1.16 kg CO_2 eq/kg Energy Corrected Milk (ECM).
- In the study of 18 commercial dairy farms, large variation was found in farm attributes and management tactics. The overall CF of the milk production from the 18 dairy farms was 1.23 ± 0.16 kg CO_2 eq/kg ECM. Effective sward management of clover within a few farms lowered the CF.

5. Opportunity/Benefit:

- The inclusion of white clover in grassland can maintain high productivity and profitability while substantially lowering greenhouse gas emissions from pasture-based dairy production. Both the measured and simulated results supported that there was a clear reduction of greenhouse gas emissions when fertilizer N was replaced by biological N fixation.

6. Dissemination:

International conferences

Li DJ, Lanigan G, Humphreys J, (2011) Use of white clover to lower soil N_2O emissions from temperate moist grassland, Oral presentation at the 'Nitrogen & Global Change' conference, Edinburgh, UK, April 11–14, 2011.

Yan, M.-J, Humphreys, J. and Holden, N.M.(2012) Carbon footprint of Irish milk production. 8th International Conference on LCA in the Agri-Food Sector, Rennes, France, 2–4 October 2012 (in press).

Yan, M-J., Humphreys, J. and Holden, M.N. (2010) Life cycle comparisons of greenhouse gas emissions from pasture-based dairy production of Ireland. Proceedings of VII International conference on Life Cycle Assessment in the agri-food sector Bari, September 2010, 22–24.

Yan M., Humphreys J., Holden N.M. (2009) LCA studies: how comparable are they? Examples of milk production in Europe, New Zealand and Canada. Oral presentation at the 2nd Chinese Conference on Life Cycle Management, Nov 15–16, 2009. Beijing, China.

Yan M.-J., Humphreys J., Holden N. M. (2009) Life cycle comparisons of greenhouse gas emissions from pasture-based dairy production in Ireland. *Irish Journal of Agricultural and Food Research*, 48, 275.

International workshops and seminars

Yan, M-J., Humphreys, J. and Holden, N.M. (2012) Carbon footprint of Irish milk production. In: Proceedings from 17th international Nitrogen Workshop, 26–29 June 2012, pages 404–405. (Oral presentation).

Yan, M-J., Humphreys, J. and Holden, N.M. (2012) Carbon footprint of Irish milk production: can white clover make a difference? In: Proceedings from 17th international Nitrogen Workshop, 26–29 June 2012, pages 409–410.

Yan, M-J., Humphreys, J. and Holden, N.M (2012) Carbon footprint of Irish milk production. Oral presentation at the annual meeting of American Society of Agricultural and Biological Engineers (ASABE), Jul 29–Aug 1st 2012, Texas, USA

Yan M., Humphreys J., Holden N.M. (2010) Methods and results of research on GHG emissions from dairy farms in Ireland. Invited speech at EGF (European Grassland Federation) pre-conference workshop 'Green effects of dairy farming', August 29, 2010, Kiel, Germany.

National Conferences and seminars

Humphreys, J., Li D, Yan M, Lalor, S., Hyde, B., Lanigan, Gary, Holden, N. and Watson, C. (2010). The role of N-efficiency in lowering nitrous oxide emissions from agriculture in Ireland. In: Proc. 'A Climate for Change' – Opportunities for carbon efficient farming, Mansion House, Dublin, 24–Jun–2010, p23–24.

Li, D., Lanigan G. and Humphreys J. (2011) Use of white clover to lower soil N_2O emissions from temperate moist grassland. *Agricultural Research Forum*, page 68. The Tullamore Court Hotel, 14–Mar–2011.

Yan, M-J., Humphreys, J. and Holden, N.M. (2012) Life Cycle Assessment of Irish milk production. Oral presentation at 2012 Sino-European Symposium on Environment and Health (SESEH), Page 54. August 20–25, 2012, Galway, Ireland.

Yan M.-J., Humphreys J., Holden N. M. (2011) Life cycle comparisons of greenhouse gas emissions from pasture-based milk production of Ireland. Agriculture Research Forum. 14th–15th March 2011. *Agricultural Research Forum*, page 65. The Tullamore Court Hotel, 14–Mar–2011.

Yan M., Humphreys J., Holden N.M. (2009) Reducing the carbon footprint of Irish dairy farming. Poster presented at AgMet Group 25th Anniversary meeting, Dec 7, 2009, Dublin, Ireland.

Open Days

There were presentations about tasks 1 and 2 of this project at the international conference entitled 'Forage Legumes in Temperate Pasture-based systems' conference visit to Solohead farm on 16 October 2009.

There was a presentation about this project at the Teagasc Agri-environment Conference 2010 which took place on 7 September in Ballykisteen Hotel, Tipperary with a visit to Solohead Research Farm in the afternoon.

Three presentations about this project were made at the Fourth General Meeting of the Dairyman project which visited Solohead Research Farm and two of the dairy farms involved in this project on 19 April 2011

Farmer discussion groups

Presentation of the results of this project was made to the dairy farmers involved in this project at Moorepark Research and Innovation Centre on 12 April 2011 and on 24 July 2012.

Many farmer discussion group visits to Solohead Research Farm during this experiment.

Main publications:

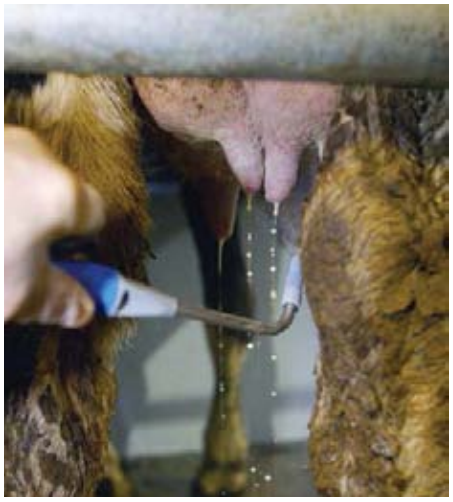
Li DJ, Lanigan G, Humphreys J, 2011, Measured and simulated nitrous oxide emissions from ryegrass – and ryegrass/white clover-based grasslands in a moist temperate climate. *Plos One*, doi: 10.1371/journal.pone.0026176.

Yan M-J., Humphreys J. and Holden N.M. (2011) An evaluation of life cycle assessment of European milk production. *Journal of Environmental Management*, Volume **92**, Issue 3, 372–379.

Yan, M.-J., Humphreys, J., Holden, M.N. The carbon footprint of pasture based milk production: can white clover make a difference? Submitted to Journal of Dairy Science

Yan, M.-J., Humphreys, J., Holden, M.N. LCA of milk production from commercial dairy farms: the influence of management tactics. Submitted to Journal of Dairy Science.

Milk quality as influenced by cow and machine



Project number:
5896
Date:
January, 2011
Funding source:
Teagasc
Project dates:
Jan 2009–Dec 2011

Key external stakeholders:

Dairy farmers, dairy processors, IMQCS, detergent product manufacturers, Teagasc advisory, milking machine companies

Practical implications for stakeholders:

The overall objective of this work is to provide guidelines and recommendations for the on-farm milk production process such that, the milk may achieve increasingly stringent hygiene quality standards. The challenges addressed in this study include minimizing the transfer of bacteria (a) from the cow, the milking machine and the environment and (b) from cow to cow.

The outcomes are:

- Clear guidance on choosing a detergent cleaning product is now available to dairy farmers. This study has resulted in better quality cleaning products being available to farmers and should result in better quality milk leaving the farm.
- Management practises such as pre-spraying of teats with disinfectant, use of some bedding materials, cluster flushing, using a sanitizer in the daily wash procedure, using daily acid cleaning will reduce bacterial numbers on teats and on milking equipment and in milk.

Main results:

1. Pre-spraying of teats with disinfectant prior to milking will reduce the levels of bacteria on teats by up to 85%.
2. Flushing of clusters between each individual cow milking, with water and peracetic acid can reduce bacterial numbers on liners by up to 93%.
3. Twenty five percent of detergent/sterilizer products on the market have been reformulated due to the information generated from this study.
4. A cleaning procedure which entails daily acid washing is results in effective cleaning of milking equipment.
5. Peracetic acid may be used as a sanitizer and as a replacement for chlorine in the milking machine wash routine.

Collaborating Institutions:
Madison University Wisconsin

Teagasc project team:
Dr. David Gleeson (PI)
Dr. Bernadette O'Brien
Dr. Kieran Jordan

External collaborators:
Professor Pamela Ruegg, Madison University, Wisconsin

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Technology

Opportunity/Benefit:

The results of the evaluation of detergent products and clear guidance on the best use of cleaning products are available on the Teagasc public website. As a consequence, the products available to farmers are of a higher quality and if used correctly should improve the quality of milk leaving the farm gate. This list is now widely used by advisory personnel and farmers when choosing products to clean milking equipment.

1. Project background:

The Teagasc Statement of Strategy sees it's mission as assisting the agriculture and food processing industries in responding profitably to consumer demands and requirements. A specific business objective of Animal & Grassland Research and Innovation Centre is to increase the value of milk. The overall objective of this work is to provide guidelines and recommendations for the on-farm milk production process such that, the milk may achieve increasingly stringent hygiene quality standards. The criteria, specifically thermoduric and total bacteria (TBC) counts requested by milk processors or by customers of milk processing outlets are becoming more strict and rigorous. The challenges being addressed in this study include minimizing the transfer of bacteria (a) into milk from the cow, the milking machine and the environment and (b) from cow to cow.

2. Questions addressed by the project:

- Could pre-spraying of teats with a disinfectant product and cluster cleaning between individual milkings with a disinfectant reduce bacterial numbers on teats and on liners?
- Can laboratory methods be introduced to Moorepark that could facilitate the accurate bacterial analysis of a larger number of milk samples to allow for undertaking of a range of field studies?
- Could detergent cleaning products containing no chlorine maintain low bacterial counts in milk?
- What equipment cleaning procedures result in residues in milk?
- Will some cubicle bedding materials result in lower bacterial numbers on teats and lower infection rates?
- Does the addition of a sanitizing agent in the rinse water of a cleaning program reduce the bacterial count in bulk milk?
- If a detergent/sterilizer solution was substituted with an acid wash as part of the daily wash routine would this have any negative effects on milk quality or equipment?

3. The experimental studies:

Task 1: Validation of a test method for thermoduric bacteria: After consultations with a number of companies a 3M Petrifilm plate reader was purchased and compared with the standard agar plate method for a range of milk thermoduric levels and TBC. A protocol for sampling and subsequent treatment of milk samples for thermoduric testing was prepared.

Task 2: Minimizing transfer of bacteria from cow to milk: The effect of cubicle bedding materials (3 studies) with both dry and lactating cows, the application of an external teat sealer (Mayo teat sealer) prior to calving, the automated cleaning of clusters between individual milkings using a newly commercially developed auto cleaning system (Dairymaster), on the bacterial count on teats, liners and in milk were evaluated in a series of studies.

Task 3: Minimizing bacterial transfer into milk from the milking machine: Three studies were undertaken to establish the effect of different washing procedures on the total bacterial count in milk. 1. Comparison of products containing different levels of sodium hydroxide with and without the addition of a sterilizer agent (chlorine). 2. Comparison of a new cleaning procedure which includes daily acid cleaning. 3. The addition of a number of sanitizers in the final rinse water of a cleaning procedure on bacterial and residue levels in milk. Task 4: Investigation of the use of new pre-milking products and procedures to reduce bacterial levels in milk: A number of pre-milking teat preparation procedures including teat wipes and disinfection dip products containing different formulations were applied to cow's teats. Teats were swabbed for bacterial counts (Staphylococcal, Streptococcal, Coliform) before and after the procedure was applied.

4. Main results:

Over 90 detergent products used for the cleaning of milking equipment in Ireland have been evaluated for chemical content and regulatory status. The investigation into the chemical content of products has resulted in the reformulation of 25% of detergent/sterilizer products and the removal of some of the inferior products from the marketplace. The list of products is updated monthly on the Teagasc website (teagasc/research&innovation/dairy) together with

guidelines on the effective use of these products. As a consequence the products available to farmers are of a higher quality and if used correctly should improve the quality of milk leaving the farm gate. This list is now widely used by advisory personnel and farmers when choosing products to clean milking equipment. The 3M Petrifilm plate reader is now used in the Teagasc microbiology laboratory and has been adapted by some processors for the measurement of TBC and thermoduric bacteria in milk samples.

Pre-spraying of teats with disinfectant followed by drying with a paper towel will eliminate up to 85% of Staphylococcal and Streptococcal bacteria on teats prior to milking. Ninety percent of teats not disinfected, will contain Staphylococcal bacteria and 35% will harbour Streptococcal bacteria.

The automatic flushing of clusters between each individual cow milking with 1 litre of water and 0.2% peracetic acid will eliminate 93% and 66% of Staphylococcal and Streptococcal bacteria, respectively, from liner, thus minimizing the possibility of cross infection and the amount of bacteria entering the bulk tank. The use of hydrated lime as a bedding material will minimize bacterial numbers on teats compared to the standard ground limestone material. The percentage of teats with no Staphylococcal (59%) and Streptococcal (68%) bacteria present was lower with hydrated lime compared to the percentage of teats with Staphylococcal (25%) and Streptococcal (27%) bacteria with Ground limestone.

The dipping of teats using the Mayo teat sealer on teats of 1st lactation cows for a five week period prior to calving did not result in lower CMT or somatic cell count at calving compared to teats not dipped.

5. Opportunity/Benefit:

The effectiveness of a range of washing procedures, cluster disinfection methods, teat disinfection products, cubicle bedding materials in reducing bacterial numbers on equipment, teats and in milk have been evaluated and the results published in popular articles and through the Irish dairy Board.

The standard of detergent products sold to Irish farmers has been greatly improved by this research. Many inferior products or products that would increase the likelihood of chemical residues have been withdrawn from the marketplace. Teagasc provide a monthly updated list of products on the Teagasc website.

6. Dissemination:

List of detergent products evaluated and advice notes on the effective use of these products is available on the Teagasc public website (research/innovation/dairy). Dissemination of information from this study was distributed through a series of technical publications at conferences (Milk Quality Forums, IGAPA, IMQCS, Moorepark Open days, Advisory staff meetings, Food Research UCC, International conferences), as a contribution to the Moorepark Milk Quality Handbook and Teagasc Dairy Manual and popular articles in the Irish Farmers Journal, TResearch, IDB newsletters.

Main publications:

Gleeson, D., O'Brien, B., Flynn, J., O'Callaghan, E.J. and Galli, F. (2009). Effect of pre-milking teat preparation procedure on the microbial count on teats prior to cluster application. Irish Veterinary Journal 62 (7) 461–467.

Gleeson, D., O'Brien, B., Flynn, J. and Jordan, K.N. (2011). Bacterial contamination on milk contact surfaces of different component materials following different cleaning procedures. In: 40th Annual UCC Food Research Conference, UCC, Cork, 31–Mar–2011, p. 17.

Gleeson, D., O'Callaghan, E.J. and O'Brien, B. (2010). Effect of individual cluster flushing between milkings on the bacterial count on liners. In: Mastitis Research into Practice: Proceedings of the 5th IDF Mastitis Conference, Christchurch, New Zealand, 21–Mar–2010, p.719.

Popular publications:

Gleeson, D. and O'Brien, B. (2011). Chemical analysis of cleaning products and guidelines for the effective use of those products for cleaning milking equipment. IMQCS. Teagasc IE Article on the Web site.

Gleeson, D. (2010). Cleaning products for milking equipment. Tresearch Vol 5 (3). 28–29.

Gleeson, D. (2010). Are you cleaning your milking machine correctly? Irish Farmers Journal p. 18–19.

Project number:
5676
Date:
September 2012
Funding source:
Teagasc
Project dates:
Jan 2007–Dec 2011

Post-grazing height and productivity of white clover-based systems of dairy production

Collaborating Institutions:
Waterford Institute of Technology
Department of Chemical and Life Sciences

Teagasc project team:
Dr. James Humphreys (PL)
Mr. Paul Phelan

External collaborators:
Dr. Imelda Casey (Waterford Institute of Technology)

Compiled by:
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Key external stakeholders:

Grassland farmers, advisors, grassland research community.

Practical implications for stakeholders:

The effect of post-grazing height (PGH; 4, 5 or 6 cm) on milk production by dairy cows, sward white clover content and sward herbage production was investigated over three years. There was no significant effect of PGH treatment on milk production or sward clover content. Herbage production was higher with the 4 cm compared with the 6 cm PGH. A target PGH of 4 cm throughout the grazing season is recommended for grass-clover swards.

Main results:

- PGH of 4, 5 and 6 cm was compared over the grazing season (Feb to Nov) of three years, two of which had exceptionally high rainfall. Annual rainfall was 990, 1228 and 1296 mm in 2007, 2008 and 2009 compared to the previous ten-year average of 1009 mm (range 797 to 1150 mm).
- PGH had no effect on annual milk yield (6202 kg cow^{-1}), solids-corrected milk yield (6148 kg cow^{-1}) or contents of fat (42.9 g kg^{-1}), protein (35.9 g kg^{-1}) and lactose (46.5 g kg^{-1}).
- PGH had no effect on cow live-weight (592 kg) or body condition score (3.01).
- PGH had no effect on sward white clover content (196 g kg^{-1} of herbage DM).
- Herbage production of both grass and clover were significantly higher with 4 cm compared with 6cm PGH. Mean annual herbage yield was 11.07, 10.16 and 9.05 t organic matter ha^{-1} for the 4, 5 and 6 cm treatments, respectively.

Technology

Opportunity/Benefit:

- Potential to carry higher annual stocking densities with 4 cm PGH.
- Increase grazed grass in the diet and feed less silage and concentrates during spring and autumn.

1. Project background:

White clover is an important legume of temperate grassland that can increase the profitability of pasture-based milk production, primarily through lower dependency on fertilizer N. Previous experiments on mown grass-clover plots showed that low cutting heights increased sward clover content and herbage production. A similar response was expected under grazing and this was tested in the present experiment. Furthermore, in some previous experiments grazing to a low PGH (typically short duration experiments with perennial ryegrass) has been associated with reduced milk yields per cow.

2. Questions addressed by the project:

- The objective of this experiment was to investigate the effect of PGH on the clover content, herbage production and milk production from dairy cows on rotationally strip-grazed grass-white clover swards over three grazing seasons.

3. The experimental studies:

- There were three target PGH treatments of 4, 5 and 6 cm imposed for three consecutive years (2007 to 2009).
- Each treatment had 21 Holstein-Friesian dairy cows with a mean calving date of 20 February.
- Each group of cows strip-grazed an area of 10.2 ha between February and November.
- PGH was measured twice each day with a rising plate meter and cows were moved to the next strip once the target PGH was reached.
- Annual fertiliser N input was 90 kg N ha^{-1} for each treatment.

4. Main results:

- PGH of 4, 5 and 6 cm was compared over the grazing season (Feb to Nov) of three years, two of which had exceptionally high rainfall. Annual rainfall was 990, 1228 and 1296 mm in 2007, 2008 and 2009 compared to the previous ten-year average of 1009 mm (range 797 to 1150 mm).
- PGH had no effect on annual milk yield (6202 kg cow^{-1}), solids-corrected milk yield (6148 kg cow^{-1}) or contents of fat (42.9 g kg^{-1}), protein (35.9 g kg^{-1}) and lactose (46.5 g kg^{-1}).
- PGH had no effect on cow live-weight (592 kg) or body condition score (3.01).
- PGH had no effect on sward white clover content (196 g kg^{-1} of herbage DM).
- Herbage production of both grass and clover were significantly higher with 4 cm compared with 6cm PGH. Mean annual herbage yield was 11.07, 10.16 and 9.05 t organic matter ha^{-1} for the 4, 5 and 6 cm treatments, respectively.

5. Opportunity/Benefit:

- Potential to carry higher annual stocking densities with 4 cm PGH.
- Increase grazed grass in the diet and feed less silage and concentrates during spring and autumn.

6. Dissemination:

International conferences

Humphreys J., Mihailescu E. and Casey I. A. (2012) An economic comparison of dairy production on N fertilized and white clover grassland. Grassland Science in Europe, 17, 774–776.

Humphreys, J., Keogh, B. Phelan, P., and Casey, I.A. (2010) Post grazing height and productivity of white clover-based systems of dairy production. *Grassland Science in Europe*, 15, 958–960.

International workshops and seminars

Humphreys, J. Keogh, B., Phelan, P. and Casey, I. A., 2010. Post-grazing height and productivity of white-clover based dairy production. Nordic Association of Agricultural Scientists Seminar 432, Hvanneyri, Iceland, 20–22 June, 137–140.

National Conferences and seminars

Humphreys, J. (2009) Post grazing height and the productivity of white clover-based systems of dairy production. *Agricultural Research Forum*, 99.

Open Days

Burchill W., Hennessy D., Boland A. and Humphreys, J. (2012) Role of white clover in grass based milk production at Solohead. Moorepark Dairy Levy Research Update, Series No. 19, 42–46.

Hennessy, D., Phelan, P., Boland, A. and Humphreys, J. (2011) Using white clover to increase profitability – Irish Dairying Planning for 2015, Moorepark'11 Open Day (29/6/11). Teagasc IE p. 76–77 ISBN

Humphreys J., Keogh B., McNamara, K., Barrett D. and Boland A. (2009) Dairy Systems Research at Solohead. Moorepark Dairy Levy Research Update, Series No. 11, 9–15.

Farmer discussion groups

Many farmer discussion group visits to Solohead Research Farm during this experiment.

Press

Humphreys J., Keogh B., Murphy P. and Boland A. (2011) Clover helps you cope with costly N. *Today's Farm*, 22 (2)11–13.

Main publications:

Phelan P., Casey I.A, and Humphreys J. (2012) The effect of target post-grazing height treatment on herbage yields and dairy production from grass-white clover swards. Journal of Dairy Science, (in press) Humphreys J., Mihailescu E. and Casey I. A. (2012) An economic comparison of systems of dairy production based on N fertilized grass and grass-white clover grassland in a moist maritime environment. *Grass and Forage Science*, (In press)

Popular publications:

Humphreys J., Keogh B., Murphy P. and Boland A. (2011) Clover helps you cope with costly N. *Today's Farm*, 22 (2)11–13.

Optimum milk quality focusing particularly on chemical residues

Project number:
5895
Date:
February, 2012
Funding source:
TEAGASC
Project dates:
Jan 2009– Dec 2011

Key external stakeholders:

Dairy farmers, Milk processors, Export markets, members of veterinary profession

Practical implications for stakeholders:

- The Dairy industry (milk producers and processors) and Teagasc, Moorepark have worked in collaboration since 2007 to identify and develop strategies for trichloromethane (TCM) residue reduction in milk and butter. A reduction in average milk values from 0.007 to 0.003 means that Irish butter exports will continue to compete favourably on the German market;
- Both dietary iodine supplementation and teat disinfection iodine individually result in milk iodine levels exceeding common target values of 250–300µg/kg. Both iodine treatments can frequently occur simultaneously on farm, thus supplementations should be monitored, particularly in light of infant feed formula manufacture;
- Traces of active ingredients of some flukicide products will migrate from whole milk to skim milk powder.

Therefore it is important that research be conducted to establish MRLs (maximum residue limits) in milk and dairy products, for the active ingredients in animal treatment products (e.g. flukicides) to ensure (a) avoidance of risk to public health and (b) prevention of animal health issues by allowing use of effective products (some have been banned due to the absence of an MRL).

Main results:

- Milk TCM levels have been reduced to 0.002 mg/kg in milk in 2011, i.e. the target level in milk that ensures TCM never exceeds 0.03 mg/kg in the butter product. These low levels have to be maintained in the long term;
- Supplementation of dietary iodine at 30 and 70 mg/day significantly increased mean milk iodine concentrations from 208µg/kg to 672 and 733µg/kg, respectively. Teat disinfection post-milking and pre- + post-milking significantly increased the mean iodine concentration from 219µg/kg to 475 and 670µg/kg, respectively;

Collaborating Institutions:
Cork Institute of Technology, Bishopstown, Cork

Teagasc project team:
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Dr. David Gleeson
Dr. Kieran Jordan
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Dr. Riona Sayers

External collaborators:
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Compiled by:
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Technology

- Between 95% and 98% of Nitroxynil (active ingredient in flukicide product) migrated from whole to skim milk. The remainder was within the cream. When skim milk was converted to skim milk powder, almost 100% of Nitroxynil was transferred into the powder.

Opportunity/Benefit:

These results may be used by (i) dairy farmers to improve their milk quality on-farm, (ii) milk quality advisory personnel to solve milk residue issues on-farm and (iii) bodies such as DAFM and IDB in promoting dairy products for the export market.

1. Project background:

TCM – Cleaning and disinfection in the milk production process on-farm is critically important to the quality of milk. Chemical solvents containing chlorine are among the most effective and economical, but there is an unintentional side effect: when chlorine comes in contact with milk, trichloromethane (TCM) is formed resulting in residues, particularly in high fat products. There are both legal limits and recommended target levels for TCM in specific dairy products.

Iodine – Iodine supplementations at farm level tend to be used in the expectation of increasing cow health and fertility. There is concern that such practices may result in high milk iodine which could affect ingredients for infant formula particularly, and thus, export markets.

Flukicides – Nitroxynil is an active ingredient in the veterinary product *Trodax* used to treat liverfluke in cattle. While this product is currently not recommended for use in lactating cows due to residues in milk, little information is available about the transfer of active ingredients such as Nitroxynil to milk products.

2. Questions addressed by the project:

TCM – to develop a strategy to resolve the TCM residue issue on a relatively small number of farms and establish if that strategy could then be applied successfully to a relatively large group of farms

Iodine – to quantify the effect of iodine supplemented concentrate feed and teat disinfection practices on milk iodine concentrations of dairy cows.

Flukicides – to establish the stability and persistence of Nitroxynil in the manufacturing process and product of milk powder.

3. The experimental studies:

TCM – a template procedure was developed, tried and tested on 43 farms. This involved identifying farms with high TCM milk, applying advice and recommendations to reduce TCM and re-measuring milks from these farms. (TCM in milk was measured by head-space gas chromatography with electron capture detector.) This strategy proved successful in significantly reducing milk TCM in the three geographical regions tested, e.g. TCM was reduced from 0.006 to 0.002 mg/kg ($p<0.05$). This strategy was then applied to farms who supplied milk to six Irish dairy processors with the objective of reducing TCM in those milks to the marketing acceptable limit of 0.002mg/kg.

Iodine – Thirty lactating cows were fed 7 kg, 3 kg and 0 kg meal (10 mg iodine/kg) during 3 periods of 14 days each. During each subsequent 7 day period, 1 of 3 teat disinfection treatments was applied to each of 3 cow groups (n=10): non-iodine post-milking; 0.5% iodine post-milking; 0.5% iodine pre-and post-milking. Cow milk yield was 21.3 kg/day. Individual cow milk samples were taken for iodine analysis on 2 milking days at the end of each treatment period.

Flukicides – Six dairy cows were treated, during lactation, with 1.5ml TRODAX® (which contained Nitroxynil 34%) / 50kg bodyweight. Samples were collected twice daily for 28 days post treatment and frozen at–20°C The samples were thawed at 4°C and pooled into 6 independent aliquots, each containing milk from each of two, 3 cow groups on Day 1–9 (P1), Day 10–15 (P2) and Day 16–28 (P3). Each aliquot was separated into skim milk and cream and the skim milk was processed to milk powder using a laboratory scale spray drier. The cream, skim and powder from each sample were then analysed for Nitroxynil using mass spectrometry.

4. Main results:

TCM – Initially, milk tankers containing milks from approximately 10–15 individual farms were sampled and analysed and tankers with high TCM (>0.002 mg/kg) identified. Individual herd milks contributing to these tankers were subsequently sampled and analysed and farms supplying high

TCM identified. Guidance and advice was provided to these high TCM milk suppliers and changes in the levels of TCM of these milk supplies were monitored subsequently. A significant reduction (minimum $p<0.05$) in milk TCM was observed in 5 of the 6 dairy processor milks (e.g. 0.007 to 0.002 mg/kg), while a numerical reduction in TCM was observed in the remaining processor milk.

Iodine – The iodine content of the milks from treated cows reflected iodine supplementation in the feed. Supplementation of dietary iodine at 30 and 70 mg/day significantly increased mean milk iodine concentrations from 208µg/kg to 672 and 733µg/kg, respectively ($p<0.05$). A human daily intake of 300g of milk from cows consuming 3kg concentrate with 10mg iodine/kg would supply an adult with 185 _g iodine (recommended daily requirement). The iodine content of milk also reflected iodine disinfection practises. Teat disinfection post-milking and pre + post-milking significantly increased the mean iodine concentration from 219µg/kg to 475 and 670µg/kg, respectively ($p<0.05$).

Flukicides – Nitroxinal levels in the milk decreased during the experimental period. All the Nitroxynil was recovered during the separating process between skim and cream. Between 95% and 98% of the Nitroxynil migrated from whole to skim milk. The remainder was within the cream. Average concentrations of Nitroxynil in the skim milk and cream fractions were 555.1 µg/1.2 litre and 9.0 µg/37 ml and 15.9 µg/1.1 litre and 0.44 µg/44 ml in Periods 1 and 3, respectively. When skim milk was converted to skim milk powder, almost 100% of Nitroxynil in skim milk was transferred to the powder product, for example, 15.3 µg of Nitroxynil was recovered in the skim milk powder in Period 3. This occurred despite the high temperatures used during the manufacturing process (spray drier inlet temperature of 185°C ± 2°C and an outlet temperature of 90°C ± 2°C.

5. Opportunity/Benefit:

TCM – this study (i) proved the concept that a milk quality problem may be resolved on a relatively small number of farms by dissemination of information and implementation of corrective action on-farm, accompanied by repeated sampling and analysis of milk samples together with continuous feedback of the results to the milk supplier, and (ii) that this strategy can be applied successfully to a relatively large group of farms. The transfer of information to dairy farmers took a number of different forms; visits to considerable proportion of farms by milk quality personnel, newsletters, Teagasc guidelines, written communications from the milk processor to individual dairy farmers and newspaper campaigns represented the most popular methods. It is suggested that the strategy developed and applied and found to be successful in solving the TCM problem on these farms could also be applied and could be successful in resolving other milk quality problems on-farm.

Iodine – The iodine in the treatment milks reflected feed supplementation with iodine. The study confirmed studies in the literature indicating the transfer of iodine from feed to milk. It may be possible to further reduce maximum iodine levels in feed. However, this would need to be done in association with feed manufacturers and members of the veterinary profession. Pre-milking disinfection can pose a substantial risk of iodine transfer to milk, as it is dependent on the degree of removal from the teats prior to cluster attachment. This practice should be reserved for extreme situations or problem farms where milk somatic cell count is high. It is important to continuously monitor the National milk iodine level. This is particularly important in winter milk production when both iodine supplemented feed and iodine disinfection are widely used. With a requirement for maximum milk iodine levels of 250 _g/kg for some products, there is little flexibility available. This study indicates the contribution of different iodine supplementations to milk iodine, so the information generated may be used to maintain milk iodine levels within the required limit.

Flukicides – The results showed that residues of nitroxynil will be present in milk after administration, will be partitioned with the skim-milk and will be present in a subsequent powder product. Thus, sufficient caution must be exercised with regard to withdrawal periods to ensure avoidance of risk to public health. Also, this research is important as it is only with an accumulation of similar data for other active ingredients that a database can be set up that will provide data for MRLs to be applied to different products. This is necessary so that appropriate products (e.g. other flukicides) may be defined as safe and allowed to be used for the betterment of health of lactating cows.

6. Dissemination:

Mainly through newsletters, Teagasc guidelines, Teagasc open days, written communications to Advisory groups and individual dairy farmers and newspaper campaigns and very importantly, 'Milk Quality Workshops' for technical personnel working at different levels of the dairy industry, e.g. as follows:

O'Brien , B. (2011). TCM in milk. In: Milk Quality Forum (Symposia), Moorepark, 22–Mar–2011.

O'Brien, B. (2011). Flukicides in milk. In: Milk Quality Forum (Symposia), Moorepark, 22–Mar–2011.

O'Brien , B. (2011). Iodine in milk. In: Milk Quality Forum (Symposia), Moorepark, 22–Mar–2011. Main publications:

Power, C., O'Brien, B., Danaher, M., Furey, A., Bloemhoff, Y., Sayers, R and Jordan, K. (2001). Residue concentrations of Nitroxynil in milk and product following administration to cows. In: *Proceedings of the 62nd annual meeting of the European Association for Animal Production*. Stavanger, Norway, 29th August – 2nd September, pp.315.

O'Brien, B, Jordan, K. and Gleeson, D. (2010). Effect of dietary iodine and teat disinfection iodine on milk iodine levels. *Proceedings of International Dairy Federation Congress*. Auckland, NZ. 8–11 November, 2010.

Ryan, S., Gleeson, D., Jordan, K.N., Furey, A. and O'Brien, B. (2011). Reducing trichloromethane levels in milk. In: 40th *Annual UCC Food Research Conference*, UCC, Cork, 31–Mar–2011, p. 51

Popular publications:

O'Brien, B., Gleeson, D. and Ryan, S. (2011). *Irish Farmers Journal*, 15th January, 2011. Milk Quality Supplement.

O'Brien, B., Jordan, J. and Gleeson, D. (2011). Reducing trichloromethane (TCM) levels in milk. *Moorepark News*, Winter, 2011.

O'Brien, B., Sayers, R. and Jordan, K. (2010). Caution required in the use of flukicides. *Irish Farmers Journal* 9/12/10.

Efficient milking systems

Project number:
5897
Date:
February, 2012
Funding source:
Teagasc
Project dates:
Jan 2009–Dec 2011

Key external stakeholders:

Dairy farmers, dairy industry, milking machine companies

Practical implications for stakeholders:

As the number of milking units increased, row time and duration of over-milking were increased and the operator idle time was reduced

- The type of routine practiced largely dictates the number of milking units one operator can handle and the overall efficiency of the milking operation.
- When minimal teat preparation prior to milking is used, the milking operator can manage more milking units.
- The use of automation in the form of automatic cluster removers (ACR)s may be used to eliminate over-milking.

Main results:

The full pre-milking routine reduced time to milk let-down and milking time, increased average flow-rate but did not affect milk yield. As milking unit number increased, the duration of over-milking (defined as time at milk flow-rate <0.2 kg/min) increased more with a full compared to minimal routine. As parlour size increased, milking row times, as well as the proportion of cows that were over-milked also increased, thereby reducing overall efficiency.

Opportunity/Benefit:

These results have implications for milking management and sizing of single-operator swing-over parlours with seasonally calved herds.

Collaborating Institutions:
DairyNZ, Hamilton, New Zealand.

Teagasc project team:
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Technology

1. Project background:

A milk quota policy change coming into effect in 2015 is expected to lead to rapid expansion of dairy herds in Ireland. Efficient milking systems, in terms of labour demand, capital investment and cow udder health are critical to successful expansion. Some Irish farmers managing larger herds that have undergone expansion are reporting issues with milking management, in particular optimizing udder health (minimizing somatic cell count and clinical mastitis) and the length of time it takes to milk the herd (efficiency). Optimum milking efficiency may be defined as when the number of milking units are appropriate for the operator work routine and the cow milk production level such that both over-milking and idle time (operator waiting time between when cows are ready for cluster attachment and when the cluster becomes available) are minimised. The criteria of operator idle time and overmilking are critical issues in relation to labour efficiency/ requirement and udder health. Overmilking is one consequence of milking management that contributes to mastitis risk. Overmilking is defined as the period when teatcups remain attached to teats after the milk flow rate from an individual cow has fallen below an arbitrary 'end-point' of milking e.g. a milk flow rate of 200 mL/minute. The operator work routine (including cow preparation for milking) is a significant influencing factor, as is cow milk production. Milking time is longer when cows are at peak lactation compared to the later stages of lactation. This is a particularly relevant scenario in both Ireland and New Zealand dairies due to the seasonal calving pattern in both countries resulting in the complete herd being at a similar stage of lactation at any particular time point. In Ireland most parlours are swingover herringbone or side-by-side without automatic cup removers (ACR).

2. Question addressed by the project:

Could the effect of parlour size (number of milking units), pre-milking routine (full and minimal) and stage of lactation on milking efficiency (milking characteristics, row time, over-milking duration and operator idle time) of spring-calved cows, in a single-operator side-by-side, swing-over milking parlour be established?

3. The experimental studies:

A 5x2 factorial design was used to study the effects of parlour size and pre-milking routine on milking performance. Over-milking duration, operator idle time and milking time were the main variables. Five combinations of parlour size (14, 18, 22, 26 and 30 milking units) were examined, each with two different pre-milking routines. With minimal pre-milking routine, clusters were normally attached directly to cows in sequence starting at cluster 1. With full pre-milking routine, the cows were sprayed with disinfectant, fore-stripped and wiped with individual paper towels in that order. The full row of cows was sprayed first to ensure adequate contact time for the disinfectant product to be effective. Then foremilk was drawn, teats were wiped and clusters attached in groups of 6–7, starting at cluster 1. This experiment was conducted when cows were at 221 (late lactation, 2009) and repeated at 50 (peak lactation, 2010) DIM (days in milk). Four rows of cows were milked at each session, giving three data points from each milking session. Each combination of routine and parlour size was tested at four milking sessions (two AM, two PM) giving a total of 12 values for each combination. Automatic cluster removers (ACRs) were used to prevent any teat damage due to over-milking and over-milking duration was calculated as the time difference between ACR activation and swing-over of a milking unit (to the next cow).

4. Main results:

Cow milking duration, milk let-down time, maximum and average milk flow-rate as well as milk yield were not affected ($P>0.05$) by milking unit number or parlour size at either peak or late lactation. Total cow entry time, pre-spray time and time taken for cows to exit all increased ($P<0.001$) in duration as parlour size increased from 14 to 30 milking units in peak lactation (ranges: 0.7–1.4 min, 0.7–1.6 min and 0.8–1.6 min, respectively).

This trend was also observed in late lactation (ranges: 0.9–2.0 min, 0.8–1.9 min and 0.6–1.4 min, respectively). Milking row time increased from 9.2 to 12.9 min as cluster numbers increased from 14 to 30, when minimal pre-milking routine was applied. The corresponding row times were 11.1 to 21.1 min when full routine was applied. Shorter row times

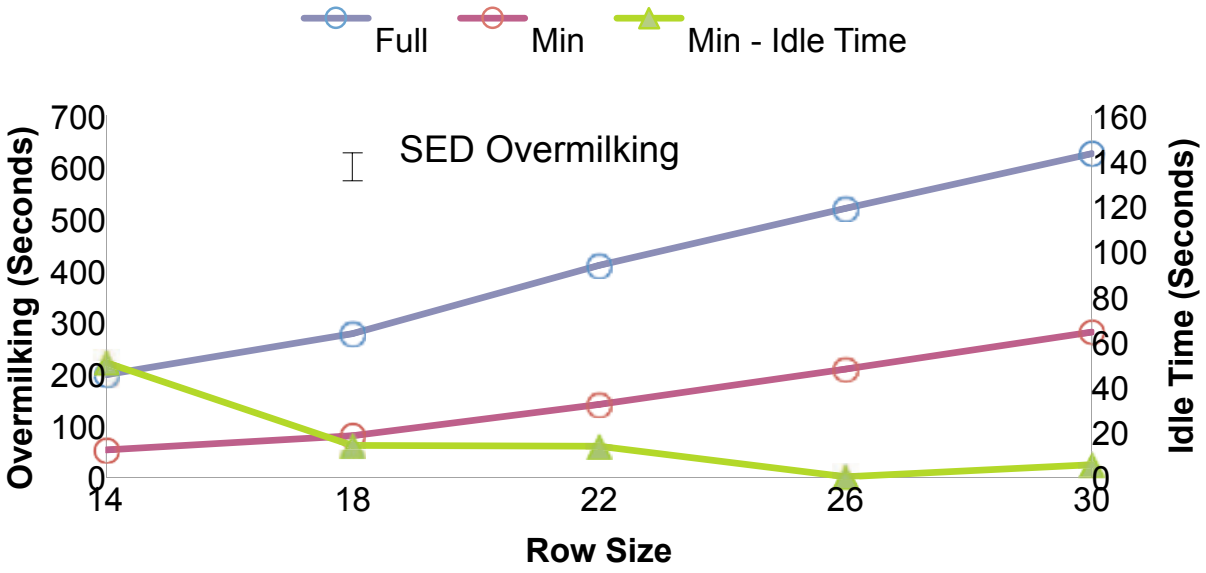

Figure 1. Over-milking time (the time between ACR detachment and attachment of that cluster to the next row) and operator idle time for cows milked in a parlour with 14, 18, 22, 26 or 30 milking units, and two different pre-milking routines, (Full: spray, strip, wipe, milking cluster attachment and Minimal [Min]: milking cluster attachment), when cows were an average of 221 (late lactation) days in milk.

were observed in late lactation with similar trends regarding cluster number and pre-milking routine. Over-milking time increased with more milking units ($P< 0.001$) and was longer with full compared with minimal pre-milking routine ($P< 0.001$) at both peak and late lactation. There was also an interaction between cluster number and over-milking time ($P< 0.001$). Using the minimal pre-milking routine, over-milking duration increased from 0.8 to 2.9 min as milking unit numbers increased from 14 to 30 at peak lactation. Using a full routine the corresponding over-milking times were 2.1 to 9.3 min. The duration of over-milking was extended in late lactation with increases of 0.9 to 4.7 min and 3.3 to 10.4 observed with minimal and full pre-milking routines, respectively. A reduced operator idle time per row was observed with the minimal pre-milking routine in both peak and late lactation; operator idle time ranged from 2:11 to 0:19 (min:sec) and from 0:51 to 0:06, respectively, generally decreasing as milking unit number (row size) increased from 14 to 30.

5. Opportunity/Benefit:

When a minimal pre-milking routine is applied throughout lactation, 22 milking clusters may be operated without over-milking of longer than ~2 min, in the absence of ACRs, The use of ACRs would allow up to 26 clusters to be managed due to the ACR effect in eliminating over-milking in late lactation. Alternatively, when a full pre-milking routine is applied throughout lactation, milking cluster numbers of 14 (peak lactation) or less (late lactation) may be operated without experiencing over-milking of longer than ~2 min in the absence of ACR. While ACR prevent over-milking when using more milking clusters, such additional units in this scenario will not allow significantly more cows to be milked within a specified time e.g. 2 h, as the pre-milking routine is the limiting factor. The full pre-milking routine resulted in a shorter milking duration, shorter time to milk flow and higher average milk flow-rate compared with the minimal

pre-milking routine at both peak and late lactation stages. However, this was not reflected in overall milking efficiency since milking row time was increased with the full pre-milking routine. Increasing milking unit number can reduce overall milking time but is limited by the increase in row time, which is influenced by both pre-milking routine and stage of lactation and which, in turn, influences cow over-milking.

6. Dissemination:

Main publications:

O'Brien, B., Jago, J., Edwards, P., Lopez-Villalobos, N. and McCoy, F. (2012). Milking parlour size, pre-milking routine and stage of lactation affect efficiency of milking in single-operator herringbone parlours. Journal of Dairy Research, In press.

O'Brien, B., Jago, J., McCoy, F. and Edwards, P. (2011). Cow over-milking in a side-by-side parlour as influenced by parlour size and pre-milking routine. In: Agricultural Research Forum, The Tullamore Court Hotel, 15–Mar–2011, p. 136.

Popular publications:

O'Brien, B. and Gleeson, D. (2011). The role of Labour Studies in Ireland in leading change in the Dairy Industry. Irish Meeting 2011 on Agricultural Occupational Health and Safety 22nd – 24th August, 2011. Castleknock Hotel, Dublin, Ireland. http://www.teagasc.ie/publications/2011/1026/IrishOHSproceedings.pdf

O'Brien, B. (2011). Milking process efficiency. Teagasc Greenfield Dairy Programme. Kilkenny Greenfield Open Day 4/5/11. Teagasc IE p. 80–92

O'Brien, B. and Upton, J. (2011). Increase milking efficiency – Irish Dairying Planning for 2015, Moorepark'11 Open Day (29/6/11). Teagasc IE p. 110–111

Development of farming systems for the future

Project number:
5668
Date:
November, 2011
Funding source:
Teagasc
Project dates:
Jan 2007– Dec 2010

Key external stakeholders:

Dairy farmers, dairy processors, government, extension officers, financial agencies, service providers and accountancy firms

Practical implications for stakeholders:

This study involved the development of two Greenfield Demonstration Dairy farms, modelling futuristic production systems and completing surveys to ascertain the future intentions of dairy farmers as well as to determine the opportunities, challenges and limitations for expansion on farms.

Two new dairy farms have been developed (one in Kilkenny and one in Bandon). The farm in Kilkenny was converted from tillage with all facilities constructed, while the farm in Bandon had existing beef housing which was converted. Full conversion costs and running costs are now available for both farms.

- A conversion model has been developed for existing non dairy farms into dairying.
- Full conversion and running costs are and will be available on an on-going basis.
- Opportunities, challenges and limitations to expansion on commercial dairy farms have been evaluated based on surveys completed on farms.

Collaborating Institutions:
Glanbia
Farmers Journal Trust
FBD
AIB
The Phelan family

Teagasc project team:
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Dr. Padraig French
Dr. Brendan Horan
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External collaborators:
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Farmers Journal Trust
FBD
AIB
The Phelan Family

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Technology

Main results:

- This project has completed two farm conversions to dairy, reporting the full conversion and running costs.
- Fifty four percent of farms planned to expand and 14% planned to exit when the surveys were completed.

Opportunity/Benefit:

This project has placed an increased focus around the requirements for expansion, from the planning phase right through to the conversion and running of the farm. The increased awareness around the potential pitfalls will increase dairy farm sustainability.

1. Project background:

When EU milk quotas are abolished it is generally accepted that the next most limiting factor to increased milk production on many dairy farms is grazing land availability. It is likely that land purchase price in Ireland will continue to be high for the foreseeable future. Therefore it is important that land use policies facilitate the availability of land for dairying through long term leasing arrangements. The most efficient model for milk production in Ireland is the production of milk from grazed grass as this is where our competitive advantage lies. It is also envisaged that herd size will increase substantially over the coming years thereby requiring large blocks of land. Many dairy farms are constrained by farm size and farm fragmentation. This study sets out to demonstrate that a dairy farm can be leased, that all resources can be remunerated and that the farm can give a positive return for the money invested.

2. Questions addressed by the project:

- To demonstrate international best practice in milk production from pasture based systems on a large scale farm.
- To demonstrate that an efficiently run dairy farm in Ireland can adequately remunerate all of the resources employed; land, labour and capital.
- To model a number of systems that might be optimum in the future with a view to developing blueprints for milk production in the new policy environment.
- To identify opportunities, challenges and limitations to expansion for dairy farmers.

3. The experimental studies:

There were three components to this study.

1. Demonstration farm

Full financial appraisals have been completed for a whole range of Greenfield dairy farms with two dairy farms set up, one in Kilkenny and one in Bandon. Both farms have been set up with the objective of providing a return to all resources employed. Milk quota has been provided under license from DAFM with the specific objective of the farm having a demonstration role. The Kilkenny farm which has three shareholders (Glanbia, Farmers Journal, Phelan family (landowners), was set up with approximately 30% equity and the remaining money borrowed through a fifteen year loan. The Bandon farm has 4 shareholders representing the four West Cork Co Ops (Bandon, Barryroe, Lisavaird and Drinagh), with again approximately 30% equity and the remaining money borrowed through a fifteen year loan.

2. Surveys

A random sample of suppliers was selected from Glanbia, Connacht Gold, Lakeland Dairies, Kerry, Barryroe, Bandon, Lisavaird and Drinagh and surveyed to determine the opportunities and limitations as well as future intentions of dairy farmers. A sample of 780, 250, 400, 700 were surveyed from Glanbia, Connacht Gold, Lakeland and Kerry while all suppliers were surveyed from Barryroe, Bandon, Lisavaird and Drinagh. The survey was completed through the telephone with the sample being posted out the survey and approximately one week later it being followed up with a telephone call.

3. Modelling

A number of scenarios were also modelling around substituting capital for labour on farm. The Moorepark Dairy Systems Model was used and all investments were evaluated over a 15 year period with interest and depreciation considered an expense. The investments considered centred around the milking process as 44% of the total labour requirement centres on the milking process.

4. Main results:

Demonstration farms

The Greenfield farm in Kilkenny was set-up in late 2009 and early 2010 with milk produced in 2010 while the Bandon farm was set up one year later. Both farms had relatively poor performance in their first year in relation to individual animal performance, however herbage production was ahead of target. Both farms generated positive operating cash surpluses in their first year of operation. In year 2 of production the Kilkenny farm has performed well, with approximately 970kg MS / ha with just under 11 tonne of herbage grown, with a projected cash surplus of €120,000.

Surveys

The average stocking rate, milk yield per cow and per hectare was 1.78 (LU/ha), 4,808L and 8,346L respectively on the sample of farms surveyed. Fifty four percent of producers were planning to expand with 14% planning to exit in the next five years (reference year 2008). Farmers that were intending on expanding had larger farm areas, a larger milk tank capacity per litre of existing milk quota, newer milking facilities, more available cow housing and more housing that could be converted at a relatively low cost. Forty five percent of producers had identified a successor, with higher likelihood of a successor being available on larger farms. Only 15% of farmers had off farm employment. Over 55% of the sample had some form of paid labour on the farm.

5. Opportunity/Benefit:

- Both the Greenfield farms in Kilkenny and Bandon have been set up with all of the conversion costs, ongoing financial performance and ongoing physical performance available.
- These farms have been set up to run for 15 years and will be generating information for farmers over that timeframe.
- Information will be available to the public via the website http://www.greenfielddairy.ie/, the farming Press and through Open Days which will be held on the farm on a continuous basis.

6. Dissemination:

Three open days were held on the Greenfield demonstration farms since their inception. Approximately 4,500 farmers have visited the farms. There are regular articles in the Farmers Journal and the farm notes are updated after the farm walk on a weekly basis. Updates are available from http://www.greenfielddairy.ie/node/86

Main publications:

O'Donnell, S., Horan, B., Butler, A.M. and Shalloo, L. (2011). A survey of the factors affecting the future intentions of Irish dairy farmers. Journal of Agricultural Science 149 : 647–654

O'Donnell, S., Shalloo, L., Butler, A.M. and Horan, B. (2008). A survey analysis of opportunities and limitations of Irish dairy farmers. Journal of Farm Management 13 (6) : 419–434

Shalloo, L., O'Donnell, S. and O'Brien, B. (2009). Economic analysis of a rotary and herringbone parlour at different size of a dairy enterprise. In: Agricultural Research Forum, Tullamore, 12–Mar–2009, p.70

Popular publications:

Shalloo, L., French, P., Horan, B. and Van Bysterveldt, A. (2010). Greenfield dairy farm – projections – Moorepark Dairy Levy Research Update : Greenfield Site Open Day, Series No. 12 on 19th & 20th January. Teagasc IE p. 7–18

Shalloo, L., O'Loughlin, J. and Long, M. (2011). Update on the Greenfield dairy farm – Irish Dairying Planning for 2015, Moorepark'11 Open Day (29/6/11). Teagasc IE p. 96–100

Shalloo, L., O'Loughlin, J., Ahern, K. and McNamara, J. (2011). Shinagh Greenfield dairy farm projections. Teagasc Greenfield Dairy Programme Shinagh Dairy Farm Open Day on 25/8/11. Teagasc IE p. 4–14

Animal and Grassland Research & Innovation Programme

Project number:
5799

Date:
November, 2011

Funding source:
Teagasc

Project dates:
Jan 2008–Dec 2010

Development of a benchmarking system to increase the sustainability of Irish dairy farmers

Key external stakeholders:

Dairy farmers, dairy processors, extension officers, financial agencies, Department of Agriculture, Food and the Marine and accountancy firms

Practical implications for stakeholders:

Useful data is generated from farm transactions that could be used to increase the sustainability of the dairy farm business. This data is currently stored in independent databases and is not used to its full potential. Dairy farm sustainability could be increased by amalgamating this data to allow the generation of useful reports for benchmarking.

- This study has developed a pilot benchmark system using data from Dairygold and ICBF.
- A number of key performance indicators have been developed and calculated within the benchmarking system.
- A Grassland data capture application with reporting functionality database has been developed for Research farms.
- Reports have been developed that can be used by farmers.
- Data Envelopment Analysis (DEA) has been used to quantify efficiency, quantify the factors effecting efficiency and to determine the total productivity growth on Irish dairy farms between 1996 and 2010.

Main results:

- This project has identified the key factors effecting efficiency and productivity on Irish dairy farms.
- Key performance indicators have been identified and quantified.
- A pilot benchmarking system has been developed to capture, validate and report the information back to farmers.

Collaborating Institutions:
UCD
Teagasc Advisory,
Teagasc/Dairygold Joint Program

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Technology

Opportunity/Benefit:

Increased focus on key performance indicators will result in increased profitability at farm level. The factors affecting profitability have been published in technical conferences, Open days and at farmer meetings. The pilot benchmarking system is producing reports with live information.

1. Project background:

Benchmarking one dairy farmer against a group of relevant dairy farmers is one of the most useful methods of determining both physical and financial performance. The usefulness of any benchmarking exercise depends on the quality of the information supplied as well as the number and type of farmers participating in the system. There are various benchmarking systems in operation around the world; these include Eprofit Monitor in Ireland, FinBin in USA and the OABS in South Africa. These systems have a common theme; that is they compare farmers based on a number of key performance indicators (KPI). A common objective of all of these systems should be that they are user friendly and that the information can easily be recorded in the systems. A variety of performance indicators are currently being captured electronically in Ireland, but this information is not subsequently being used to increase the sustainability of dairy farmers. This information is being accumulated by numerous groups including milk processors, banks, meat processors, marts, accountants, the Irish Cattle Breeding Federation, Department of Agriculture and Food, etc. Through the development of a central database and an application to provide reports, this data could be used to help farmers to increase their overall sustainability.

2. Questions addressed by the project:

- Could a pilot benchmarking system with data flowing from Dairygold and ICBFbe developed?
- Could a grassland database for the capture of grassland related information be developed?
- Could the factors affecting efficiency on farm be quantified?
- Could the productivity change over time and the factors affecting productivity change be quantified?

3. The experimental studies:

Efficiency is the ratio of observed to optimum performance. DEA is a non parametric linear programming form of frontier analysis used for the measurement, analysis and evaluation of the performance of a business. DEA was used to measure the technical, economic and allocative efficiency of dairy farms for 2008 and to quantify productivity change between 1996 and 2010. A second stage analysis was used to determine the factors that were associated with efficiency and productivity change.

A pilot benchmarking system was developed using the Moorepark Oracle database. Three hundred and eighty Dairygold dairy farms signed up for the project with data flowing from Dairygold on a daily basis and ICBF on a weekly basis for these farms. Four reports have been developed around milk production and milk quality both current and historical. The reports can be generated at discussion group level or can be generated individually for a particular farmer. Various benchmark criteria can be used depending on the requirements of the individual such as a comparison to a particular region, discussion group, performance level, etc.

A Grassland data capture application with reporting functionality has been developed using the Oracle database. The system which captures on farm data provides the users with a decision support tool, while also allowing the capture of on farm data in the background.

4. Main results:

This study has highlighted that a potential to increase production through increased technical efficiency exists on Irish dairy farms. Productive factors such as milk solids per hectare and milk solids per cow have been highlighted as key performance indicators which differ significantly among more technically efficient producers and technically inefficient producers. Land quality and managerial differences remain the key factors associated with differences in efficiency at farm level. Increasing the quantity of grazed grass through a longer grazing season has been shown in this study to result in greater production and profitability. Producers with an early Spring mean calving date, a shorter breeding season, greater milk quality and greater use of services such as milk recording and AI were found to be more efficient. Greater levels of specialisation in dairying and

membership of a discussion group resulted in greater technical and economic efficiency. This study also investigated the associations of demographic information with efficiency and it was found that efficiency increased and then declined with age. Despite quota constraints this study has found that a potential exists to increase productivity through increasing scale of operation which highlights the huge potential of the Irish dairy industry to expand efficiently post quota. Greater levels of technical efficiency were found with larger scale farms. It was found that hired labour and land were also key factors associated with optimum scale of production. Productivity increased by 10.4% between 1996 and 2010 with milk yield per cow, costs per lire, nitrogen per hectare and milk price the key factors associated with differences in productivity.

5. Opportunity/Benefit:

- DEA has quantified the factors effecting efficiency and productivity change over time on Irish dairy farms.
- Key performance indicators have been developed from these components.
- The Teagasc Pilot Benchmarking system demonstrates a system where information flows are automated and live which allows report generation of up to date data. ICBF currently have developed a capture mechanism for data from the processors with components from this research integrated into their system.
- The potential use of grassland information that has been captured through a mechanism such as that developed here will significantly add to potential productivity of grassland systems.

6. Dissemination:

Research findings were presented at numerous conferences including the 62nd Annual Meeting of the European Federation of Animal Science (2011) and the Agriculture Research Forum (2009 & 2011).

Main publications:

Kelly E., Shalloo, L., Geary, U., Kinsella, A. & Wallace, M. (2011) An Application of DEA to measure technical and scale efficiency on a sample of Irish Dairy Farms Irish Journal of Agricultural and Food Research (submitted)

Kelly E., Shalloo, L., Geary, U., Kinsella, A., Thorne, F. & Wallace, M. (2011). The associations of management and demographic factors with technical, allocative and economic efficiency of Irish dairy farms Journal of Agricultural Science (accepted)

Kelly E., Shalloo, L., Geary, U., Kinsella, A., Thorne, F. & Wallace, M. (2011). An analysis of the factors associated with technical and scale efficiency of Irish dairy farms. Farm Management (submitted).

Popular publications:

Shalloo, L., Kelly, E. & Geoghegan, A. (2009) 'Benchmarking will improve dairy farm sustainability' Article in Moorepark News Spring 2007 Issue 27

Kelly, E., Shalloo, L., O'Loughlin, J. & Geoghegan, A. (2009) 'Performance evaluation and benchmarking on specialist dairy farms' Poster Moorepark Open Day 2009

Shalloo, L., Kelly, E. & Geoghegan, A. (2008) 'Benchmark for useful reports' Article in Teagasc Today's Farm November-December 2008; 19 (6) Pg14–16.

The role of total mixed ration (TMR) feeding in pasture-based dairy systems

Project number:
5673
Date:
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Funding source:
Teagasc
Project dates:
Nov 2006–Oct 2009

Key external stakeholders:

Dairy farmers-national; feed and nutrition companies; consultancy agencies

Practical implications for stakeholders:

In a post-milk quota scenario, supplementing pasture with total mixed ration (TMR) could be used to increase milk output from a limited land base. A high level of pasture utilization is essential for profit, so decisions to supplement the milking herd diet with TMR must be based on pasture supply.

- TMR feeding should be considered as a means of increasing stocking rate rather than simply to improve milk yield per cow. High stocking rate systems are more sensitive to milk and feed price changes, therefore greater fluctuations in farm profit are to be expected.
- There is no clear benefit to animal performance of using a dry cow TMR containing high levels of straw compared to grass silage.
- Body condition and blood mineral status are the key drivers of dry period nutrition, and these can be successfully managed on a grass silage diet. Consequently, there is little justification for incurring the additional cost of feed and extra machinery required for the TMR system.

Main results:

- Buffer feeding with TMR in a high stocking rate scenario increased milk output per grazing hectare but did not affect milk yield per cow.
- The profitability of high stocking rate systems is very sensitive to milk price and feed cost changes.
- Compared to grass silage alone, feeding a dry cow diet containing high levels of chopped straw did not improve subsequent milk production, health or fertility.

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Technology

Opportunity/Benefit:

Protocol developed for efficient use of feed supplements on high stocking rate dairy farms.

Updated guidelines for nutrition and management of spring-calving cows during the dry period.

1. Project background:

The guiding principle for a grazing system is to maximize grass in the diet and use supplements to balance forage supply with herd demand. However, at a practical level other concerns are commonly brought to bear on feeding decisions, such as improving milk yield per cow, balancing the nutrient composition of pasture, or improving health status. This often translates into more complex feeding practices involving greater mechanization and use of imported feed. Total mixed ration (TMR) feeding is one such system, which operates on the idea that offering a consistent diet, with all ingredients physically blended together, will improve animal performance. Use of TMR feeding has been adopted on many Irish dairy farms in advance of independent research.

A large degree of farm-to-farm variation in feed costs is evident even after correcting for factors like land type and stocking rate. It is therefore essential that the rationale for using supplements in pasture-based milk production is clearly defined. This project sought to address some of the issues surrounding use of TMR feeding in particular. The three main objectives were to benchmark milk productivity of pasture versus TMR, to clarify the role of buffer feeding with TMR (i.e. feeding TMR in conjunction with grazing), and finally to examine the efficacy of high-fibre TMR for dry cows.

2. Questions addressed by the project:

- How does milk production on pasture compare to a TMR diet formulated for maximum milk output?
- What are the main nutritional limitations to milk production from pasture?
- What are the health and welfare implications of an indoor milk production compared to pasture-based milk production?
- What is the role for buffer feeding in a pasture-based feeding system?
- Are there production and health benefits to be gained from feeding a high fibre TMR to dry cows?

3. The experimental studies:

Three experimental studies were carried out under this project:

- **Benchmarking pasture versus a total mixed ration.** 48 Holstein Friesian cows were assigned equally to either pasture or 100% TMR (maize silage, grass silage, concentrate blend, molasses and straw) for a full lactation. The TMR group was housed for the duration of the experiment. The energy, fibre, and protein content of the TMR were formulated for maximum milk yield. Pasture-fed cows were offered swards managed to a target pre-grazing mass and post-grazing height. Measurements included milk production, feed intake, BCS and blood profiles.
- **Comparison of pasture and buffer feeding systems.** This study took the approach of looking at buffer feeding for a high stocking rate scenario. Two systems were compared:
  - ***Partial TMR (PMR)*** **–** Stocked at 4.0 cows per hectare and supplemented with total mixed ration (maize silage, grass silage, concentrate blend and molasses).
  - ***GRASS*** **–** Stocked at 2.5 cows per hectare with moderate concentrate input – Buffer feeding with TMR was used to balance pasture supply for the PMR group.

  Measurements included milk yield, pasture use efficiency, feed intake, blood profiles and fertility.
- **Comparison of high-fibre TMR and grass silage for dry cows**. 58 mature spring-calving Holstein cows were assigned equally to one of two diets for the duration of the dry period:
  - **Grass silage** (72% DMD)
  - **High-fibre TMR** (Comprising 40% straw, 25% grass silage, 25% maize silage, 10% soybean meal). The high-fibre TMR ingredients were mixed in a diet wagon prior to feeding. Diets were offered ad-lib and supplemented with the necessary minerals/vitamins.

  Both groups were fed pasture plus concentrate after calving. Health, BCS, blood profiles and subsequent milk yield were monitored.

4. Main results:

100% TMR versus Pasture

- Pasture-fed cows produced 21% lower milk solids yield (486kg versus 591kg) compared to TMR—fed cows.
- Energy intake was the main factor limiting milk production at pasture.
- Both diets supplied protein in excess of requirements for delivered milk yield.
- Cows fed TMR had greater bodyweight and body condition score (BCS) gain from mid-lactation.
- Cows at pasture had lower incidence of hoof disorders and mastitis throughout lactation.

Buffer Feeding with TMR at pasture

- Milk solids yield per cow was similar at 456kg and 465kg for GRASS and PMR, respectively.
- Milk solids output per hectare was 63% greater for PMR due to a higher stocking rate.
- Pasture quality and post grazing heights were similar for both treatments.
- The GRASS system used 0.45t DM concentrate per cow and was self-sufficient for forage. The PMR system used 0.74t DM concentrate per cow, and imported 1.5t DM of forage per cow for use during lactation and the dry period.

High-Fibre TMR versus grass silage for dry cows

- Cows fed high-fibre TMR had lower BCS at calving compared to silage-fed cows (3.11 versus 3.48).
- Dry period diet had no effect on milk production over the full lactation.
- Dry period diet had little effect on blood metabolite or mineral profiles post calving.
- No difference in health or fertility.

5. Opportunity/Benefit:

The outcomes of this research, in conjunction with existing research, were used to develop a protocol for efficient use of feed supplements on high stocking rate dairy farms. The outcomes also provided updated guidelines for nutrition and management of spring-calving cows during the dry period.

6. Dissemination:

Results of the project were presented under the dairy cow nutrition section for the Moorepark Open Day 2009, the Ballyhaise College Dairy Open Day 2009 and at Teagasc Feed and Forage Events (2008–2009). Findings have also been presented at other Teagasc seminars, invited industry events, to Teagasc advisory staff and to dairy discussion groups visiting Moorepark as well as through popular publications, e.g. Today's farm, IFJ, Farmer's Monthly.

Popular publications:

- Butler M., Patton J., Murphy J.J., and Mulligan F.J. (2010) 'Evaluation of a high-fibre total mixed ration as a dry cow feeding strategy for spring-calving Holstein Friesian dairy cows. *Livestock Science 136 (2): 85–92*
- Butler M., Patton J., Mulligan F.J. and Murphy J.J. (2009) 'Comparison of milk production performance of Holstein Friesian cows managed under pasture or partial mixed ration feeding systems' *Agricultural Research Forum, Tullamore, 12–Mar-2009, p.25*
- Patton J., Murphy J.J., and Butler M. (2009) 'Comparison of total mixed ration and pasture feeding systems' – *Irish Dairying New Thinking for Challenging Times (Moorepark Open Day 2009). Teagasc IE pp. 107–109*

Animal and Grassland Research & Innovation Programme

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Solid-liquid separation of pig manure and manure management

A fixed decanter centrifuge

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Key external stakeholders:

Pig farmers, tillage farmers, agricultural consultants, food manufacturers, policy makers

Practical implications for stakeholders:

- The outcomes of this study allow pig producers to make well-informed decisions regarding the implementation of solid-liquid separation systems on their farm.
- Knowledge regarding the use of separated solid and liquid manure fractions as crop fertilisers to increase crop performance was generated from this project.
- In addition, the outcomes provide pig farmers with knowledge and models to enable appropriate animal feeding and water management to minimize nutrient excretion and manure volume. This not only allows pig farmers to reduce their costs of production but also enables them to reduce their environmental load and to adhere to the regulations under the Nitrates Directive.

Technology

Main results:

- For solid-liquid separation a fixed decanter centrifuge proved to be the most effective method of removing dry matter from the liquid into the solid fraction. However direct land spreading of raw pig manure is still the most economic method of utilising pig manure. Therefore solid-liquid separation is not currently considered to be cost-effective.
- Separated liquid manure fractions proved to be a useful N source for winter wheat production, helping to reduce fertilizer costs. However, land application of the solid fraction is limited by its high phosphorus content.
- Reducing dietary crude protein and increasing dietary fibre for pigs reduced manure volume, ammonia emissions and increased manure dry matter. However, including dietary fibre reduced separation efficiency and consequently did not increase the dry matter content of the separated solid fraction from pig manure.

Opportunity/Benefit:

Pig farmers are well informed of the benefits and costs of solid-liquid manure separation and are provided with options (such as dietary changes and reduction of water use) to improve manure composition and reduce manure volume on their farms. Crop farmers are informed of the financial opportunities of using the liquid and solid fractions of separated pig manure in addition to chemical fertilizers on winter wheat.

1. Project background:

The Nitrates Directive Action plan imposes restrictions on the use of pig manure on intensive grassland. Separation of manure into solid and liquid fractions gives the possibility of utilising the two fractions in different situations (e.g. the solid fraction which is rich in phosphorus (P) might be used on tillage land and the liquid which is relatively rich in nitrogen (N) might be used for grassland or even on growing cereal crops). In addition, it would allow the liquid fraction to be applied at a higher rate to land in the vicinity of the pig unit and the solid fraction could be transported more economically to land further away where nutrient requirements are higher. However, not much is known about the practical and economical benefits of solid-liquid separation for both pig and tillage farmers.

In addition, the variable composition of pig manure and the generally low nutrient content, limits the attractiveness of pig manure as a crop fertilizer. Reducing the manure volume by reducing water wastage and/or by optimising the water to meal ratio on pig units, would increase the dry matter content of pig manure. Manure of high dry matter has many advantages. It will occupy less storage space, cost less to transport and spread and has more nutrients per unit weight/volume.

The amount of nutrients excreted in manure (total per pig produced) can be minimised by feeding diets which are formulated to more closely match the nutrient requirements of the pig at each stage of growth. Reduced surpluses of nutrients in the diet will result in an overall reduction in manure nutrients and also a redistribution of nutrients between the faeces and urine. Other dietary influences include high fibre levels in diets which result in increased N excretion in faeces and reduced N excretion in the urine. The aim here was to determine how such dietary adaptations could be combined to minimize nutrient excretion and manure volume, and to determine their influence on solid-liquid separation.

2. Questions addressed by the project:

- What is the current composition of pig manure on Irish farms?
- Is solid-liquid separation an efficient option for treating manure?
- What is the fertiliser value of the separated solid and liquid fractions of pig manure?
- Can the composition of pig manure and the separated fractions be improved by changing diet composition?
- Is solid-liquid separation currently cost-effective compared to traditional land spreading?

3. The experimental studies:

A manure survey was carried out on a sample of 11 farms to give an indication of current pig manure composition. Samples were taken from under-slat storage tanks and analysed for pH, dry matter, N, P and K.

The performance of a fixed decanter centrifuge for solid-liquid separation was monitored and compared to other mechanical separators. In addition, tests were carried out to determine the effect of chemical pre-treatments on separation

efficiency. A field study was carried out to test the fertiliser value of the separated solid and liquid fractions for winter wheat. The latter was carried out over a two year period.

Several tests were run to determine the effect of pig diet composition on manure output. Pigs were fed diets with different levels of crude protein, dietary fibre (sugar beet pulp inclusion) and phosphorus in a set-up that allowed complete monitoring of input (feed) and output (urine and faeces). Manure output was analysed for nutrient composition and ammonia emissions. In a further test, the manure output was submitted to solid-liquid separation to determine the effect of diet on the partitioning of manure into the solid and liquid fractions.

The costs of solid-liquid separation by a decanter centrifuge and of manure haulage and spreading on land were modelled based on previous outcomes and compared. The economic implications of water management were also modelled.

4. Main results:

Based on the manure survey, current manure composition values are estimated at: dry matter: 48.0kg/m^3 (SD ± 3.8), N: 2.4kg/m^3 (SD ± 1.3), P: 1.3kg/m^3 (SD ± 1.4), K: 2.3kg/m^3 (SD ± 1.5), and pH: 7.55 (SD ± 0.58). Thereby the main finding is that nitrogen concentrations have decreased since the last manure survey (1996). A large variation between farms was found, illustrating the importance of management factors.

The fixed decanter centrifuge was found to produce solid fractions of up to 35% dry matter, thereby outperforming the other mechanical separators tested. The centrifuge proved to have a good performance regarding P removal, but its effect on N removal was poorer. Increasing doses of a coagulant (a liquid mixture of Polydadmac and Poly Aluminium Chloride) and a flocculant (a high molecular weight/highly cross linked Cationic Polyacrylamide), that were added during the separation process, were found to increase the separation efficiency of P and DM.

In the study with winter wheat, the average N uptake efficiency of separated liquid pig manure N was 67.3% with chemical N being 82.1%. Liquid pig manure use at the stem elongation phase of crop growth made a significant contribution to crop performance increasing grain yield and grain protein levels, compared to inorganic N use alone. Separated solid pig manure application increased grain yield and crop nitrogen uptake of spring barley compared to untreated treatments, but also increased crop lodging. Solid pig manure application may be a useful N source for spring barley on lower N index soils. However, its high phosphorus content will limit its rate of application.

Inclusion of dietary fibre (sugar beet pulp) reduced manure output possibly reflecting the reduced water and dry matter intake of pigs offered diets containing sugar beet pulp. Moreover it reduced the urine: faeces output ratio and therefore increased the dry matter content of the manure. However, dietary fibre did not increase the dry matter of the separated solid fraction, due to a decrease in separation efficiency. Reducing crude protein levels and including sugar beet pulp in diets resulted in lower ammonia emissions from manure. The effects were additive, with a low crude protein diet formulated to include sugar beet pulp delivering the lowest emission value. Thus, lowering crude protein and including sugar beet pulp in pig diets will increase manure quality, but does not improve the separated solid and liquid fractions.

The annual costs of separation with a fixed decanter centrifuge were estimated at €123,067 (€11.7 per m^3 of manure) for a 500 sow integrated pig farm, producing 10,500m^3 manure per year at 4.8% dry matter. After separation, however the two separated fractions still need to be transported and spread on land. In comparison, transport of the raw liquid pig manure with a tractor and tanker for a distance of 1km and spreading would cost €13,877 (€1.32 per m^3 of manure) per year. Haulage with a truck for 100km and spreading would cost €123,830 (€11.79 per m^3 of manure) per year. Thus, direct land spreading remains the most cost-effective manure management option. With regard to water management as a means of reducing manure volume and haulage costs, reducing the water: meal ratio (without affecting animal welfare) was calculated to yield the greatest immediate benefit.

5. Opportunity/Benefit:

The findings of this project have been communicated to pig farmers, who can use this information to make well considered decisions with regard to manure handing, animal feeding and water management. Crop farmers were informed of the benefits and limitations of using separated pig manure fractions as crop fertilisers. The results have been published in scientific and popular articles and were communicated to pig farmers in workshops.

6. Dissemination:

Main publications:

O'Shea, C.J., Lynch, B., Callan, J.J., Lynch, M.B. and O'Doherty, J.V. (2010) 'Effect of cereal type and crude protein concentration of high and low phosphorus pig diets on nutrient digestibility, nitrogen and phosphorus excretion and composition of separated liquid and solid pig manure fractions' *Journal of Animal Science* 88:1411–1420.

Meade, G., Lalor, S.T.J., McCabe, T. (2011) 'An evaluation of the combined usage of separated liquid pig manure and inorganic fertiliser in nutrient programmes for winter wheat production' *European Journal of Agronomy* 34(2): 62–70

Popular publications:

Lynch, B. (2006). Manure processing. Teagasc pig newsletter Vol. 9 (2): 7–1

Treanor, S. (2008) Pearls from pigs. Today's Farm Vol. 19 (1): 36–37.

Lynch, B. (2008). Costing pig manure handling. Teagasc pig newsletter Vol. 11 (2): 6–7

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Effect of low phosphorus diets on pig health and welfare

Measurement of pig bone strength with a DXA scanner

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Key external stakeholders:

Pig farmers, feed manufactures, veterinarians, policy makers

Practical implications for stakeholders:

- The outcomes of this study provide information for pig farmers and feed manufacturers regarding the effect of low phosphorus (P) diets on pig growth, bone strength and the excretion of P by pigs. Additional knowledge was generated regarding the pros and cons associated with practices used to decrease P excretion, such as phytase supplementation and compensatory growth (early feed restriction followed by a period of realimentation). Based on this information pig diets based on growth stage can be developed to minimize P excretion without compromising pig health, welfare and growth performance.
- New knowledge is also provided with respect to the incidence and onset of joint pathology and lameness in breeding sows.

Main results:

- Reducing phosphorus levels in pig diets reduced P excretion, but also reduced bone strength and growth performance of both slaughter pigs and replacement gilts. Phytase may compensate for this, but not in cases where P restriction is too severe. After a period of being fed low P diets, pigs showed partial compensation in growth performance and bone mineralisation following realimentation, but a long period of realimentation was necessary to accomplish this. Minimum P requirements for optimum bone development are estimated at 5.8–6.7g/kg total P or 3.2–3.7 g/kg digestible P for weaners and 5.5 g/kg total P or 2.8 g/kg digestible P for finishers.
- Multiple parities in sows did not reduce bone integrity in sows, but the incidence of lameness was high (~50%). Lameness was not correlated to joint pathology, suggesting that alternative indicators should be looked at to determine joint pathology. Stiff hind limbs correlated negatively to sow longevity. Early signs of lameness appear as early as after the first service.

Technology

Opportunity/Benefit:

Pig farmers are informed of several strategies to reduce P excretion from pigs though dietary intervention. The outcomes of this study enable them to minimize P excretion without compromising pig health, welfare and growth performance. Information on the high incidence of joint pathology and lameness in breeding sows from this study will stimulate further research to identify appropriate management practices to prevent these conditions.

1. Project background:

Reductions in dietary phosphorus will reduce the level of P in manure with consequent reduced handling costs and reduced environmental risk. However, there may be consequences for bone strength due to reduced P deposition in bone when low P diets are fed. Reports of an increased incidence of bone fractures in pigs at slaughter and in breeding sows may indicate a related health/welfare problem which merits investigation.

There is concern among veterinarians that bone fractures in live pigs have become more common and that broken ribs before or during slaughter are causing a downgrading of product. This is consistent with data from poultry plants in the US processing chickens fed low P diets. Supplementing diets with phytase has become increasingly common as a method to improve the availability of P in plant ingredients containing high levels of phytate P. Animals subjected to early P restriction followed by a period of realimentation with high P diets in order to promote compensatory growth may also contribute to these problems.

In addition, little information existed on the consequences of low P diets for sow health/longevity. Bone strength is especially important for breeding stock, yet replacement gilts are usually fed diets created for grow-finisher pigs (high protein, low P). Body P stores at first mating are depleted over the following parities and it is inevitable that sows with less initial P reserves are most at risk. Lameness is a common cause of culling in sows and a significant welfare problem. Therefore this condition requires further investigation.

2. Questions addressed by the project:

- What is the effect of dietary P and phytase supplementation on bone characteristics of slaughter pigs?
- What is the effect of dietary P during rearing on bone characteristics of replacement gilts?
- Do multiple parities affect the bone strength of breeding sows?
- Which characteristics of gilts can be used as predictors of sow longevity and lameness?

3. The experimental studies:

Growing pigs were fed diets varying in P levels, crude protein and phytase addition at different growth stages (weaner, finisher or both) in a series of experiments. Effects on nutrient digestibility, P excretion, growth performance, bone mineral density at slaughter and immune response were measured. Periods of low P intake were followed by periods of high P intake to determine if pigs were capable of demonstrating compensatory growth.

In another series of experiments, replacement gilts were fed diets varying in P level at different stages of growth and effects on growth performance and bone strength were measured. Bone strength was determined with the use of a dual energy X-ray absorptiometry (DXA) scanner, which allowed the determination of bone mineralisation in live pigs. Gilts were not served, but rather were slaughtered at 100kg. Periods of low P intake were followed by periods of high P intake to determine if gilts were capable of demonstrating compensatory growth.

Two surveys on bone strength, lameness and joint pathology were carried out on culled sows form a number of commercial farms. The effects of parity number and piglets produced/sow were investigated.

Replacement gilts were monitored for gait and conformation on entry to the breeding herd. They were followed up to first serving or to slaughter.

4. Main results:

Feeding grow-finisher pigs low P diets significantly reduced P excretion, but also compromised growth performance and bone mineralisation. This was found especially during the finisher phase. Minimum P requirements for healthy bone development were determined as 6.4g/kg total P in the weaner stage (11 to 30kg) and 4.4g/kg total P or 2.0g/kg digestible P in the finisher stage (45–100kg). Pigs were capable of demonstrating compensatory growth. If pigs were fed a low P diet (4.2g/kg total P or 1.7g/kg digestible P) up to day 59 post-weaning, followed by a high P diet (5.8g/kg total P or 2.9g/kg digestible P) up to 131 days (slaughter), growth

performance and bone strength were similar to that of pigs fed a high P diet throughout their life (6.0g/kg total P or 3.0g/kg digestible P up to day 59, followed by 5.8g/kg total P or 2.9g/kg digestible P up to slaughter) Including phytase in the diet decreased faecal P excretion, and increased growth performance, compared to diets without phytase inclusion. However, in finisher pigs, phytase inclusion in low P diets (3.7g/kg total P or 1.5g/kg digestible P) resulted in pigs that had a similar carcass weight, but weaker bones than pigs offered medium (4.4g/kg total P or 2.0g/kg digestible P) or high P diets (5.3g/kg total P or 2.5g/kg digestible P) without phytase. Reducing dietary P levels (from 6.0g/kg total P or 3.6g/kg digestible P to 4.2g/kg P or 1.8g/kg digestible P) did not increase susceptibility to the Newcastle disease in pigs from 11kg to 50kgs.

In replacement gilts, the dietary P level also positively affected bone strength in both the weaner (8–26kg) and finisher stage (34–100kg). Based on this, the minimum dietary P requirements for optimum bone development in replacement gilts were determined at 6.7g/kg total P or 3.7g/kg digestible P in the first 4 weeks of the weaner stage, followed by 5.8g/kg total P or 3.2g/kg digestible P in the second weaner stage and 5.5 g/kg total P or 2.8 g/kg digestible P for finishers. In the finishing stage, decreasing the dietary total P from 4.6–7g/kg (2.2 g/kg digestible P) to 3.7–8g/kg (1.6g/kg digestible P) also decreased growth performance. Replacement gilts were not found to be capable of compensatory growth if the deficiency period (weaners: 5.6g/kg total P or 3.0g/kg digestible P for 28 days, finishers: 4.0g/kg total P or 1.6g/kg digestible P for 35 days) was followed by a realimentation period (weaners: 6.3g/kg total P or 3.5g/kg digestible P, finishers: 5.6g/kg total P or 2.3g/kg digestible P) of the same duration. However, in finishers full recovery (compared to a continuous high P diet of 5.6g/kg total P or 2.8g/kg digestible P for 35 days followed by 5.6g/kg total P or 2.3g/kg digestible P to slaughter) was possible if the deficiency period was followed by a realimentation period of twice the length (70 days) of the restriction period.

No evidence was found to suggest that bone integrity in sows reduced due to multiple parities. Stiff hind limbs were negatively correlated with longevity. About half of the surveyed sows (48%) exhibited clinical lameness. Joint pathology was not correlated with clinical lameness.

At entrance to the herd (at approximately 90–100kg), 16% of the gilts showed early signs of lameness, and this increased to 71% after first service. Heavier gilts at entry to the herd had a higher lifetime productivity than gilts that were lighter at entry (group average: 93kg).

5. Opportunity/Benefit:

The findings of this study provide new knowledge on the effect of reducing phosphorus levels in diets on the health and welfare of both grow-finisher pigs and breeding sows. Feeding low dietary levels of P (<6.4 in the weaning stage and <4.4g/kg in the finishing stage) compromises bone strength and growth performance, especially in the finisher stage. Compensatory growth may be used to reduce P levels by about 1.6–2.0g/kg (1.2–3g/kg digestible P) for a short period (up to 59 days) in the pig's life, without compromising pig performance and bone strength at slaughter. However, this is only possible if pigs are given high P levels (5.6–8g/kg P or 2.3–9g/kg digestible P for finishers) during a realimentation period of twice the length of the deficiency period. The severity of lameness and its early onset in young breeding females is evident from this study. Further studies on the prevention of lameness through improved nutrition and management are warranted.

6. Dissemination:

Main publications:

Varley, P.F., Lynch, P.B., Callan, J.J., and O'Doherty, J.V. (2011) Effect of dietary phosphorus and calcium level and phytase addition on performance, bone parameters, apparent nutrient digestibility, mineral and nitrogen utilization of weaner pigs and the subsequent effect on finisher pig bone parameters. *Animal Feed Science and Technology* 165 (3–4), 201–209

Ryan W. F.; Lynch P. B.; O' Doherty J. V. (2010) A survey of bone integrity from cull sows in Ireland. *Irish Veterinary Journal* 63 (12), 754–758

Ryan W. F.; Lynch P. B.; O' Doherty J. V. (2011) Effect of dietary phosphorus on the development of bone mineral density of pigs assessed using dual energy X-ray absorptiometry. *Livestock Science* 137 (1–3), 101–107

Impact of the social environment on the welfare and meat quality of pigs in entire male production systems

Project number:
5825
Date:
Nov, 2011
Funding source:
Teagasc
Project dates:
Jan 2008–Dec 2010

Key external stakeholders:

Pigmeat processors, pig producers, consumers

Practical implications for stakeholders:

- The social environment can influence aggression and sexual behaviour in pigs with resulting welfare improvements. Although these do not translate into improved growth performance or carcass traits they can be easily and cheaply adopted by producers and could contribute towards reduced veterinary bills.
- We found little evidence that boar taint levels can be modified by changes to the pigs social environment. This means that immunocastration remains the most promising method of controlling boar taint in the future.
- Bruising to the loins resulting in the downgrading of pigmeat products and financial losses to pigmeat processors could be reduced by the adoption of practices to reduce mounting behaviour in entire male pigs by producers.

Main results:

- In restrictively fed pigs split marketing reduces aggression at feeding by increasing trough space allowance; this does not improve growth performance although carcass variation is reduced.
- Pig welfare is improved (mounting behaviour and resulting skin damage reduced) in mixed sex compared to all-male pens but growth performance is not affected.
- Reductions in aggression and sexual (i.e. mounting) behaviour arising from manipulation of the pigs social environment have little beneficial impact on growth performance of pigs or on boar taint levels in pigmeat.

Collaborating Institutions:
Queen's University Belfast, Northern Ireland
Agri-Food Biosciences Institute (AFBI), Hillsborough, Do. Down, Northern Ireland
Waterford institute of Technology (WIT)

Teagasc project team:
Dr. Laura Boyle (PI)
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External collaborators:
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Technology

Opportunity/Benefit:

Teagasc in conjunction with WIT developed capabilities for measuring compounds responsible for boar taint in the meat of uncastrated male pigs using Gas Chromatography Mass Spectrometry (GC/MS) analysis. Further development of this technique will ensure that capabilities exist to examine the risks for boar taint of different management, nutritional etc. practices in pig production thereby helping to reduce the risk to consumers of purchasing boar tainted pigmeat. This project identified practical ways in which pig behaviour can be modified through changes to the animal's social environment. These can be easily and cheaply adopted by pig producers to benefit pig welfare.

1. Project background:

In Ireland male pigs are not castrated which is advantageous for their welfare. However, the trend towards higher slaughter weights means that entire male pigs are sexually mature at the end of the finishing period. The intense aggressive and sexual behaviours they perform gives rise to a different, though no less serious, set of welfare problems, including stress and injury not only to the male pigs but also to the females they are housed with. Mounting is the main sexual behaviour performed by entire male pigs and where this is intense the loin area can be severely bruised. This results in increased trims and downgrading of product resulting in significant losses for pigmeat processors. Sexual and aggressive behaviour is also associated with the production in the males of androstenone, a steroid hormone, and one of two main compounds responsible for boar taint. This is an offensive smell and taste that emanates from the meat of entire male pigs when it is cooked. Consumers who experience boar taint are unlikely to purchase the product again so the problem seriously threatens our export markets. The fact that male piglets are not castrated gives the Irish pig industry an important welfare advantage over its European competitors. However, this advantage can only be exploited in our export markets if the problems of boar taint and welfare issues for pigs in entire male production systems are addressed.

There are potentially 3 options for addressing these problems. The first is castrate male piglets. However, surgical castration is unlikely to be re-introduced to Ireland as even with modern genotypes, boars still grow more efficiently making them more profitable to rear than castrates. In any case, castration of young pigs is controversial and is soon likely to be limited in the EU to circumstances where analgesics and/or anaesthetics are employed. Immunocastration offers the most promising solution for the future as it addresses the problems of boar taint, aggression and sexual behaviour without the need for painful surgery. However, there are doubts as to whether the practice will be acceptable to pigmeat consumers in the EU owing to the perception that hormones are involved in the process. The third option is to manipulate housing/grouping and marketing strategies to try to reduce the problems of sexual and aggressive behaviour and thereby reduce boar taint. This was the focus of the current project.

2. Questions addressed by the project:

- What are the implications for growth performance and carcass traits of increasing the slaughter weights of entire male and female pigs?
- Are the aggressive and sexual behaviours performed by heavy entire male pigs influenced by the social environment?
- Are growth performance and carcass traits influenced by the pigs social environment?
- Does the pigs social environment influence boar taint levels?
- Is aggressive behaviour affected by removing pigs from an established group of pigs?

3. The experimental studies:

In the first study the effect of 3 slaughter weights (80, 100 and 105kg) on behaviour, growth performance and carcass traits of entire male and female pigs was assessed. In the 2nd study 200 hundred pigs were grouped according to within group weight variation (high vs low variation) and group gender composition (all male vs mixed gender) until slaughter at 21 weeks of age (c. 90kg). The 3rd study aimed at evaluating a split marketing (SM) strategy whereby some pigs in a pen are slaughtered earlier than the others. Twenty-eight single sex groups of 14 pigs were assigned to one of 4 treatments: Male Split, Female Split, Male Control and Female Control. In the control groups all pigs were slaughtered after 6 weeks on trial (c. 105kg) whereas the 3 heaviest pigs were slaughtered 2 weeks earlier in the SM groups. In both of these studies pig behaviour, growth performance, carcass traits and boar taint was measured. The objective of the 4th study was to determine the effect of the removal of the heaviest growing pigs on the dominance hierarchy in the remaining pigs. At 6

weeks of age 64 pigs were assigned to 4 groups of 8 females and four groups of eight males. Aggressive behaviour was recorded 5 days after grouping and pigs were subjected to a feed competition test after 18 hours of food deprivation. A dominance score was calculated for each pig according to the no. of pigs it displaced and the number of pigs that displaced it.

4. Main results:

The implications of mixed versus all-male groups for aggression depend on the feeding system in use. No effect on aggression was detected when pigs were fed *ad libitum* probably because this system is not associated with much competition between pigs for access to food. However, there are lower levels of aggression in mixed compared to all-male groups when pigs are fed restrictively i.e. a highly competitive feeding system (Boyle and Bjorklund, 2007). Furthermore, pig welfare is improved in mixed sex compared to all-male pens because of the lower overall rates of mounting and consequent benefits for skin health. In spite of these (potential) welfare benefits we do not wish to change previous recommendations (e.g. O'Connell and Lawlor, 2005; Teagasc Pig Conference) that pigs should be kept in single sex groups to facilitate feeding gender appropriate diets. The reasons for this are as follows:

- The experiment looking at different target slaughter weights showed that females are less efficient than males at converting feed into body weight at the heavier weights confirming that they have different nutritional requirements to males at heavier weights. Feed efficiency is crucial to profitability in this era of escalating feed costs and this can only be achieved by splitting the genders into single sex groups and feeding gender appropriate diets.
- Although there are welfare advantages for pigs in mixed sex groups these mostly benefit the males; females are generally better off in all-female groups where they are not exposed to any mounting by males.
- In spite of the welfare improvements for males in mixed sex groups there were no associated improvements in growth performance or carcass quality and most importantly no reduction in boar taint levels which weakens the case for keeping pigs in mixed sex groups.

So in spite of the increased workload we should strive to house males and females separately so that gender specific diets can be fed. We must look to some of the other strategies investigated in this project to improve the welfare of heavy finisher pigs, particularly the entire males.

The strategy of creating groups with high weight variation in an attempt to reduce aggression did not work. If the variation between pig weights had been greater the pigs may have been better able to establish the dominance hierarchy without aggression. However, the variation seen in slaughter and carcass weights would have worsened. Clearly this is undesirable as the risk of incurring penalties imposed by the slaughter plants for pigs outside the desirable weight range is increased. On the other hand, while grouping pigs uniformly led to reduced within group variability in slaughter and carcass weights this strategy led to more injuries among the males reared in single sex groups. The potential implications for entire males of housing in all-male groups of differing degrees of weight variation requires more investigation.

Behavioural patterns of pigs in studies 1 and 3 indicated that there was a lot of competition for access to the trough at the heavier weights. This was in spite of the trough space allowance per pig being 367mm. This is considerably higher than the 280–300mm feeder space allowance recommended for pigs between 90–120kg. SM resulted in a significant reduction in feeding related aggression because the removal of the 3 heaviest pigs increased the trough space allowance of those pigs remaining. These findings indicate that trough space allowances for heavy pigs should be revised upwards and that SM is a successful marketing strategy to improve the welfare of heavy pigs in entire male production systems. Unfortunately the reduction in feeding related aggression arising from SM did not result in a reduction in boar taint. However, SM also reduced within pen variation in carcass weight thereby reducing the risk of incurring penalties for pigs outside the desirable weight range.

SM not only increases the trough space but also the floor space allowance of pigs which is normally considered positive for pig welfare. However, we considered that the male pigs may have spent longer fighting outside of the feeding times because they had more floor space. The findings of Study 4 disputed this and confirmed that SM probably caused pigs to spend longer fighting because they were trying to re-establish the dominance hierarchy which had been disrupted following removal of the heaviest animals. We do not think that the associated stress would override the benefits arising from SM in terms of reducing feeding related

aggression. In Study 4 the dramatic increase seen in aggression following removal of two pigs from a pen has important practical implications. It means that in addition to limiting re-mixing of pigs, producers should try to limit the removal of pigs from established groups to avoid stress unless absolutely necessary e.g. because of tail biting.

It must be stressed that these findings were based on only one removal of 25% of the pigs from the group. Repeated removal of pigs from a group as might occur with very high weight variation groups, might lead to a very different response in terms of behaviour and performance. Furthermore, small numbers of removed pigs will be exposed to more unfamiliar animals during transport and lairage than if marketed on per pen basis and this will have negative implications for their welfare.

5. Opportunity/Benefit:

Teagasc in conjunction with WIT developed capabilities for measuring compounds responsible for boar taint in the meat of uncastrated male pigs using Gas Chromatography Mass Spectrometry (GC/MS) analysis. Further development of this technique will ensure that capabilities exist to examine the risks for boar taint of different management, nutritional etc. practices in pig production thereby helping to reduce the risk to consumers of purchasing boar tainted pigmeat. This project identified practical ways in which pig behaviour can be modified through changes to the animal's social environment. These can be easily and cheaply adopted by pig producers to benefit pig welfare but they will have limited implications for the problem of boar tainted meat.

6. Dissemination:

Main publications:

Conte, S., Boyle, L.A., O'Connell, N.E., Lynch, P.B., and Lawlor P.G. 2011. Effect of target slaughter weight on production efficiency, carcass traits and behaviour of restrictively-fed gilts and intact male finisher pigs. *Livestock Science* 136: 169–174.

Conte, S., O'Connell, N.E., Lawlor P.G., and Boyle, L.A. 2011. Effect of split marketing on the welfare, performance and carcass traits of finishing pigs. *Journal of Animal Science* doi:10.2527/jas.2010–3453.

Boyle, L.A., Lawlor, P.G., Conte, S. and O'Connell, N.E. 2010. Grouping and slaughter management of entire male pigs. *TResearch,* 5 (1), Spring 2010. pgs. 32–33.

Conte, S., O'Connell, N.E., Lawlor, P.G. and Boyle, L.A. 2010. Behavioural implications of grouping and marketing strategies for entire male pigs. Meeting of the EAAP Working Group on the Production and Utilisation of Meat from Entire Male Pigs, Bristol, UK, 18th March 2010. p. 24.

Conte, S., Boyle, L.A., Lawlor, P.G. and O'Connell, N.E. 2010. Influence of within pen gender composition and weight variation on the welfare and growth performance of finishing pigs. In: Advances in Animal Biosciences. Proceedings of the BSAS and the Agricultural Research Forum, Belfast, 12th April 2010. p. 184.

Boyle, L.A., Conte, S. and Lawlor, P.G. 2009. Rearing entire male pigs. In: Proceedings of the Teagasc Pig Farmer's Conference, Cavan, 10th November 2009. p.9.

Conte, S., Lawlor, P.G., Lynch, P.B., O'Connell, N.E. and Boyle, L.A. 2009. Effects of split marketing on agonistic behaviour and carcass characteristics of entire male pigs and gilts in a restricted feeding system. In: *Proceedings of the* 43rd *Annual Congress of the ISAE*, Cairns, Australia, 6th July 2009. p. 51.

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Popular publications:

Housing pigs in mixed sex groups could reduce aggressive behaviour Sarah Trickett, *Farmers Weekly*, 19th April 2010 http://www.fwi.co.uk/Articles/2010/04/19/120847/Housing-pigs-in-mixed-sexed-groups-at-finishing-could-reduce-aggressive.htm

Feeding and management of high performing sows in pregnancy and lactation

Project number:
5366
Date:
August, 2012
Funding source:
Teagasc
Project dates:
Jan 2005–Dec 2007

Key external stakeholders:

Pig Producers, Feed Industry Personnel, Teagasc Pig Advisors

Practical implications for stakeholders:

Improvements in genetics have resulted in sows with higher milk production and maintenance requirements. The results from this project demonstrate that liquid feeding curves for lactating sows can be increased by 30% and where dry feeding, ad-libitum feeders should be used to increase lactation feed intake so that:

- lactation weight loss is reduced
- litter performance is improved
- subsequent litter size is increased

During the critical embryonic period, a foetus is highly responsive to environmental factors such as nutrition. This project found that increased maternal nutrition alters skeletal muscle phenotype in the offspring by changing fibre-type proportions but does not influence offspring growth or feed conversion efficiency.

Main results:

- Feed intake during lactation can be increased by as much as 30%.
- Increasing feed allocation from day 25–80 of gestation had minimal effects on offspring growth and feed efficiency.
- Increasing feed allocation between day 80 and 112 of gestation improved subsequent farrowing rate.

Collaborating Institutions:
RVC, London

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Technology

Opportunity/Benefit:

Sow and offspring performance can be improved by increasing feed intake in late gestation and during lactation. Where sows are fed 30 MJ DE per day in gestation this can be increased to 45 MJ DE per day between day 80 and 112 of gestation to increases subsequent farrowing rate. Commonly used lactation feed curves are frequently too low and in the case of our study could be increased by 30% to increase lactation feed intake.

1. Project background:

Sow productivity in Ireland has failed to keep pace with improvements seen in other countries. Nutrition and management play a huge role in sow fertility and prolificacy. In particular, body reserves of fat and protein at each farrowing are very important. Current recommendations are based on data dating from the 1970s and 1980s, when sows had greater fat reserves, litter size was smaller and annual output was lower. Current feeding levels in pregnancy and lactation may be inappropriate for the modern high producing sow. The objectives of this study are: (1) to document current sow management practices and their relationship to body weight and condition, sow longevity and productivity; (2) to examine nutritional and management factors which could contribute to increasing sow output, namely feeding of pregnant and lactating sows. Criteria to be assessed include sow feed intake, changes in body weight, body condition and backfat, piglet birth weight, piglet weaning weight, piglet viability, post weaning growth rate, carcass composition, muscle histology.

2. Questions addressed by the project:

What is the appropriate feed curve for lactating sows when liquid fed? Can *ad-libitum* feeders be used to increase feed intake in lactating sows?

What is the effect of increasing feed allocation during three different time periods of gestation on the muscle fibre phenotype in the offspring and on offspring growth and feed efficiency?

Is there a benefit from increasing the feed allocation for sows in late gestation?

3. The experimental studies:

Two lactation experiments each involving 75 sows were conducted to determine the optimum lactation feed curve for liquid fed sows. Another lactation experiment involving 75 was conducted to determine if *ad-libitum* feeders could be used to increase lactation feed intake where dry feeding is practiced and to compare the results achieved with liquid feeding using the optimum feed curve identified in the first 2 experiments.

A gestation study examined the effect of increased sow feed levels during early, mid and late gestation on sow and offspring performance. Sows (n = 238) were assigned to the following gestation feed treatments: 2.3 kg/d throughout gestation (C), increased feed allowance to 4.6 kg/d from gestation d 25 to 50 (E), from gestation d 50 to 80 (M) and from gestation d 25 to 80 (EM). A fifth treatment increased feed allowance to 3.5 kg/d from gestation d 80 to 112 (L). Backfat depth and body weight of sows was recorded at d 0, 25, 50, 80 and 110 of gestation and at weaning. Lactation feed intake and reproductive performance of sows were recorded. Muscle fibre analysis was performed on progeny at the RVC and progeny growth and feed efficiency was followed through to slaughter at ~100kg with pigs penned as individuals and in groups.

4. Main results:

Mean daily lactation feed intake was increased from 78 MJ DE / day to 105 MJ DE /day by increasing the standard liquid feed curve (25 MJ DE /day at farrowing to 98 MJ DE / day by day 21 of lactation) by 30% or by providing additional dry feed along with the standard liquid feed curve. Where the higher curve is used, feed should be provided in 3 splits (morning, mid-day and evening). In this case personnel should be prepared to monitor troughs (1 hour after each feed) and when significant quantities of feed are left, individual valves should be "minused". *Ad-libitum* dry feeding resulted in mean daily feed intakes which were intermediate between those achieved on the standard and the improved liquid feed curves.

The large gestation study definitively showed that increasing feed allowances at various gestation time points, did not benefit growth and feed efficiency in offspring compared to the recommended gestation feed allocation of 2.3 kg/d. Even the lighter littermates who would have been expected to benefit most did not benefit from increased maternal feed intake. However, nutritional intervention at d 50 to

80 may aid in the reduction of intra litter variation in piglet birth weight. In addition, increasing feed allowance at d 80 to 112 of gestation increased subsequent farrowing rate. Increased maternal nutrition altered skeletal muscle phenotype in the offspring by changing fibre-type proportions, leading to an increased oxidative capacity due to an increase in Type IIA fibres. No change in total muscle area, total muscle fibre number, or fibre cross-sectional area was observed. There were also some alterations in gene expression in response to increases in gestation feed intake.

5. Opportunity/Benefit:

Arising from this project we have more precise guidelines on feeding sows during gestation and lactation so that both sow and offspring performance can be maximised.

6. Dissemination:

Main publications:

Lawlor, P. G. and Lynch, P.B. (2005). 'Effect of sow feed intake during gestation on the growth performance of progeny to slaughter'. *Archives of Animal Breeding* 50: 48–55

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McNamara, L.B., Giblin, L., Markham, T., Stickland, N.C., Berry, D.P., O'Reilly, J., Lynch, P.B., Kerry, J.P. and Lawlor, P. G. (2011). 'Nutritional intervention during gestation alters growth, body composition and gene expression patterns in skeletal muscle of pig offspring'. *Animal* 5: 1195–1206

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McNamara, L., Lawlor, P.G., Lynch, P.B., O'Connell, M.K. and Stickland, N.C. (2007). 'Influence of five gestation feeding regimes for sows on lactation feed intake, lactation weight loss and subsequent farrowing rate and litter size'. In: *Book of Abstracts of the COST 925 working group meeting*. September 6th–7th, Viborg, Denmark, p.8.

Lynch, P.B and Lawlor, P.G., (2007). 'Factors affecting voluntary feed intake in the lactating sow'. In: *Book of Abstracts of the* 58th *Annual Meeting of the European Association for Animal Production*, p.327.

Lawlor, P.G., Lynch, P.B., O'Connell, M.K., McNamara, L., Reid, P. and Stickland, N.C. (2007). 'The influence of over-feeding sows during gestation and piglet birth weight on piglet growth performance to slaughter'. In: *Book of Abstracts of the* 58th *Annual Meeting of the European Association for Animal Production*, p.50.

Lawlor, P. G., Lynch, P.B., O'Connell, M.K., Reid, P.T. and Stickland, N.C. (2006). 'The influence of over feeding sows during gestation, piglet birth weight and gender on pig growth performance to slaughter'. In: *Cost* 925, Turkey, 21–Sep–2006, 1

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Popular publications:

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Crops Environment & Land Use Programme

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Crops, Environment & Land Use Programme

The aim of the Teagasc Crops, Environment and Land Use Programme is to develop and transfer cost-effective crop production systems along with evidence based knowledge to support and underpin the development of a profitable, competitive and environmentally sustainable agri-food sector.

Given the current and burgeoning future challenges to our food supply and to the environment, **sustainable intensification** of agricultural production is emerging as a priority for policymakers and international development agencies. Sustainable intensification has been defined as producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services.

The Teagasc Crops, Environment and Land Use Programme is at the heart of the sustainable intensification of the Irish agri-food sector.

1. Crops Research

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Introduction

The objective of the Crop Research Programme is to develop *cost effective* crop production systems, including crops for energy and bio-processing, which improve *competitiveness, profitability* and product *quality*, and minimise impact on the *environment*. This objective is achieved through the implementation of research projects conducted in three sub-programme areas:

Crop Agronomy and Sustainable Crop Production Systems

The overall objective of this sub-programme is to acquire knowledge to facilitate the development of productive, competitive, sustainable production systems for Irish arable crops.

To achieve this objective the sub programme focuses on

- **Crop Yield**: Maximising a crop's yield potential is the primary production objective on tillage farms for both economic and environmental reasons. There is a need to develop our understanding of the soil, crop, management and climate factors that limit crop yield. This will lead to improved agronomic practices to deliver increased crop yield potential.
- **Cost Reduction**: To be competitive and economically sustainable in difficult and volatile markets, cost reduction and cost optimization strategies which are compatible with high yields are essential for profitable enterprises.

Crop Improvement and Biotechnology

The objective of this sub-programme is to contribute to the profitability, competitiveness and sustainability of Irish agriculture by providing a platform for the continued development of improved varieties of forage, tillage and alternative crop species and to monitor the population structure of the major fungal pathogens.

The specific objectives are:

- To breed improved varieties of potato for a variety of markets and end uses
- To develop biotechnology-based tools for the genetic improvement of perennial ryegrass, white clover, potatoes and other crop species
- To assess the impact of novel transgenic crops in Irish tillage agriculture. This encompasses providing support for policymakers, and developing management strategies for GM crops
- To monitor the population structure of the most important pathogens in Irish tillage agriculture with an emphasis on their ability to overcome fungicides and varietal resistance

Energy Crops and Bio-processing

The overall objective of this sub-programme is to develop viable bio-energy systems that will

- Improve fuel security
- Maximise sustainability
- Create new revenue streams for farmers
- Expand rural employment
- Increase national wealth

To achieve these objectives the research has focused on the use of renewable biomass as fuel for engines and boilers. These projects have examined the combustion of a range of energy crops as well as grain and straw, the pelleting of these materials to render them suitable for domestic stoves and boilers, and the quality requirements of both liquid and solid biofuels.

2. Crops Knowledge Transfer

The major objective is to improve farm profit by increasing output while keeping costs under control. Improving yield and quality and adding value through innovation in technical and business methods will be key to success. The main focus is on Tillage crops but energy crops are also being developed. Soil and plant nutrition are given specialist attention.

Four Crops Specialists work closely with crops Researchers in Oak Park and Johnstown Castle to develop the Tillage & Energy Crops Programme in consultation with Business & Technology Tillage Crops Advisors and stakeholders representing the crops sector including farmers, the input and output trades and public bodies.

Knowledge is also procured from outside agencies both within Ireland (e.g. Department of Agriculture and UCD) and further afield in the UK and across the world.

A broad range of communication technologies are used to impart the messages from the various sources:

- Group activities and 1 to 1 farm visits
- Public events including conferences, seminars, farm events etc.
- Publications including Crops and Harvest Reports, Newsletters and Web
- Training of Advisors, Farmers and the Industry
- Teagasc Crops BETTER farm programme aims to assist Irish tillage farmers to avail of cutting edge farm technology and business methods, to improve profitability and to develop links between research, advice and tillage farms

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3. Environment, Soils and Land Use Research

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Introduction

The objective of the Environment, Soils and Land Use research programme is to develop technologies and management strategies that facilitate farmers to combine economic sustainability with environmental sustainability, thus allowing farmers to farm profitably while conserving or improving environmental resources. The work of the department covers a wide range of research areas.

Soils

The Soils research programme is focussed on improving our knowledge of spatial variability and classification of soils at a national scale. Research areas being studied include:

- Development of a national soil map at 1:250,000 scale and an associated digital Irish Soil Information System (ISIS)
- Understanding the role of soil biodiversity and ecology in soil functions, processes and quality
- Soil compaction and sustainable soil drainage systems

Nutrient Efficiency

Current priorities include:

- Development of soil specific nutrient advice for nitrogen and phosphorus
- Technologies for fertilizer and manure management to increase efficiency of nutrient uptake and reduce losses
- Tools to aid with nutrient management planning and cross compliance
- Development of nutrient advice for farmers

Gaseous Emissions

This area of research focuses on:

- Technologies for reducing gaseous emissions on farms
- Refinement of emissions factors for gaseous emissions that are currently adopted in national inventories
- Quantifying and mitigating nitrous oxide emissions from soils
- Carbon cycling in agricultural soils, including evaluation of the carbon sequestration potential of grasslands
- Assessing pollution swapping in engineered systems to mitigate N losses

Water Quality

The emphasis here is on:

- Reducing nitrate leaching through understanding and managing the soil nitrogen cycle
- Development of end-of-pipe technologies for attenuation of nutrients from point and diffuse sources
- Quantifying and reducing the sources and impact of sedimentation on stream and river ecology
- Time lag and transformational processes from source to receptor
- Assessing mitigation strategies to minimise incidental and chronic nutrient losses

Agro-ecology

This area of research is focussed on developing the scientific knowledge base required to underpin policy and farming activity that will contribute to conservation of farmland biodiversity and ecological resources. Current priorities include:

- Improving the environmental effectiveness and economic efficiency of management plans for High Nature Value farming systems
- Improving the understanding of the relationship between diversity and ecosystem function within agricultural systems
- Development of effective indicators for farm-scale assessments of sustainability that include farmland wildlife

4. Agricultural Catchments Programme

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The Agriculture Catchments Programme (ACP) works in partnership with farmers to evaluate Ireland's Nitrates Action Programme and support sustainable farming. It's an integrated research/advisory project operating in six catchments which represent important farming/nutrient-loss-risk scenarios.

The same experiment is conducted in each catchment looking at the continuum from nutrient *sources* to *mobilisation* via *pathways* and *delivery* to water, where an *impact* **may** occur. By understanding this continuum and its socio-economic background the programme aims to reveal what governs the fate of the nutrients.

Phase 2 of the programme (2012–2015) builds on Phase 1 which found that intensive farming can, potentially, deliver good water quality, however with some substantial lag times between farm practice changes and reduced risk to water quality. By capitalising on its platform of high resolution data and well-matched collaborations the ACP is delving deeper into the nutrient continuum thus maximising its benefits for Irish farmers, the environment and catchment science.

5. Environment Knowledge Transfer Department

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Introduction

The main objective is to improve the sustainability of Irish Agriculture in terms of water quality, GHG emissions, biodiversity and soil fertility while meeting the objectives set out in Food Harvest 2020.

The department has five specialists who integrate with research and advisory colleagues to deliver a programme which integrates with all other Teagasc programmes.

Knowledge Transfer

Farmer clients are supported in the implementation of technology aimed at increasing their competitiveness and profitability while at the same time achieving stringent environmental standards and Cross Compliance. REPS and AEOS scheme participants are also supported.

Research Integration

The Environment KT department interacts effectively with the Environment and other research departments to ensure that research that has a capacity to improve environmental outcomes is integrated into KT programmes and to provide a feedback mechanism to researchers and policy makers from farmers and advisers.

Education

The Environment KT department develops, resources and oversees the delivery of a wide range of courses for farmers and students.

6. Horticultural Development Department

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Introduction

The Horticultural Development Department (HDD) is an integrated research and advisory unit. The HDD provides advice, training and research on horticultural related matters. The HDD is grouped into four enterprise teams – mushrooms; vegetables; fruit; nursery stock and cut foliage.

Major Focus

The major focus of the HDD will be to implement the recommendations of the "Plan for the Development of Horticulture in Teagasc 2010–2013" and the recommendations of Food Harvest 2020 by:

- Exploiting the development potential of horticulture, prioritising mushrooms, fruit / vegetable and nursery stock/cut foliage sectors
  - Support innovation that adds value in the food sector taking advantage of the positive healthy profile associated with fruit/ vegetables
  - Support innovation that creates diversity in the nursery stock/cut foliage sector – Implement Teagasc plan for development of Cut Foliage Sector
  - Use Producer Organisations to drive investment and consolidate market developments where possible
- Knowledge procurement and transfer will be advanced by:
  - Collaboration with outside agencies e.g. new Memorandum of Understanding with Horticultural Development Company (HDC) Universities and Institutes of Technology
  - Regulatory compliance is being addressed by appropriate publications, courses and advisory activities. Priority issues include nutrition, pesticides and hygiene
  - The priorities in research include the ongoing projects in mushrooms, vegetable crops, strawberries, nursery stock, phytochemicals in vegetable crops and potatoes, enhancing nutrient content of brassicas and bio-control in a range of crops. A cut foliage project is supporting the establishment of the sector and the enhancement of exports and job creation
  - A range of communications techniques are used to achieve knowledge transfer including:
    - Group activities and 1 to 1 farm visits
    - Public events including conferences, seminars, farm events etc.
    - Publications including Technical notes, Newsletters and Web
    - Short Training courses and study tours

The Horticulture Research facilities at the Food Research Centre Ashtown consist of 5 laboratories, dedicated to research areas such as Plant Pathology, Plant tissue culture, Mushroom Pathology, Entomology and compost research. There are dedicated Molecular and microbiology laboratories to support these areas. Other facilities include a Lachat FIA Soil and Plant analyser and a large plant growth room. There is a 1500m^2 research glasshouse complex along with a modern nursery, consisting of polytunnels. The Horticulture unit also has modern ground cultivation, planting and spraying equipment suitable for research and observational trials.

7. Forestry Development Department

Introduction

The Forestry Development Department provides integrated forestry research, advisory and education services which allows for rapid and effective dissemination of research through knowledge transfer and educational initiatives.

Objectives

The objective of the forestry research and knowledge transfer programme is to develop forests and forest management systems that maximize the potential of farm forestry from economic, social and environmental perspectives.

Forestry Research

Forestry research focuses on broadleaf tree improvement, broadleaf silviculture and thinning and harversting management. Forestry research projects currently include:

- FORGEN: Birch and Alder tree improvement
- Improvement and selection programme for ash, sycamore and cherry
- B-SilvRD: Broadleaf Silviculture Research – management and thinning
- Supply Chip: facilitating the supply of wood chip from forestry
- Confier management and thinning research
- AGROCOP: novel Agroforestry – Short Rotation Coppice System

Knowledge Transfer

Focus on the following areas:

- Unbiased assessment of the suitability of a farm forest enterprise.
- Access to technologies and information to assess the status of their crops, the need for thinning and harvesting and mechanisms to effectively and profitably market their produce.
- Forestry promotion through different media channels.

Successful knowledge transfer is achieved using a number of tools:

- National and regional events
- Wide range of training courses

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- Group meetings, and forest walks and consultations
- Initiation and support of various development initiatives
- Wide range of publications
- Website, e-News and social media

The Teagasc forestry knowledge transfer and training programme is provided in collaboration with the Forest Service of the Department of Agriculture, Food and Marine.

Forest Owner Groups

A particular area of focus is the formation and support of Forest Owner Groups. Forest owners are finding it difficult to single-handedly thin their plantations as the cost of harvesting and transportation can outweigh the financial returns on an individual basis.

To achieve economies of scale and realise an economic return to growers, the organisation of individual growers into local forest groups is seen to be critical. These groups, supported by Teagasc and Local Development companies are striving to achieve a greater understanding of the potential of an individual forest and how to achieve this potential through cooperation with other growers.

Forestry research is carried out on Teagasc lands and on farm forestry sites throughout the country. Up-to-date experimentation, monitoring, evaluating and recording equipment is used in gathering data from trial sites. In addition research facilities are located at Teagasc. Athenry and Teagasc, Ashtown. Laboratory facilities include well-resourced soils, molecular and microbiology laboratories and a large plant growth room. In addition to the dedicated forestry facilities, extensive laboratory and analytical facilities are also available within the AFRC. In 2013 heated and unheated glasshouse, polytunnels and capillary beds will also be constructed.

Agronomy of oilseed rape in Ireland

Project number:
5542
Date:
Sept, 2012
Funding source:
Teagasc
Project dates:
Jan 2006–Dec 2008

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Key external stakeholders:

Growers, advisers and agronomists, seed suppliers

Practical implications for stakeholders:

There has been relatively little recent research on the agronomy of winter oilseed rape under Irish conditions. With renewed interest in the crop combined with significant developments in the agronomy of the crop abroad this work aimed to investigate the agronomy of the crop under Irish conditions. The work showed that:

- On average hybrid cultivars out yielded conventional cultivars but effects were cultivar specific.
- Seed rates giving maximum yields were generally in the range 60–80 seeds/m^2 where volunteer oilseed rape was not present.
- There was no consistent difference between hybrid and conventional cultivars in terms of the seed rate that gave maximum yield.
- Significant yield responses to fungicide application were not common and tended to occur only where visible disease was present at the time of fungicide application.

Main results:

Restored hybrid cultivars gave, on average, a higher yield than conventional cultivars but individual conventional cultivars could out yield the majority of hybrid cultivars.

No consistent difference between hybrid and conventional cultivars in terms of the seed rate giving maximum yield was observed. Seed rate giving maximum yield of winter oilseed rape was generally in the range of 60–80 seeds/m^2.

Disease levels were generally low and significant responses to fungicide applications, which were infrequent, tended to occur where robust rates were applied to crops with visible disease.

Opportunity/Benefit:

The work demonstrated that high yields of oilseed rape can be achieved under Irish conditions making it a potentially profitable crop Optimum seed rates for winter oilseed rape under Irish conditions have been established showing that there is little consistent difference, in terms of yield, between different cultivar types.

Hybrid cultivars can be used to achieve higher yields but the best conventional cultivars can give similar yields to the majority of hybrid cultivars.

Fungicide applications to oilseed rape should be made on the basis of the presence of disease rather than on a prophylactic basis to avoid unnecessary use of fungicides.

The results of the project have been incorporated into Teagasc advisory recommendations for oilseed rape production.

1. Project background:

Lack of non-cereal break crops, interest in alternative sources of fuel and increased prices have increased interest in production of oilseed rape in recent years. However there has been little recent research on oilseed rape production under Irish conditions. There have been significant advances in oilseed rape production techniques in other countries such as the introduction of restored hybrid cultivars and the use of lower seed rates than would have been used in Ireland previously. The effects of these factors on yield potential under Irish conditions have not been assessed. The requirement for fungicide application at different stages in the crop growth cycle has also received little recent attention under Irish conditions. In addition a range of new fungicides have become available, the efficacy of which have not been assessed on oilseed rape under Irish conditions.

2. Questions addressed by the project:

What is the optimum seed rate for autumn sown oilseed rape under Irish conditions?

Do hybrid cultivars give higher yields than conventional cultivars under Irish conditions? Does cultivar type affect seed rate?

What is the fungicide requirement of winter oilseed rape in Ireland?

3. The experimental studies:

Field trials were carried out over three seasons (2006 to 2008) at Oak Park Research Centre with winter oilseed rape to examine (a) the effect of seed rate on yield of a conventional cultivar (cv. Winner), a low biomass conventional cultivar (cv. Castille) and a restored hybrid cultivar (cv. Excalibur) (b) the effect of cultivar type (conventional or hybrid) on yield of OSR and (c) effects of different fungicide programmes on oilseed rape yield. For seed rate experiments seed rates of between 13 and 135 seeds/m^2 were compared.

For cultivar comparisons a range of cultivars, both hybrid and conventional, were compared.

To determine the importance of fungicide timings on winter oilseed rape an experiment comparing single applications in the autumn, early spring or at early pod formation and combinations of these timings was carried out over three seasons 2006 to 2008 with the cultivar Castille. Caramba (0.75 l/ha) was used as the autumn application in 2006 and 2007 (MBC (0.5 l/ha) was included in 2007), Prosaro (0.9 l/ha) was used in 2008. Caramba (1 l/ha) was used as the spring application and Rovral as the early podding application in all seasons.

4. Main results:

There was no consistent interaction between seed rate and cultivar indicating that there was no difference between cultivars in terms of their yield response to increasing seed rate. When there was a difference it occurred between the two conventional cultivars rather than between a conventional cultivar and a hybrid cultivar. This suggests that, when sown in good conditions, there is no reason, other than cost, for using a lower seed rate with hybrid cultivars compared to conventional cultivars. Seed rates giving maximum yields were generally higher than has been observed in other countries and were generally in the range 60–80 seeds/m^2. However these trials were carried out on land that had no recent history of oilseed rape production and there were no volunteer oilseed rape present, which if present, would reduce the seed rate required to give maximum yield as volunteer plants would substitute for plants from sown seed. There were indications that when yield potential was reduced, as occurred in one of the three seasons, the response to seed rate was decreased. Oil content decreased as seed rate increased although differences between the lowest and highest seed rate were generally small (~0.5%).

A comparison of a range of hybrid cultivars with conventional cultivars indicated that, on average, hybrid cultivars can give a small yield advantage over conventional cultivars. The average yield advantage of hybrids over conventional cultivars was 0.3 t/ha in 2007 and 2008 and 0.1 t/ha in 2006. However individual conventional cultivars can outyield individual hybrid cultivars.

Disease levels were low in the majority of the fungicide experiments and no statistically significant yield response to fungicide application was obtained in the majority of experiments. Any statistically significant yield responses to fungicide application that were obtained tended to be associated with robust two or three-spray (autumn, spring +/- early podding) programmes applied to crops with some visible disease present. This suggests that prophylactic applications of fungicides to oilseed rape in Ireland are unlikely to give a consistent economic response and that fungicide application should be targeted at crops that have visible disease present. As the area of oilseed rape the occurrence of disease may change.

5. Opportunity/Benefit:

The work provides guidelines on the production of winter oilseed rape under Irish conditions and in particular gives guidance on appropriate seed rates, choice of cultivar type and the requirement for fungicide of oilseed rape.

6. Dissemination:

Hackett, R. (2006) Oilseed rape agronomy. Teagasc Crops Research Centre Oak Park Research report 2006 pp 26–28

Hackett, R. (2007) Evaluation of the agronomic potential of oilseed rape in Ireland. Teagasc Crops Research Centre Oak Park Research report 2008 pp 13–15.

Hackett, R. (2008) Evaluation of the agronomic potential of oilseed rape in Ireland. Teagasc Crops Research Centre Oak Park Research report 2008 pp 25–28.

Hackett, R. (2011) Making oilseed rape profitable Teagasc National Tillage Crops Forum 2011 September 2011 Newbridge (http://www.teagasc.ie/publications/2011/1024/Richie_Hackett_teagasc.pdf)

Hackett, R., Dunne, B., Kennedy, T., Forristal, D. and Burke, J.I. (2006). Growing oilseed rape in Ireland. Teagasc, Carlow 26pp.

Field trials were also presented at a number of open days during the course of the project.

Results have been incorporated into Teagasc advisory recommendations for oilseed rape production.

Project number:
5772
Date:
September, 2012
Funding source:
DAFM – RSF – 07 352
Project dates:
Dec 2007–April 2012

Identifying challenges to the coexistence of GM and non-GM potatoes

Collaborating Institutions:
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Key external stakeholders:

Policymakers, tillage farmers and advocacy groups

Practical implications for stakeholders:

Although a national strategy for the coexistence of GM and conventional/ organic crops in Ireland was published in 2005, the coexistence of GM and non-GM potato crops was identified as a subject requiring further research. Output from this study has begun to address this knowledge gap by identifying the specific challenge points in current conventional potato practises that would act as barriers to achieving efficient coexistence. In addition, the propensity for gene flow via pollen and/or seed transfer from commercial potato crops was also quantified.

Main results:

- A survey of over 30 commercial potato farms identified groundkeeper emergence in the rotation after potatoes as a significant problem in current production practises, which will present a challenge to effective coexistence if specific measures are not implemented.
- The average dispersal distance of potato pollen in neighbouring crops is 11m.

Opportunity:

Output from this project will inform stakeholders of the most pertinent issues relating to the potential coexistence of GM and non-GM potato crops in Ireland. This is of most relevance to regulatory agencies and policymakers who would be required to implement national guidelines to preserve the genetic integrity of non-GM potato crops, should GM varieties be placed on the market.

Technology

1. Project background:

A crop's propensity to spread its genes through pollen and/or seed transfer is significant in light of European Union (EU) guidelines on the coexistence of genetically modified (GM) and non-GM crops and the labelling and traceability of GM material through food and feed pipelines. Coexistence relates to the adoption of crop-specific management regimes to maintain potential GM content in conventional/organic commodities below the EU's 0.9% labelling threshold for food or feed. In short, coexistence is focused on restricting the potential for and consequence of a crop's gene flow, whether via seed and/or pollen.

While there is an on-going debate in the public domain as to the justification for testing the efficacy of GM potato, engineered to express durable resistance to late blight disease, the National Co-existence Strategy (2005) stipulated that "research must be undertaken to ascertain the appropriate management regime for the cultivation of GM potato under Irish agro-ecological conditions". The objective of this project was to address the knowledge gaps identified in this strategy so that should GM potatoes be considered by Irish farmers in the future, a coherent coexistence strategy could be quickly implemented to ensure the genetic integrity of neighbouring non-GM potato crops.

2. Questions addressed by the project:

- Identify the challenge points in existing potato management regimes that would prevent efficient coexistence from being achieved.
- What is the rate of gene flow (both pollen and seed) from a potato crop?

3. The experimental studies:

The project did not require the field cultivation of GM potatoes. The first part of the study focused on quantifying the rate of pollen-mediated gene flow between two commercial potato varieties in two separate field studies at Oak Park, over 3 successive years. Employing the biotechnology technique of DNA fingerprinting, it was possible to trace the rate of pollen dispersal between the pollen donor plots (containing var. Desiree) and the pollen receptor plots (var. British Queen). The same technique was also used to quantify the consequence of insect-mediated pollen transfer between varieties.

The propensity for volunteers to persist at each trial site was also monitored in the absence/presence of standard tillage practises. As a result of this work, a survey of commercial potato farms was undertaken to quantify the rate of tuber loss at harvest and critically the rate of groundkeeper emergence in subsequent crops. As a result over 30 fields were surveyed across two consecutive seasons in order to gauge the level of seed loss post-harvest and the resulting flush of volunteers for two years post-potato cultivation.

To identify the challenge points in a coexistence-based production system, commercial potato operations in Carlow, Louth and Dublin were visited at the pre-sowing, planting and harvesting stages.

4. Main results:

Specific challenge points in current conventional potato practises have been identified which will act as barriers to achieving the effective coexistence of GM and non-GM potatoes. They include,

- Storage and handling pre-planting
- Field operations
- Post-harvest management
- Processing
- Waste management
- Long-term storage

Of the 6 challenge points, guidelines can be implemented to negate issues that may arise for Points 1, 2, 4, 5 and 6. These guidelines would be similar to what is already required of segregating seed and ware production at the same site and as such would have a nominal impact on processing. In contrast, the issue of controlling volunteers (No. 3, Post-harvest management) was significant. In spite of the severe winters experienced in Ireland in 2009 and 2010, groundkeepers were recorded across all 30 commercial sites surveyed during the project. In addition, field recordings noted that each successive generation was capable of producing adequate tuber numbers to maintain the next crop of groundkeepers. The most appropriate control system was the application of a sprout suppressant before harvesting of the original potato crop or where that is not possible the use of timely herbicide treatments in the first rotation crop was essential to exert adequate control.

The field studies provided adequate data to quantify the level of pollen-mediated gene flow across neighbouring potato crops. Berry formation (indicating successful pollen flow) was recorded at an average of 11m and up to a maximum of 23m from the pollen donor plots of var. Desiree. Over three year's of field trials, a total of 1367 F1 seedlings were analysed using DNA fingerprinting to confirm parentage and pollen-mediated gene flow. The primary insects found to populate potato plots in flower were hoverflies, butterflies and bumblebees.

5. Opportunity/Benefit:

This research is the first study to quantify the degree of gene flow, be that pollen-or seed-mediated, from commercial potato crops. This is of critical importance to establishing effective guidelines for any future coexistence strategy, should it be required. This will be of benefit to policy makers, regulators, tillage farmers and the general public at large.

6. Dissemination:

Phelan, S., Byrne, S., Meade, C. and Mullins, E. (2010). Towards the Development of a Coexistence Regime for the Production of GM Potato in Ireland. Presented at the Irish Plant Scientist's Association Meeting, UCD, June 3rd–4th.

Byrne, S., Phelan, S., Mullins, E., Meade, C. (2010). Quantifying the risk of pollen-mediated gene flow between potato crops. Presented at the Irish Plant Scientist's Association Meeting, UCD, June 3rd–4th.
Phelan, S., Meade, C. and Mullins, E. (2009). Issues pertaining to the effective coexistence of GM and non-GM potato. Presented at the 4th International Conference on the Coexistence of GM and non-GM crops, Melbourne, Australia, November 10th–12th.

Phelan, S., Luna, J., Meade, C. and Mullins, E. (2008). Coexistence of GM and non-GM potato. Presented at the Agricultural Biotechnology International Conference, University College Cork, August 22nd–25th .

Luna, J., Phelan, S., Mullins, E. and Meade, C. (2009). Insect and wind-mediated gene flow in potato. Presented at the Irish Plant Scientist Association Meeting, March 18th–20th, Trinity College Dublin.

Nitrogen value and greenhouse gas footprint of digestate from anaerobic digestors

Project number:
5819
Date:
August, 2012
Funding source:
DAFF 07 506
Project dates:
Nov 2007– May 2011

Key external stakeholders:

- Farmers
- Anaerobic digestor operators
- Bioenergy Industry Policy Makers Scientific Community

Practical implications for stakeholders:

- Farmers and operators of anaerobic digestors benefit from the availability of quantitative information on the value of digestate as a nitrogenous fertilizer.
- Policy makers benefit from the knowledge that digestate is an effective nitrogen fertiliser on grassland with a low environmental impact.
- The scientific community benefits from this project as new information is now available on the use of digestate as a fertilizer as well as on the environmental footprint of using digestate as a fertilizer.

Main results:

- Grass yield response to digestate as a source of nitrogen was similar to that of urea but lower than that of calcium ammonium nitrate.
- Greenhouse gas emissions from digestate application were lower than those from calcium ammonium nitrate but similar to those from urea.
- Greenhouse gas emissions were dominated by nitrous oxide, methane emissions represented only a few percent of the global warming potential of the nitrous oxide emissions.

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Technology

Opportunity/Benefit:

Anaerobic digestion offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. This project has shown that the waste material from the anaerobic digestion process (digestate) can be used as an effective nitrogen fertilizer on grassland with a low environmental impact. The availability of such a product from the anaerobic digestion process represents an additional benefit.

1. Project background:

In Ireland today, in excess of 90% of our energy is imported. This imported energy is primarily fossil fuel and is responsible for most of our greenhouse gas emissions. In contrast, most of our agricultural produce is exported although some farmers are now considering alternatives to food production as a result of falling farm incomes. One popular alternative is that of growing energy on the farm. Producing renewable energy within Ireland reduces our dependency on foreign imports but also reduces our emissions of greenhouse gases. Anaerobic digestion offers one possible way of generating renewable energy. This energy conversion technology converts waste material (such as slurries and manures) or energy crops (such as grass and maize) into biogas and a nutrient rich waste material called digestate. Over 4000 on farm anaerobic digestors operate in Germany supplying renewable electricity to the German grid. Ireland's predominantly grass based farming system produces considerable quantities of slurries and manures from which energy can be extracted by anaerobic digestion. Grass also represents an excellent feedstock for anaerobic digestors which can be harvested and stored using existing equipment and know-how.

Digestate

The anaerobic digestion process converts carbon in the feedstock to methane and other compounds which can subsequently be combusted to generate heat and electricity. This conversion process is carried out by bacteria which convert more complex carbon compounds into simpler compounds. This process also releases nutrient elements previously bound up in complex organic compounds and thus unavailable for plant uptake when material such as slurry is used as a fertilizer. Thus, the anaerobic digestion process not only produces a nutrient rich waste material which can be used as a fertilizer but nutrient availability in the waste material is higher than in the original feedstock. In cases where grass is used as a feedstock, digestate from the anaerobic digestor can be returned to the grassland as a fertilizer thus completing the cycle. There are two principal advantages of using digestate as a fertilizer. The first advantage is economic, the cost of grass production is minimised as the cost of chemical fertilizer is eliminated or reduced.

Emissions of Greenhouse Gases from Grassland

The second advantage relates to greenhouse gas emissions. Considerable quantities of greenhouse gases are released during the manufacture of nitrogenous fertilizer, these emissions are avoided when digestate is used as a fertilizer instead of chemical fertilizers. But, what is the greenhouse gas balance when digestate is applied to grassland as a fertilizer? While areas under grass are generally considered to be a net sink for atmospheric carbon dioxide (CO_2) until the soil is saturated with carbon, grasslands can also emit other greenhouse gases (GHG) like nitrous oxide (N_2O) and methane (CH_4). Emissions of N_2O are of particular concern, as it is 298 times as powerful in contributing to global warming as CO_2. Therefore, fertiliser applications have the potential for the generation of large emissions of GHG. Rewetting of dry soil as well as freezing and thawing have been identified as further events with a potential for large N_2O emissions.

CH_4 is another important agricultural greenhouse gas. Its global warming potential is 25 times that of CO_2. Agricultural soils may act as net sinks for CH_4. The sink function is due to the oxidation of CH_4 to CO_2 by methanotrophic microorganisms in the soil and has been reported to be greater for grassland than for arable soils.

2. Questions addressed by the project:

What is the value of digestate as a nitrogen fertilizer and how does it compare with chemical fertilizers?

How does the use of digestate as a fertilizer affect GHG emissions from grasslands?

3. The experimental studies:

The experiment was conducted at the Teagasc research centre in Oak Park, Carlow during 2009 and 2010. In order to quantify the value of digestate as a nitrogen fertilizer and the greenhouse gas emissions arising from digestate application, we applied different quantities of digestate, and thus different quantities of nitrogen to grass plots.

Digestate was obtained from an anaerobic digestor operated by the Agri-Food and Biosciences Institute, Hillsborough, Co. Down. Identical quantities of nitrogen fertilizer were also applied either as calcium ammonium nitrate or as urea. All plots received equal applications of other nutrients to ensure that supplies of these nutrients were non-limiting and that the experiment was purely a comparison of nitrogenous fertilizers. Digestate and inorganic N fertilizer were applied on three occasions during each growing season and grass yield was also quantified three times during each growing season. Emissions of GHG were measured before each application and for a long period after each application. GHG emissions of N_20, CH_4 and CO_2 were measured used a closed chamber technique in which chambers were placed in the water filled trough of a frame that had been inserted into the soil. Gas samples were taken by withdrawing a sample with a syringe through a rubber septum, the samples were subsequently analysed using gas chromatography.

4. Main results:

- Grass yield response to digestate as a source of nitrogen was similar to that of urea when this chemical fertilizer was used as a source of nitrogen. However, grass yield response to digestate was lower than that to calcium ammonium nitrate. This is thought to be largely because the form of nitrogen in digestate is identical to that in urea (ammonium) whereas calcium ammonium nitrate contains both nitrate and ammonium.
- GHG emissions: There were no significant emission peaks that were not connected to fertilizer application indicating that factors such as drying-wetting and freezing –thawing may be less important in Ireland compared to other countries. GHG emissions varied with year (ie meteorological conditions) as well as with fertilizer type.
- Fertilizer applications were followed by distinct GHG emission peaks which declined over time. GHG emissions from digestate application were lower than those from calcium ammonium nitrate but similar to those from urea. GHG emissions were dominated by N_20.
- CH_4 Fluxes: A net uptake of atmospheric ammonia occurred in plots which received chemical fertilizers. Emissions of CH_4 were initially higher in plots which received digestate due to methane from the digestion process which was dissolved in the digestate. However, this peak decreased quickly and plots which received digestate became a sink for atmospheric methane a few days after digestate application. CH_4 emissions represented only a few percent of the global warming potential of the nitrous oxide emissions which occurred after digestate application.

5. Opportunity/Benefit:

Anaerobic digestion offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. This project has shown that the waste material from the anaerobic digestion process (digestate) can be used as an effective nitrogen fertilizer on grassland with a low environmental impact. The availability of such a product represents an additional benefit.

6. Dissemination:

The results of the project were disseminated to farmers at two open days held at Oak Park. The results were also disseminated to the scientific community at conferences in Ireland and Germany.

Main publications:

Dieterich, B., J. Finnan, P. G. H. Frost, S. Gilkinson, and C. Müller (published online). The extent of methane (CH_4) emissions after fertilisation of grassland with digestate. Biology and Fertility of Soils DOI 10.1007/s00374–012–0714–1.

Dieterich B, J. Finnan, S. Hepp, T. Hochstrasser and C. Mueller (2010) "Fertiliser value and environmental impact of digestate application on permanent grassland." Grassland in a changing world, *Grassland Science in Europe* **15**: 57–59.

Dieterich, B., J. Finnan, S. Hepp, T. Hochstrasser and C. Mueller (2010) Fertiliser value and environmental impact of digestate application on permanent grassland. *Teagasc conference "A Climate for Change", Dublin*. 24–25 June 2010.

Hepp, S., B. Dieterich, C. Augustenborg, R. Laughlin, A. Farrell, G. Lanigan, J. Finnan, T.Hochstrasser and C. Müller (2009) Evaluating Irish grassland under different management regimes as a source of bioenergy – Part 1: Greenhouse gas emissions. *International Soil Science Conference, Johnstown Castle, Wexford, Ireland*. 9–11 September 2009.

Dieterich, B., S. Hepp, J. Finnan, R. Laughlin, A. Farrell, C. Augustenborg, T. Hochstrasser and C. Müller (2009). Evaluating Irish grassland under different management regimes as a source of bioenergy – Part 2: Biogas yield. *International Soil Science Conference, Johnstown Castle, Wexford, Ireland*. 9–11 September 2009.

Popular publications:

1. Finnan, J.; B. Dieterich; and T. Hochstrasser (2011) Grass to energy and back again. *TResearch* 6(1):18–19. ISSN: 1649–8917.

Developing biotechnology-based resources for white clover

Project number:
5762
Date:
Sept 2012
Funding source:
DAFF-RSF 07–566
Project dates:
Dec 2007–Dec 2011

Key external stakeholders:

Plant breeders, forage genetics community

Practical implications for stakeholders:

Biotechnology-based breeding approaches are increasingly becoming routinely deployed in many of the most significant crop plant species. White clover has complex genetics and poor genome-based resources that currently limit application of such approaches. The main goal of this project was to increase the DNA sequence based resources for the species, and explore advanced genetical approaches for dissecting key traits for the improvement of the species. The results contribute to an increased capacity within the international forage research community to develop biotechnology-based breeding approaches in white clover.

Main results:

A reference transcript set of approximately 70,000 expressed sequence tags was developed for white clover using 454–sequencing.

Over 200,000 single nucleotide polymorphisms, which can be used as the basis for molecular marker development, were identified in white clover.

Association mapping using a candidate gene approach and half-sib families was validated in the species, and an association between leaf size and an orthologue of the PHANTASTICA gene was identified.

Opportunity/Benefit:

The research provides a rich DNA sequence based resource for further exploitation in the path towards the deployment of biotechnology-based breeding approaches in white clover. Sequence data will be placed in the public domain to maximize its utility to the scientific community.

Collaborating Institutions:
Institute of Biological, Environmental and Rural Sciences, UK.
International Trifolium Network (ITN)

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External collaborators:
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Technology

1. Project background:

Because of its nitrogen fixing capacity, white clover has an important potential role in both animal nutrition and fertilizer input reduction in grassland based production systems. White clover shows the potential to maintain high levels of productivity under low fertilizer N input conditions while reducing animal-based methane emissions and sequestering atmospheric carbon. Thus, white clover is a key component of the drive towards "sustainable intensification" of pasture-based production systems central to the goals of Food Harvest 2020. However, the ability to produce improved varieties of white clover suitable for a range of production systems and environments is central to the long term success of this role. Teagasc is actively involved in the breeding of improved white clover varieties specifically for Irish pastoral production systems.

Biotechnology-based breeding approaches are increasingly becoming routinely deployed in many of the most significant crop plant species. The successful application of these technologies in the breeding of a species is based on a combination of favourable reproductive genetics (inbreeding diploid species are the most optimal systems for deployment of the technology), well developed genome-based resources, and in some cases, an ability to rapidly phenotype very large numbers of genotypes of the target plant for complex traits using simple, single step approaches. White clover is an outbreeding allotetraploid with a breeding system that does not favour the easy application of biotechnology-based breeding approaches. In addition, genome-based resources for the species are very poor.

2. Questions addressed by the project:

The rationale behind this project was to fill some of the aforementioned knowledge and resource gaps. Little can be done regarding the unfavourable genetics of white clover. Instead this project focused on two main areas. Firstly, we aimed to develop a significant sequence based resource for the species using novel next-generation sequencing approaches. Secondly, we aimed to test the potential in white clover for an approach called "association mapping", which identifies associations between genes/markers and important phenotypic characteristics – an important step in dissecting the genetics of such traits.

3. The experimental studies:

In the first part of the study, we addressed the extreme paucity of genome-based resources for white clover through the development of a large scale SNP resource for the species. Radical improvement in next generation sequencing technology experienced over the recent years allowed us to generate several hundred thousand sequences from cDNA of a single white clover inbred line using 454–sequencing. These were assembled into a "reference transcript set", to which tens of millions of shorter reads generated from multiple further genotypes using the Illumina sequencing platform, were aligned using a bioinformatics pipeline based on programmes designed to handle nucleotide alignments from next generation sequencing experiments. This process allowed nucleotide variation over the white clover genome to be identified, as described in more detail below.

Subsequently, we tested the potential of an approach called "association mapping" for the genetic dissection of traits of interest to breeders in white clover. Association mapping is an approach originally developed in human genetics whereby large populations of unrelated or partially related individuals are characterised for specific traits (phenotyped), their DNA extracted, and the genome of each individual subsequently surveyed for DNA polymorphisms showing a statistically significant association with the traits that were originally surveyed. Occurrences of such associations are indicative of genes (or alleles thereof) that are important in the control of the trait in question, and this is the first step in being able to use molecular marker-based approaches to select for these loci in breeding programmes. This project represented the first attempt to perform this type of analysis in white clover. In addition, the population type used (a half-sib family-based population) was specifically designed to enable the transfer of the population to multiple research groups worldwide. During the course of the project the traits leaf area (length and width) and digestibility traits; neutral and acid detergent fibre (NDF and ADF) content were measured in the population, the latter using near infrared spectroscopy. A candidate gene approach was used for association analysis whereby nucleotide polymorphisms in genes involved in pathways related to the underlying traits were tested for association with the traits measured in the population. The sequence based resource generated in the first part of the project acted as the source of the candidate genes in question.

4. Main results:

We used the Roche 454–sequencing approach to generate 750,000 EST sequences of a white clover inbred line, assembled these sequences into approximately 70,000 "reference transcript sequences", and partially annotated these sequences using a BLAST-based similarity approach. To further exploit this resource against a backdrop of sequencing technology improvements, we designed an additional experiment to generate a further 100 million sequences in 2 additional white clover inbred lines and 25 million sequences in a mixed sample of 24 divergent white clover genotypes using the Illumina HiSeq2000 and GAII platforms. Using a strategy originally developed for allotetraploid *Brassica* species as a template, we developed a bioinformatics pipeline for this dataset that allowed the identification of over 200,000 polymorphic single nucleotide polymorphism (SNP) sites in the genome of white clover. Significantly, this cutting-edge approach allowed us to distinguish allelic and homeolog-specific variation in this allotetraploid species, a major limitation for the deployment of SNPs for marker development in white clover. This resulted in a highly useful database of reference sequences and associated SNPs to use as a basis for marker development for the global white clover genetics and breeding community.

An association mapping population of 384 half-sib clover families was planted in a field trial at Oak Park. Plant material was harvested from all plots on four occasions (three in 2010 and one in 2011) for NDF and ADF analysis. ADF and NDF measurements were carried out on three of the four harvests using NIRS, subsequent to chemistry-based calibration. In addition leaf size was measured and recorded for the entire population in both years. Candidate genes for NDF and ADF (from the phenylpropanoid pathway) and leaf size were identified from the literature, and the sequences of these genes in white clover were established by comparing published sequences in other species to the reference transcript assembly of 70,000 sequences developed in the previous part of the study. In total, 4 candidate genes were assayed on the entire population: three from the phenylpropanoid pathway (two representatives of the HCT multigene family, and one from the 4CL family) and a white clover ortholog of the meristem patterning gene PHANTASTICA/AS1, which has been shown to be involved in leaf size in other species as diverse as poplar and maize. Analysis of the phenylpropanoid (PP) pathway gene sequences has shown no strong associations with variation for ADF or NDF in the population. Analysis of the PHANTASTICA ortholog revealed an association of a SNP haplotype with variation in leaf size over two years. Although the lack of association for variation in PP gene sequences is disappointing, the association for leaf size is, to the best of our knowledge, the first demonstration of successful association mapping in white clover to date.

5. Opportunity/Benefit:

The long term impact of the research will enable the deployment of biotechnology-based breeding approaches in white clover.

6. Dissemination:

The technical nature of the project meant that results were disseminated entirely through the scientific literature and appropriate scientific meetings.

Main publications:

Peer-reviewed publications:

Magee AM, Aspinall S, Rice DW, Cusack BP, Sémon M, Perry AS, Stefanović S, Milbourne D, Barth S, Palmer JD, Gray JC, Kavanagh TA, Wolfe KH. (2010) *Localized hypermutation and associated gene losses in legume chloroplast genomes* Genome Research (12):1700–10.

Nagy I, Barth S, Mehenni-Ciz J, Abberton MT, Milbourne D. *A hybrid next generation transcript sequencing-based approach to identify allelic and homeolog specific single nucleotide polymorphisms in white clover* Submitted to BMC Genomics

Scientific abstracts or articles including those presented at conferences:

Hybrid NGS-based transcript sequencing to identify inter-and intra-homeolog single nucleotide polymorphisms in allotetraploid white clover. Presented by Dan Milbourne at the 29th Triennial Meeting of the EUCARPIA Fodder Crops and Amenity Grasses Section Meeting, Dublin Castle, Ireland , 4th–8th Sept 2011

Generation of SNP markers from next generation sequencing technologies for the forage species white clover (Trifolium repens L.) towards association mapping Poster Presentation byJeanne Mehenni-Ciz at the Irish Plant Scientist Association Meeting (IPSAM), May 2010.

Project number:
5633
Date:
September, 2012
Funding source:
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Sep 06–April 10

Managing Bumblebee Imports to Maintain Pollinator Diversity

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Collaborating Institutions:
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Key external stakeholders:

Producers of pollinated horticultural crops; Policymakers; Bee researchers; Commercial bumblebee suppliers; Environmental and biodiversity stakeholders.

Practical implications for stakeholders:

The outcome/technology or information/recommendation is:

- The current practice of importing bumblebee colonies for pollination of horticultural crops is effective but poses serious risks to native populations and possibly biodiversity.
- Drift from imported bumblebee colonies poses a significant disease transmission and hybridisation risk requiring industry/legislative action to reduce these risks. Developing effective policies/actions is challenging however, as they are likely to impact negatively on the effective pollination provided by commercial bumblebee colonies.
- The development of novel genetic markers will be a valuable tool for: bumblebee rearing companies; environmental protection agencies and researchers.

Main results:

- The effectiveness of bumblebees as pollinators has been determined and the economic benefits of bumblebee pollination in strawberries can now be quantified through the establishment of plant abundance and hive density effects.
- Disease transmission and hybridisation risks are real and question current bumblebee colony importation and management practices.
- The use of existing and development of novel genetic techniques has allowed effective and detailed population and movement studies to be carried out.

Technology

Opportunity/Benefit:

This study provides information which will allow new bumblebee pollinator management practices and polices to be developed. These policies should target the protection of our native bumblebee populations, while recognizing the utility of commercial bumblebee colonies for pollination of horticultural crops. The genetic marker techniques developed will prove an invaluable tool in reliably differentiating between native and non-native bumblebee populations and offers scope to be developed into a rapid screening tool of benefit to bumblebee rearing companies and environmental monitoring agencies.

1. Project background:

Bees are the most important insect pollinators, pollinating over 90% of the world's 254,000 flowering plant species. Bee pollination generated €14.4 million of horticultural produce in Ireland in 2008 in addition to honey sales of €992,000. Bee pollinators also facilitate the maintenance of sexual reproduction in a host of wild flowers and trees which provide a myriad of other services. In total pollination is estimated to be worth from €52–200 million p.a. to the Irish economy.

The International Pollinators Initiative (IPI) was set up in 2000 to address concern about declines in pollinator populations worldwide. IPI research has confirmed that the abundance and diversity of wild bees are in decline. In Europe, Britain and the Netherlands have lost 52% and 67%, respectively, of their bee biodiversity since 1980; and 25% of bee species in France and Belgium are in decline. In Ireland, 30% of our 101 bee species are considered threatened. Reliance on a single bee species for commercial crop pollination is unsustainable. About 20 years ago the horticultural industry responded by domesticating bumblebees (alternative group) with now over one million bumblebee hives exported worldwide each year worth over €55 million. In Europe, Bombus terrestris, a species that naturally occurs throughout Europe and North Africa, is commercially reared, for year-round export. B. terrestris includes a recognised number of subspecies, in particular B. terrestris audax which is found only in Ireland and Britain. Currently, the breeding-stock of commercial bumblebees is not native to Ireland and unregulated importation could pose a serious risk to our native species of bees. Studies in both Canada and Japan have shown that imported bumblebees have been responsible for spreading both diseases and parasites to native bumblebees. Imported bumblebees can also escape from glasshouses and successfully compete with native bumblebees. Finally, imported bumblebees may successfully breed with native B. terrestris audax and over time it may lose any unique physiological adaptations to Irish conditions through genetic dilution.

2. Questions addressed by the project:

In recognition of the need of Irish growers to import bumblebees for pollination and the risks involved in importing non-native bees, the following questions were addressed:

- Can management of imported bumblebees be improved to increase pollination efficiency?
- Can we reduce drift between hives and escapes from areas of importation?
- What level of genetic differentiation exists between B. terrestris audax and non-native B. terrestris?
- What is the risk of hybridization and establishment of non-native bumblebees?
- What is the disease and parasite load of imported bumblebees and the risk to native bumblebees?

3. The experimental studies:

A survey of 137 horticultural growers was carried out to establish the extent of bumblebee importation, and to assess the impact of our recommendations on bumblebee management. To establish the population genetics of European B. terrestris, novel genetic screening protocols were applied to over 630 bees sampled from 20 countries across Europe, and 2 commercial populations from the Netherlands.

Polytunnel trials with strawberry crops allowed determination of: optimal plant/bee density for pollination and fruit production; and the pollination efficiency of bumblebee vs. honeybees. Field studies were conducted at six strawberry production sites along the East coast. At 5 discreet distances: 250 m, 500 m 1 km, 2 km, and 10 km from the sites, 2700 wild bumblebees were sampled. Imported bees from 68 hives were also sampled. These wild-caught and hive samples were then screened for disease and genetically screened to identify native, hybrid and imported bumblebees. Four nuclear and a novel mitochondrial marker were used, facilitating the rapid identification of native, hybrid and imported genotypes. Also 540 pollen samples were collected

from imported bumblebees at each site to determine the impact of cropping system (glasshouse, polytunnel or open field) on bee escape and to assess the level of competition between imported and native bees. Finally, using our drift, permeability, disease and hybridisation results, a risk-assessment was conducted on imported B. terrestris using the UK Non-Native Organism Assessment Scheme to quantify the risk of entry, spread, establishment and impact on the Irish economy and environment.

4. Main results:

- About 1450 bumblebee hives are being imported into Ireland p.a. mainly to the East and Southeast.
- Growers disposing of hives correctly increased from 5% to 28% following targeted dissemination.
- Strawberries require 1–5 visits by bumblebees to achieve 100% pollination, increasing fruit yield by 26% and decreasing the incidence of fruit deformity by 47%.
- Bumblebees, per visit, are 2.5 times more efficient pollinators than honeybees.
- Plant abundance did not effect the number, weight or quality of fruit. One commercial colony should pollinate 5,000 plants in protected crop systems.
- Low plant abundance (120 plants/hive) increased the incidence of drift. Drifting bees were usually larger females seeking out weaker colonies to parasitically lay eggs within. Drift from imported bumblebee colonies poses a significant disease transmission and hybridisation risk.
- In glasshouses, polytunnels and field crop, respectively 28%, 75% and 88% of pollen collected by imported bumblebees was not strawberry pollen indicating unhindered opportunities to interact with native bees. The utility of importing bumblebees for field grown crops is highly questionable.
- Mitochondrial markers reveal that the European subspecies of B. terrestris are still very closely related and statistically cannot be separated using conventional DNA methods.
- The Mitochondrial DNA gene Cytochrome Oxidase I (COI) does contain three diagnostic sites that can reliably differentiate native Irish and British B. t. audax from continental subspecies.
- The fast evolving microsatellite markers reveal that inbreeding can be detected in the majority of B. terrestris populations across Europe. However current population genetic diversity remains high.
- There is significant recent genetic differentiation between European populations of B. terrestris with both commercial stocks tested being genetically distinct from wild populations.
- Microsatellite and novel mitochondrial markers have been successfully developed to identify native, non-native and hybrid B. terrestris.
- Markers confirm that imported bumblebees can be found up to 10 km from the site of importation.
- Imported bumblebees can successfully mate, produce reproductive queens, compete for hibernation sites, hibernate over winter and produce workers in the following season.
- Of the 68 commercially imported bumblebee hives screened, 1.47% contained Apicystis bombi, 32.29% Crithidia bombi, and 60.29% Nosema bombi, and no tracheal mites were detected.
- The incidence of A. bombi and C. bombi was significantly elevated within 2 km of glasshouses, suggesting that diseases are being transmitted to wild populations.

5. Opportunity/Benefit:

This is the first study to quantify the economic benefit of bumblebee pollination and to illustrate the impact of plant abundance on drifting behaviour in bees. The plant abundance/bumblebee hive density is relevant to the 56 countries worldwide currently importing commercially reared bumblebees for strawberry pollination, particularly as the cost:benefit ratio for investing in pollination can now be accurately calculated for this crop. Furthermore, the permeability of glasshouses and polytunnels, and the striking lack of time spent on open field crops, suggest a change in management practices regarding containment of pollinators in protected crop systems and questioning the current practice of investing in imported bumblebee pollinators for non-protected crops.

The significance of microparasites in commercially imported colonies and transmission of parasites to wild populations must be highlighted. Although current EU and national legislation focuses exclusively on honeybee pathogens, this is under

constant review and the licensing of bumblebee colonies based on the presence/absence of honeybee disease will cease in the near future. Once this occurs, there may be severe restrictions placed on the importation of non-native bumblebees and responsibility for licensing bee importation may devolve to national governments. If this occurs, there will be an immediate negative impact on Irish horticultural production and competitiveness due to lack of suitable pollinators and consequent reduction in yields. Additionally, there may be increased costs involved in state-controlled licensing and independent disease screening of imported hives.

Finally, the development of a novel mitochondrial genetic marker to reliably differentiate between native Irish and non-native B. terrestris will be an invaluable tool. The utility of microsatellite markers in differentiating native, hybrid and non-native genotypes has been proven. Further refinement of these genetic tools would facilitate rapid screening practices of benefit to bumblebee-rearing companies and environmental protection agencies.

6. Dissemination:

The results of this research were presented in 17 scientific / technical publications or conferences. Key publications are listed below:

Main publications:

Murray, T.E., Kuhlmann, M., Potts, S.G. (2009). Conservation ecology of bees: populations, species and communities. Apidologie 40 211–236.

Murray, T.E., Davis, E.S., Paxton, R.J. (2009). Microsatellite loci for a rare solitary bee, Colletes floralis (Hymenoptera: Apidae), and their variability in other colletid bees. Molecular Ecology Resources 9 1460–1466.

Horgan FG, Murray, T, Kehoe, E (2008) Bumblebee importations into Ireland: growers' understanding of rewards and risks. XXII International Congress of Entomology. 6–12 July 2008, ICC, Durban, South Africa.

Davis, E, Murray, TE, Fitzpatrick, U, Brown, MJF, Paxton, RJ (2008) Conservation ecology and genetics of a rare mining bee, Colletes floralis. Proceedings of III European Congress of Apidology. 7–11 September 2008, QU Belfast. Pg 24–25.

Popular publications:

Murray, T., Horgan, F., Kehoe, E. (2008) Bee-careful: considerate crop pollination in Ireland. Published abstract; Teagasc Soft Fruit Conference and Trade Show. Enniscorthy, Wexford. Pg 14–23.

Horgan FG, Coffey ML & Murray T (2007) Plight of the Bumblebee. T-Research 2: 24–27

Murray T, Horgan F, Kehoe, E (2007) Bee Aware. Today's Farm 18 (6): 10–11.

Horgan, F., Murray, T., Kehoe, E. (2008) The responsible pollinator. In: Irish Soft-fruit Growers Association Newsletter. May 2008

Murray, T.E., Moreira, S., Kehoe, E., Kakouli-Duarte, T., Horgan, F.G. (2009) Bumblebee importation: a question of balancing risks and benefits. T-Research 4(3) 30–31

Project number:
5771
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Aug 2008–Dec 2010

Field trials of the oilseed crop camelina sativa and properties of the obtained oil

Key external stakeholders:

Camelina breeders, Teagasc Food Research Centre, vegetable oil plants, food manufacturers and Camelina growers.

Practical implications for stakeholders:

- Camelina oil can be stabilised with synthetic and natural antioxidants to the level of commercial oils. It should be possible therefore to exploit the health benefits of camelina oil by using the stabilised oil in spreads, functional foods and other vegetable oil based products.
- The relation between chemical structure and antioxidant activity in camelina oil, and the effect of ascorbyl palmitate on carbonyl rates shown in the present work, could be very useful information in the formulation of new antioxidants for the stabilisation of camelina and other oils with high omega–3 fatty acid content.

Main results:

- Unrefined camelina oil met CODEXSTAN specifications for cold pressed virgin oil, but it had lower oxidative stability in terms induction times and carbonyl rates than rapeseed or sunflower oil.
- Camelina oil could be stabilised with both synthetic and natural antioxidants.
- Induction times of the evaluated antioxidants in camelina oil depends on the position of hydroxyl groups on the phenyl ring and, within the same type of phenols, (i.e. ortho hydroxyphenols) on the molar concentration phenylhydroxyl groups per weight of antioxidant.

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Technology

- Camelina oil obtained from camelina seeds grown under Irish conditions was found to be somewhat more stable in terms of induction times, and had about the same oxidative stability in terms of peroxide and carbonyl rates as the commercial oil.

Opportunity/Benefit:

Potential for camelina oil to be used as a commercial oil.

1. Project background:

Camelina sativa, a member of the Brassicae family, is an annual oilseed plant. Also known as false flax or golden pleasure, it has been grown widely in Central Europe until the 1940's when it was replaced by rapeseed. Interest in the crop was revived in the 1990's, on account of its relatively low production costs in Northern Europe including Ireland and the high linolenic acid content of its oil.

Linolenic acid is an omega–3 fatty acid occurring in substantial amounts only in flax and fish oils and its anticholestemic effect should provide similar health benefits. Furthermore camelina oil is considerably cheaper than fish oil and it has none of the objectionable taste and odour of the latter. In spite of its obvious advantages camelina has not been commercially successful, and only a small amount of commercial camelina oil is produced in Europe at present, mainly for the health food industry.

High linolenic acid content of camelina oil might be a nutritional advantage, but it could also be an indicator of low stability. Hence if camelina oil is to be commercially successful its oxidative stability needs to be investigated, and if necessary, the oil will need to be stabilised to the level of commercial edible oils. Considering that sunflower methyl ester, which was shown to have the same primary oxidation rate as camelina oil, could be stabilised with synthetic and natural antioxidants, it should be also possible to stabilise camelina oil.

2. Questions addressed by the project:

- What is the oxidative stability of camelina oil relative to commercial edible oils such as rapeseed and sunflower oils?
- How can the oxidative stability of camelina oil with food grade antioxidants be improved?
- What is the oxidative stability of camelina oil obtained from seeds grown under Irish conditions relative to commercial camelina oil?

3. The experimental studies:

Commercial unrefined camelina oil obtained from a small seed oil producer and commercial rapeseed and sunflower oils obtained from local supermarkets were characterised in terms of composition, impurities including fatty acids, water, oxidation products formed during storage and oxidative stability. Oxidative stabilities of the three oils were evaluated by oil stability index induction time which determines the time elapsed to the formation of volatile organic acids as determined by the Rancimat® instrument, referred to as induction time, and by oven storage test, with daily monitoring of peroxides and of carbonyl compounds as p-anisidine values. Oven storage test data was expressed as rates of increase of peroxides and carbonyl compounds, referred to as peroxide and carbonyl rates.

Stabilisation of camelina oil was evaluated with twenty one food grade synthetic and natural antioxidants and antioxidant formulations obtained from several commercial sources. Antioxidant effects were determined at four concentrations. Maximum concentration of synthetic antioxidants (200mg/kg) was set as per current EU food additive directive, but there are no regulatory limits at present on the maximum concentration of natural antioxidants permitted in foodstuffs. Therefore, threshold concentration or the effect of added plant extract on the odour and flavour of camelina oil was the criteria for the upper limit (2000 mg/kg) of the added natural antioxidant.

Oxidative stabilities of the camelina oils with added antioxidant were determined as per oils without antioxidants, except conjugated dienes and tocopherols were also monitored in the oven storage test to indicate structural changes and loss of stability. Induction times and carbonyl and peroxide rates of camelina oil with antioxidants were used as stability parameters, and they were compared to those of pure camelina, sunflower and rapeseed oils.

Irish camelina oil was obtained from six varieties of camelina, Slovenian Landrace, Calinta, Sonny, Ligena, Calena and Lindo, grown at Oakpark, Carlow in 2009 in small plots. Harvested seeds were cleaned and dried and oil was extracted by cold pressing using a bench scale screw press. Oxidative stabilities were evaluated as per commercial camelina oil and stabilising effect of selected antioxidants were determined by induction times.

4. Main results:

Unrefined camelina oil met CODEXSTAN specifications for cold pressed virgin oil, but it had lower oxidative stability in terms induction times and carbonyl rates than rapeseed or sunflower oil. The order of induction times and carbonyl rates were: rapeseed(8.5h) > sunflower(4.5h) > camelina(2.4h) and sunflower(0.7) < rapeseed(2.4) < camelina(5.9), respectively.

Camelina oil could be stabilised with both synthetic and natural antioxidants. Two formulated antioxidants namely a TBHQ citric acid formulation (V101, donated by Vitablend Ltd.) and rosemary extract ascorbyl palmitate formulation (RPT40 donated by Kemin Food Technologies) increased oxidative stability of camelina oil in terms of induction times and carbonyl rates to the level of rapeseed and sunflower oils, respectively.

Induction times of the evaluated antioxidants in camelina oil depended on the position of hydroxyl groups on the phenyl ring, and within the same type of phenols (i.e. ortho hydroxyphenols) on the molar concentration phenylhydroxyl groups per weight of antioxidant. Carbonyl rates could be reduced very effectively with the synergyst ascorbyl palmitate.

Camelina oil obtained from camelina seeds grown under Irish conditions was found to be somewhat more stable in terms of induction times, and had about the same oxidative stability in terms of peroxide and carbonyl rates as the commercial oil. Evaluated antioxidants had a stronger stabilising effect on the Oak Park camelina oils, and average induction times of TBHQ/citric acid and rosemary extract/ascorbyl palmitate were 19 and 50% longer than of the commercial camelina oil used in the present work. However the longer induction times could be caused by the shorter storage period of the Oak Park camelina oils.

5. Opportunity/Benefit:

Potential for camelina oil to be used as a commercial oil.

6. Dissemination:

Main publications:

Fröhlich, A., O'Dea, G., O'Beirne, D. (2011). Stabilisation of camelina oil with synthetic and natural antioxidants. Journal of the American Oil Chemists' Society, under review http://www.agresearchforum.com/publicationsarf/2011/Page%in press.pdf

Weed control with herbicides in forage maize in Ireland

Project number:
5618
Date:
November, 2011
Funding source:
Teagasc
Project dates:
Jan 2007–Dec 2010

Key external stakeholders:

Maize growers, advisers and agronomists, ag-chem companies

Practical implications for stakeholders:

Since atrazine, which provided a simple and effective means of weed control in maize, was banned alternative herbicide strategies using new and/or existing herbicides that provided consistent control under Irish conditions were required.

- Allows maize growers to effectively deploy new and existing herbicide products to achieve acceptable levels of weed control in forage maize in Ireland.
- Provides independent assessment of available herbicides in maize to growers and advisers/agronomists.
- Provides information to support registration in Ireland of new herbicide products.

Main results:

- Good weed control is essential to achieving high yields of good quality forage maize.
- Excellent weed control can be achieved using a combination of existing herbicides and new herbicides introduced to replace atrazine
- Herbicides applied at sowing will give good weed control under the plastic in crops sown with a plastic mulch.
- Weed control in the uncovered areas between the plastic, where unsuitable conditions for residual herbicides are experienced can be poor, requiring a follow-up herbicide application.

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Technology

- An alternative strategy is to apply herbicide under the plastic at sowing and apply a post-emergence herbicide in the uncovered areas.
- In crops sown without a plastic mulch, a post emergence herbicide with both contact and residual activity gives consistently good results.

Opportunity/Benefit:

The results have been incorporated into Teagasc advisory recommendations for weed control in maize.

1. Project background:

Control of broadleaved and annual grass weeds is one of the critical factors in successful forage maize production. Some 50% of the maize crop in Ireland is grown under plastic mulch. This provides the ideal micro-climate for maize germination and early growth but also provides ideal conditions for weed growth. Weed competition can severely stunt the growth of maize seedlings making early control of weeds vital for high yields. The presence of the plastic mulch requires that effective weed control under the plastic must be achieved by herbicide application at the time of sowing. Weed control in maize grown without a plastic mulch can be achieved through pre-emergence and/or post emergence herbicide applications.

Atrazine, an effective pre-emergence residual herbicide, had filled an important role in maize weed control for decades but the European Union banned its use in Ireland after 2007. Therefore effective alternative strategies were required. A number of new herbicides had become available to replace atrazine but little was known regarding their use for pre and post emergence weed control and their effects on the crop under Irish conditions.

This study aimed to examine how these herbicides could be best deployed to achieve effective weed control under Irish conditions in both maize crops grown with and without a plastic mulch.

2. Questions addressed by the project:

Can new and existing herbicides be used to achieve acceptable weed control in forage maize, sown both with and without plastic, in Ireland in the absence of atrazine?

How do pre-emergence and post emergence herbicide strategies compare for maize sown with and without plastic?

3. The experimental studies:

Four trials examining weed control in maize crops sown with a plastic mulch were carried out between 2008 and 2010. Three of the trials were located at Knockbeg, Co. Laois, where the site had a history of maize production and presented a high weed challenge and one at Kildalton College, Co. Kilkenny, where maize was only grown occasionally and which presented a low weed challenge. All trials with plastic were sown, and herbicides applied, using the Samco drill system (Samco Agricultural Machinery, Co. Limerick, Ireland), with the exception of one treatment in 2010 where herbicide was applied under the plastic at sowing and then a post emergent herbicide was applied in the uncovered areas.

Five trials examining weed control in maize crops sown without a plastic mulch were carried out between 2008 and 2010. Three of the trials were located at Knockbeg, Co. Laois and two at Kildalton College, Co. Kilkenny. These trials included both pre-emergence and post emergence herbicide applications.

A range of herbicides, including those commercially available in Ireland and products not yet available were included in both the plastic and open sown trials. Weed control was assessed 1–3 months after herbicide application and for a selection of the trials yield was assessed.

4. Main results:

The trials demonstrated that where poor weed control was achieved silage yields and grain content can be reduced significantly, reinforcing the need to achieve effective weed control. In crops grown without plastic silage yield where no herbicide was applied was reduced by between 15% and 95% compared to the best herbicide treatments depending on season. In crops grown with a plastic mulch silage yield where no herbicide was applied was reduced by between 50% and 85% compared to the best herbicide treatments depending on season. As well as reducing silage yield the grain content of the silage was also significantly reduced where there was no weed control However the trials also indicated that total weed control is not necessary to achieve maximum yields and the presence of a low level of weeds, as indicated by control levels greater than approximately 80%, but less than 100%, in these trials generally does not have a significant negative effect on yield. However, where weeds with potential deleterious effects on livestock production

such as nightshade exist full control should be the objective. Additionally where weeds are not fully controlled they can produce seeds which can add to the soil weed seed bank and lead to increased weed populations in future crops.

Weed control in crops grown without plastic

Excellent control of both broadleaved and grassweeds in maize crops sown without a plastic mulch can be achieved with products available currently on the market. Control can be achieved using either a pre-or post emergence herbicide or a mixture of herbicides.

Products containing pendimethalin tank-mixed with Cadou Star, applied at sowing, gave good control of a range wide range of weeds but should be avoided where either redshank or bindweed are likely to be prevalent. Where a pre-emergence herbicide is used a follow-up post emergence application may be required, particularly where conditions during the period after sowing are not suitable for the activity of residual herbicides applied at or soon after sowing.

However in these trials the most consistent weed control in crops grown without plastic was achieved where a herbicide with both contact and residual activity was applied post emergence, when the crop had reached the 3–4 leaf stage. In this regard Calaris applied at 60–100% label rate gave excellent and consistent control of broadleaved weeds and gave reasonable control of the low populations of grassweeds encountered in the trials. In these trials there was little evidence of reduced efficacy on broadleaved weeds where reduced rates of Calaris were used. Other options for post-emergence use include Callisto or Bromotril, although these options require careful timing to achieve season long control. Where scutch or large populations of other grassweeds are present a graminicide will need to be included as part of a tank mix. Options include either Titus or Accent both of which are post-emergence herbicides.

Weed control in crops grown with plastic

Achieving good weed control consistently in crops sown with a plastic mulch with a single herbicide application at sowing remains difficult especially when conditions during the period after sowing are not suitable for the activity of residual herbicides. While very good control can be achieved under the plastic mulch using a pendimethalin formulation applied alone, where the weed challenge is low, or tank-mixed with either Calaris or Cadou Star for high weed challenge situations, persistency of control in the uncovered area between the plastic mulch is often less than satisfactory. The poor control in the uncovered area would appear to be as a result of an uneven and sometimes cloddy surface that makes persistent control using pre-emergence residual herbicides difficult. A follow-up post-emergence treatment may be required to give control of these weeds in the uncovered area although note needs to be taken as to the maximum number of applications in a season of the herbicides being used; in some cases a product may only be used once in a season.

As an alternative to attempting to achieve season long control in the uncovered areas in crops sown with a plastic mulch with a single herbicide application at sowing, a two spray strategy that applies herbicide under the plastic at sowing and in the uncovered areas after crop emergence can be effective. Such a strategy gave very good control in 2010 when control in the uncovered areas following herbicide application at sowing was poor.

Problematic weeds such as knotgrass and wild oats did not occur at high enough levels in these trials to provide information as to the most effective way to achieve good control.

5. Opportunity/Benefit:

The results will support maize growers and their advisers in the decision making process regarding herbicide use in maize crops. It provides independent assessment of the products currently on the market. The work can also be used to support the registration and introduction of new herbicides onto the Irish market, thereby increasing the range of herbicides available to Irish growers.

6. Dissemination:

O'Donovan, T. Maize weed control update 2008. Irish Farmers Journal Crop Protection Supplement April 2008

Oak Park Crops Research Open Day 2009 Burke, J.I. Maize – weed control options for 2009. Irish Farmers Journal April 11 2009

Maize Field Event, October 1 2009 Kildalton College, Co. Kilkenny Hackett, R., Burke, J.I. and O'Donovan, T. 2010. Weed control in maize. Irish Farmers Journal Crop Protection Supplement April 2010

O'Donovan, T. and Hackett, R. Maize weed management strategies and variety update for 2010 Teagasc National Maize seminars 2010 February 2 and February 4 2010. http://www.teagasc.ie/publications/2010/20100205/

Teagasc Tillage Crop Reports 2008–2010– Recommendations for weed control in maize

Popular publications:

O'Donovan, T. Maize weed control 2008. Irish Farmers Journal Crop Protection Supplement April 2008

Burke, J.I. Maize – weed control options for 2009. Irish Farmers Journal April 11 2009

Hackett, R., Burke, J.I. and O'Donovan, T. 2010. Weed control in maize. Irish Farmers Journal Crop Protection Supplement April 2010

Sequencing the potato genome and exploiting the results to produce better potato cultivars

Project number:
5545
Date:
Jun, 2011
Funding source:
RSF (06/RD/567) &
Teagasc
Project dates:
Feb 2006–Jul 2010

The PGSC at a meeting in Teagasc Oak Park Crops Research Centre

Key external stakeholders:

Potato breeders, Teagasc commercial partners (Irish Potato Marketing Ltd.), potato growers and seed producers.

Practical implications for stakeholders:

- An increased capacity to produce potato cultivars combining high agronomic performance with traits such as disease resistance, increasing profitability and decreasing inputs in the potato production cycle.
- Allows Teagasc to apply a cutting-edge breeding approach referred to as marker assisted selection (MAS) within its established potato breeding programme.

These implications arose from; (i) Teagasc's membership of the international consortium that sequenced and released the first publicly available draft of the potato genome in September 2009, and (ii) further research at Oak Park focused on creating a high quality sequence in a region of potato chromosome 4 that confers resistance to late blight and potato cyst nematodes (PCN).

Main results:

The key results were:

- The potato genome sequence was released by PGSC in September 2009.
- The project has developed a high quality, manually edited and annotated sequence of the major disease resistance locus on chromosome 4 of the potato genome which will be used to develop blight and PCN resistant potato cultivars in the Teagasc Potato Breeding Programme.

Collaborating Institutions:
See Below

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See end of Project

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Technology

Opportunity/Benefit:

The potato genome sequence can be accessed by all potato researchers and can be used as the foundation for future basic and applied research in potato genetics, breeding and biology.

1. Project background:

Potato breeding is a lengthy process, with approximately 12 to 15 years required to develop a cultivar. During this period, selection is performed for over 50 traits. Initially, sexual crosses are performed between over 100 parental plants, producing over 100,000 progeny genotypes, which are reduced to approximately 2,500 in the first four years of selection. However, for logistical reasons, many of the most important traits, including disease resistance and tuber quality traits can only be selected for quite late in the breeding cycle, at which point much of the genetic variation has been lost from the populations under selection. A biotechnology-based approach called marker assisted selection, (MAS), based on selection using molecular markers linked to the genes underlying these key traits, offers several routes which would circumvent the late selection for these important traits. However, genetic markers of diagnostic value in breeding programmes are very challenging to develop. The availability of the complete genome sequence of potato would radically enhance our ability to develop genetic markers for potato breeding.

The potato genome consists of 12 chromosomes, containing a total of 840 million nucleotides (letters of the genetic code). Sequencing such a large genome is a huge undertaking and, in order to achieve this goal, a worldwide collective of 17 research groups (including Teagasc Crops Research Centre) formed the Potato Genome Sequencing Consortium (PGSC), whose goal was to elucidate the complete genome sequence of potato by the end of 2010.

2. Questions addressed by the project:

- Could Teagasc contribute directly to the sequencing of the potato genome by performing high throughput genome sequencing on the two potato genotypes being sequenced by the PGSC?
- Could a very high quality, annotated sequence of the major disease resistance gene locus on potato chromosome 4 be developed in order to provide a basis for the development of genetic markers linked to disease resistance traits, for use in potato breeding?

3. The experimental studies:

As mentioned previously, the potato genome is approximately 840 million nucleotides long. In order to sequence the genome, potato DNA was fragmented into smaller pieces called subclones, each of which was sequenced individually. The overall sequence of the genome was subsequently reassembled from the sequences of these subclones by looking for overlaps between them. This approach requires the sequencing of a total length of DNA many times in excess of the length of the genome, and the final sequence of the genome involved sequencing over 100 potato genome equivalents. Teagasc directly contributed by sequencing approximately five genome equivalents. One region of potato chromosome 4 is of particular interest to the breeding programme at Teagasc Oak Park Crops Research Centre, because it harbours an extensive cluster of genes that confer resistance to the main pathogens of potato in temperate agricultural regions, namely late blight and potato cyst nematodes (PCN). Previous work had shown that this region was responsible for blight and PCN resistance in germplasm from the Teagasc Potato Breeding Programme. Because of this, the development of genetic markers in this region of chromosome 4 was a high priority in order to deploy MAS in the breeding programme. The draft sequence of the potato genome was produced using a largely automated computational approach. In previous genome sequencing projects (for instance, in humans) this was followed by a “finishing” phase in which extensive manual editing of the automated assemblies and gene predictions is undertaken. Finishing a genome is a highly laborious task, and is not currently within the remit of the PGSC. Because of our interest in this resistance gene region, which spans 1 million nucleotides on chromosome 4, we carried out a careful manual reassembly and annotation of the region in order to develop a very accurate picture of the gene content along this portion of the chromosome. This accurate picture is an incredibly useful tool for the development of genetic markers linked to genes in the region.

4. Main results:

- The first publicly available draft of the potato genome sequence was released by the PGSC in September 2009. This draft of the sequence can be accessed by all potato researchers worldwide, and will form the foundation of all future basic and applied research in potato genetics, breeding and biology.
- We have developed a high quality, manually edited and annotated sequence of the major disease resistance locus on chromosome 4 of the potato genome which can be used to develop genetic markers for MAS-based approaches for the production of blight and PCN resistant cultivars in the Teagasc Potato Breeding Programme.

5. Opportunity/Benefit:

The primary stakeholder for this research is the Teagasc Potato Breeding Programme, the strategic nature of the project means that the benefits of the project will be conferred to public stakeholders via the exploitation of these results by the breeding programme. The benefits of the project will be realised in a commercial setting via the use of the output of the project to develop superior potato varieties.

6. Dissemination:

Main publications:

Visser, R.G.F., Bachem, C.W.B., de Boer, J.M., Bryan, G.J., Chakrabati, S.K., Feingold, S., Gromadka, R., van Ham, R.C.H.J., Huang, S., Jacobs, J.M.E., Kuznetsov, B., de Melo, P.E., Milbourne, D., Orjeda, G., Sagredo, B. and Xiaomin Tang, X. (2009) 'Sequencing the Potato Genome: Outline and First Results to Come from the Elucidation of the Sequence of the World's Third Most Important Food Crop.' *American Journal of Potato Research* 86 (6): 417–429 DOI 10.1007/s12230–009–9097–8

Popular publications:

The Investigators (popular science TV documentary series), December 2008 Milbourne and Griffin appeared in an episode entitled "Crops for the Future" http://www.rte.ie/tv/theinvestigators/s2prog2.html

Sequencing of the potato genome will mean better spuds William Reville, *The Irish Times* Science Section Thursday, June 25, 2009 http://www.irishtimes.com/newspaper/sciencetoday/2009/0625/1224249487291.html

External collaborators:

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Instituto de Investigaciones Agropecuarias, Chile (Boris Sagredo)

International Potato Center (CIP), Peru (Merideth Bonierbale, Marc Ghislain)

Italian National Agency for New Technologies, Energy and Sustainable Development, Italy (Giovanni Giuliano)

Michigan State University, USA (Robin Buell)

New Zealand Institute for Plant & Food Research, New Zealand (Jeanne Jacobs)

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Wageningen University, The Netherlands (Christian Bachem, Richard Visser)

The genetics of self-incompatibility in white clover

Project number:
5761
Date:
January 2012
Funding source:
Teagasc
Project dates:
Jan 2008–Dec 2010

Key external stakeholders:

Plant Breeders, seed companies.

Practical implications for stakeholders:

Self incompatibility, the genetic mechanism preventing self fertilisation, is a major feature of the reproductive biology of plants. Understanding the genetic basis of this important process in white clover will provide a basis for the potential manipulation of the trait in the future, impacting the way in which white clover is bred. In the longer term, it could form part of the basis of the development of F1 hybrid varieties of white clover.

Main results:

Self-incompatibility (SI) is the genetic mechanism by which outbreeding plants prevent both self fertilisation and the fertilisation of related plants, thus preventing inbreeding. At the outset of the project, the knowledge of the genetic control of SI in white clover came largely from classical genetical studies. These suggested that white clover exhibited a mechanism called gametophytic self incompatibility, and that this was controlled by a single locus. Our goal was to confirm this hypothesis and to identify the specific chromosomal location of the genetic locus via a process called genetic linkage mapping. Using a white clover population developed by our collaborators in IBERS, we successfully identified a single locus controlling SI on white clover homeologue-group (chromosome) 1. This represents the first step in identifying the genes underlying SI in white clover.

Collaborating Institutions:
Institute of Biological, Environmental and Rural Studies (IBERS), UK

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Technology

Opportunity/Benefit:

Identification of the genes underlying self-incompatibility in white clover, the logical next step to the research described above, will be central to the routine development of self-fertile lines of white clover in which SI has either naturally broken down, or in which knowledge of the genes has allowed the SI mechanism to be overcome artificially. This in turn will lead to an ability to produce inbred lines of the species. This is not currently possible for clover because of SI, and clover varieties are produced by selecting and vegetatively propagating several superior parents, and performing a random "bulk-polycross" of these parents to produce seed. While many high-performing clover varieties have been produced using this method, it results in an inherent genetic and phenotypic variability in clover varieties that represents a distinct limitation in addressing certain performance barriers such as increased persistency and variable seasonal response. Inbred lines offer advantages such as completely uniform varieties of bi-parental origin, with key traits fixed in every plant from the variety, F_1 hybrid varieties exhibiting hybrid vigour, and the effective exploitation of rare traits, by releasing, and then capturing hidden recessive genetic variation.

1. Project background:

Self-incompatibility (SI) is considered to be one of the most important strategies used by flowering plants to circumvent the tendency toward self-fertilization. Classic genetic studies in the early 20th century revealed two major classes of SI systems, gametophytic and sporophytic. In many cases, SI is controlled by a single genetic locus, the S-locus consisting of a large number of alleles. In most families, GSI has been found controlled by a single locus (the S-locus) which harbours separate pistil and pollen specific S-genes. Self incompatibility is determined by the haploid genotype of the pollen, relative to the diploid genotype of the pistil. Two mechanistically different systems have been investigated extensively at the molecular level. One is the S-RNase system, originally found in members of the Solanaceae and more recently reported in the Rosaceae, Scrophulariaceae and Campanulaceae (McCubbin & Kao, 1999). The other system is found in the Papaveraceae (Hiscock & McInnis, 2003).

In the S-RNase-based SI system, incompatible pollen germinates and grows normally on the stigma, and the pollen tube is arrested by the time it has reached about one-third of the way through the style. Studies in *Nicotiana alata* led to the cloning and sequencing of the first pistil specific S-gene, and this allowed the identification and cloning of a large number of alleles of this gene from members of the Solanaceae and other species. The genes involved encode highly polymorphic RNases (called S-RNases) with two hypervariable regions (HVa and HVb) and five highly conserved regions (C1 to C5). These S-RNases are thought to cause premature termination of the pollen tube in incompatible reactions by degradation of ribosomal RNA in the developing tube. The most likely candidate for the pollen S-determinant in the S-RNase mechanism is an F-box gene SLF (S-locus F-box), first identified from *Antirrhinum hispanicum* (Scrophulariaceae) and recently obtained from several *Prunus* (Rosaceae) species. The identity of these F-box genes as the pollen specific S-factor is supported by the fact that they have been located at the S-locus, at physical distances between only 400bp and 50kb of the pistil specific S-RNase genes in a variety of plant species, including *Antirrhinum*, sweet cherry and *Prunus*, (eg. Lai *et al.* 2002).

The body of knowledge regarding self-incompatibility in white clover is not extensive. Studies on the inheritance of SI in white clover suggest that SI mechanism is gametophytic, and that the trait is indeed controlled by a single locus in this species. Interestingly, work by Lawrence *et al.* (1996) suggests that both white and red clover have amongst the highest number of S-alleles (in excess of 100) in any species studied to date. Although, anecdotally, white clover has a very strong self-incompatibility system, work in the breeding programme at Oak Park has shown variation in the apparent strength of the SI response in breeding material, and work at both Oak Park and IBERS in Wales has resulted in the identification of a limited number of consistently self-fertile lines (Connolly 2001). Despite the difficulties associated with inbreeding depression as a result of repeated rounds of self-pollination, at IBERS this work has progressed to the development of a number of stable, morphologically uniform inbred lines, which when crossed, exhibit strong hybrid-vigour in the F1 generation. Taken together, these observations suggest the existence of allelic variants at the S-locus in white clover that effectively represent self-fertility (SF) alleles rather than SI alleles.

References:

Connolly V. (2001) Breeding improved varieties of white clover. End of project report 1198. Teagasc (ISBN 1841702005)

Hiscock SJ, McInnis SM. (2003) Pollen recognition and rejection during the sporophytic self-incompatibility response: Brassica and beyond. Trends Plant Sci. (12):606–13. Review; Erratum in: Trends Plant Sci. 2004 Feb;9(2):64

Lai Z, Ma W, Han B, Liang L, Zhang Y, Hong G, Xue Y. An F-box gene linked to the self incompatibility (S) locus of Antirrhinum is expressed specifically in pollen and tapetum. 2002 Plant Mol. Biol. 50:29–42

Lawrence, M. J.; Afzal, M., and Kenrick, J. Genetic-Control of Self-Incompatibility in Papaver-rhoeas. Heredity. 1978; 40:239–253.

Mccubbin, A. G. and Kao, T. H. Molecular Recognition and Response in Pollen and Pistil Interactions. Annual Review of Cell and Developmental Biology. 2000; 16:333–364.

2. Questions addressed by the project:

- Is the single locus model of SI in white clover suggested by classical genetical studies correct?
- If the answer to the above is yes, where in the white clover genome is this locus?

3. The experimental studies:

An F1 mapping population consisting of 94 progeny individuals was created by crossing two highly divergent white clover genotypes referred to as S1S4 (female parent) and R3R4 (male parent). To identify the genetic location of the S locus, a genetic linkage map of each parent was constructed using 64 white clover SSRs and 339 AFLP markers. The presence of SSR markers from previously published maps of white clover on the maps of S1S4 and R3R4 allowed the identification of resulting linkage groups (LGs) belonging to the eight homoeologue groups (HGs or chromosomes) of white clover. Plants in the mapping population, identified by numbers 1 through 94, were cross-pollinated by hand to determine incompatibility relationships within the population. Cross-pollinations were scored as compatible or incompatible after ca. 7 days by checking the seed pods of pollinated flowers visually and by tactile examination to determine whether or not seeds were developing. In some cases, this was verified by dissection using a scalpel and a stereo microscope. An absence of seeds was taken to indicate a self-incompatible reaction resulting from the parental plants sharing the same S genotype. Presence of seeds indicated a compatible reaction, indicating that the parents possessed at least one different S haplotype. A scoring matrix identifying the segregation of four different S alleles was developed from these data, and incorporated with the marker segregation data used to develop the genetic linkage map, allowing the location of the S-locus on the genetic map to be determined via linkage analysis.

4. Main results:

Using the genetic mapping approach described above, we have identified the chromosomal location of the locus determining self incompatibility in white clover. The S-locus is located on the distal end of one of the linkage groups comprising Homoeologue Group 1 in white clover.

White clover is allotetraploid (2n=4x=32), comprising two well preserved ancestral subgenomes each with a basic (haploid) complement of 8. The extant representatives of the ancestral genomes are thought to be *Trifolium occidentale* and either *T. pallescens, T. nigrescens* or an unidentified species. The ancestral genomes assort independently on meiosis, but are very similar in terms of gene content and order, and thus genetic maps reveal 8 homoeologue groups, each consisting of two linkage groups (chromosomes), one derived from each of the ancestral donors. The S-locus maps to "Chromosome 1" of one of the 2 ancestral subgenomes. At the time of writing, it is not possible to distinguish the ancestral origin of linkage groups comprising HGs. Interestingly however, modern *T. occidentale* is self compatible, while *T. pallescens* and *T. nigrescens* are self-incompatible, suggesting that the latter are the most likely donors of the trait to white clover.

5. Opportunity/Benefit:

Most seed-dispersed crops are inbreeders, allowing the production of uniform varieties by reducing or eliminating heterozygosity through inbreeding, and the fixing of many important characteristics in the population because individual plants are completely or nearly genetically identical (clonal). In addition, in inbreeding systems, all of the previous characteristics can be combined with the advantages offered by maximising heterosis by producing F_1 hybrid varieties from genetically divergent inbred parents. This is not possible for

clover because of SI, and clover varieties are produced by selecting and vegetatively propagating several superior parents, and performing a random "bulk-polycross" of these parents to produce seed. While many high-performing clover varieties have been produced using this method, it results in an inherent genetic and phenotypic variability in clover varieties that represents a distinct limitation in addressing certain performance barriers such as increased persistency and variable seasonal response.

The ability to produce inbred-lines of white clover would offer the possibility of exploring a different strategy for the production of varieties that would have many of the advantages listed above. Inbred lines offer advantages such as completely uniform varieties of bi-parental origin, with key traits fixed in every plant from the variety, F_1 hybrid varieties exhibiting hybrid vigour, and the effective exploitation of rare traits, by releasing, and then capturing hidden recessive genetic variation. Inbred lines also offer a tool to more easily dissect the genetics underlying complex polygenic traits in white clover, facilitating the use of marker-assisted selection (MAS) based approaches for breeding in the species. The discovery of the chromosomal location of the S-locus in white clover is the first step in the development of the tools required for biotechnology-based approaches for the routine production of inbred lines in white clover. The data developed in this project are an ideal starting point for the isolation of the genes underlying SI and their subsequent exploitation for breeding.

6. Dissemination:

The results were of a scientific/technical nature and were disseminated via the scientific literature.

Main publications:

Casey NM, Milbourne D, Barth S, Febrer M, Jenkins G, Abberton MT, Jones C, Thorogood D. (2010) The genetic location of the self-incompatibility locus in white clover (*Trifolium repens* L.). Theor Appl Genet.121(3):567–76.

Project number:
5621
Date:
November, 2011
Funding source:
EPA STRIVE
Project dates:
Aug 2006–Aug 2010

Assessing the relevance and impact of GM crop management on the Irish landscape

Collaborating Institutions:
NUI Galway
NUI Maynooth

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Key external stakeholders:

Policymakers, tillage farmers and advocacy groups

Practical implications for stakeholders:

Although the potential of GM crops is often discussed, a specific list of GM crops of most relevance to the Irish agri-environment has yet to be compiled. In addition, little is known about the overall impact(s) of GM crop management on the wider landscape. In response, output from our research has:

- Identified a series of GM traits that are most relevant to the Irish tillage sector in light of future challenges facing the industry.
- Developed a semi-quantitative biodiversity index to identify areas in the wider landscape where biodiversity is likely to be negatively or positively impacted by Irish-specific GM crops.

This index (termed 'CINMa') provides stakeholders with a clear indication as to the broad impact of specific GM crops as well as identifying agricultural zones which may, or may not benefit from the land use change associated with the management of GM crops.

Main results:

- GM traits with significant agronomic potential include; late blight resistant potato, Septoria resistant wheat and herbicide tolerant winter oilseed rape and maize.
- Enhanced nitrogen-use efficiency would clearly benefit the tillage sector in light of EU-based restrictions on nitrogen usage.

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- Herbicide resistance can be transferred from GM herbicide tolerant oilseed rape into related Irish wild species but this will not confer an advantage to the weedy species unless they are sprayed with the specific herbicide.
- It is the management of the GM crop, and not the GM crop itself, that has the greatest potential for biodiversity impact.

Opportunity/Benefit:

The project output will (i) inform stakeholders of the most relevant GM crops to the Irish tillage sector and (ii) provide a biodiversity score to highlight the potential ecological impact of each GM crop and their associated management regimes. Further details are available on the project's website www.gmoInfo.ie.

1. Project background:

To be in a position to describe the impact of a range of different GM crops/traits on Irish biodiversity, it is first necessary to identify those GM crops that could be suited to Ireland's agri-environment over the next 20 years against a backdrop of future agricultural challenges. These include (but are not exclusive to):

- mitigating biodiversity loss,
- responding to climate change predictions
- addressing environmental legislation requirements
- producing sustainable biofuels
- preparing for changes to the Common Agricultural Policy

Against these challenges, the European Union (EU) must meet the current and future demands for food/fuel security but in doing so, species and habitat diversity in rural landscapes will be subjected to continual and increased stress. An urgent need exists therefore to mainstream sustainable agricultural and land management practices.

In order to monitor the possible ecological impacts of a novel crop there is also a need to augment, and ultimately harmonise, risk assessment strategies especially when technologies such as GM crops are incorporated into established agricultural landscapes. Under the terms of European Directive 2001/18/EC, the post-market environmental monitoring of GM crops within the EU must adopt both case specific monitoring and general surveillance strands of assessment. General surveillance is intended to ascertain the possible unintended effects of a GM crop release, but general surveillance is not adequately defined from a practical point of view.

Indeed, much of the GM crop research completed thus far has focussed on issues such as crop co-existence, genetic introgression and volunteer dynamics, often in the context of the on-farm environment. As a result, far less is known about the possible impacts of crop management (GM or non-GM derived) on the wider landscape. Overall, impact assessment research is fraught with the difficulty of identifying, from the outset, what is to be assessed, what an impact may be and where to look for this impact. While there is the need to focus on GM crops in order to satisfy requirements, little attention has been focussed on non-GM crops and this imbalance is generally believed to have served to reinforce concerns on GM crop impact. We believe that the impact of GM and non-GM crops can be jointly assessed using a broad index that encapsulates the management of both cropping systems and the corresponding stresses each may cause to landscape biodiversity.

2. Questions addressed by the project:

Is it possible to identify a cohort of GM crops that would be of most relevance to Irish farmers in light of future challenges to the Irish tillage sector?

Can a crop-specific index be developed to:

(i) quantify the impact of a specific GM crop and its non-GM counterpart based on a series of potential biodiversity stressors?

(ii) assist policy-makers and regulators to address the knowledge deficit that often arises from the legislated requirement for post-market general surveillance of commercialized GM crops?

3. The experimental studies:

The identification of Irish relevant GM crops was achieved by first quantifying the inputs to Irish tillage systems and then assessing how the macro-challenges listed previously will impact on these inputs and on the viability of each respective cropping system. To test the ecological impact of each GM crop trait, it was necessary to examine all aspects of land management – such as crop rotations and treatments, crop type and variety and length of operations. While geography, biology and taxonomy are key areas of ecological impact and will exert stress on biodiversity, it was decided that such

stressors would be unmanageable on a practical level for the construction of a biodiversity index. Therefore, we used the four main areas where data are available and upon which farmers can exert the most control: the level of chemical input, potential for gene introgression from GM crops into non-GM relatives, requirement for nutrient load on the specific crop, crop management strategy designed to accompany the designated GM crop.

The resulting CINMa index was designed as a semi-quantitative representation of a qualitative analysis of the literature (published and peer-reviewed material and expert-driven reports). Thus some of the underlying variables were collated using different sources, landscape locations and experimental methodologies. The resulting CINMa grades were derived from sources with relevance to heterogeneous landscapes and allocated based on significance to Irish landscapes or species located within those landscapes. As assessments must specifically identify the impact area, the CINMa index is focused on four impact zones across a typical agricultural landscape: the managed field, semi-natural landscape within 10m of the managed field, the soil column and watercourses within the influence of the managed field.

4. Main results:

The crops with the greatest potential for genetic modification in Ireland are those grown on a large scale, namely barley, wheat, oilseed rape and maize and/or currently receive very high applications of pesticides and fertilisers (e.g. potato). Applying a sample of these crops to analysis using CINMa, the ecological impact of the crops is variable and is dependent on the trait, but most specifically, the management of the trait and the crop through rotation.

For GM oilseed rape, engineered for herbicide tolerance, CINMa indicated that there was a modest potential benefit for soil organisms under a newer management regime for herbicide tolerant crops. The potential for trait transfer into wild relatives was noted but these GM-wild hybrids will not possess a fitness advantage unless sprayed with the specific herbicide that the GM crop is modified to resist. For GMHT maize, CINMa yields a higher likelihood of this variety positively impacting upon biodiversity as there is zero risk of gene introgression as maize does not have any wild relatives growing in Ireland.

For GM late blight resistant potatoes, CINMa reported a positive benefit from management regime change, though again there are no data on potential impacts on the typical semi-natural habitats such as hedgerows that may be found in heterogeneous landscapes. The practical reduction or elimination of farm traffic, tanker washing, chemical mixing, and soil compaction have a high likelihood of reducing biodiversity stress. However, the use of GMLBR potatoes will impose an evolutionary pressure on the late blight pathogen to evolve resistance against the GM traits, as has been recorded for previous potato varieties bred through more conventional approaches.

5. Opportunity/Benefit:

This research is the first study to specifically identify what GM traits are relevant to Irish agriculture and significantly detail the possible ecological impact of the GM crops and their respective management regimes.

This will be of benefit to policy makers, regulators, tillage farmers and the general public at large.

6. Dissemination:

Main publications:

Collier, M. and Mullins, E. (2010). The CINMa Index: Assessing the potential impact of GM crop management across a heterogeneous landscape. Environmental Biosafety Research, 9, 135–145.

O'Brien, M. and Mullins, E. (2009). Relevance of genetically modified crops in light of future environmental and legislative challenges to the agri-environment. Annals of Applied Biology, 154, 323–340.

O'Brien, M., Spillane, C., Meade, C. and Mullins E. (2008). An insight into the impact of arable farming on Irish biodiversity: A scarcity of studies hinders a rigorous assessment. Biology and Environment, Proceedings of the Royal Irish Academy, Volume 108B, Issue 2, pp 97–108.

Popular publications:

www.gmoInfo.ie

A novel method for the genetic transformation of plant cells

Project number:
5630
Date:
July, 2011
Funding source:
Teagasc
Project dates:
Apr 2007–July 2010



Key external stakeholders:

Plant scientists from the crop biotech industry, universities and private research institutions working on the application of genetic engineering to improve the agronomic potential of existing plant varieties.

Practical implications for stakeholders:

The primary technique for the generation of engineered or 'biotech' crops utilises the bacteria Agrobacterium tumefaciens in a process used worldwide by public-sector agencies, private industries and universities. Yet to the end user, trying to commercialise a product developed through Agrobacterium-based technology is not feasible due to a series of key patents on transformation technology. Output from our research has:

- Identified a novel bacterium Ensifer adhaerens OV14 that will successfully transfer single/multiple gene(s) of interest into plant cells at rates equivalent to standard Agrobacterium-based technology.
- Noted that E. adhaerens OV14 is genetically distinct from Agrobacterium and as such circumvents existing transformation patents on plant species but with no loss of efficacy.
- Discovered that E. adhaerens OV14 does not require challenging conditions or processes for its growth and can be integrated into existing Agrobacterium-based technology with no additional optimisations required.

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Main results:

- A novel transformation platform has been developed around the bacterium E. adhaerens.
- Using E. adhaerens circumvents existing patent restrictions on the genetic transformation of plant species.
- Ensifer-mediated transformation produces equivalent rates of transformation to the existing Agrobacterium-based system.

Opportunity/Benefit:

Utilising E. adhaerens OV14 will provide companies and/or institutions working on plant biotechnology with the opportunity to work with an equivalent market alternative to the patent restrictive Agrobacterium-based technology, which will not require additional end-user training, above what is traditionally required for Agrobacterium-based technologies.

1. Project background:

The current challenges in biological research are to understand how genes function together in metabolic pathways so that real world problems can be addressed, ranging from improving crop yields to generating varieties that produce novel fuels and/or high value products. Disrupting the function of a specific gene through random and/or precise modifications has made it possible to address many of these challenges. This process of gene mutagenesis can be completed through several techniques but the bacteria A. tumefaciens is the favoured tool for genetic engineering.

A soil inhabiting bacteria, A. tumefaciens is a natural pathogen of plants causing 'crown gall' disease across a broad host range. A. tumefaciens is able to infect plants by effectively shuttling specific genes of interest into a target cell, where in they are switched on. Scientists have capitalised on this phenomenon and equipped A. tumefaciens with genetic machinery that makes the process efficient and reproducible. As a result A. tumefaciens has underpinned the development and commercialisation of biotech crops. Since their commercialisation in 1997 the global acreage of licensed biotech crops has increased annually; 104 million hectares were grown in 2009 with an estimated global market value in excess of $7.5 billion.

However, the application of A. tumefaciens is comprehensively covered by patents that have placed a stranglehold on transformation technology. Hence the potential for end-users of A. tumefaciens-based transformation to develop commercially viable products/varieties/technologies is severely curtailed due to the comprehensive licensing structure that is in place. So while multiple examples exist detailing the development of novel varieties through A. tumefaciens-based transformation, this has not translated in to an increased number of products for stakeholders as patent holders continue to restrict competition.

In an attempt to design around the patent issue the potential of non-Agrobacterium strains was described in 2005. Using Sinorhizobium melliloti, Mesorhizobium loti and Rhizobium NGR 234 (collectively called Transbacter™), it was demonstrated that these non-Agrobacterium strains could be used to genetically engineer plant cells. However, the transformation efficiency of these Transbacter™ strains was poor compared to standard A. tumefaciens-based transformation and their integration into research programmes has been nominal.

2. Questions addressed by the project:

- Can we develop a method to isolate from the roots of crop plants a collection of soil-borne bacteria?
- Can this collection of plant-associated bacteria be screened for individuals with the capacity to genetically transform plant cells?
- Can we comparatively assess any positive bacteria strains against the existing transformation systems (A. tumefaciens and Transbacter™)?

3. The experimental studies:

The bacteria library was generated by washing the root systems of commercially grown plants and spreading this wash suspension on selective microbiological media. The collected bacteria strains were then characterised to determine their suitability for genetic transformation studies. Each bacteria isolate was tested for their:

(i) capacity to take up large pieces of DNA containing 'virulence' genes, which drive the genetic transformation process

(ii) ability to remain viable after long periods of storage (~6 months)

(iii) resistance/susceptibility to specific antibiotics.

The latter was important as antibiotic resistance is a trait commonly used in plant transformation protocols to facilitate the rapid screening of large plant populations for those individual plants that have been genetically modified. Quite simply, a specific gene conferring resistance to an antibiotic (e.g. hph, resistance to hygromycin) is attached to the gene of interest and both are transferred into the target plant cell. So if an emerging plant has the capacity to grow in the presence of the antibiotic at concentrations that would otherwise be toxic it must be successfully transformed.

The small cohort of bacteria strains that graduated through this criteria-based selection process underwent sequence-based identification. This was achieved by reading the code of the 16S rRNA gene for each bacteria and comparing each sequence read against that of A. tumefaciens and the three Transbacter™ strains.

4. Main results:

A total of 320 bacteria strains were isolated using the root wash protocol. From this population only four strains graduated for sequence-based identification after which each was tested for their ability to transform the model plant species Arabidopsis. Only one of the four strains was successful in this regard. Identified as Ensifer adhaerens OV14, this bacterial strain had the capacity to genetically transform the important food and non-food crops, potato and tobacco respectively, at rates equivalent to standard A. tumefaciens. Significantly, the transformation efficiency of E. adhaerens OV14 was 6–fold greater than the best reported Transbacter™ strain and was equivalent to that of A. tumefaciens; thereby making E. adhaerens OV14 a viable alternative to existing transformation platforms.

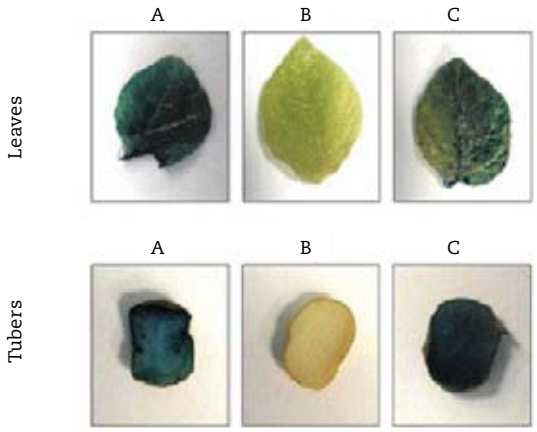

Fig. 1 Staining of potato leaves and tuber slices taken from a potato line genetically transformed using Ensifer adhaerens (A) and the market competitor Agrobacterium tumefaciens (C). The non-treated controls are clear in colour (B). Staining is representative of high levels of transformation efficiency, hence indicating the effectiveness of EMT versus AMT.

5. Opportunity/Benefit:

To protect the licensing potential of this technology a patent was submitted in December 2009 detailing the isolation and characterisation of E. adhaerens OV14. Interest has been expressed from both industrial and academic sources, in obtaining a license to use E. adhaerens OV14 for specific purposes. In partnership with the technology transfer service within University College Dublin, information detailing the commercialisation potential of utilising E. adhaerens OV14 over A. tumefaciens is available at www.teagasc.ie.

6. Dissemination:

Main publications:

Wendt T., Wincklemann D., Doohan F. and Mullins E. (2010). Gene transfer into Solanum tuberosum via Rhizobium spp. Transgenic Research, Vol. 20, No.2, p377–386.

Mullins E. (2009). A method for transforming plant cells. Patent submitted to European Patent Office (No. EP09180700.8) and US Patent Office (No. USSN61/289,853), submitted December 23rd.

Wendt, T., Doohan, F. and Mullins, E. (2011). Ensifer-Mediated Transformation: A Novel Platform for the Transformation of Plant Genomes. Presentation to the International Plant Transformation Technology Conference, Vienna, February 19th-23rd.

The role of energy crops in effluent disposal, energy supply and soil remediation

Project number:
5543
Date:
November, 2011
Funding source:
DAFF (RSF 05218)
Project dates:
Jan 2006–Dec 2009

Key external stakeholders:

Farmers, local government, solid biofuel suppliers, consumers, policy makers, scientific community

Practical implications for stakeholders:

- Farmers can benefit from the knowledge that the practice of applying organic wastes to energy crops should not cause damage to the environment. Additionally, farmers may take advantage of a lower cost method for drying willow chips.
- Policy Makers can now take into account that application of organic wastes to energy crops should not cause damage to the environment. Additionally, information on factors which influence the willingness of farmers to adopt energy crops can be used to structure future bioenergy incentives.
- Scientific Community benefits from this project as new information is now available on the environmental risks associated with organic waste amendment to energy crops, on willow chip drying as well as on the economics of energy crops and the willingness of farmers to adopt energy crops.
- Local Authorities benefit from the knowledge that organic waste from wastewater treatment plants can be applied safely to energy crops.

Main results:

- Sewage sludge application to energy crops should not lead to a build-up in soil pathogens provided the sludge is treated appropriately i.e. limed.
- Losses of nutrients and heavy metals to surface water following application of organic wastes to energy crops were small in comparison to losses to groundwater yet losses to groundwater did not result in a deterioration in groundwater quality as groundwater threshold values were not exceeded

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with the exception of levels of phosphorus in plots which received the highest concentration of brewery effluent. No threshold values were exceeded when sewage sludge was applied to energy crops.

- Willow chips can be dried at a low cost by blowing ambient air through a clamp of chips covered by a breathable material at an airflow rate of 150 m^3/tonne wet chips for 12 hours a day.
- Willingness to adopt bioenergy crops was found to be significantly influenced by the agricultural educational level of farmers, farm size, and farm system. Biomass targets are more likely to be achieved when fixed prices are offered for biomass in comparison to variable prices.
- The uncertainty surrounding risky variables such as the costs of production, yield level, price per tonne and opportunity cost of land make it difficult to accurately calculate the returns for biomass crops. Simulations, however, show Miscanthus generally has higher certainty equivalents, and therefore farmers may be more likely to invest in Miscanthus rather than willow.

Opportunity/Benefit:

This project has shown that energy crops can be used for safe disposal of organic wastes and this use increases the range of benefits offered by energy crops to stakeholders specifically as well as to the community in general. Additionally, the project has shown that willow chips can be dried in a farmyard at low cost, reducing the cost of drying willow chips should increase the attractiveness of this crop to farmers.

1. Project background:

Energy crops have many attractions as sources of secure, locally-produced and locally-used renewable energy. At the same time disposal options for organic wastes are becoming more limited as restrictions tighten on organic waste entry to land-fills and animal health concerns are restricting their application on pasture. Municipal sewage sludge volumes may be expected to increase as new treatment plants come on stream.

The use of local energy crop plantations for the disposal of suitable municipal and food industry wastes could benefit local authorities and local waste-generating industries as well as farmers and energy users. Energy crops could also provide a productive and restorative use for contaminated land that is unsuitable for food or feed production. Various aspects of these possibilities have been researched in several countries with generally favourable results.

Yet commercial uptake of energy crops to date has been slow. The energy crops that have shown most promise in Ireland to date are willows and Miscanthus. Both are high-yielding crops suited to the Irish climate and which could be used for bioremediation (disposal of organic waste). If this combined energy/waste disposal concept is to develop, a number of issues have to be addressed:

- For regulatory agencies, assurance is needed that the effluents are applied to the sites in a way that does not lead to any pollution of air or water, or create any health hazard for humans or wild life inhabiting the site.
- For heat users, practical systems for drying harvested biomass must be developed and demonstrated.
- For land-owners considering the establishment of energy crop, their investment must be shown to be profitable in comparison with traditional enterprises.

The project was designed to address these issues.

2. Questions addressed by the project:

- Are microbial pathogens a problem after sewage sludge is applied to energy crops?
- Does water quality suffer due to losses of nutrients and heavy metals after application of organic effluents to energy crops?
- Is it possible to develop a low-cost system for drying willow chips?
- What are the economic returns to farmers from growing biomass crops and what is the likely uptake of energy crops among farmers?

3. The experimental studies:

Sewage sludge and brewery effluents were applied to existing willow and Miscanthus plantations. Concentrations of nutrients and heavy metals in groundwater, overland flow, soil and plant biomass were measured. The objective of these measurements was to determine the fate of nutrients and heavy metals in organic wastes applied to bioenergy crops. Measurements were also conducted to determine the fate of pathogens in municipal solid waste applied to bioenergy crops.

Systems for drying of willow chips were examined with a view to identifying a low-cost system and determining drying cost.

Crop production , harvesting, storage/drying and utilisation costs were determined for willow and Miscanthus and the value of the fuel produced was estimated. A net present value model of energy crop profitability was constructed and stochastic modelling was used to determine the level of risk from different energy crop options. A survey was conducted of farmers willingness to adopt bioenergy crops.

4. Main results:

Microbial Pathogens in Soil after Application of Sewage Sludge to Energy Crops

- The sufficiency of liming of the sewage sludge prior to application was found to be important as it was found that biosolids with a lower pH allowed for the survival of E.coli and for the transfer of this pathogen to soil.
- Based on the data gathered and analysed over 3 years, sewage sludge application should not be followed by a build-up of soil pathogens provided the sludge is treated appropriately i.e. limed Loss of Nutrients and Heavy Metals to Water after Application of Sewage Sludge to Energy Crops.

Loss of Nutrients and Heavy Metals to Water after Application of Sewage Sludge to Energy Crops

- For Phosphorus, Potassium, Copper and Zinc, there was a clear relationship between the quantity of organic waste applied and the mean concentrations of these elements in groundwater. For nitrate, chromium, cadmium, nickel, lead and zinc there was no clear relationship between the quantity of waste applied and the mean concentration of these elements in groundwater.
- For surface water, there was a relationship between the quantity of organic waste applied and the concentrations and total exports of nitrate, potassium, phosphorus, chromium, lead, cadmium, copper and zinc in surface run-off (overland flow). There was no clear relationship between the quantity of effluent applied and the levels of lead or nickel occurring in surface run-off.
- Losses of nutrients and heavy metals to surface water in overland flow events were small due to the fact that overland flow events were relatively rare and typically involved small volumes of water. Losses to surface water were small in comparison to losses to groundwater yet losses to groundwater did not result in a deterioration in groundwater quality as groundwater threshold values were not exceeded with the exception of levels of phosphorus in plots which received the highest concentration of brewery effluent. No groundwater threshold values were exceeded when sewage sludge was applied to energy crops.

Development of a low-cost system for Drying Willow Chips

- It is possible to dry willow chips at low-cost by blowing ambient air through a clamp of chips constructed in a farmyard. In this system a single phase fan blows air through a pipe with holes along its length, a border for the clamp can be constructed using pallets and the clamp should be covered by a material through which air can pass. Air is blown through the clamp for 12 hours a day at an airflow rate equivalent to 150 m^3/hr/wet tonne. The final trial was conducted during the summer of 2008 when, in spite of the wet summer, the chips in the pile dried from 52% at the start of the experiment (April) to 18.2% (July) over an 82 day period. 617 units of electricity were used to dry the chips which represented an electricity cost of just under €5 per wet tonne.

Drying Willow Chips

The economics of biomass production at farm level

- The uncertainty surrounding risky variables such as the costs of production, yield level, price per tonne and opportunity cost of land make it difficult to accurately calculate the returns to biomass crops. A stochastic budgeting model was developed to estimate distributions of returns from willow and Miscanthus. The results of these simulations show Miscanthus generally has higher certainty equivalents, and therefore farmers may be more likely to invest in Miscanthus rather than willow.
- Willingness to adopt bioenergy crops in Ireland was significantly influenced by the agricultural educational level of farmers but also by farm size, and farm system.
- A target of 30 percent substitution of biomass for peat in the three peat fired power stations from 2015 has been set by the Irish Government. In order to achieve the target, approximately 40,000 hectares of biomass crops will need to be planted. A policy mechanism of a fixed price has a large effect on the economic returns from biomass crops, and therefore on the level of adoption. The target area could be achieved at a fixed price per tonne of €70 and €65 for willow and Miscanthus respectively. This is compared to the current prices for willow and Miscanthus of €55 and €60 per tonne, which were not fixed and therefore subject to year on year variation.

5. Opportunity/Benefit:

Energy crop cultivation offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. This project has shown that energy crops can be used for safe disposal of organic wastes and this use increases the range of benefits offered by energy crops to stakeholders specifically as well as to the community in general.

Additionally, the project has shown that willow chips can be dried in a farmyard at low cost, reducing the cost of drying willow chips should increase the attractiveness of this crop to farmers. Thus, the project has increased the utility and attractiveness of energy crops. This benefit is available to all stakeholders.

6. Dissemination:

This research was presented as part of an MSc and two PhD theses in conjunction with UCD.

Main publications

Clancy, D., Breen, J, Butler, A.M. and Thorne, F. (2009). A Discounted Cash Flow Analysis of Financial Returns from Biomass Crops in Ireland. Journal of Farm Management Volume 13, No. 9, pp. 595–611

Clancy, D., Breen, J, Moran, B., Thorne, F. and Wallace, M (2011). Examining the socio-economic factors affecting willingness to adopt bioenergy crops. Journal of International Farm Management Vol.5. Ed.4–June 2011 ISSN 1816–2495

Galbally P, Fagan C, Ryan D, Finnan J, Grant J and MacDonnell K (2012) Journal of Environmental Quality 41, 1–10.

Feasibility of production and combustion of pellets from straw and energy crops

Project number:
RMIS 5613
Date:
August, 2010
Funding source:
DAFF (RSF 06347)
Project dates:
Oct 2006–Dec 2009

Key external stakeholders:

- Energy Crop and Tillage Farmers Biofuel Pellet Manufacturers
- Solid Biofuel Suppliers
- Consumers

Practical implications for stakeholders:

- Policy Makers
- Scientific Community

The significance of this research for stakeholders is as follows

- *Farmers* may be able to take advantage of a new market for their energy crops and tillage residues.
- *Industry* can use the data from this project to build a pellet production industry based on non-woody feedstock.
- *Policy Makers* can now take into account that a pellet production industry based on non-woody feedstock can be economically viable in Ireland and make a contribution towards national Bioenergy and greenhouse gas targets.
- *Consumers* benefit from the availability of information on the quality of non-wood pellets and their performance during combustion.
- *Scientific Community* Little systematic information has been available up until now on the production, quality and combustion of pellets from non-woody material. The data which has come from this project has increased the technical information available to the scientific community in this area.

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Main results:

- Pellets can be produced from a range of materials including willow. miscanthus, rape straw, barley straw and wheat straw. The best quality pellets were those manufactured from willow followed by those manufactured from miscanthus.
- Pellet production rate was highest for willow followed by miscanthus. Rape straw, wheat straw and barley straw proved comparatively difficult to pellet.
- Pellets manufactured from feedstock mixtures exhibited chemical characteristics intermediate between their parent materials.
- Particulate emissions, gaseous emissions and boiler wall deposits were lowest for willow pellets followed by Miscanthus pellets. Emissions and boiler wall deposits were higher during the combustion of pellets manufactured from cereal and rape straws.
- Feedstock costs represented 66% of pellet production costs on average, other major costs were pelleting and cooling (11%), grinding (10%) and personnel (9%). Considering current energy prices, the production of non-woody biomass pellets competes favourably with oil and gas price and is considered economically viable.

Opportunity/Benefit:

This project has shown that pellets can be manufactured from energy crops and tillage crop residues. Thus, the project has increased the utility and attractiveness of energy crops and tillage crop residues.

1. Project background:

Many factors are set to accelerate the use of biomass as fuel: increasing mineral fuel prices, the need to abate greenhouse gas emissions and reduce dependence on imported fuel, and pressures to achieve EU substitution targets. In Ireland, biomass pellets used in stoves or small boilers could achieve a substantial saving in the use of oil and gas for residential/commercial heating, which currently accounts for 14% of our total greenhouse gas emissions and 18% of total energy demand.

The use as fuel of pellets made from sawdust and shavings has been increasing rapidly throughout Europe. Sweden and Denmark have already virtually exhausted this source. In Ireland, the estimated supply of sawdust is about 200,000 wet tones.

Recently-announced grant schemes for domestic and commercial biomass stoves and boilers are likely to stimulate a rapid increase in demand for pellets, which are already being imported from many countries. With several pellet plant projects at an advanced stage of planning, sawdust supplies are likely to become depleted in the near future.

Pelleting upgrades the fuel and facilitates its utilisation in several ways:

- It reduces dust emission in the handling of the fuel.
- It improves the flow properties, which simplifies conveying and storage.
- It increases the bulk density, which eases storage and transportation.
- It leads to a more stable, uniform product with more efficient combustion control.

These advantages are likely to stimulate its use in small stoves and boilers, where its enhanced properties will outweigh its extra cost. However, several issues remain to be resolved before a market for non-wood pellets can develop. First, the technology to process the various potential feedstocks into durable, stable pellets needs to be established. Second, the fuel properties of the pellets and any effects on boiler/stove performance and flue emissions have to be measured. Finally, all the costs of raw material production, assembly and processing, and the effect of plant scale on these costs, are necessary information for any potential investor.

2. Questions addressed by the project:

- Can solid biofuel pellets be produced from non-woody feedstocks?
- What are the chemical and physical characteristics of non-wood pellets and how do they compare with wood pellets?
- What are the combustion characteristics of non-wood pellets?
- Is the production of non-wood pellets likely to be economically viable?

3. The experimental studies:

A pilot scale pellet plant was installed at Oak Park, Carlow and used to manufacture pellets from willow, Miscanthus, rape straw , barley straw and wheaten straw. The rate of pellet production for pellets of each feedstock was quantified and the physical and chemical properties of the pellets were measured in the laboratory.

Combustion tests of the pellets from the different feedstocks were conducted in a combustion test rig (below) which was built at Oak Park. Combustion efficiency and deposition on chamber walls were measured during the combustion tests, measurements were also made of particulate and gaseous emissions.

Geographical information systems were used to determine the optimum location for pellet plants based on non-woody biomass. The project also quantified the economic cost of non-woody pellets.

4. Main results:

- Pellets were produced from a range of materials including willow. miscanthus, rape straw, barley straw and wheat straw. Pellet production rate was highest for willow followed by miscanthus. Rape straw, wheat straw and barley straw proved comparatively difficult to pellet and, consequently, pellet production rates were low. The energy required for pellet production was inversely proportional to production rate. Pellets were manufactured from mixtures of both miscanthus, willow and rape straw.
- Laboratory analysis revealed that the best quality pellets were those manufactured from willow followed by those manufactured from miscanthus. Pellets manufactured from cereal and rape straws had relatively high concentrations of ash, sulphur, nitrogen and chloride which would be expected to lead to higher emissions in addition to boiler corrosion.
- Pellets manufactured from feedstock mixtures exhibited chemical characteristics intermediate between their parent materials demonstrating that this practice can be used to make the best of one characteristic of a parent material to alleviate the worst properties of another parent material.
- Combustion Trials: Particulate emissions, gaseous emissions and boiler wall deposits were lowest for willow pellets followed by Miscanthus pellets. Emissions and boiler wall deposits were higher during the combustion of pellets manufactured from cereal and rape straws. High concentrations of carbon monoxide and particulate matter were emitted during the combustion of rape straw pellets.

Piolet Scale Pellet Plant

- Feedstock costs represented 66% of pellet production costs on average, other major costs were pelleting and cooling (11%), grinding (10%) and personnel (9%). Considering current energy prices, the production of non-woody biomass pellets competes favourably with oil and gas price and is considered economically viable.

5. Opportunity/Benefit:

The use of non-woody pellets offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. This project has shown that pellets can be manufactured from a range of feedstocks including willow, Miscanthus, rape and cereal straw. Among non-wood pellets, pellets manufactured from willow and Miscanthus were easiest to make, had the highest quality and had the lowest levels of particulate and gaseous emissions on combustion. Although pellets manufactured from rape and cereal straw had less favourable characteristics, it was found that these feedstocks could be successfully incorporated into pellets manufactured from a mixture of feedstocks in which the best characteristics of one parent material were used to alleviate the worst characteristics of another parent material. Thus, the project has increased the utility and attractiveness of energy crops and tillage crop residues. This benefit is available to all stakeholders.

6. Dissemination:

The results of the project were disseminated to the public and to the industry at the following events

- Open Day, Oak Park, 26 June 2007
- Bioenergy 2007, Oak Park, Carlow 30 August 2007
- Green Energy Fair, Gowran, 27–29 October 2007
- Bioenergy 2008–Athenry
- Open Day, Teagasc Knockbeg Farm, 25 June 2009
- Pellet Open Day, Oak Park, 16 April, 2009

Main publications:

Carroll, J and Finnan, J (2012) Physical and chemical properties of alternative biomass pellets. *Biosystems Engineering* (in print)

Carroll JP and Finnan J (2012) Particulate and gaseous emissions from the combustion of alternative biomass pellets. *Biosystems Engineering* (submitted)

Nolan A, MC Donnell K, MC Siurtain M, Carroll JP, Finnan, J and Rice, B (2009) Conservation of Miscanthus in Bale form. *Biosystems Engineering* **104**, Issue 3, 345–352

Nolan A, Mc Donnell K, Devlin GJ, Carroll JP and Finnan J (2010) Potential availability of non woody biomass feedstock for pellet production within the Republic of Ireland. *International Journal of Agricultural and Biological Engineering* **3** (1)

Nolan A, Mc Donnell K, Devlin GJ, Carroll JP and Finnan J (2010) Economic Analysis of Manufacturing Costs of Pellet Production in the Republic of Ireland Using Non-Woody Biomass. *The Open Renewable Energy Journal* **3**, 1–11

Carroll JP, Nolan A and Finnan J (2008) Comparison of Miscanthus and Wood Pellets. Carroll, Nolan and Finnan. – Agricultural Research Forum Tullamore, March 2008.

Basic genetic characterization of *Adonis* spp. germplasm for breeding and domestication

Project number:
5544
Date:
September 2012
Funding source:
DAFF RSF 05–214
Project dates:
Sept 2006–Oct 2009

Key external stakeholders:

Food Ingredients and Functional Foods Sector, Aquaculture Sector, Alternative Crops Sector

Practical implications for stakeholders:

Adonis palaestina is a potential alternative crop, producing a high value compound, the red pigment astaxanthin, with potential nutraceutical and food ingredient applications. We show that the genetic diversity of currently available unadapted germplasm is sufficient for the foundation of a fast-track breeding process, and that small and large flowered variants cannot be hybridised successfully due to divergent genome sizes. The results provide a knowledge framework to proceed with the effective rapid domestication of the species.

Main results:

Genome and taxonomic relationships between small and large flowered variants of *Adonis palaestina*, and the ornamental species *Adonis aestivalis* are poorly understood, and need to be better resolved in order to maximally exploit the available germplasm for domestication of the species for astaxanthin production.

The genetic diversity of currently available germplasm of the large flowered variant of *Adonis palaestina* is sufficiently high to act as a primary genepool for domestication efforts.

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Technology

Opportunity/Benefit:

The majority of agricultural crop species have been domesticated through a mixture of unconscious and conscious selection over a millennial timescale. Species that exhibit potential as novel agricultural crops for the production of high value compounds are frequently completely undomesticated, and little may be understood of their reproductive biology. In order to fast-track this domestication process, breeders need to have a solid understanding of several parameters including the taxonomic relationships of the best candidate species/families for domestication and the genetic diversity of the germplasm that will be used as a foundation of future "elite" selected material. The results outlined here provide baseline information that helps to inform the route for domestication of *Adonis* spp.

1. Project background:

Bright-red flowers of *Adonis palaestina*, a wild plant that originates from the middle-east, are a potential natural source of the red pigment astaxanthin, a carotenoid which is used as both a feed additive for fish farming of salmonid species, and as a nutraceutical due to its strong antioxidant properties. Currently, a programme of accelerated domestication is underway for this species at UCC. While early work on adapting the species for cultivation focused on a small flowered variant with a double row of petals, current work is focusing on a larger flowered variant, because of the increased astaxanthin yield potential of this type relative to the small-flowered type. Due to the lack of successful sexual hybridization between the large and small flowered variety, and other preliminary data, it has been thought that the large flowered variant is a tetraploid form of the small flowered variant. Recent domestication efforts have focused on the use of the large flowered variant, so knowledge of the likely ploidy level of this form, and its taxonomic relationship to the small flowered variant are important characteristics.

In order to develop baseline information to assist in the domestication process, we performed a preliminary assessment of the ploidy/genome size, genetic diversity and relative taxonomic relationships of *Adonis* germplasm being used in the UCC domestication programme.

2. Questions addressed by the project:

Is there sufficient diversity in the germplasm of large flowered Adonis *palaestina* to allow response to selection and to avoid a genetic bottleneck during the domestication process?

What is the relationship between the best candidates for domestication, namely, putative large and small flowered variants of *Adonis palaestina*, and the ornamental species *Adonis aestivalis*?

3. The experimental studies:

Genetic diversity of large flowered *Adonis palaestina*

When initiating a domestication process it is useful to establish the amount of genetic diversity existing in the germplasm upon which the domestication programme will be based, in order to ensure sufficient genetic variation exists to allow response to selection during breeding, and to avoid the eventual generation of adapted germplasm with a narrow genetic base. We tested a subset of lines of the available large-flowered *Adonis* germplasm available at UCC using AFLP analysis.

Genome size and taxonomic relationships of available *Adonis* germplasm

The ploidy of a species is another important factor to establish at the beginning of a process focused on the rapid domestication of a species. Ploidy level (diploid vs auto-or allo-polyploid) affects both the inheritance of traits and factors such as the number of generations required to achieve complete homozygosity in an inbreeding species. As an initial experiment to assess the ploidy of the large-flowered variant of *Adonis*, we used flow cytometry to compare the nuclear DNA content of the 2 variants of *Adonis* and estimate their genome size relative to a species with a known genome size – in this case the oat genome.

Based on the flow-cytometry results, more information relating to the real taxonomic organization of the available germplasm was required. Therefore, PCR primers designed to amplify an approximately 800bp region of the nuclear ribosomal RNA gene (between the 18S and 26S subunits) were applied to 86 accessions of *Adonis*, including 48 of the large flowered variant, 26 of the small flowered variant and 15 accessions of *A. aestivalis*, a small flowered *Adonis* species that has been partially domesticated for use as an ornamental plant (summer pheasants eye).

4. Main results:

Genetic diversity of large flowered *Adonis palaestina*

Pairwise similarity values (based on Jaccard's Index) ranged from 0.195 to 0.449 for the breeding material tested indicating that extensive genetic diversity is present in the germplasm being used as the foundation of the domestication programme in this species.

Genome size and taxonomic relationships of available *Adonis* germplasm

The small flowered variant exhibited a nuclear DNA content similar to that of oat, which has a haploid genome size of 12,961 Mbp. Based on our initial assumption that the large-flowered *Adonis* variant was a tetraploid version of the small-lowered variant, we expected flow cytometry analysis to reveal that the nuclear DNA content in the former was approximately twice that of the latter. However, contrary to expectation, analysis reveals that the nuclear DNA content of the large-flowered variant is significantly smaller (by almost 50%) than that of the small-flowered variant. The results of the flow-cytometry analysis call into question our original assumption of the relative ploidy levels of the two flower-size variants of *Adonis*. The radically divergent genome sizes suggest that either the small flowered variant is actually polyploid relative to the large flowered variant, or that the proposed species relationship between the variants is not correct.

The PCR products generated from the rRNA gene were sequenced and aligned using MEGA 4.1 to reveal numerous single nucleotide polymorphisms between the accessions. Further analysis revealed that the SNP data divide the genotypes into two easily distinguishable subgroups. However, contrary to expectation, the sequence data places the small flowered variant of *Adonis palaestina* and *Adonis aestivalis* in one subgroup, while clearly separating the large flowered variant into another subgroup. The fact that the small flowered variant is more closely related to the ornamental species *A. aestivalis* suggests that the taxonomy proposed for this small group of closely related *Adonis* species is incorrect.

5. Opportunity/Benefit:

The results indicate that the process of domestication underway for the large flowered variant at UCC will not be hampered by a lack of genetic variation in the starting material. Better resolution of the species and genome size relationships between large and small flowered variants of *Adonis* spp. currently being used suggests that large flowered *Adonis* is reproductively isolated from both the small flowered variant, and the species membership of the germplasm should be clarified to identify the appropriate genepool for any future introgression work required. The output of the project has specific benefits to an on-going effort to realise the commercial potential of this species.

6. Dissemination:

Results were disseminated mainly at scientific meetings including the Irish Plant Scientists Association Meeting (IPSAM) and the Agricultural Biotechnology International Conference (ABIC).

Project number:
5629
Date:
June 2012
Funding source:
DAFM/RSF/06/342
Project dates:
Oct 2006–April 2009

Towards the development of an Irish coexistence strategy for GM and non-GM oilseed rape

Collaborating Institutions:
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Key external stakeholders:

Policy makers, tillage farmers

Practical implications for stakeholders:

Although a national strategy for the coexistence of GM and conventional/ organic crops in Ireland was published in 2005 measures pertaining to the coexistence of GM and non-GM oilseed rape crops were omitted due to a scarcity of Irish-specific research. Output from this study has begun to address this knowledge gap by:

- Developing a computer model to quantify the potential impact of pollen and/or seed spread from GM oilseed rape fields on EU coexistence thresholds across an Irish landscape.
- Identifying crop-specific measures (e.g. isolation distance, field clustering) to minimise the potential spread of material from GM herbicide tolerant (HT) oilseed rape fields.
- In addition, a complimentary study was completed to identify the demographic factors most likely to affect farmer's decision to adopt GM crops suited to the Irish agri-environment.

Main results:

- The GeneSys gene flow model predicted that the incorporation of GMHT oilseed rape into an existing winter wheat-based rotation without a complimentary modification to the cropping regime would rapidly compromise the EU coexistence labelling threshold of 0.9% in neighbouring non-GM oilseed rape crops.

Technology

- Enhanced herbicide efficacy, the application of robust volunteer control, the inclusion of a single spring crop (potato, barley, maize) post-oilseed rape would reduce regional harvest impurities in non-GM oilseed rape crops below the 0.9% threshold.
- The establishment of GM zones by clustering GMHT oilseed rape fields presents a potentially viable mechanism to achieve effective coexistence with neighbouring non-GM oilseed rape sites.
- Economic analysis determined that the likely early adopters of GM technology will be specialist farmers with large acreage and who have formal agricultural education and access to high-quality soils.

Opportunity/Benefit:

Output from this project will inform stakeholders of the most pertinent issues relating to the coexistence of GM and non-GM oilseed rape in Ireland. This is of most relevance to regulatory agencies and policymakers.

1. Project background:

A crop's propensity to spread its genes through pollen and/or seed transfer is significant in light of European Union (EU) guidelines on the coexistence of genetically modified (GM) and non-GM crops and the labelling and traceability of GM material through food and feed pipelines. Coexistence relates to the adoption of crop-specific management regimes to maintain potential GM content in conventional/organic commodities below the 0.9% labelling threshold for food or feed. In short, coexistence is focused on restricting the potential for and consequence of a crop's gene flow, whether via seed and/or pollen.

Oilseed rape has significant gene flow potential via pollen dispersal and seed loss post-harvest. Furthermore, the high fecundity and long-term persistence of volunteers as a result of seed dormancy along with the emergence of ferals outside the confines of the agri-environment ensures the persistence of oilseed rape populations through a rotation. Hence, it can be expected that in the absence of appropriate controls, the cultivation of GM oilseed rape will see EU labelling thresholds surpassed with the movement of GM traits across production systems.

Obtaining reproducible field-based spatial and temporal gene flow experimentation at a landscape level is logistically and economically unfeasible. An alternative is to employ a spatial model (e.g. GeneSys) which can simulate the movement of a GM trait via seed and pollen over diverse landscapes through multi-year rotations against varied farm management practises. The objective of the project was to employ GeneSys to develop an Irish-specific management strategy for both policymakers and potential early adopters of GMHT oilseed rape in Ireland. In addition, a parallel economic analysis would determine the cost-effectiveness of individual measures and also complete an adoption factor analysis.

2. Questions addressed by the project:

- Can existing crop management regimes be employed to maintain the effective coexistence of GM and non-GM oilseed rape crops?
- What additional crop stewardship measures could be adopted to facilitate the efficient segregation of GM material from neighbouring non-GM oilseed rape cropping systems?
- What is the impact on coexistence thresholds of forming regional clusters of GM oilseed rape fields?
- What factors influence the decision of Irish farmers to adopt GM technology should they be given a choice in the near future of selecting between GM and non-GM varieties of crops?

3. The experimental studies:

The gene flow model Genesys was adapted to the Bridgetown landscape of Co. Wexford. A digitised map of Bridgetown, was created from a suite of aerial photographs and consisted of 607 cropped fields and 58 no-vegetation areas (roads, farms. . .). Borders (mainly hedgerows) along roads and fields were added manually. Briefly, the GeneSys input variables include (1) the field pattern consisting of fields and semi-natural areas (hence "borders") where feral oilseed rape can grow; (2) the crop cultivated each year in each field; (3) the cultivation techniques used to manage each crop (tillage tools and dates, sowing date and density, herbicide efficiencies and application stages, mowing dates, efficiency of mechanical weeding, harvest date) and (4) the genotype of the OSR varieties. These input variables influence the annual life-cycles of cultivated, volunteer and feral OSR populations.

The impact of six crop rotations was assessed for three possible GM adoption levels (5%, 15% and 30%) across the landscape. Additional scenarios examined included; enhanced weed management strategies, impact of isolation zones and the grouping of GM fields into 'GM clusters' to facilitate coexistence management.

For the adoption factor analysis, datasets from the 2006 National Farm Survey were employed, representing 841 farmers, which represents a population of 82,091 farmers using a weighting system representing size and system of production.

4. Main results:

For a 5% regional uptake of GMHT oilseed rape, the introduction of such a GM crop into a standard winter wheat rotation (e.g. Year 1 GMHT oilseed rape, Year 2 winter wheat, Year 3 winter wheat, Year 4 winter wheat) with no additional modifications resulted in a mean of 17% of non-GM fields exceeding the 0.9% food labelling threshold and thus being discarded from the non-GM food chain. If the GM adoption rate increased through 15% and 30% the percentage of non-GM oilseed rape fields that would exceed the EU coexistence threshold rose to 50.04% and 89.18%, respectively.

The degree of contaminated non-GM oilseed rape fields dropped significantly with the substitution of spring barley (or maize, potato) into year 3 and year 4 of the rotation. Also, increasing herbicide efficiency (to 99%) or the number of herbicide applications (×2/growing season) significantly reduced the levels of regional harvest contamination at either of the three GM adoption levels, but as expected this led to a substantial increase in farmer costs.

The effect of clustering the cultivation of GMHT oilseed rape into 'de facto' GM zones substantially reduced the average level of harvest pollution across the landscape (5% regional adoption), as the size of individual clusters increased. By increasing the size of each cluster but decreasing the number of clusters, the level of harvest impurities for the 10% GM adoption level was significantly reduced below the food labelling 0.9% threshold, compared to the non-clustering control treatment.

The inclusion of a 50m buffer zone in which no oilseed rape was cultivated around each cluster had the greatest impact of all treatments considered in the study. Irrespective of the cluster arrangement, the level of harvest impurities did not exceed 0.2% (for 5% GM uptake), implying that the combination of this spatial arrangement with reasonable isolation distances presents a powerful method to limit the potential for gene flow from GMHT oilseed rape. This was reflected in the % of fields with harvest impurities in excess of 0.9%, which in the absence of clustering was simulated at 17.24% at GM adoption level of 5% across the landscape. A combination of clustering and buffer zones reduced this 50–fold.

The adoption factor analysis concluded that farmers likely to be early adopters of GM crops will be those with large farm acreage who are specialist crop farmers and who have formal agricultural education and access to high-quality soils. This result is in accordance with similar ex-post adoption studies on Bt and HT corn adoption in the United States.

5. Opportunity/Benefit:

Using a landscape modelling system, this research is the first study to identify Irish-specific agronomic measures that could facilitate the development of a coexistence regime for GM and non-GM oilseed rape crops. This will be of benefit to policy makers, regulators, tillage farmers and the general public at large.

6. Dissemination:

Main publications:

Keelan, C., Thorne, F., Flanagan, P., Newman, C. and Mullins, E. (2009). 'Willingness to Adopt GM Technology at Farm Level'. AgBioForum, The Journal of Agrobiotechnology Management and Economics,12: 394–403.

Tricault, Y., Flanagan, P., Fealy, R., Colbach, N. and Mullins E. (2009). 'Towards an optimal management regime to facilitate the coexistence of GM and non-GM oilseed rape'. European Journal of Agronomy, 34: 26–34.

Cereal grains and crop residues as feedstocks for combustion

Project number:
5377
Date:
April 2012
Funding source:
Teagasc
Project dates:
Jan 2005–Dec 2008

Key external stakeholders:

Energy crop and tillage farmers, biofuel pellet manufacturers, solid biofuel suppliers, biomass boiler manufacturers, consumers, policy makers, scientific community

Practical implications for stakeholders:

The significance of this research for stakeholders is as follows

- Farmers may be able to take advantage of a new market for their tillage crops and energy crops.
- Policy Makers can now take into account that a wide range of biomass feedstocks can be used for combustion. These feedstocks can make a contribution towards national bioenergy and greenhouse gas targets.
- Industry can use to data from this project to assess the suitability of a range of biomass feedstocks for combustion in different biomass boilers. Data from this project can also be used to design biomass boilers suitable for more challenging feedstocks.
- Consumers can benefit from this project from the availability of information on biomass feedstocks which they may be offered as fuel for their boilers.
- Scientific Community benefits from this project as new information is available on the physical and chemical properties of a wide range of biomass feedstocks as well as on their combustion and emissions. The project has also shown how techniques such as thermogravimetric analysis and differential thermal analysis can be used in boiler design.

Main results:

The project established that a wide range of biomass feedstocks can be burnt in boilers. The most difficult materials to burn are those which exhibit properties of high moisture, low bulk density and poor flow properties. However, these properties can be mitigated by drying and densification. Materials with low ash melting points such as Miscanthus need to be combusted in boilers which employ either flue gas recirculation, water cooled grates or mechanical agitation of clinker.

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Technology

Successful combustion of cereal grains depends on species, agronomic practice and moisture content. Oats and triticale can be successfully combusted at moisture contents below 20%, other grain species are less suitable for combustion. The cultivation of cereals for combustion should ensure that grain nitrogen levels are as low as possible in order to avoid high emissions of oxides of nitrogen from combustion.

Opportunity/Benefit:

The use of biomass for combustion offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. The project established that a wide range of biomass feedstocks can be burnt in boilers and has identified the most challenging feedstocks. However, the project has established how the most deleterious properties of challenging feestocks can be mitigated as well as the combustion technologies most suited for these feedstocks. Thus, the project has categorized the suitability of a wide range of feedstocks for combustion but also demonstrated how more challenging feedstocks can be utilized. Hence, the project has increased the utilization of a range of biomass feedstocks, this benefit is available to all stakeholders.

1. Project background:

National and international plans to increase the provision of renewable energy and to mitigate greenhouse gas emissions will require a substantial increase in the use of biomass feedstock for the generation of heat and electricity. It is desirable that such feedstocks be produced locally. In Ireland, the supply of wood and forest residues will be insufficient to meet all demands so therefore, other biomass resources such as energy crops, agricultural crop residues and by-products and wastes will be needed. Biomass materials that are available or could be grown in significant quantities in Ireland include short-rotation willow, miscanthus, cereal straw and cereal grains.

2. Questions addressed by the project:

Could the combustion characteristics of a broad range of biomass materials, that could be used as solid fuels, be examined? In particular,

- Could the physical and chemical characteristics of the experimental solid biomass fuels be determined?
- Could thermogravimetric and differential thermal analysis techniques be used to determine the patterns of mass loss and heat flux from the combustion of each of the fuels?
- Could the combustion performance of the experimental solid biomass fuels in full scale boiler trialsbe evaluated?

3. The experimental studies:

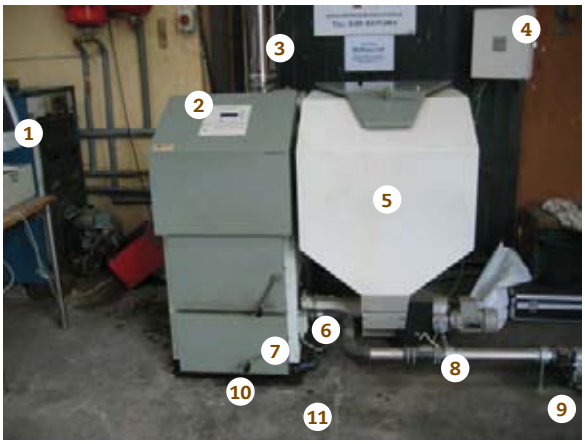
The combustion characteristics of a broad range of potential biomass feedstock materials were tested in this project. The biomass materials tested included wood, Miscanthus, willow, cereal and rape straws, rape cake and cereal grains. There were three tasks in the work programme

(i) Laboratory analysis of the physical and chemical properties of the experimental materials;

(ii) Thermogravimetric analysis (TGA) and Differential Thermal Analysis (DTA) were used to study the thermal decomposition of the experimental material with the objective of using the data for a more analytical approach to biomass fuelled boiler design. These two techniques are carried out with the same equipment. In this procedure, a small sample of the experimental material is burnt during which the mass loss and the heat fluxes to and from the sample are quantified. The resulting data allows the calculation of mass loss and heat flux during the different phases of the combustion process (dehydration, volatilization, oxidation and decomposition)

(iii) Boiler Tests The experimental materials were fired in either of two types of boilers (KWB 100kw boiler, Benekov 15kw boiler), their performance and emission measurements were used to evaluate the efficacy of the material as a feedstock for combustion.

Benekov boiler in test configuration



1. PC (data link)
2. Boiler
3. Stack
4. Data logger
5. Fuel Silo
6. Stoker auger
7. Combustion chamber
8. Pulse meter
9. Air supply
10. Ash bin
11. Thermocouple

4. Main results:

The following are the conclusions from the project:

- Boiler performance is affected by a wide range of fuel properties. The effect of some properties, e.g. gross and net calorific values and moisture content, are reasonably predictable; the effects of other properties, such as particle size, densification method and ash melting behaviour, are more complex and require a deeper understanding of the combustion process. Boilers are already on the market that can cope with wood-derived fuels of suitable moisture, particle size and bulk density. However, biomass materials with high moisture, low bulk density, poor flow properties and low ash melting points present major difficulties. The physical problems can be mitigated (though at some cost) by drying, size reduction and densification. For low-melting-point materials, control of the temperature within the combustion chamber is critical. Boilers which possess the ability to reduce the temperature in the combustion chamber (eg flue gas recirculation, water cooling) can handle a wide variety of fuels with ash-related problems.
- Woody materials are the least problematic biomass fuel. Such material provide the highest heat output and thermal and combustion efficiencies and the cleanest stack emissions, and can be burned in a wide range of boiler designs.
- Loose Miscanthus and cereal straw fuel present some difficulties mainly due to their low bulk density and low ash melting temperature. The former can be overcome by densification methods such as pelleting, the latter makes considerable demands on the design of the boiler combustion chamber and controls e.g. flue gas recirculation, water-cooled grates, mechanical ash removal etc. The use of additives containing calcium may be beneficial, though this will lead to an increase in ash content.
- Successful combustion of cereal grains depends very much on the grain species, its moisture content and the agronomic practices used in its production. Oats and triticale can be successfully combusted at 15% moisture; if they are harvested at moistures below 20% they can still be burned; heat output and emissions will be adversely affected although it is unlikely that this will justify the cost of drying. To keep NO_x levels low, agronomy practices should be as for malting barley. Barley and wheat dried to 15% can be burned, but no attempt should be made to burn them at higher moistures.
- TGA/DTA analysis can provide detailed information on the progress of the combustion process through its various stages, and helps to explain the differences in the combustion performance of different biomass materials. Taken along with property analyses, it allows the calculation of boiler design variables such as the separation of primary and secondary air and combustion chamber volume requirements for efficient combustion. Further study may lead to the quantification of other boiler design and operation parameters, and allow a more analytic approach to be made to the design and operation of boilers burning specific fuels.

5. Opportunity/Benefit:

The use of biomass for combustion offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. The project established that a wide range of biomass feedstocks can be burnt in boilers and has identified the most challenging feedstocks. However, the project has established how the most deleterious properties of challenging feestocks can be mitigated as well as the combustion technologies most suited for these feedstocks. Thus, the project has categorized the suitability of a wide range of feedstocks for combustion but also demonstrated how more challenging feedstocks can be utilized. Hence, the project has increased the utilization of a range of biomass feedstocks, this benefit is available to all stakeholders.

6. Dissemination:

The results of the project were disseminated to the public at the several events, including; Teagasc Open Day, Oak Park, Carlow, June 26th 2007 and June 25th 2009; Bioenergy 2007, Carlow and Bioenergy 2008, Athenry; Green Energy Fair, Gowran, Co. Kilkenny, 27th–29th October 2007.

Main publications:

Keppel, AR (2010) Characteristics of Cereal Grains and Crops Residues as Solid Biomass Fuel. MEngSc, University College Dublin.

Keppel AR (2008) Cereal grain as a fuel. In. Farm Energy. Farm Diversification Manual. ISBN 1 84170 507 1

Cereal Grains as a Boiler Fuel (2006) Teagasc Tillage Specialists Factsheet No 5.

Strategies for the control of Potato late blight caused by *Phytophthora infestans* (Mont.) de Bary

Project number:
5373
Date:
September 2012
Funding source:
Teagasc
Project dates:
Jan 2005–Sep 2008

Key external stakeholders:

Potato growers. Retail trade and potato consumers

Practical implications for stakeholders:

Potato late blight is the most destructive disease of potato worldwide. This project examined the physiological characteristics of late blight genotypes in the 2007 population. These characteristics included mating type, resistance to the fungicide metalaxyl and also the ability of late blight isolates to overcome known resistance genes (Blacks differential indicators R1–11) present in cultivated potato. This information ensures that fungicides are used appropriately and informs potato breeders about the durability of resistance genes to blight for use in potato breeding strategies. The ability to increase the interval between fungicide applications was also examined which would represent a significant saving to growers if feasible.

Main results:

Physiological race characterisation showed very little change from a previous survey conducted in 1996. Of 11 known resistance genes (Blacks differential set) virulence was found to all genes. The most common race in Ireland is 1, 3, 4, 7, 10, 11, while races pathogenic on R2, R6, R8 and R9 were very rare. Only one isolate was found which could overcome the R9 indicator. No A2 mating type isolates were found during this survey period. Metalaxyl resistance was confirmed to be extremely low validating the continued use of this fungicide up to 2007. Trials undertaken comparing the efficacy of applying blight fungicides at seven or ten day intervals showed reducing the spray interval delayed the onset of disease, reduced the level of foliage blight at the end of the season but only had a slight positive effect on tuber yield.

Collaborating Institutions:
None

Teagasc project team:
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External collaborators:
N/A

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Technology

Opportunity/Benefit:

Confirmation that certain R genes still confer usable resistance to late blight and may be used in potato breeding for resistance breeding strategies. Confirmation that the A2 mating type remains absent from the population up to 2007 reduces the possibility of emergence of fitter strains by sexual recombination. Additionally the project shows the potential to decrease the number of fungicide applications when weather permits.

1. Project background:

Potato late blight, caused by the oomycete fungus Phytophthora infestans (Mont.) de Bary, is the most destructive disease affecting the potato worldwide. Annual losses in Ireland have been estimated at €10.2 m. Disease control requires regular application of fungicides at high rates and short intervals throughout the growing season. P. infestans is a fungus which is constantly changing. There is evidence that the fungus is becoming much more complex in terms of physiological race specialisation while resistance to the phenylamide fungicide metalaxyl was confirmed in 1981. The existence of a second (A2) mating-type was confirmed in 1989. This could lead to increased virulence and aggressiveness through sexual hybridisation. Regular monitoring of the population for physiological race specialisation, fungicide resistance and mating-type is required so that the most appropriate control measures can be put in place.

Current disease control relies almost exclusively on the routine application of a wide range of different fungicides. Metalaxyl has been a mainstay of control programmes in the past and because of its systemicity and known resistance risk has been used primarily early in the season to protect rapidly growing crops and reduce selection for resistant strains. However with a rapidly changing population, the efficacy of this fungicide in controlling P. infestans needs to be continually assessed so that most effective products can be chosen.

Conventional potato crops rely on up to 15 fungicide applications in a season. Given work constraints and weather conditions many growers spray their crops on a weekly basis to ensure good protection from late blight. The frequency of spraying has increased over time. Experiments were conducted to examine the efficacy of two different protectant fungicide products Dithane and Shirlan (mancozeb and fluazinam respectively) applied at seven and ten day intervals on disease control.

2. Questions addressed by the project:

Determining phenotypic variation in the Irish population of *Phytophthora infestans* in relation to phenylamide resistance, physiological race specialisation and mating-type during the project period 2005–2007 and assess the impact of the findings on disease control.

Examine if an increase in spray interval from seven to 10 days is feasible examining two commonly used protectant fungicides.

3. The experimental studies:

Samples of late blight from infected commercial potato crops around the country were sent by Teagasc potato advisers and Department of Agriculture potato inspectors during 2007 to Teagasc Oak Park for characterization. Blight was isolated into pure culture and subjected to mating type determination by pairing the isolates with known A1 and A2 mating types and examining the cultures for oospore production. Isolates generally only produce oospores with opposite mating types. Spore suspensions of the bulk samples of late blight infected foliage from the fields were inoculated onto leaf discs of potato floating on three different concentrations of metalaxyl (0, 5 And 100 ppm). Resistant isolate were able to grow on all levels while sensitive strains could only grow on the 0 concentration. Isolates were also inoculated onto detached leaflets of potato varieties known to contain individual resistance genes to late blight (Blacks differential indicators containing genes R1–11). The race or virulence spectrum (ability to overcome resistance genes) was recorded for each isolate tested.

To determine the effect of increasing spray intervals form seven to ten days, fungicide trials were undertaken. The foliage susceptible cultivar Rooster was used in trials conducted at Oak Park Research Centre, Carlow from 2002 to 2007. This variety is moderately susceptible to foliage blight and has a resistance rating of 5 on a scale of 1 to 9 (Dowley *et al.*, 2008). The design for each trial was a randomised complete block with 5 treatments and 4 replications per treatment. The five treatments were an unsprayed control, 7 and 10–day programmes using the protectant fungicide mancozeb as well as 7 and 10–day programmes using the protectant fungicide fluazinam.

4. Main results:

Physiological Races

Eighty five isolates of P. infestans were tested for physiological race specialization. A total of 21 different physiological races were identified compared with 16 in 1986 and 4 in 1981. Two new virulence genes (8 and 9) were identified in Irish isolates of *P. infestans* for the first time in 2007. The most complex race contained all 11 virulence genes and the least complex contained 4 virulence genes. This is the first record of a race with all resistance breaking genes being confirmed in Ireland. The least complex races also contained two more virulence genes than in the previous year. This confirms that the physiological races of *P. infestans* in Ireland have become more complex.

Metalaxyl resistance

A total of 91 isolates were tested for resistance to the phenylamide fungicide metalaxyl, of which 13 isolates (14%) were resistant. However, of the 91 isolates tested, 14 came from outside the Republic of Ireland and of these 64% were resistant to metalaxyl. In the remaining 77 isolates from the Republic of Ireland, only 5% were shown to be resistant to metalaxyl. This confirms the continued downward trend in the % metalaxyl resistance in Irish isolates from recent years. Of the resistant isolate 50% contained a virulence gene for R2.

Mating type

During 2007 a total of 65 isolates were tested for mating type. All isolates were confirmed to be of the A1 mating type.

Effect of increasing the spray interval from seven to ten days.

Shirlan performed better than Dithane at both spray intervals resulting in less foliage and tuber blight at the end of the season. Shirlan at seven day intervals was the most effective treatment in the trials. The effect of increasing spray interval was consistent for both fungicides. Reducing the fungicide application window to seven days also gave better disease control by reducing the total level of foliage blight in the trials throughout the season and by delaying the onset of disease. The effect on total yield at the end of the season was small. However, given the vagaries of the Irish climate the risk of spraying at ten day intervals cannot be discounted. This data does suggest that when weather conditions are favourable spray intervals can be stretched to ten days.

5. Opportunity/Benefit:

The low frequency of the R genes R2, 6, 8 and 9 suggest these may be viable targets for potato breeders to incorporate in new varieties. The non detection of the A2 mating type and the low level of Metalaxyl resistance suggest the population has remained relatively stable and also this validated the continued use of Metalaxyl on potato crops up to 2007. The comparison of seven and ten day fungicide spray intervals shows superior control of blight by the seven day regime but small differences in total and marketable yield. This suggests that intervals may be extended however given the unpredictable nature of the Irish weather this should only be done during periods of dry weather when the crops has already received a number of fungicide applications.

6. Dissemination:

A late blight technical control manual was published as part of this project. The results were also disseminated at a major potato open day in Oak park on September 30th 2008.

Main publications:

Dowley, L.J., Grant J., and Griffin, D. 2008. Yield losses caused by late blight (*Phytophthora infestans (Mont.) de Bary*) in potato crops in Ireland. Irish Journal of Agricultural and Food Research 47: 69–78, 2008

Andrivon, D., Avendaño-Córcoles J., Cameron, A. M., Carnegie, S. F., Cooke, L.R., Corbière, R., Detourné, D., Dowley, L. J., Evans, D., Forisekova, K., Griffin, D. G., Hannukkala, A., Lees, A. K., Lebecka, R., Niepold, F., Polgar, Z., Shaw, D. S., Thompson, J., Trognitz, B., van Raaij, H. M. G. and Zimnoch-Guzowska, E. 2011 Stability and variability of virulence of *Phytophthora infestans* assessed in a ring test across European laboratories. Plant Pathology. 60: 556–565

Popular publications:

Potato Late Blight Control Technical Manual. 2008. L. J. Dowley, D. Griffin and M. Hennessy. ISBN 1–84170–505–5 Teagasc, Crops Research Centre Oak Park.

Crops
Environment
& Land Use
Programme

Project number:
5375
Date:
Sept, 2012
Funding source:
Teagasc
Project dates:
Jan 2005–Dec 2008

An assessment of the potential of cultivar mixtures in Ireland

Collaborating Institutions:
University College Dublin

Teagasc project team:
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Key external stakeholders:

Cereal growers, advisers and agronomists, cereal seed suppliers

Practical implications for stakeholders:

Using cultivar mixtures rather than single cultivar monocultures has been shown internationally to have potential in low input and organic production systems. However cultivar mixtures have not previously been extensively assessed under Irish conditions and in particular under high input conditions. Results from this work indicate that cultivar mixtures offer little advantage or disadvantage, other than the cost of mixing seed, over single cultivar stands for winter wheat and spring barley under high input Irish conditions. Similarly there was little evidence to support the use of cultivar mixtures under organic conditions in Ireland.

Main results:

There was no grain yield or grain quality benefit, compared to using single cultivar monocultures, of mixing cultivars of either winter wheat or spring barley under Irish conditions under conventional high input or organic conditions.

There was some indication that mixtures could reduce variation in yield and quality between environments but effects were small.

There was no indication that cultivar mixtures were more efficient than single cultivar stands in terms of nitrogen use efficiency.

Opportunity/Benefit:

The work suggests that the use of cultivar mixtures under productive Irish conditions gives little benefit and growers should continue to use single cultivar stands.

Technology

1. Project background:

Most cereals in Ireland are grown in cultivar monocultures with high levels of external inputs. However cultivar monocultures can have disadvantages such as vulnerability to diseases and yield instability as a result of year to year and site to site variation in environmental conditions. International work would suggest that the use of cultivar mixtures could offer a potential method of reducing the need for external inputs, increasing yield through better resource utilization and increasing yield stability over sites and seasons. Much of the previous work with cereal cultivar mixtures has focused on their ability to reduce the effects of fungal pathogens, particularly in low input systems. Their potential in systems where fungal diseases are controlled with fungicides and high levels of inputs are applied, as occurs in Irish cereal production systems, has received relatively little attention.

2. Questions addressed by the project:

Are mixtures of cultivars higher yielding than single cultivar stands for winter wheat and spring barley in high input Irish production systems?

Do mixtures offer greater yield stability between sites and seasons than single cultivars? Do mixtures utilize resources more efficiently than single cultivar stands?

Do cultivar mixtures outperform single cultivar stands under organic conditions?

3. The experimental studies:

A series of field experiments with winter wheat and spring barley were carried out over three seasons 2006–2008 with normal commercial levels of pesticide and fertilizer inputs. Spring barley experiments were repeated at four locations in each season. Four cultivars of spring barley were compared with a range of mixtures of these cultivars varying in number and proportion of component cultivars. Winter wheat experiments were carried out at one location and the cultivars and composition of the mixtures used varied between seasons. Some experiments included different fertilizer N levels to determine if cultivar mixtures, by using nitrogen more efficiently, could lead to a reduced requirement for fertilizer N. Grain yield, grain quality and in some experiments the cultivar composition of the mixtures at harvest was determined.

A comparison of four-component cultivar mixtures with their component cultivar monocultures of spring barley was carried under organic conditions in two seasons (2006 and 2007) at Oak Park Research Centre.

4. Main results:

Results of experiments carried out under conventional inputs did not show any advantages of cultivar mixtures over cultivar monocultures in terms of grain yield or quality enhancement due to better resource use efficiency for the two crops investigated under Irish conditions. Grain yield of mixtures was similar to the mean yield of the component cultivars grown in monoculture. There was also no indication, in any of the experiments carried out, that the use of cultivar mixtures might allow the reduction of fertiliser N inputs. Results did suggest that mixtures can be beneficial in terms of grain yield and quality stability across environments but effects were small and inconsistent. Overall the work did not show any significant benefits of mixtures of either spring barley or winter wheat in conventional production systems. There was also no indication of any consistent advantage of using cultivar mixtures under organic conditions in terms of either grain yield or grain quality.

5. Opportunity/Benefit:

The results indicate that cultivar mixtures of either winter wheat or spring barley are of little advantage to Irish cereal producers compared to cultivar monocultures.

6. Dissemination:

Fabre, P. 2010 An assessment of cereal cultivar mixtures in Ireland. PhD thesis, Faculty of Agriculture, University College Dublin.

Fabre, P. et al. (2008) Stability of spring barley cultivar mixtures and monocultures., *Agricultural Research Forum*, Tullamore , 12–13 Mar 08.

Hackett, R and Fabre, P. 2005 An assessment of the potential of cultivar mixtures under conventional and organic management systems in Ireland. Crops Research Centre Oak Park Research Report 2005 p. 30

Hackett, R and Fabre, P. 2006 An assessment of the potential of cultivar mixtures under conventional and organic management systems in Ireland. Crops Research Centre Oak Park Research Report 2006 pp17–18

Cereal production systems

Project number:
5249
Date:
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Funding source:
Teagasc
Project dates:
Jan 04–May 07

Key external stakeholders:

Cereal and crop growers; Crop production industry; Other research teams.

Practical implications for stakeholders:

- Growers need to consider their level of input application carefully and should challenge the notion of fixed levels of inputs. There is scope to save costs and improve profits, but decisions need to be crop, site, and season specific.
- Rotations offer benefits to growers but their overall adoption will require significant development in production technology and particularly in the provision of stable markets.

Main results:

Profit margin can be increased by optimising input levels rather than adopting an inflexible, high-input strategy. Low-input approaches in winter wheat production can be more profitable whereas spring barley profit may be reduced by lowering the spend on inputs.

Crops grown in beneficial parts of a rotation yield better than those grown in monoculture; due mainly to disease reduction. However the relatively poor performance of the break crops can result in the profitability of the entire rotation being no better than continuous production of a cereal crop.

Collaborating Institutions:
IT Carlow and Cork IT (separate studies using this trial site)

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Technology

Opportunity/Benefit:

There is scope for growers to improve their profit margins by attempting to tailor their inputs to crop needs and by managing their crops in an integrated manner including varietal choice, sowing date and disease control strategy. The work highlights the need for continuing research to more accurately guide growers decisions about input levels in particular crop situations. While crop rotation can benefit crop yield there is a need to develop markets and production technologies for specific break crops to facilitate the profitable uptake of this research.

1. Project background:

The production of cereals in Ireland has largely been based on relatively high inputs of fertilisers, herbicides and fungicides, as growers have sought to exploit the high crop-yield potential of our climate. Variation in weather conditions has steered growers towards strategies of input application where high and relatively fixed levels of inputs are used to ensure that near maximum yields can be achieved in any given season. This may not be the optimum approach as the response to inputs in a single crop type will vary with site and seasonal weather effects. There may also be a relationship or interaction between levels of different inputs. If for example early autumn sowing of a winter cereal is coupled with high fertiliser nitrogen rates and the use of a disease-prone variety, then it's possible that the response to a high input disease control programme will be much greater than with a later sown, more disease resistant variety, grown with less fertilizer nitrogen.

The role of rotations in modern cropping systems also needs to be addressed. As crop production has become more specialised, the practice of monoculture has increased with many growers prepared to accept reduced yield potential for simplified cropping systems, and the less variable crop performance and market opportunities than that associated with many rotation break-crops. However, the impact of crop rotation on crop performance in high-input crop production systems is not fully known. The possible interaction between rotation and input level i.e. the potential reduced need for high input levels with crops grown in rotation, has not been addressed.

2. Questions addressed by the project:

- What is the impact of level of inputs (fertiliser, herbicides, fungicides etc) on the performance of the main cereal crops grown in Ireland?
- Where high levels of inputs give greater yields, is this the economic optimum for crop producers?
- Do rotations benefit crop production; specifically what is the effect of a break-crop on the subsequent cereal crop performance?
- Can an exclusively cereal rotation deliver benefits comparable to a traditional break-crop rotation?
- How do complete rotation systems compare economically with cereals produced in monoculture?

3. The experimental studies:

The research questions were addressed in a large-plot (30m x 12m) field trial on a moderately heavy textured soil at Knockbeg, adjacent to the Teagasc Oak Park research centre. Two levels of inputs: high and low, were applied to a range of cereal crops (winter wheat, spring barley, winter barley and winter oats) over the duration of the trial. The 'high' level of inputs were similar to that used by commercial growers which included the maximum recommended rates of fertilizer, and recommended rates of plant protection products for weed and disease control. For winter wheat, a high yielding variety was sown in the beginning of October. The 'low' level of inputs used 80% of the fertilizer nitrogen applied to the high-input crops and 50% of all plant protection products applied at the same timing as in the 'high' strategy. For winter wheat, a later sowing date (mid-October) and more disease resistant variety were used.

Two rotations were compared with monoculture (i.e. continuous cereal) in the same trial. A five course break-crop rotation had a: winter bean; winter wheat; spring barley; spring oilseed rape; winter barley cropping sequence. A cereal rotation was also included (winter oats; winter wheat; winter barley). Production in these rotations was compared with both winter wheat and spring barley grown in monoculture. As winter wheat was grown in monoculture and both rotations, the trial facilitated detailed analysis of this crop. The input levels and rotations were combined in a field trial design that allowed the combined impact of these factors to be assessed. The impact of input level and rotation was

measured by assessing crop performance including plant establishment, disease development and harvest grain yield and quality. Also as both input level and the crop type used in a rotation can impact on production costs, a financial analysis of crop performance was carried out to produce individual crop, and entire rotation, production margins.

4. Main results:

The main results of the trial were:

- High input levels increased winter wheat grain yield by an average of 8.4% (0.9t/ha) but there was a substantial season effect with high inputs giving no increase in one year and a 23% yield increase in a season with high yield potential.
- With winter barley, the use of high levels of inputs increased yield by an average of 14% with a lesser level of variation than winter wheat (12 to 20%).
- Winter oats had an average of 11% increase in yield with little seasonal variation where a higher level of inputs was used.
- Surprisingly spring barley had the biggest yield benefit from the application of high levels of inputs, with an average 18% grain yield increase at the Knockbeg site.
- With winter wheat, the low input strategy gave the highest production profit margin overall, as the savings in production costs were equivalent to 1.4t/ha in grain yield. However season had an effect with the high-input system being marginally more profitable in one year which had high yield potential.
- On this site, normal practice, in terms of input application, for spring barley, was close to optimal whereas normal practice for winter wheat was excessive, resulting in poorer profit in most years.
- Input level had little impact on winter barley profitability as the yield increase with the high-input strategy was cancelled out by the extra production costs.
- With winter oats, the relatively modest increase in costs associated with higher levels of inputs gave a small financial gain.
- Spring barley gave the biggest economic response to higher levels of inputs where the 1.2t/ha average yield benefit easily outweighed the equivalent 0.7t/ha additional cost of the strategy.
- Winter wheat grown after a break crop yielded between 6% and 8% more than monoculture wheat. Where low inputs were used, the benefit of the break crop was slightly greater. Winter barley also yielded more when grown in a favourable position in a crop rotation.
- The level of the root disease 'take-all' was halved in wheat grown after both a break crop and oats compared to monoculture; allowing wheat in the cereal rotation to perform as well as in the break-crop rotation.
- The profit margin from wheat produced within a rotation was between 20% and 31% greater than from monoculture wheat.
- When the profit margins of all the crops within the rotations were taken into account, the monoculture wheat was as profitable as either of the two rotations due to the poor financial performance of the other crops in the rotations. This result is influenced by the market prices used and by the favourable performance of wheat on the particular site.
- The impact of rotation type or input level on disease levels and grain quality was small.

5. Opportunity/Benefit:

- The low-input systems used in these trials generally reduced yields, but the level of yield response and the effect of this response on profit margin were determined by crop and season. There is scope with winter wheat to increase profit by reducing input levels. Conversely the spring barley results indicate that a universal input reduction approach cannot be justified.
- The concept of using easily-managed high-input systems with pre-determined rates of inputs should be challenged to promote the development and application of more appropriate systems that respond to crop needs and seasonal variations. This will ultimately involve the development of appropriate decision support systems based on, and/or validated by, Irish crop research data; a significant task that should not be underestimated.
- Crop rotation can bring yield and production margin benefits to individual corps within the rotation, however this work clearly shows the need to develop suitable markets and production methodology for break crops to improve their profitability.

6. Dissemination:

In addition to the publications highlighted here, this project provided a centre point for visiting groups (growers, advisors, industry including groups from other countries) Main publications:

Forristal, P.D., Hogan, J.J. Burke, B. (2005) 'Rotations: a new role in a new era' In Proceedings of the National Tillage Conference 2005, Teagasc, Oak Park, Carlow.

Forristal, P.D., Burke, B. (2007) 'Can we reduce costs and increase profits' In Proceedings of the National Tillage Conference 2005, Teagasc, Oak Park, Carlow.

Forristal, P.D. Forristal, P.D. (2007). The effect of input level on winter wheat and spring barley on grain yield and production margin on disease prone site. In: In Proceeding of the Agricultural Research forum 2007, Tullamore, 12–Mar–2007

Popular publications:

Forristal, P.D. (2004). Crops open day booklet and presentation, Teagasc Oak Park 2004

Forristal, P.D. (2007). Crops open day booklet and presentation Teagasc Oak Park 2007

Forristal, P.D. (2007). Can we reduce costs and increase profits. Todays Farm 18 2 2 pp

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Jan 2005–Dec 2007

Agronomy of triticale under Irish conditions

Key external stakeholders:

Cereal growers, advisers and agronomists, livestock producers.

Practical implications for stakeholders:

Triticale has the potential to be a reduced-input alternative to winter wheat as a source of grain and whole-crop forage but relatively little work has been carried out on its agronomy under Irish conditions. This work has shown that under Irish conditions

- Triticale can be grown with lower inputs of fungicides but the requirement for other inputs, such as fertiliser N, seed rate and take-all seed treatment is similar to that of winter wheat.
- Whole-crop forage and grain yield of triticale is similar to or greater than that of winter wheat but forage and grain quality can be lower. In particular triticale is susceptible to pre-harvest sprouting.

Main results:

Triticale can produce grain yields comparable to or better than winter wheat under Irish conditions but grain quality can be lower.

The majority of currently available cultivars are prone to pre-harvest sprouting.

Triticale can outyield winter wheat in take-all situations in the absence of Latitude seed treatment but still responds to the application of Latitude.

Triticale can achieve forage yields higher than that of winter wheat but the feeding value can be lower. Triticale has a lower response to fungicide dose than wheat suggesting that lower fungicide inputs are required.

Collaborating Institutions:
None

Teagasc project team:
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External collaborators:
None

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Technology

Opportunity/Benefit:

While triticale has the potential to give higher grain yields than winter wheat, often with a reduced requirement for fungicides, pre-harvest sprouting can reduce the value of triticale grain produced.

Triticale can be used as a source of whole-crop forage, or for crimping of immature grain, which avoids issues with pre-harvest sprouting.

Triticale is particularly suited to sites where there is a high risk of take-all as it can outperform winter wheat but will give economic responses to Latitude seed treatment in these situations.

The results have been incorporated into Teagasc advisory recommendations for triticale production.

1. Project background:

Triticale, the product of a cross between rye and wheat, could have the potential to reduce unit production costs of grain in Ireland in certain circumstances. It has greater disease resistance than wheat and is also thought to be more suited than wheat to lighter and more marginal soils and to take-all prone sites. There is increasing grower interest in triticale. However, very little research has been carried out on the agronomy of triticale under Irish conditions. This project aimed to study aspects of triticale production, including seeding rates, fertiliser N inputs, suitability to take-all prone sites relative to wheat and its response to fungicide. Its suitability as a whole-crop forage and the potential of new varieties were also examined.

2. Questions addressed by the project:

How does grain yield and quality of triticale compare to that of winter wheat in productive soils in Ireland? Is triticale less susceptible to take-all than winter wheat?

Does triticale respond to Latitude seed treatment?

How does the whole crop forage yield of triticale compare to that of winter wheat? Does triticale need less fungicide than winter wheat?

Does triticale have a lower N requirement?

3. The experimental studies:

A range of field trials were carried out between 2005 and 2007 at Oak Park Research Centre. Trials compared the grain yield and forage yield of winter triticale with that of winter wheat grown with the same input levels. Trials also compared the response to fungicide and fertilizer N inputs of winter triticale compared to winter wheat, and the response to Latitude seed treatment of triticale and wheat. A comparison of the agronomic characteristics of a range of new varieties as well as trials comparing the effect of seed rate on triticale yield was also carried out. Trials were for the most part carried out on productive, moisture retentive soils.

4. Main results:

Winter sown triticale has the potential to produce significantly higher forage and grain yields compared to winter wheat under Irish conditions. This yield advantage of triticale occurred even on deep moisture retentive, productive soils. However both forage quality, as indicated by the proportion of grain present in the forage, and grain quality, as indicated by hectolitre weight, of triticale can be lower than that of winter wheat. The forage quality of triticale could be increased by increasing the cutting height thereby reducing the amount of straw in the whole-crop silage. When pre-harvest conditions were poor grain quality of triticale can be further compromised by pre-harvest sprouting.

A comparison of a range of seed rates suggested that the optimum seed rate for winter sown triticale was similar to that recommended for winter wheat (250–400 seeds/m^2 depending on soil conditions at sowing). When grown in high take-all risk slots (second cereal after a break crop) triticale had the potential to significantly outyield winter wheat where seed treatments effective against take-all were not used. However, despite its lower susceptibility to take-all, triticale still gave an economic response to treatment with Latitude seed treatment when grown in a high take-all risk slot.

Comparison of the response to fertilizer N of winter triticale and winter wheat suggested that grain yield of both responded similarly to fertilizer N. This suggests that fertilizer N recommendations for winter wheat can be used for winter triticale. However there is a greater risk of lodging with triticale as the rate of fertilizer N applied increases and therefore where a cultivar susceptible to lodging

is being grown fertilizer N inputs to triticale should be reduced by ~10% compared to what would be recommended for winter wheat in a similar situation.

Triticale gave a lower response to fungicide (comparing no fungicide with half-rate fungicide input) than winter wheat cultivars with which it was compared, even when compared to wheat cultivars with a high degree of disease resistance. It generally gave no response to increasing fungicide inputs from approximately half label rate to full label rate. If the area of triticale grown was to increase significantly fungal disease may become more prevalent on the crop and fungicide requirements may then need to be reevaluated.

A comparison of a range of new varieties suggested that there was considerably variability between varieties in terms of grain yield, height and lodging resistance. Varieties with relatively short stiff straw with good yielding ability could be identified. However in a poor harvest year all varieties were susceptible to pre-harvest sprouting, which remains a significant deterrent to the use of triticale as a grain crop under Irish conditions. Before triticale is grown on a larger area an ongoing and more rigorous evaluation of cultivars would be required.

5. Opportunity/Benefit:

The results will support growers and their advisers in the decision making process regarding various aspects of triticale cultivation in Ireland. It will allow more efficient production of triticale whole-crop silage and provides an overview of the potential risks associated with triticale grain production in Ireland.

6. Dissemination:

Hackett, R. and Burke, J.I. (2004) Potential for Triticale in Low Cost Production Systems. Proceedings National Tillage Conference pp88–102 Teagasc, Carlow.

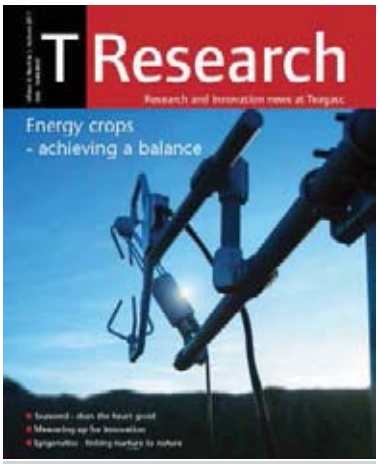
Hackett, R. 2006 Investigations into aspects of the agronomy of triticale under Irish conditions. Oak Park Crops Research Centre Research Report 2006 pp 32–33.

Hackett, R. 2007 Investigations into aspects of the agronomy of triticale under Irish conditions. Oak Park Crops Research Centre Research Report 2007 pp 16–17.

Experiments with triticale were regularly exhibited during open days and farmer visits to Oak Park Research Centre during the course of the project.

Results have been incorporated into Teagasc advisory recommendations for triticale production.

Assessing the greenhouse gas budget of biomass and biofuel crops



The field-scale CO_2 eddy covariance monitoring equipment at Johnstown Castle, Wexford

Project number:
5801
Date:
August, 2012
Funding source:
DAFM 07 R&D 527
Project dates:
Oct 2007– Mar 2012

Key external stakeholders:

- Farmers/bioenergy producers
- Department of Agriculture, Food & the Marine
- Environmental Protection Agency

Practical implications for stakeholders:

This research demonstrates that perennial biomass crops have a large greenhouse gas (GHG) mitigation potential. The can offset between 12–15 tonnes CO_2 per hectare per year (t CO_2 ha^{-1} yr^{-1}) as well as playing a vital role in displacing fossil fuel emissions.

- **Farmers/bioenergy producers:** This research demonstrates that perennial biomass crops have a much higher GHG efficiency (and lower C footprint) compared to conventional annual crops used for biofuel production (OSR, maize etc). It quantifies the offsetting potential that would be required for growers to obtain credits in the event of any domestic offsetting scheme.
- **Policymakers:** This research demonstrates that land-use change to biomass production has the potential to become a significant component to meeting future Greenhouse Gas (GHG) targets.
- **Scientific:** This research quantifies the nitrous oxide and soil organic carbon balance associated with miscanthus and reed canary grass cultivation in Ireland for the first time and is one of only a handful of studies worldwide.

Opportunity:

The research clearly shows that the establishment of biomass crops is beneficial in terms of overall Greenhouse Gas balance compared to grassland.

Collaborating Institutions:
Trinity College Dublin
University College Dublin,
University of Cambridge

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Technology

Main results:

Winter cover crops, straw incorporation and minimum tillage were all observed to reduce soil organic carbon (SOC) loss, with cover crops the most effective and minimum tillage the least effective individual measure. Nitrous oxide emissions were highest for straw incorporation but were lower than the increased carbon sequestration delivered. Combinations of strategies were found to be additive and had the highest carbon sequestration levels.

1. Project background:

Legislation demands that energy policy and climate change goals are closely aligned. The EU Climate and Energy Package has set twin goals of both a 20% *increase* in renewable energy production and a 20% *decrease* in greenhouse gas (GHG) emissions by 2020. Meeting both these targets will involve a large element of land-use change and as 90% of agricultural land is grassland, the most likely scenario is that biomass/biofuel cultivation will be at the expense of grassland. Associated with this land-use change will be an alteration in GHG emissions. Biomass currently accounts for almost two-thirds of the total renewable energy and 18% of renewable electricity in Europe. At a national level, the three peat burning power stations are required to adopt 30% co-firing by 2015. However, the total land area under biomass production is currently less than 3,000 hectares, the majority of which is miscanthus.

Land-use change to biomass production can contribute towards meeting both national and international renewable energy and emissions targets. Already, land-use change to forestry (LULUCF) offsets almost 1.5 million tonnes of emissions per annum and the conversion of pasture or annual cropland to perennial biomass crops and/or short rotation coppice (SRC) also has the potential to become a significant component to meeting future Greenhouse Gas (GHG) targets. However, realisation of this mitigation potential is dependent on a) the conversion of a substantial portion of land to biomass, b) selection of suitable crop types, c) development of reliable combustion systems, and d) rigorous measurement of emissions and carbon sequestration during cultivation.

2. Questions addressed by the project:

This project assessed the impact on GHG emissions of changing from intensive pasture and marginal grassland to biomass crops, particularly:

- What is the impact of on soil carbon stocks of converting a grassland system to a perennial biomass crop (miscanthus), an intermediate perennial crop (canary grass – *Phalaris* spp.), and annual crops (oil seed rape, maize)?
- What is the impact of land conversion on nitrous oxide (N_2O) emissions?

3. The experimental studies:

The impacts of establishing miscanthus and reed canary grass (RCG) were studied by ploughing and cultivating four hectares of permanent pasture on a well to moderately drained brown earth soil at Johnstown Castle, Wexford. Measurements were made prior to, during and after establishment on two miscanthus fields and two RCG fields, with each field approximately one hectare in area, over a three year period. Grassland fields were also monitored as a control. In order to investigate the impacts of annual crop cultivation, emissions were also measured from maize plots (1.5 ha) at Johnstown Castle and Oil Seed Rape (OSR) plots at Ballycarney, Co. Wexford.

Field-scale measurements of carbon dioxide (CO_2) uptake and release were measured by the eddy covariance technique. This technique enabled the measurement of CO_2 and water fluxes at a one hectare scale. Soil respired carbon and nitrous oxide emissions were also measured before and after cultivation using static chambers, where emissions were calculated as the increase in gas concentration over time.

The Net Carbon Balance of the system was defined as:

$$\textbf{Net Carbon Balance} = \mathbf{P} - (\mathbf{R}_{eco} + \mathbf{C}_{export})$$

where **P** is amount of carbon taken up by the crops during photosynthesis, $\mathbf{R}_{eco}$ is the carbon released by the soil and plants and $\mathbf{C}_{export}$ is the carbon removed in grain and straw from the field at harvest. The difference between **P** and the sum of $\mathbf{R}_{eco}$ and $\mathbf{C}_{export}$ is the net carbon remaining in the soil.

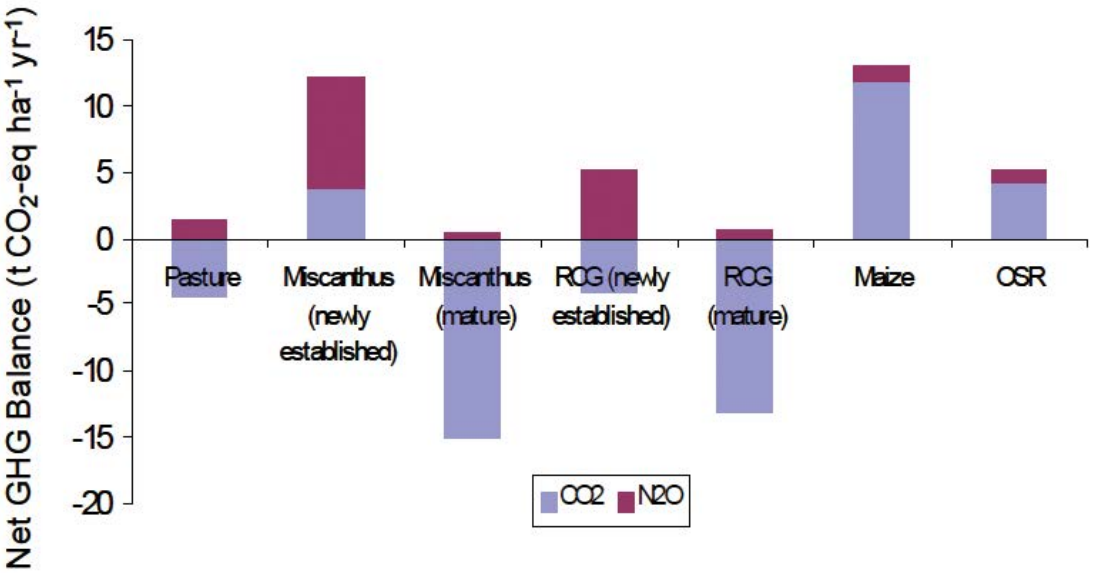

Figure 1: Net greenhouse gas (GHG) balance of various land-uses. Negative values indicate GHG uptake and positive values GHG emissions.

4. Main results:

The impact of ploughing of permanent pasture

Most of this carbon loss during pasture conversion to other land-uses is assumed to be associated with both ploughing and extended fallow period, with losses of over 10 t ha^{-1} of CO_2 being associated with pasture conversion. However, our measurements demonstrated that the initial C loss after ploughing was much lower (20–100 kg ha^{-1} of CO_2) and that total site preparation carbon losses could be limited to 2 t ha^{-1} of CO_2 – provided the fallow period is minimised. However, nitrous oxide emissions associated with pasture conversion were found to be considerable at 18 kg ha^{-1} yr^{-1} of N_2O-N. As N_2O is 296 times more potent a GHG than CO_2, this corresponded to 5.3 t ha^{-1} of CO_2 equivalents. This high level of emissions was probably due to mineralisation of high levels of soil organic N in the grassland upon ploughing.

Carbon Sequestration and Nitrous oxide Emissions

Pasture was observed to sequester 4.4 t ha^{-1} yr^{-1} of CO , with nitrous oxide emissions emitting 1.5 t ha^{-1} yr^{-1} of CO_2 equivalents (Figure 1). This resulted in net GHG uptake of 2.9 t ha yr^{-1} of CO_2. In contrast, annual crops (maize and OSR) were net GHG sources, with the majority of these losses associated with soil carbon loss. Upon conversion, miscanthus was observed to be a large net GHG source (t ha^{-1} yr^{-1} of CO_2), with most of this due to N_2O release. Miscanthus also established slowly, with growth energy directed into the rhizome for the first two years. However, these emissions lasted for only one year, with miscanthus being carbon neutral in the second year after establishment and by the third year, miscanthus stands had matured and were strong GHG sinks (–14.6 t ha^{-1} yr^{-1} of CO_2). This was due to both a very high leaf area index by year 3 and high N use efficiency, resulting in low N_2O emissions as only 80 kg ha^{-1} of N was required for fertilization. Indeed, this sink should increase and reach a maximum within the next 3–6 years.

Reed canary grass (RCG) established more quickly, and even though it was still a net source of over 1 t ha^{-1} yr^{-1} of CO_2 , the net CO_2 uptake was high and was similar to that of grassland. The large N_2O emissions associated with ploughing were also somewhat ameliorated by higher sward N utilization. In subsequent years, RCG exhibited large GHG uptake (–12.5 t ha^{-1} yr^{-1} of CO_2) although these values were lower than miscanthus. RCG also requires re-establishment every six years and so will not be as large a sink during its lifespan. However, it provides high yields even on wet marginal land and may provide a biomass solution in these areas.

5. Opportunity/Benefit:

The primary stakeholders for this research are both farmers and policy makers. This research demonstrates that while annual biofuel crops have a poor field GHG balance, perennial biomass crops had very high rates of CO_2 sequestration and low N_2O emissions. This may provide agriculture with a strategy to 'offset' emissions during cultivation of these crops as well as displacing fossil fuels emissions during combustion.

6. Dissemination:

Awareness of the project and relevant results were, and continue to be disseminated via scientific peer-reviewed journals as well as the popular press and media.

Main publications:

Journal article:

Kromdijk, J., Schepers, H.E., Albanito, F., Fitton, N., Carroll, F., Jones, M.B., Finnan, J., Lanigan, G.J., Griffiths, H. (2008) "Bundle Sheath Leakiness and Light Limitation during C4 Leaf and Canopy CO_2 Uptake.' *Plant Physiology* 148: 2144–2155

Don, A., Osborne, B.A., Hastings, A., Skiba, U., Carter, M.S., Drewer, J., Flessa, H., Freibauer, A., Jones, M.B., Lanigan, G.J., Mander, U., Monti, A., Valentine, J., Walter, T., Zenone, T. (2012) Land-use change to bioenergy production in Europe: implications for the greenhouse gas balance and soil carbon. *Global Change Biology-Bioenergy* 4: 372–391

Willems, A.B, Augustenborg, C.A., Hepp, S., Lanigan, G.J., Hochstrasser, T., Kammann, C., Müller, C. (2011) Carbon dioxide emissions from spring ploughing of grassland in Ireland. Agriculture Ecosystems & Environment 144 : 347–351

Technical:

Lanigan, G.J. and Finnan, J. (2010) *Energy crops and greenhouse gases.* Carlow, Teagasc.

Conference:

Otero, S., Lanigan, G.J. and Osborne, B.A. (2009) 'Future Climatic Conditions for Irish Energy Crops: Friend and Foe?' *IPSAM Proceedings 6–7 June 2011* Trinity College Dublin

Otero, S., Marsh, D., Lanigan, G.J., and Osborne, B.A. (2011) 'Effects of simulated climate change over energy crops in Ireland' *Geophysical Research Abstracts EGU,* Vienna 3–8 April 2011

Lanigan, G, Finnan, J., Fealy, R. and Jones, M. (2010). 'Growing returns: the role of land-use change in influencing GHG emissions.' *Proceedings of A Climate for Change Conference* Dublin 24–25 June. Conference Book of Abstracts

Popular publications:

Lanigan, G.J., NiChoncubhair, O. and Krol ,D. (2011) 'Energy Crops – Achieving a Balance' *TResearch* 6 (3): 12–14

Drivetime April 2010–Discussion with Mary Wilson and Prof. John Sweeney on RTE Drivetime

Crops Environment & Land Use Programme

Assessing the greenhouse gas budget of tillage mitigation options for arable systems.

Project number:
5802
Date:
August, 2012
Funding source:
DAFM 07/R&D/528
Project dates:
Oct 2007– Apr 2012

Key external stakeholders:

- Arable farmers
- Department of Agriculture, Food & Fisheries
- Environmental Protection Agency
- Eddy covariance system for field CO_2 measurement

Practical implications for stakeholders:

This research demonstrates the impact of minimum tillage, straw incorporation and cover cropping on greenhouse gas emissions (GHG) and soil organic carbon (SOC) compared to conventional inversion ploughing in arable systems. The study demonstrates that a combination of reduced tillage combined with cover crops is the most effective strategy at conserving SOC.

- **Farmers:** This research demonstrates that minimum tillage, particularly in combination with straw incorporation and/or cover cropping can significantly reduce soil organic carbon loss in arable systems. In addition, it can significantly reduce the C footprint of cereals.
- **Policymakers:** This research has quantified the abatement benefits of adopting minimum tillage and/or promoting green winter cover. Results are also feeding into a revision of the national greenhouse gas inventories.
- **Scientific:** This research quantifies the nitrous oxide and soil organic carbon losses associated with alternative cultivation techniques for the first time in Ireland.

Collaborating Institutions:
Trinity College Dublin
University College Dublin
University of Aberdeen

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Technology

Opportunity:

The research clearly shows the advantages of altered cultivation techniques for reducing soil organic carbon (SOC) loss as well as their impact on nitrous oxide emissions.

Main results:

Winter cover crops, straw incorporation and minimum tillage were all observed to reduce soil organic carbon (SOC) loss, with cover crops the most effective and minimum tillage the least effective individual measure. Nitrous oxide emissions were highest for straw incorporation but were lower than the increased carbon sequestration delivered. Combinations of strategies were found to be additive and had the highest carbon sequestration levels.

1. Project background:

Food Harvest 2020 envisages increased profitability from the tillage sector whilst simultaneously enhancing the sustainability of production. In particular, the Food Harvest 2020 Report identified reducing the greenhouse gas (GHG) intensity of agricultural activities and enhancing carbon sinks as key to maintaining sustainability. Strategies to reduce agricultural GHG's are urgently required, particularly in light of EU 2020 Climate and Energy Package and its associated Burden-sharing agreement, where Ireland has been set a 20% reduction target for its non-Emission Traded Sectors. In addition, revisions of the Good Agricultural and Environmental Conditions (GAEC) for the tillage sector are expected to focus on reducing soil carbon losses associated with cultivation.

2. Questions addressed by the project:

This project had two principle research goals.

- What are the effects of minimum tillage on GHG balance at a field scale?
- What are the effects of crop residue incorporation and cover crops on GHG emissions and carbon sequestration?
- What are the effects of these strategies in terms of life-cycle analyses for crops at a farm scale?

3. The experimental studies:

Minimum Tillage, Straw Incorporation and Cover Crops: A series of experiments were carried out on Spring Barley systems in order to assess the individual and combined effects of minimum tillage, straw incorporation and cover cropping on soil organic carbon and nitrous oxide emissions compared to conventional inversion-ploughing cultivation systems. In all treatments, minimum tillage was defined as a non-inversion till to 15cm, with straw incorporation involving all straw post-harvest incorporated to a depth of 15cm. Cover crops (mustard) were sown within two weeks post harvest (early September), sprayed off the following February, with the dead biomass incorporated into the soil during ploughing or minimum tillage in March.

The difficulty with measuring soil organic carbon changes is that they occur over a long time-scale. So two approaches were taken:

a) **The flux measurement and modelling approach:** The Net Carbon Balance of the system was defined as:

$$\textbf{Net Carbon Balance} = \mathbf{P} - (\mathbf{R}_{eco} + \mathbf{C}_{export})$$

where **P** is the amount of carbon taken up by the crops during photosynthesis, $\mathbf{R}_{eco}$ is the carbon released by the soil and plants and $\mathbf{C}_{export}$ is the carbon removed in grain and straw from the field at harvest. The difference between **P** and the sum of $\mathbf{R}_{eco}$ and $\mathbf{C}_{export}$ is the net carbon remaining in the soil. Field-scale measurements of carbon uptake and release were measured by the eddy covariance technique. Soil respired carbon and nitrous oxide emissions, following ploughing and fertilizer application, were also measured using static chambers, where emissions were calculated as the increase in gas concentration over time. These measurements were subsequently used to validate process models which simulate the carbon and nitrogen cycle.

b) **Measurement of soil carbon from long-term trials:** The soil organic carbon content (SOC) of long-term (nine-year old) winter wheat minimum tillage trials (with and without straw incorporation) was compared to soil carbon stocks from inversion-ploughed winter wheat trials. In addition, SOC from long-term cover crop trials were also measured.

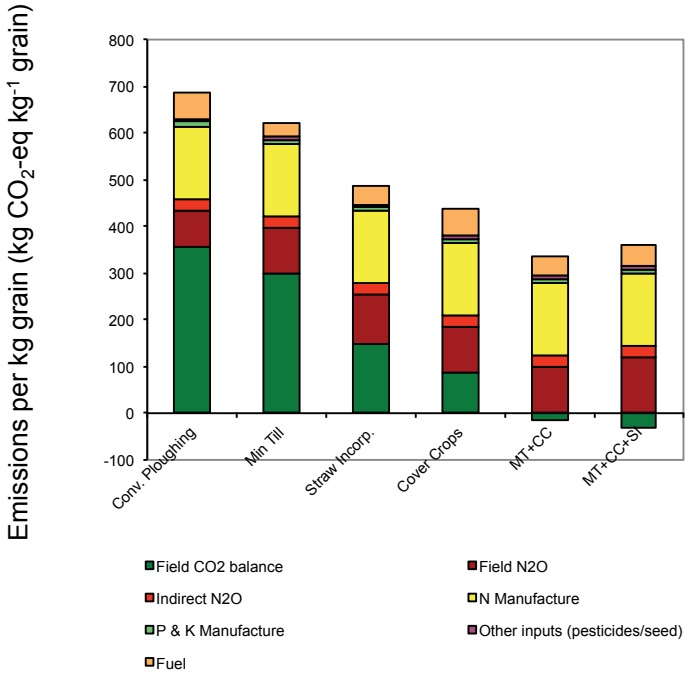

Figure 1: Carbon footprint (kg CO_2–equivalents kg^{-1} grain) for spring barley cultivated using conventional ploughing, minimum tillage, ploughing + straw incorporation, ploughing +cover crops, minimum tillage + cover crops and minimum tillage + straw incorporation + cover crops.

Life-Cycle Analysis: A life-cycle analysis was performed in order to assess the impact of the above mitigation options on the carbon footprint (also known as Emissions Intensity) of arable systems. The carbon footprint is defined as **kg CO_2–equivalent emissions / kg production yield**. The analysis was performed at a farm gate level. The boundary of the analysis included on-farm emissions (soil carbon, direct and indirect nitrous oxide emissions, and fuel usage. It also included so-called 'up-stream' emissions which comprise of N, P and K fertilizer manufacture as well as herbicide/pesticide manufacture. As the analysis ended at the farm gate, no downstream emissions such as transport to processors or energy used for grain drying were included. All emissions were expressed as kg CO_2 equivalents.

4. Main results:

Using annual flux measurements, spring barley fields cultivated using minimum tillage were observed to sequester more carbon compared to conventionally ploughed fields by an average of 0.3 tonnes C ha^{-1} yr^{-1}. However, there was considerable year-to-year variation, ranging from 0–0.7 tonnes C ha^{-1} yr^{-1}. Measurements of soil organic carbon stocks on long-term (~9 years) winter wheat trials revealed that minimum-tilled plots sequestered 0.18 t C ha^{-1} yr^{-1} in the top 15 cm of soil compared to minimum-tilled plots, mainly due to reduced rates of decomposition. Minimum tillage was observed to have only a small effect on N_2O, with emissions increasing by 0.049 tonnes C-equivalent ha yr^{-1} (note that N_2O is expressed as carbon equivalents as this gas is 296 times more potent as a greenhouse gas than CO_2).

Straw incorporation was observed to increase SOC content by 0.44 t ha^{-1} yr^{-1} of C. This meant that 21% of the incorporated straw was sequestered into the soil. However, N_2O emissions increased by 0.14 tonnes C-equivalents, offsetting some of these gains. This was due to the release (as N_2O) of some of the N within the straw, as well as changes in water-holding capacity of the soil. When minimum tillage and straw incorporation were combined, the effects appeared to be additive, with sequestration increasing by 0.6 t ha^{-1} yr^{-1} of C.

Winter cover crops (mustard) were effective as they limited C loss during the fallow period. The duration of the fallow period was observed to be the principle driver of annual C balance. Values of carbon sequestration derived from annual fluxes and from SOC stocks from long-term trials were similar at 0.51 t ha^{-1} yr^{-1} of C. There was no discernible effect on N_2O emissions as any increase in soil N availability was reduced due to decreased winter N loss. The combination of cover crops and minimum tillage

increased sequestration rates to circa. 0.7 t ha^{-1} yr^{-1} of C This was significant as it converted the arable system from a carbon source to a net carbon sink. However, the combination of minimum tillage, straw incorporation and cover crops did not yield much extra benefit in terms of C sequestration (0.74 t ha^{-1} yr^{-1} of C) but did increase N_2O emissions (0.2 tonnes C-equivalent ha^{-1} yr^{-1}). The combination of all three strategies is also not economically sustainable without incentives as it meant that fuel savings associated with minimum tillage were greatly outweighed by loss of income on straw as well greater input costs for cover crops (mustard seed, sprays and associated ground preparation).

Impact on carbon footprint. Altered cultivation techniques had a significant impact on the carbon footprint of spring barley systems, once soil organic carbon was included in the analysis. In all analyses, soils carbon, field nitrous oxide, and N fertilizer manufacture emissions from were the dominant emission sources (Figure 1). Minimum tillage had a marginal impact on soil C emissions but also reduced fuel emissions significantly. Both straw incorporation and cover crops impacted greatly on soil C loss but less on other emissions. When minimum tillage and cover crops (MT+CC) were combined, this halved the C footprint and resulted in the field absorbing CO_2. However, The combination of all three strategies marginally increased the C footprint compared to MT+CC. This was due to higher nitrous oxide emissions as well as higher fuel and herbicide/pesticide usage.

5. Opportunity/Benefit:

The primary stakeholders for this research are both farmers and policy makers. This research demonstrates the effectiveness of changing cultivation techniques in order to reduce soil carbon loss. In particular, it demonstrates that altering cultivation technique can reduce and indeed reverse C loss as well as significantly reducing the C footprint of cereal production.

6. Dissemination:

Main publications:

Journal Article:

Davis, P. A., Clifton Browne, J., Saunders, M., Lanigan, G., Wright, E., Fortune, T., Burke, J., Connolly, J., Jones, M. B. and Osborne, B. A. (2010). 'Assessing the effects of agricultural management practices on carbon fluxes: spatial variation and the need for replicated estimates of net ecosystem exchange.' *Agricultural and Forest Meteorology* 150: 564–574.

Conference:

Lanigan G. (2009) The carbon balance of European croplands: the influence of gross primary production during non optimal growth periods *Irish Plant Scientists Annual Meeting Proceedings. April 2009, UCD, Dublin* 4.

Benefits of agronomic plant diversity in forage mixtures

Project number:
5583
Date:
July, 2011
Funding source:
Teagasc
Project dates:
Aug 2006–Dec 2010

Key external stakeholders:

- Policymakers
- Participants in agri-environment schemes
- Extensive farmers
- Environmental NGOs

Practical implications for stakeholders:

Modest increases in sward diversity to four-species mixtures can increase yield and reduce weed invasion, compared to monocultures. These results are applicable to nitrogen fertiliser applications of about 200 kg ha^{-1} yr^{-1} of nitrogen per annum.

Main results:

Four-species grassland mixtures generally provided greater yield than monocultures. Mixtures consisted of perennial ryegrass, timothy, red clover and white clover. Beneficial effects of sward diversity occurred across nitrogen levels of 50 and 200 kg ha^{-1} yr^{-1}. On average, the beneficial effect on yield due to increased sward diversity at 50 kg ha^{-1} yr^{-1} was comparable in magnitude to the addition of 150 kg ha^{-1} yr^{-1}. Compared to monocultures, mixtures greatly reduced the biomass of weeds in the sward.

Opportunity/Benefit:

The use of simple agronomic mixtures with legumes offers potential further investigation of their contribution to ecosystem services from agricultural ecosystems, such as soil carbon sequestration, and mitigation of greenhouse gas emissions through the ability of legumes to fix atmospheric nitrogen. These may be options for future greening measures.

Collaborating Institutions:
UCD

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1. Project background:

Recent ecological research provides evidence that an increased number of plant species in semi-natural grasslands is strongly associated with increased biomass productivity, and provides a wide range of other ecosystem benefits. This suggests that increases in species diversity in agricultural ecosystems may similarly lead to increased benefits.

Traditionally, agronomic science suggests that, compared to more species-rich mixtures, species-poor mixtures or even monocultures of high-yielding species will maximise yield under productive and highly fertilised conditions. Although the maximisation of yield is often the dominant reason for use of monocultures, other advantages of agricultural monoculture systems include the synchronisation of farm management and the simplified harvesting associated with a single crop type. Both the increasing cost of nitrogen fertiliser and agri-environmental legislation are causing a re-evaluation of the use of fertiliser nitrogen on farms and a search for lower-cost and environmentally compliant alternatives. Forage legumes offer the potential to lower fertiliser costs on farms and may offer a more sustainable option for pasture-based production, not just economically but also in terms of other environmental impacts. Whether increased crop diversity in species-poor agronomic systems could improve the provision of ecosystem services remains largely untested due to the rarity of multi-species agronomic experiments that use more than two species.

2. Questions addressed by the project:

The main objectives were:

- Do mixtures provide more yield than monocultures?
- If so, can mixtures maintain the yield benefit across different levels of nitrogen?

3. The experimental studies:

A field experiment was used to investigate the objectives. Main plots (n=56) were laid out (8.1 m × 4 m) and sown in mid-September 2006 with communities of four commonly used agronomic grassland species (*Lolium perenne* cultivar cv. Lacerta; *Phleum pratense* cv. Motim; *Trifolium pratense* cv. Merviot; *Trifolium repens* cv. Milo). Sowing proportions of these four species were systematically varied according to a simplex design giving 25 distinct communities: four monocultures, six binary mixtures (50:50) and 15 four-species mixture communities. The four-species mixtures consisted of four communities dominated in turn by one species (88:4:4:4), four communities dominated in turn by one species (70:10:10:10), six communities co-dominated in turn by two species where (40:40:10:10) and one community where all four species were equally represented (25:25:25:25) All communities were sown at two levels of initial overall community biomass based on seed weight. Main plots were divided into four equally sized sub-plots. Split-plot treatments consisted of two levels of nitrogen (approximately 50 and 200 kg ha^{-1} yr^{-1} of nitrogen) and two levels of cutting severity at harvest (7 cm and 2 cm) in factorial combination.

Plots were harvested by mowing. Wet conditions over all three years limited harvesting to three occasions in 2007 and 2009 (spring, summer and autumn) and two in 2008 (late spring and late summer).

4. Main results:

Aboveground biomass was 16.5% higher in mixtures than in monocultures while weed biomass was reduced in mixtures by up to 99%. The effect of increased plant diversity (including legumes) was at least as big as the effect of adding 150 kg ha^{-1} yr^{-1} of nitrogen. The nitrogen content of biomass yield depended on the type of species and was increased by species richness. An increase in community evenness was associated with a decrease in the variation of biomass; thus, sward evenness conferred greater stability of biomass yield. Overall, effects of species interactions were positive and equivalent, leading to an evenness-driven effect of diversity on aboveground yield. Application of nitrogen fertiliser affected species differentially, and increased grass biomass but not legume biomass. Diversity effects remained stable until the third year, when community composition became dominated by *Phleum pratense*. Cutting had an overall negative effect on biomass but did not influence diversity effects. Mixtures had significantly lower weed biomass than monocultures.

5. Opportunity/Benefit:

These results signal the merit of further investigation of the contribution of simple agronomic mixtures to soil carbon sequestration, and mitigation of greenhouse gas emissions through the ability of legumes to fix atmospheric nitrogen.

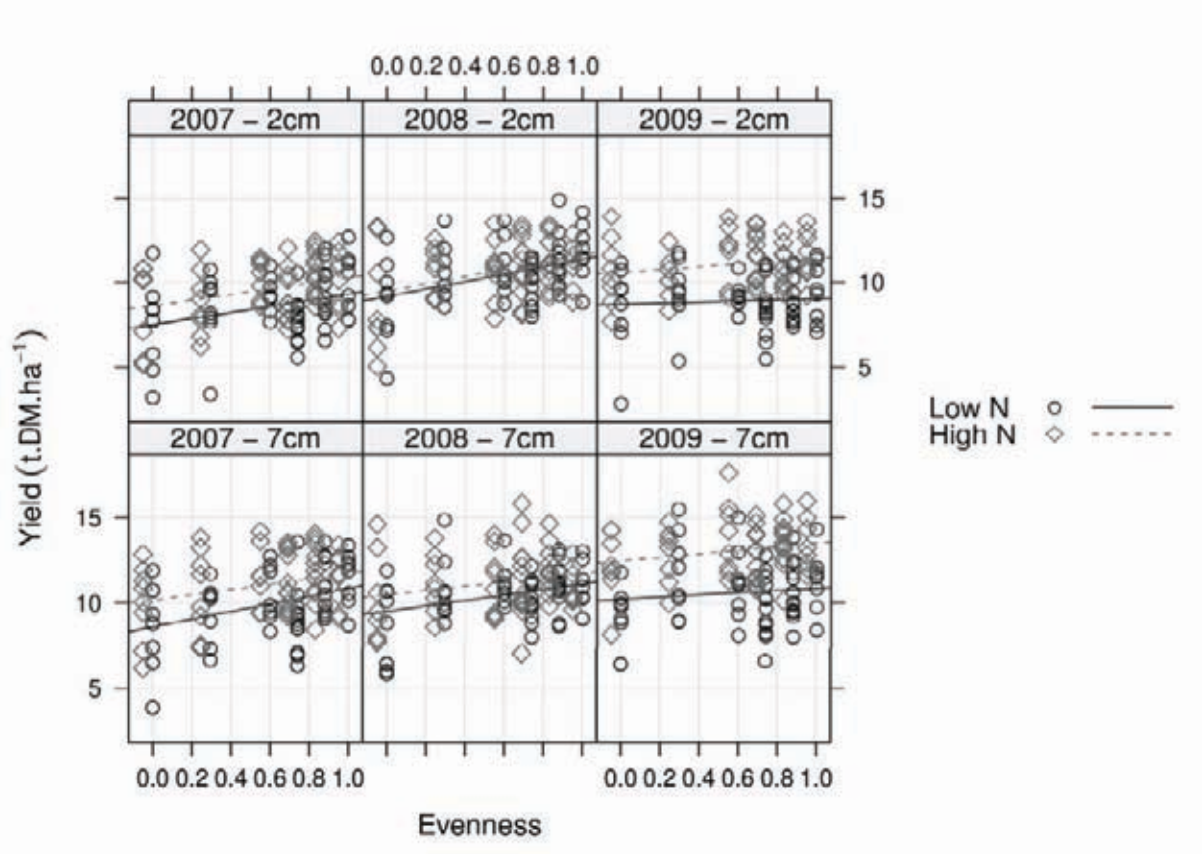

Figure 1 Effect of nitrogen level and evenness on aboveground biomass (tonnes per hectare of dry matter) across each year and cutting treatment (cutting to 2 cm height in top panels, and cutting to 7 cm height in bottom panels). Regression lines show the relationship between sward evenness and yield. Highest evenness value =1 corresponds to the equal mixture of all four species; evenness value = 0 corresponds to the average of the four monoculture species.

6. Dissemination:

This work was presented at a number of Open Days and visits by national and international groups of farmers to Johnstown Castle. It was also presented at several national and international conferences, as follows: Irish Plant Scientists' Association Meeting in 2008; Agricultural Research Forum in 2008 and 2009; Irish Environmental Researchers Colloquium in 2007, 2008 and 2009; Joint Meeting of the 21st International Grassland Congress and the 8th International Range-land Congress in 2008; the British Ecological Society Annual Meeting in 2007 and 2008.

Main publications:

Finn J.A., Carnus T., Kirwan L., Cuddihy A. and Connolly J. (2009) 'Four-Species Mixtures Enhanced Yield at Low and High Levels of Nitrogen Addition Over Two Years' *Irish Journal of Agricultural and Food Research* 48: 272.

Connolly J., Bell T., Brophy C., Carnus T., Finn J., Kirwan L., Lüscher A., Sebastia M.T. and Weigelt A. (2010) Multi-Species Mixtures – New Perspectives on Models and Mechanisms. *Proceedings of 23rd General Meeting of the European Grassland Federation*, Kiel, Germany, 782–784

Popular publications:

Carnus, T., Finn, J.A., Kirwan, L., Cuddihy, A. and Connolly, J. 2009. Benefits of Sward Diversity in Productive Grassland Systems. In: *Ireland's Rural Environment: Research Highlights from Johnstown Castle*. Teagasc, pp 98–99, ISSN 1841705438.

Carnus, T., Finn, J.A., Kirwan, L. and Connolly, J. (2007). Does Plant Diversity Stabilise Ecosystem Function? In: *Ireland's Rural Environment: Research Highlights from Johnstown Castle*. Teagasc, p. 85, ISSN 18 4170 4776

Project number:
5757
Date:
August, 2010
Funding source:
Teagasc
Project dates:
Mar 2009–Jan 2010

Monitoring the environmental impacts of the Rural Environmental Protection Scheme: a scoping study

Key external stakeholders:

Policymakers, participants in agri-environment schemes, extensive farmers and environmental NGOs.

Practical implications for stakeholders:

To date, Ireland has not implemented a national-scale, comprehensive monitoring programme to measure the environmental impacts of REPS. There will be increasingly demanding requirements to demonstrate the environmental effectiveness (and especially biodiversity benefits) of agri-environment schemes. This desk study aimed to support decision-making about the appropriate design and implementation of an environmental monitoring programme for Irish agri-environment schemes.

Main results:

- The majority of REPS payments are now directed toward measures, supplementary measures and options with biodiversity objectives. These should be highest priority for investigation and validation of their environmental effectiveness.
- Environmental monitoring of selected REPS measures, supplementary measures, biodiversity options and Measure A is estimated to cost about €3.4 million over a 4-year period. The average annual budget for the monitoring programme (~€0.86m) would be about 0.25% of recent annual expenditure on REPS.
- There is strong overlap in the identity of measures between REPS and the new AEOS agri-environment scheme implemented in 2010. Thus, an assessment of the environmental impacts of REPS could be used to more quickly measure the environmental effectiveness of similar measures that are implemented in the AEOS (or future schemes with the same measures).

Collaborating Institutions:
n/a

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External collaborators:
n/a

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- Demonstration of the environmental impacts of both the REPS and AEOS is important for the long-term justification of expenditure on such schemes. Monitoring can identify benefits, but it can also help identify and rectify any weaknesses, and thus help learn to improve the schemes. More importantly, the positive environmental effects of schemes can be identified and communicated to farmers, and to the public that pays for these schemes.

Opportunity/Benefit:

This scoping study indicates possible approaches and related costs of a monitoring programme that could contribute to environmental assessment of REPS, but could be extended to other such schemes. Signals from the post–2013 CAP reform to date indicate that environmental requirements and greening measures may become more prevalent. If so, these will also require validation of their environmental effect, to justify the allocation of CAP budgets toward such greening measures.

1. Project background:

Agri-environment schemes in the EU are now one of the most important policy mechanisms for the protection of public goods, and offer payments to farmers in return for undertaking management practices (measures) that are intended to maintain, enhance or restore the rural environment. REPS has become a widely adopted scheme (over 54,000 participants in 2009), and provides an important financial contribution to farm incomes in Ireland. Since 1994, REPS has paid a total of over €3.1 billion to Irish farmers, and paid over €330 million in 2009.

EU Member States are obliged to monitor and evaluate the environmental, agricultural and socio-economic impacts of their agri-environment programmes (Article 16, EC Regulation No. 746/96). Most of the recent evaluations of AESs have strongly criticised the over-reliance on data on levels of uptake and expenditure as measures of scheme performance. Thus, the environmental performance of many schemes is not clearly known.

A number of different forces are aligning that will likely result in various pressures on agri-environment schemes. These include an increase in the number of EU Member States that will receive funding from the Common Agricultural Policy and Rural Development Programme, increased pressure on EU budgets, and increased pressure on the ability of individual member States to provide co-financing. In addition, the EU Court of Auditors is due to report its audit of the effectiveness of EU agri-environment schemes. The World Trade Organisation (WTO) also requires that the environmental benefits of agri-payments are clearly demonstrated, to prove that such payments are not disguised trade subsidies. At the same time, there are strong suggestions of an increased importance for provision of public goods in the post–2013 CAP, and agri-environment schemes will be an important policy instrument to achieve this (as well as others).

One of the best ways to address these various pressures is to be able to demonstrate the environmental benefits of agri-environment schemes. This highlights the need for measurement of their environmental impact.

2. Questions addressed by the project:

- What is the currently available evidence on environmental performance of the REPS?
- What are the operational issues confronting an environmental assessment?
- What would an outline of a monitoring programme for REPS be?

3. The experimental studies:

The desk study involved an overview (that was not intended to be exhaustive) of available publications relevant to the environmental effectiveness of REPS. Conceptual issues affecting the design and implementation of a monitoring programme were reviewed. The distribution of payments across different environmental objectives of REPS was examined.

A number of REPS options and measures were selected as priorities for inclusion in an environmental assessment programme, and were usually those with highest participation, (as these generally involve greatest expenditure). Aims are suggested for the sampling of each of the measures and options. Several of the measures or options were not included because they have too few participants, or there is already sufficient information available.

4. Main results:

- Overall, the monitoring of selected REPS measures, supplementary measures, biodiversity options and Measure A is estimated to cost about €3.4 million over a 4 year period. The budget estimates are based on Teagasc research cost conventions. The monitoring programme would need to recruit 18 different staff (eight of which would be part-time). The cost of measuring the environmental performance of REPS should be viewed as an investment in securing the future of agri-environment schemes in Ireland.
- There is considerable overlap and similarity between the existing REPS measures and options, and those included in the new Agri-Environment Options Scheme (AEOS) that will replace REPS. Thus, an assessment of the environmental impacts of REPS could be used to more quickly assess the environmental effectiveness of similar measures that are implemented in the AEOS.
- An overview of available publications confirmed the absence of a comprehensive, national-scale study of the environmental impacts of REPS. For selected measures/options, some evidence exists on their likely effectiveness.
- The majority (about 80%) of the REPS basic payment is dedicated toward biodiversity objectives; in addition, supplementary measures and options are dominated by biodiversity issues. Thus, measurement of the effectiveness of biodiversity measures and options should be a priority for environmental monitoring.

5. Opportunity/Benefit:

A report on an audit of the environmental effectiveness of EU agri-environment schemes is expected from the EU Court of Auditors in 2011. This is highly likely to result in increased emphasis on the evaluation and demonstration of the environmental benefits of agri-environment schemes. This scoping study indicates possible approaches and related costs of a monitoring programme that could contribute to environmental assessment of such schemes. Signals from the post–2013 CAP reform to date indicate that environmental requirements and greening measures may become more prevalent. If so, they will also require validation of their environmental effects, to justify the allocation of CAP budgets toward such greening measures.

6. Dissemination:

Main publications:

Finn, J.A. (2010) 'Monitoring the environmental impacts of the Rural Environmental Protection Scheme: a scoping study' End of Project Report, RMIS 5757, Teagasc.

Popular publication:

Finn, J.A., Dunne, L. and Ó hUallacháin, D. (2009) 'Agri-Environment Schemes For The Delivery Of Public Goods: A European Perspective', *TResearch* 4: 28–29.

Efficient and reliable utilisation of nutrients in animal manures

Project number:
5512
Date:
September, 2010
Funding source:
DAFF (RSF 2005)
Project dates:
Jan 2006–Mar 2010

Members of the Project Team and International Steering committee at the Project Conference held in Johnstown Castle Research Centre on 26 November 2009

Key external stakeholders:

Farmers, agricultural contractors, agricultural machinery manufacturers and retailers, fertilizer industry and policy makers.

Practical implications for stakeholders:

This research was conducted to investigate strategies for organic manure application that maximise their nitrogen fertilizer replacement value (NFRV). Application methods and timings for cattle and pig slurry were assessed in grassland and cereal crop systems. The research also studied the logistical issues associated with pig manure by calculating the transport distance required to locate arable spreadlands for pig manure application.

Main results:

- In grassland, cattle slurry application using trailing shoe under optimum weather conditions (spring application) achieved the highest NFRV. Optimising weather conditions through spring application is the most cost effective way to maximise NFRV.
- The target NFRV of 40% for cattle slurry is achievable on grassland, but only under optimal weather conditions and by using high-cost trailing shoe technology. The target of 40% is only achievable when the recovery of N in subsequent years following application is included.
- The target NFRV of 50% for pig manure in cereal crops is achievable where the manure is incorporated into the soil within hours of application.
- The transport distance required to utilise pig manure on tillage crops is highest in northern and western counties. The transport distance is dependent on the willingness of tillage farmers to take manure.

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Technology

Opportunity/Benefit:

- The advice regarding the reliability and precision of using cattle and pig slurries to offset chemical fertilizer requirements has been improved.
- The fertilizer replacement potential of organic fertilizers will be incorporated into future editions of Teagasc's Nutrient Advice publications.
- Managing organic fertilizers more effectively can result in improved nutrient recycling on farms, potentially reducing both fertilizer costs and environmental impacts of nutrient surpluses on farms.
- The results of the project are also relevant to future manure management policy development, and to the development of landspreading methods and technologies.

1. Project background:

The Nitrates Directive regulations impose limits to nitrogen (N) and phosphorus (P) inputs onto livestock and tillage farms. This is having a large impact on both cattle/dairy farms and pig farms.

Cattle and dairy farming systems are required to make more efficient use of nutrients. International experience suggests that significant gains in nutrient efficiency can be made by increasing the utilisation of N in slurry. Data from Teagasc, Johnstown Castle, suggested N-utilisation efficiencies from slurry as low as 5% under existing practices, whereas international literature suggests that there is scope to raise efficiencies to 40–80%. Despite the relatively low utilisation in practice, the Nitrates regulations set an NFRV target of 40%, presenting a considerable challenge for the grassland sector.

In addition, the ceiling to nutrient inputs imposed under the Nitrates Directives made it difficult for many livestock farmers to continue to accept pig slurry as a fertilizer onto their farm. As a result, the potential for the traditional practice of spreading slurry on grasslands has been reduced significantly. Returning pig slurry to arable land allows a more closed nutrient cycle to operate, since cereal grains constitute a significant proportion of the diet of pigs. However, this creates a major logistic challenge where arable land and pig farms are not closely located.

2. Questions addressed by the project:

- What are strategies and methods for the application of cattle slurry to grassland that maximise the NFRV and reduce the variability associated with predicting the nutrient utilisation in the year of application?
- What is the residual effect of cattle slurry applications to grassland on the NFRV in subsequent years?
- What is the fertiliser replacement value of pig slurry applied to cereal crops?
- What are the transport distance implications at a national scale of transporting pig slurry to suitable tillage areas?

3. The experimental studies:

Four separate experimental studies were conducted to address the four project objectives.

A field study was carried out over 3 sites and 3 years to compare the effect application method (splashplate and trailing shoe) and application timing (April and June) on the NFRV of cattle slurry in grassland. This experiment was carried out on field plots using farm-scale slurry application machinery.

A similar study was also conducted to examine the long-term effects of the residual N release from cattle slurry in the years following application. This experiment was carried out on small scale plots and soil cores, and included ^{15}N stable isotope technology to trace the pathways of slurry-N in the soil and plant system over time.

The NFRV of pig manure applied to cereal crops was assessed in a total of 18 field experiments in five separate locations over four years. The field trials compared the grain yield and N uptake in spring barley between chemical N fertilizer and pig manure. Pig manure was applied and incorporated rapidly into the seedbed by ploughing. Yield response curves to fertilizer N with and without pig manure were used to calculate the NFRV of the pig manure.

The fourth part of the project was a desk study of the transport distances required to find arable spreadlands for pig manure. Datasets of land use, road networks and pig farm locations were analysed to calculate the average travel distance required in order for pig manure to be applied to arable land. The analysis facilitated regional comparisons of the average travel distances required.

4. Main results:

The experiments with cattle slurry application on grassland show that the NFRV in the year of application was affected by application method and timing. Cattle slurry applied with splashplate had an NFRV of 21% in April and 12 % in June. Application using trailing shoe increased the NFRV to 30% in April and 22% in June. Changing application timing from summer to spring with existing splashplate machinery is the most cost effective strategy for improving NFRV.

Approximately 4% of the total slurry N applied was recovered in the second year after application. For repeated applications over a number of years, models indicate that the maximum cumulative residual recovery would be 12–14% of the annual slurry N application rate. It would take approximately 10 years of repeated slurry applications for the residual N release to reach this maximum level.

The NFRV target of 40% set in the Nitrates regulations was only achieved when the residual N release was included, and when best practice strategy of trailing shoe application in April was adopted. Spring application of slurry is often restricted by soil trafficability, particularly on poorly drained soils. The trailing shoe application method can provide more flexibility for spring application as grass contamination is reduced compared to splashplate.

The NFRV of pig manure on cereal crops was 50% on average. This is in agreement with the target in the nitrates regulations. However, the NFRV of 50% is only achievable under best practice whereby the manure is incorporated into the soil immediately (< 2 hours) after application. The NFRV of 50% refers to the actual total N content of the pig manure being applied. This can differ from the total N content assumed in the Nitrates regulations. There can be considerable variation in the total N content of all manure types.

In a best case scenario where all arable spreadland was available to receive pig manure, the national per-parcel manure transport distances from pig farms to arable farms was 22 km. This transport distance was increased when the willingness of farmers to use pig manure, and the variation in the P requirements of soils and crops was taken into account. The transport distance varied considerably between regions, and results confirmed expectations concerning counties in the south east and east of Ireland with the average distance to parcel by county well below the modelled national average of 22 km, while counties in the north and west had average travel distances that were far higher.

5. Opportunity/Benefit:

The findings of this project have substantially increased the reliability and precision of using cattle and pig slurries to offset chemical fertilizer requirements and costs in grassland and arable systems. The information generated regarding the fertilizer replacement potential of organic fertilizers has been widely publicised, and will be incorporated into future editions of Teagasc's Nutrient Advice publications. The use of this information in managing organic fertilizers more effectively can result in improved nutrient recycling on farms, potentially reducing both fertilizer costs and environmental impacts of nutrient surpluses on farms. The results of the project are also relevant to future manure management policy development, and to the development of landspreading methods and technologies.

6. Dissemination:

Main publications:

Lalor, S.T.J., Schröder, J.J., Lantinga, E.A., Oenema, O., Kirwan, L. and Schulte, R.P.O. (2011). 'Nitrogen fertilizer replacement value of cattle slurry in grassland as affected by method and timing of application.' Journal of Environmental Quality, 40(2): 362–373.

Hoekstra, N.J., Lalor, S.T.J., Richards, K.G., O'Hea, N., Dungait, J.A.J., Schulte, R.P.O. and Schmidt, O. (2011). 'The fate of slurry-N fractions in herbage and soil during two growing seasons following application.' Plant and Soil, 342: 83–96.

Hoekstra, N.J., Lalor, S.T.J., Richards, K.G., O'Hea, N., Lanigan, G.J., Dyckmans, J., Schulte, R.P.O. and Schmidt, O. (2010). 'Slurry (NH_4)-$N^{-15}N$ recovery in herbage and soil: effects of application method and timing.' Plant and Soil, 330 (1–2): 357–368.

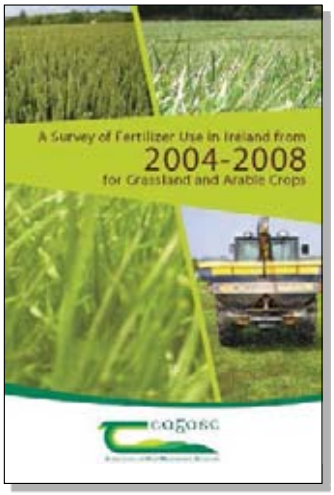
Selected Popular publication:

Lalor, S.T.J. and Schulte, R.P.O., 2008a. Slurry application using trailing shoe – potential benefits come at a price, TResearch, pp. 35–37.

Hoekstra, N.J., Richards, K., Schmidt, O., Lalor, S.T.J. and Schulte, R.P.O., 2010a. The fate of slurry nitrogen in grassland, TResearch 5:1, pp. 28–29.

Project number:
5943
Date:
December, 2010
Funding source:
Teagasc
Project dates:
Jan 2009–Dec 2010

Survey of fertilizer use in Ireland from 2004–2008 for grassland and arable crops



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Key external stakeholders:

Farmers, fertiliser industry, advisors, soil analysis services and policy makers.

Practical implications for stakeholders:

The main activity of this project was to analyse and report the National Farm Survey data on fertilizer use in Ireland between 2004 and 2008 on grassland and arable farms. The trends in fertilizer usage are important statistics to collect and report so that fertilizer use trends can be monitored over time, and compared with other data such as soil fertility, agricultural output, environmental indicators and policy impacts.

Main results:

The key results were:

- Fertilizer N, P and K usage have decreased by 20, 40 and 37%, respectively, between 2003 and 2008.
- The most dramatic decrease has occurred on grassland.

Opportunity/Benefit:

For farmers to improve the utilisation of animal manures in a climate of increasing costs of fertilizers; decreasing product prices and farm income; and regulation of nutrient usage.

Technology

1. Project background:

The National Farm Survey (NFS) is carried out each year by the Teagasc NFS Unit in order to determine the financial situation on Irish farms and to measure the current levels of farm performance. It provides a database for agricultural economics and rural development research projects.

The NFS is Ireland's contribution to the Farm Accountancy Data Network of the European Union (FADN). The objective of the FADN is to determine the income on farm holdings across the EU. A subset of the data from the NFS was made available in order to conduct a Fertilizer Use Survey (FUS).

This survey uses NFS data on the amount and types of chemical fertilizer used by the farmers for different crops together with data on areas under grassland and agricultural crops, livestock numbers, land use class and animal numbers.

2. Questions addressed by the project:

- What are the amounts of N, P and K nutrients and types of fertilizer used on grassland and arable crops?
- What are the relationships between fertiliser use and such factors as geographic region, farm size, stocking rate and soil use class?

3. The survey method:

Farm management data for the years 2004–2008 from the Teagasc National Farm Survey were used as the basis for this fertilizer use survey. The mean values obtained for different crops were weighted according to the area of the crop on the farms in question. A total of 1232 farms were included in the survey in 2008. The survey was conducted on a stratified random selection of farms that represented the major farm systems and sizes. Farms are classified into four major farming systems; namely dairying, cattle, sheep and tillage.

The fertilizer usage information supplied by the NFS Unit for this survey consisted of a number of farm records, each containing the area under each of 16 tillage crops, together with the area under hay, silage and grazing and total grassland. For each crop, the types and quantities of up to six fertiliser applications (up to 11 applications for grazing) was also given.

N, P and K fertilizer application rates were calculated for each crop and related to geographic regions, farm enterprise, stocking rate, and soil use class. The mean values quoted for different crops were weighted according to the area of the crop on the farm in question.

The survey results were validated by comparing the national annual sales of N, P and K published by the Department of Agriculture Fisheries and Food with the estimated total usage as calculated from the survey results. The total usage was estimated from the survey data by collating the fertilizer N, P and K usage on different crops with the published national areas under those crops using the appropriate weightings from the NFS to calculate weighted means. The agreement between the calculated consumption from the survey and the nationally published fertilizer sales figures of N, P and K was very strong, with deviations of only -1.1 %, -1.4 % and -0.5 %, respectively, for the three elements. The agreement between fertilizer use and official national statistics of fertilizer consumption indicates that the results of this fertilizer use survey are valid.

An analysis of the soil analysis results for agricultural samples submitted in 2008 to the Teagasc soil laboratories at Johnstown Castle was undertaken to find out the percentage of soil samples that were at Index 1, Index 2, Index 3 and Index 4 for P and K. Taking the appropriate factors into account, the mean fertilizer recommendations were calculated from the percentages of soils in each Index point for P and K. The calculated mean advice rates were compared with the P and K use for each crop, as determined by the fertilizer use survey.

4. Main results:

The data on national fertilizer consumption show a steady decrease in the usage of fertilizer consumption on a national level (Figure 1). National fertilizer sales of N, P and K have decreased by 20, 40 and 37%, respectively, between 2003 and 2008. The total national usage of fertilizer P and K have decreased to 1950's levels, while N fertilizer usage has not been so low since the early 1980's.

There was a larger decrease in fertilizer usage on grassland than on tillage crops. The average usage of fertilizer nutrients applied to grassland in 2008 was estimated at 86, 5 and 14 kg/ha for N, P and K, respectively. The mean N usage on grassland was

Crop	N	P	K
	—— kg/ha (% change from 2003) ——		
Grazing	65 (-38%)	3 (-63%)	9 (-50%)
Silage	101 (-16%)	7 (-46%)	24 (-41%)
Grassland Overall	**86 (-30%)**	**5 (-55%)**	**14 (-48%)**
Winter wheat	179 (-12%)	19 (-17%)	52 (-5%)
Spring wheat	139 (-9%)	20 (-17%)	49 (-8%)
Winter barley	163 (-2%)	25 (-17%)	64 (-10%)
Spring barley	118 (-4%)	21 (-19%)	45 (-18%)
Malting barley	117 (4%)	16 (-20%)	48 (-9%)
Winter oats	141 (2%)	23 (-12%)	51 (6%)
Spring oats	75 (-34%)	11 (-56%)	23 (-53%)
Cereal crops Overall	**137 (-10%)**	**20 (-20%)**	**48 (-14%)**
Forage maize	152 (30%)	41 (52%)	96 (57%)
Fodder beet	155 (20%)	51 (6%)	184 (14%)
Potatoes	93 (-19%)	73 (-28%)	170 (-24%)
Root crops Overall	**106 (-24%)**	**46 (-21%)**	**138 (-18%)**

Table 1. Fertilizer usage on grassland and tillage crops in 2008, and percentage change in nutrient usage since 2003 (in parenthesis)

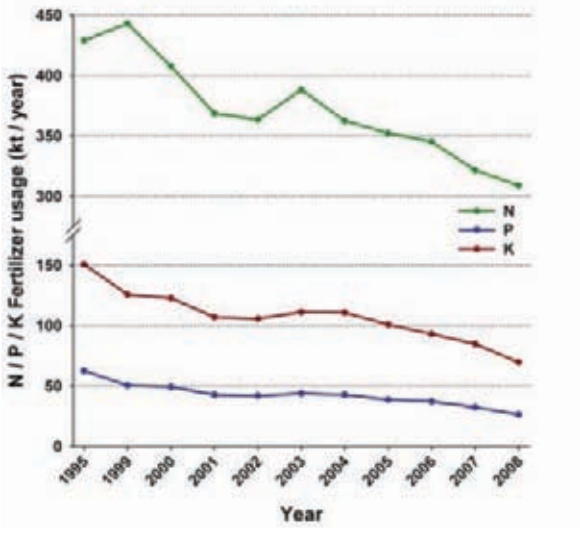

Figure 1. National usage of N, P and K fertilizer in Ireland from 1995 to 2008.

30% lower than that estimated for 2003. There was a 55% decrease in P usage, and a 48% decrease in K usage since 2003. The decrease in usage of all nutrients was higher on grazed swards than on silage swards (Table 1).

The types of fertilizers used for grassland showed a continuing trend towards relying on high N fertilizer compounds (e.g. 24–2.5–10 and 27–2.5–5) rather than high P K compounds (e.g. 0–10–20 and 0–7–30) to supply the P and K for both grazed and cut swards. The dependence on straight N fertilizers (CAN and urea) has also increased. This has resulted in the relatively larger decrease in the usage of P and K than that of N. This trend was also noted in previous surveys.

The average fertilizer usage over all cereal crops was 137, 20 and 48 kg/ha for N, P and K, respectively, representing a decrease in the usage of all three nutrients by 10% for N, 20% for P, and 14% for K. The fertilizer usage on each individual cereal crop was lower on every cereal crop type, with the only exceptions being N on malting barley, and N and K on winter oats. The fertilizer N, P and K usage on the major tillage

crops, and the percentage change in usage since 2003 is shown in Table 1. Fodder beet and forage maize were the only crops in the survey that showed increased use of all nutrients in 2008 compared with 2003.

Comparing fertilizer usage in 2008 with Teagasc nutrient advice showed that usage rates were generally lower than advised rates for almost all crops, particularly in the case of P and K. For example, the K usage rates on cereals crops were typically only approximately 60% of the rates advised. This indicates that farmers are relying more on soil P and K reserves to sustain crops, and are not fully replacing the nutrients being removed in crops. While this may be possible and will save money in the short term, it will lead to reduced soil fertility levels in the future.

5. Opportunity/Benefit:

The findings of the survey are published in print, and online on the Teagasc website (www.teagasc.ie). The survey highlighted dramatic decreases in fertilizer usage in Ireland. Possible reasons for the reduced usage include: improved utilisation of animal manures; increasing costs of fertilizers; decreasing product prices and farm income; and regulation of nutrient usage. Reduced fertilizer inputs represent cost savings to the farmer, and may indicate more efficient nutrient use and reduced environmental losses. The maintenance of soil fertility, particularly of P and K are essential to maintain the production capacity of soils, and must not be compromised in the future.

6. Dissemination:

Main publications:

Lalor, S. T. J., Coulter, B. S., Quinlan, G., and Connolly, L. (2010). A survey of fertilizer use in Ireland from 2004–2008 for grassland and arable crops. Teagasc, Johnstown Castle, Wexford. 89pp.

Lalor, S. T. J. (2010). Fertilizer use in Ireland – getting the balance right. In: Agri-Environment Conference 2010. Tipperary and Solohead Research Farm. Teagasc, pp.12–15.

Popular publications:

Lalor, S. T. J., Coulter, B. S., Quinlan, G., and Connolly, L. (2010). Decreasing trend of fertilizer use. TResearch, Vol. 5:2, pp.26–27.

Lalor, S. T. J., Coulter, B. S., Quinlan, G., and Connolly, L. (2010). Fertilizer P and K usage back to 1950's levels. Irish Farmers Journal, Vol. 63 No. 13. 27 March 2010.

Project number:
5800
Date:
August, 2012
Funding source:
TEAGASC
Project dates:
Feb 2008– Oct 2010

Greenhouse gases mitigation and agriculture

A dairy cow with a collar for methane collection

Collaborating Institutions:
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External collaborators:
Prof. Mike Jones (TCD)

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Key external stakeholders:

- Farmers
- Department of Agriculture, Food & the Marine
- Environmental Protection Agency

Practical implications for stakeholders:

This research shows that Irish agriculture has decoupled greenhouse gas emissions from production since 1990. Future climate change will marginally impact on summer grass yields but total annual production should be less affected. Greenhouse gas emissions will increase with soil C release and higher N_2O emissions

- **Farmers:** This research demonstrates that Irish beef and dairy production has become increasing C efficient. Future sustainable intensification should reduce emissions intensity further.
- **Policymakers:** This research shows that considering the relative efficiency of Irish agriculture, future climate policy should not result in carbon leakage.
- **Scientific:** This research demonstrates that nitrous oxide and soil organic carbon emissions in arable and grassland systems are likely to increase. This may eventually result in many grassland C sinks turning into sources.

Opportunity:

This research demonstrates that current and future Irish agriculture is carbon efficient and that any policy that restricts production may lead to perverse outcomes (i.e. an increase in global agricultural emissions.) Also, it identifies that climate change will result in an increase in emissions, particularly nitrous oxide, without climate-proofed abatement strategies.

Technology

Main results:

The C footprint of beef has reduced by 20% reduction from 1998 to 2009 and, milk production has also lowered its C intensity by 25%. Future climate policy should ensure that agricultural production is optimised in these regions where efficiencies are greatest (Europe and North America). Future climate change will inevitably lead to an increase in farm greenhouse gas emissions due to a decrease in pasture carbon sinks and an increase in nitrous oxide emissions. Abatement strategies should be 'climate-proofed' before being recommended to farmers.

1. Project background:

The EU has set a long-term climate protection target to limit increases in mean global temperatures to no more than 2°C which will require a projected 20% reduction in emissions by 2020 and an 80% cut in global emissions by 2050. In this context, Ireland has been set a target of 20% reduction in greenhouse gas (GHG) emissions by 2020. However these reductions apply only to the agriculture, transport, residential and waste management sectors as heavy industry and energy generation are being administered directly by the European Commission.

Although one of the largest sectoral GHG emitters, comprising 30.5% of the national total agricultural emissions have decreased by 9% since 1998. To date the sector has been relatively unaffected by government policy but post-Kyoto scenarios will put agriculture under pressure to deliver reductions. Hence there is a pressing need to assess agricultural GHG emissions in the context of higher production demand, a reduction in quota's and a more stringent limit on national emissions. This study seeks to address the current state of agricultural emissions, current and future research requirements, assess future policy structures that are required and suggest options for climate change mitigation and adaptation that will serve Irish agriculture post 2012.

2. Questions addressed by the project:

What is the current 'state of play' as regards GHG emissions (i.e. current legislation, policy and agricultural GHG inventory data) and climate change (rates of increase, scenario predictions and predicted effects)? What are the future climate change effects on greenhouse gas emissions from agriculture?

Can we make stakeholders more aware of greenhouse gas issues and impending legislation?

3. The experimental studies:

An analysis of greenhouse gas emissions and their relationship with agricultural production over time was conducted using the methodologies laid down by the Intergovernmental Panel on Climate Change (IPCC). This methodology allowed us to generate 'carbon footprints' for Irish agricultural produce over time (years 1990–2007). This subsequently enabled us to explore whether agricultural emissions were 'decoupling' from production.

A process model (DAYCENT) was used in order to assess future climate impacts on GHG emissions from both arable and grassland systems. Weather data was generated from the A1 climate scenario using outputs from the HadCM4 climate prediction model up to 2070. The basic assumptions of this model were a 20% increase in winter rainfall, a 20% decrease in summer rainfall and a 1.4°C temperature increase. Outputs from DAYCENT included carbon sequestration, N_2O emissions, leached N and grass/crop production. Workshops were held in order to raise awareness of the issue of greenhouse gases and contributions were also made to national reports (see below).

4. Main results:

Irish emissions and production have decoupled.

Agricultural emissions were 9.1% lower than the reference (1990) levels and 17.1% lower than the 1998 maximum by 2009. This reduction was driven by decreases in both methane (60% of emissions) and nitrous oxide (38.5% of emissions).

Methane

The reduction in total methane emissions has been driven primarily by decreases in the total number of beef cattle and sheep. However, whilst sheep emissions have decreased linearly with ovine meat production (30%), there has been a decoupling between cattle emissions and total production. Methane emissions for beef and dairy cattle fell by **10%** and **13%** respectively between 1998 and 2006, whilst beef and milk production remained static. This decoupling was mainly driven by improved efficiency of production, specifically reduced finishing times in the beef sector and increased milk production per head in the dairy sector. An important caveat in this observation is that further improvements in production efficiency will be incrementally more challenging to obtain. As a result, this historic decoupling of livestock numbers and GHG emissions cannot and should not be symmetrically projected into future scenarios.

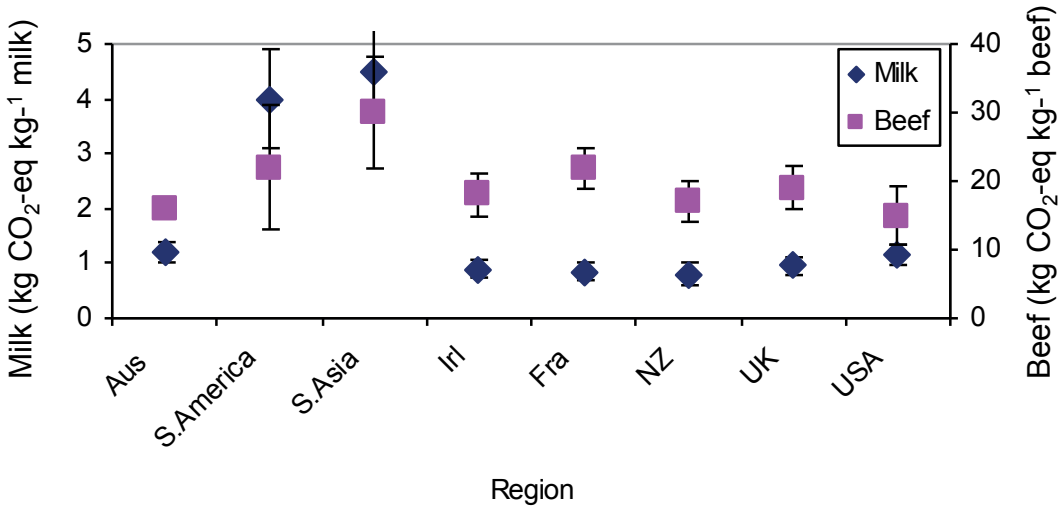

Figure 1: Total agriculture-based emissions intensity for beef and dairy produce across a range of geographical locations

Nitrous oxide

Nitrous oxide (N_2O) emissions arise as a result of the deposition of urine and faecal nitrogen (N) from livestock, the application of chemical and organic nitrogen fertilizers and, indirectly, from ammonia volatilisation and leached N. Total agricultural N_2O emissions have decreased by **11%** relative to 1990 and over **20%** relative to 1998 peak emissions. Decreased N_2O emissions arising from animal deposition, termed pasture, paddock and range (PPR) emissions, have followed a similar trend to methane emissions, with the principal reductions arising from sheep (38%) and non-dairy cattle (11%). Similarly, reductions in the application of mineral fertilizer resulted in a **28.9%** decrease in associated emissions between 1998 and 2008, associated with a 30% increase in fertilizer costs since 2000. Whilst inputs of mineral N have decreased, the use of organic fertilizer (and associated emissions) has remained constant despite decreases in the total livestock numbers.

Impact on carbon footprint

These reductions in both methane and nitrous oxide emissions have resulted in a decrease in the C footprint of beef reducing from 26 kg CO_2-equivalents kg^{-1} beef in 1998 to 19 kg CO_2-equivalents kg^{-1} beef in 2009. This represents a 20% reduction and is due to decreases in animal finishing times. Similarly, milk production has lowered its C intensity by 25% for 1.6 kg CO_2-equivalents kg^{-1} 2009.

Impact of carbon leakage

Carbon leakage results in a global net increase in GHG emission if the region where production is displaced to has a higher 'emissions intensity' (GHG emissions per unit product) than the region where production had contracted. This anomaly could have potentially significant impacts on net global GHG emissions. Figure 1 shows the emission intensity of dairy and beef production for a range of geographical locations, calculated using IPCC-defined agricultural emissions (Lanigan et al., 2011). It shows that emissions from South America and South Asia were almost double those of Irish, EU and New Zealand emissions, even without taking into account the effects of land use change, i.e. expansion of the agricultural area at the expense of natural habitat. If land-use emissions were to be included (with only residue burning and soils emissions allocated to the land-use change), the emissions per unit product would double for South America.

Simple calculations based on the values presented in Figure 1 show that displacement of 50% of current Irish beef exports to South America would result in a net increase of global emissions by between c. 3.6 Mt CO_2eq per annum, equivalent to c. 20% of total current Irish agricultural emissions. This conservative estimate disregards emissions associated with landuse change; if these emissions were to be taken into consideration, the estimated value would be two to three times higher.

Impacts of future climate change on agricultural emissions

Outputs from the DAYCENT process model showed that net carbon balance of grasslands may fall by over 50% from 3.7 tonnes C $ha^{-1}yr^{-1}$ to 1.5 tonnes C $ha^{-1}yr^{-1}$. This is due to a significant increase in ecosystem (soil and plant) respiration relative to photosynthesis. Based on this rate of decrease, grassland sinks may convert to net sources by 2100. Seasonally, summer growth was shown to decrease relative to present-day conditions by 10% due to moisture deficits, while winter growth increased by 8%. Nitrous oxide emissions increased by 17% relative to present day for grassland systems and 11% for arable systems. This is principally due to increased spring and winter losses associated with higher soil moisture during these periods. Higher indirect N_2O emissions are also likely to result from increases in winter leaching of N and summer volatilization.

5. Opportunity/Benefit:

The primary stakeholders for this research are both farmers and policy makers. This research demonstrates that current and future Irish agriculture is carbon efficient and that any policy that restricts production may lead to perverse outcomes (i.e. an increase in global agricultural emissions). Irish agriculture should look to exploit its low C footprint in terms of market strategy and defending the sector in future climate negotiations. Also modelling may be an efficient tool in terms of decision-support for 'climate-proofing' abatement measures.

6. Dissemination:

Awareness of the project and relevant results were, and continue to be disseminated via scientific peer-reviewed journals as well as the popular press and media.

Main publications:

Journal article:

Smith, P .,Lanigan, G., Kutsch, W., Buchman, N., Eugster, W., Aubinet, M. and Osborne, B. A. (2010). Measurements necessary for assessing the net ecosystem carbon budget of agricultural systems.' Agriculture, Ecosystems and Environment 139: 302–315

Schulte, R.P.O. and Lanigan G.J. (2011) *Irish Agriculture, Greenhouse Gas Emissions and Climate Change: opportunities, obstacles and proposed solutions.* Carlow, Teagasc Report.

Popular publications:

Lanigan, G.J. (2009) Greenhouse gas emissions form agriculture. TResearch, Lanigan G.J. '*Mitigation strategies for Irish Agriculture*' IIEA Conference, Dublin Castle, January 2009. http://www.youtube.com/watch?v=sLHQc1IvUf0

Lanigan G.J. '*Greenhose gases from Irish Agriculture*' http://www.youtube.com/watch?v=kjklpr_uYwg

Lanigan, G.J. Pat Kenny Show, Six-One News and TV–3 News, Farmfest 20 June 2008.

Project number:
5768
Date:
July, 2011
Funding source:
Teagasc
Project dates:
Jan 2009–May 2010

Creating and enhancing farmland habitats: a review of options and evidence

Key external stakeholders:

Agri-environment policymakers, participants in agri-environment schemes, extensive farmers and environmental NGO's.

Practical implications for stakeholders:

- A booklet is available for policymakers and farmers that provides accessible information on the effectiveness of a variety of selected agri-environment measures for biodiversity.
- The use of expert groups is an efficient and effective method through which to learn how to improve agri-environment measures and could be useful at the design stage of agri-environment measures/schemes as a structured approach for eliciting expert comments on the likely ecological and environmental effectiveness of proposed measures.

Ecological research has extensive literature on the creation, enhancement and management of farmland habitats. Unfortunately, this information was not in a readily available format for policymakers, which frequently inhibited its transfer and incorporation into the design of agri-environment measures.

Main results:

- Novel agri-environment measures were identified that could be applied to:
  - maintain existing habitats of good ecological value (this should always be a priority);
  - restore or enhance existing habitats of good ecological value e.g. species-rich grassland;
  - assist more intensive farmers to create new habitats on their farms: e.g. ponds, field margins, and;
  - control invasive alien species.

Collaborators:
NUIG

Teagasc project team:
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External collaborators:
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Technology

- The experts considered that most biodiversity options in REPS 4 appear to be adequately designed and implemented by farmers.
- Based on both the experts' judgements and a review of evidence, several of the REPS 4 biodiversity options would be expected to have little or no benefit for biodiversity. For most of these options, the primary reason is that participation levels are too low to achieve an environmental impact.
- The potential for the biodiversity objectives of REPS to be better aligned with national and international conservation priorities was highlighted.

Opportunity/Benefit:

Details from the literature review and the experts' assessments will aid policy-makers with the design of future agri-environment schemes and measures and several potential measures for the conservation of biodiversity were highlighted.

1. Project background:

Ecological research has an extensive literature on farmland biodiversity, and on the creation and enhancement of farmland habitats. Unfortunately, this information and understanding is not in a readily available format, which frequently inhibits its transfer to policymakers. For example, a 2003 review of the effectiveness of European agri-environment schemes for wildlife objectives concluded that 46% of studies found few or no benefits associated with the relevant scheme. We collated the evidence base from ecology journals and research reports, with the aim of identifying methods for the creation and enhancement of farmland habitats and presenting them in a more accessible format.

There has been a widespread lack of environmental monitoring and assessment of agri-environment schemes. As a consequence, they have an impaired ability to identify either successes or failures, and to learn how to improve their environmental effectiveness. In the absence of relevant empirical data, we used experts' judgements to identify strengths and opportunities for improvement in current habitat management recommendations in the Rural Environment Protection Scheme (REPS).

Overall, this study can harness existing ecological knowledge, and present it in a more accessible format for policymakers. This will aid the identification of agri-environment measures that are appropriate to the biodiversity objectives both of the existing REPS, and of future agri-environment schemes.

2. Questions addressed by the project:

- What is the rationale for habitat creation and enhancement techniques?
- What are examples of best practice within existing REPS and what are potential improvements?

3. The experimental studies:

We collated a number of agri-environment measures to conserve or enhance farmland biodiversity, and provided an overview of the evidence-base relevant to their wildlife benefits. A small number of case studies were used to highlight relevant issues and potential agri-environment measures. This information was used in a booklet to improve the accessibility of relevant knowledge to policymakers and farmers.

Additionally, a group of eight Irish agri-environmental experts assessed the wildlife value of current supplementary measures and options in the REPS 4 scheme. In the absence of environmental data from monitoring, the assessment utilised a novel methodology which used experts' judgements of the effectiveness of the REPS options and supplementary measures that are relevant to biodiversity. The experts scored each option using a scoring scale for each of five criteria. A group meeting of the experts allowed them to discuss each option, elaborate on the justification for their decisions and achieve consensus.

4. Main results:

There is likely to be a greater onus on agri-environment schemes to target farmland habitats and species of highest conservation concern and value. In general, conservation efforts will be most effective (and cost-effective) if they target extensively farmed areas that support high levels of biodiversity.

The effectiveness of agri-environment measures can be significantly assisted through design that is informed by available evidence. Generally, there is scope for environmental effectiveness to be increased through a greater contribution of ecological evidence to the design phase of agri-environment. The objectives and measures for agri-environment schemes should be developed in a way that ensures good linkages among biodiversity research outputs, legislative obligations, national targets for biodiversity policy and delivery of targets. This can be facilitated by consultation with the appropriate state and non-governmental organisations.

The design, implementation and assessment of agri-environment measures can be greatly facilitated by clear statements about their intended impact, and how the proposed management prescriptions are intended to achieve this impact. This will also assist farmers and land managers to achieve the biodiversity objectives.

Depending on the environmental status of farmland, appropriate options may include measures to safeguard priority habitats, create new habitats, restore and enhance existing habitats and prevent negative impacts from damaging farmland habitats. Greater consideration should be given to opportunities to maximise the biodiversity value of agri-environment schemes through the 'bundling' of complementary measures to create an appropriate mosaic of habitats.

In relation to agri-environment measures/options, the experts recommended that the aims and objectives of the scheme and individual options should be stated with greater clarity and precision. The objectives should clearly identify the type of biodiversity to be benefited/ targeted, and better explain how this will be achieved by the management prescriptions.

A number of recommendations were more relevant to design and implementation choices at the scheme-scale:

- The experts recommended a move away from a 'one-size-fits-all' approach, and toward one that better facilitates spatial targeting.
- There is scope for the design stage to consider the additional environmental effectiveness that may be achieved from spatial targeting or incentivised participation of groups of farmers. This approach should also consider the level of participation that is required to achieve specific environmental objectives.
- Experts suggested a reduction in the choice of measures within the agri-environment scheme. A tiered approach was recommended, with the choice of options being more strongly guided toward those best suited to the farm conditions and its environmental priorities.

The use of expert groups proved to be an efficient and effective method to:

- Assess the likely environmental effectiveness of biodiversity option.
- Identify specific aspects of options that are in need of improvement.
- Highlight modifications which should improve environmental effectiveness.

5. Opportunity/Benefit:

Details from the literature review and the experts' assessments will aid policy-makers with the design of future agri-environment schemes and measures.

The literature review highlights several potential measures for the conservation of biodiversity, and indicates sources of associated evidence on their effectiveness.

The experts' assessments offers a method to get high-quality and relevant information on environmental effectiveness within a short timeframe. In the absence of relevant empirical data, the use of expert groups proved to be an efficient and effective method with which to learn how to improve agri-environment measures. This approach could be especially useful at the design stage of agri-environment measures (or schemes) as a structured approach for eliciting expert comments on the likely ecological and environmental effectiveness of proposed measures. In this way, it could contribute a methodology for use in ex ante (and ex post) evaluations.

6. Dissemination:

Main publications:

Ó hUallacháin, D., Finn, J.A., Gormally, M. and Carlin, C. (2011) Experts' assessments of biodiversity options and supplementary measures in REPS 4. In: Conserving Farmland Biodiversity: lessons learned and future prospects, Ferrycarrig Hotel, Wexford, 25th May–2011, pp 82–83.

Carlin, C., Finn, J., Ó hUallacháin, D. and Gormally, M. (2010). Biodiversity options in agri-environment schemes in Ireland: Doing the job right or doing the right job? Aspects of Applied Biology 100, Agri-environment schemes – What have they achieved and where do we go from here? pp. 449–454. (Reviewed and published paper as part of International Conference.)

Carlin, C., Finn, J., Ó hUallacháin, D., & Gormally, M. (2010). Biodiversity options in agri-environment schemes in Ireland: Doing the job right or doing the right job? Fourth Annual Environmental Change Institute/MRI Conference.

Popular publication:

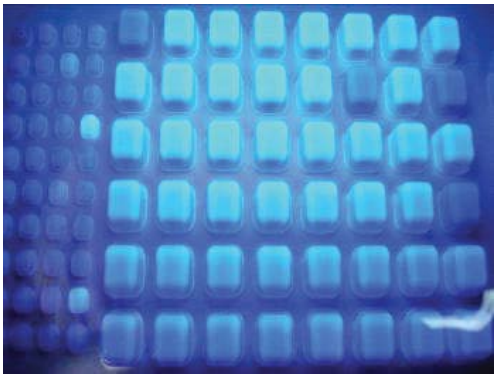
Carlin, C., Gormally, M., Ó hUallacháin, D. and Finn, J.A. (2010). Farmland Biodiversity: Measures to create and enhance farmed habitats. NUIG/Teagasc. 32 pages. ISBN 978–0–9537544–2–7

Carlin, C., Gormally, M., O hUallacháin, D and Finn, J (2009). Identification of agri-environment measures to improve farmland biodiversity. Johnstown Castle Research booklet, Teagasc, p. 84–85.

Carlin, C., Gormally, M., and Finn, J (2009). Bridging the researcher-user interface: Reviewing the evidence for agri-environmental measures to create and enhance farmland habitats. 19th Irish Researchers' Colloquium. 9th–11th February, Waterford Institute of Technology, p. 71.

Project number:
5728 & 5191
Date:
Feb 2011
Funding source:
IRCSET
Project dates:
Jun 2007–Nov 2010

Landspread Pathogen Survival and Transport in Irish Soils



Collaborating Institutions:
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Cranfield University, UK
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Teagasc project team:
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Key external stakeholders:

- Farmers
- Environmental Protection Agency
- Local Authorities Policy makers Scientific community General public

Practical implications for stakeholders:

This research provides important data on the survival and transport of landspread enteric microorganisms in Ireland under a range of soil types and conditions.

- This research highlights the importance of soil structure (macropore flow) as the dominant mechanism for pathogen leaching.
- This research will help to identify areas with soils that are more prone to pathogen loss to groundwater from slurry application.
- The data from this project can be used in quantitative microbial risk assessment to help farmers and water managers protect the microbial quality of drinking water.

Main results:

- Soil type has a significant impact on risk of pathogen transport with poorly drained (well structured) soils representing the greatest risk due both to their inherent capacity to support pathogen survival and their pronounced network of macropores, which facilitate transport.

Opportunity/Benefit:

- *E.coli* can become naturalised and survive long-term in Irish soils. As such, its presence in soils and waters may not be indicative of recent landspreading or other activities. This has implications for its use as an indicator of water quality.

Technology

Figure 1 Soil flow paths stained blue with *E. Coli* concentrations superimposed in white.

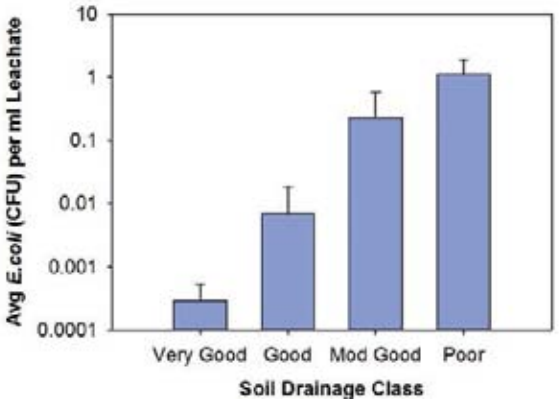

Figure 2 Average E. coli leaching on 4 soils with drainage from very good to poor. E. coli leaching was inversely related to soil drainage (adapted from Brenan et al. 2010b).

1. Project background:

Microbial contamination of groundwater, including sources of drinking water, continues to be of worldwide concern due to the human and animal health implications which can result as a consequence. Reports by the Environmental protection Agency (EPA) indicate that nationally, a high proportion of groundwater sources are contaminated with faecal coliforms. The high numbers of groundwater sources found to be contaminated with faecal bacteria, and thus considered to be unfit for human consumption, presents a worrying statistic, particularly as the majority of private groundwater supplies in Ireland are untreated or inadequately treated prior to consumption, thereby increasing the risk of gastroenteric and other waterborne diseases. The sources of contamination are varied, but international evidence suggests that the landspreading of animal slurries, manures, and soiled waters is a significant contributor. These organic fertilisers can contain a large range of pathogenic microorganisms including *Campylobacter, Cryptosporidium and Salmonella* spp., which are released into the environment during landspreading. Some of the pathogenic microorganisms in organic amendments applied to soil have been observed to leach through the soil into groundwater thus affecting drinking water quality and posing a risk to public health. As such, understanding how these organisms survive and move in soil has become critical in the assessment and mitigation of the risk to groundwater posed by agricultural activities.

2. Questions addressed by the project:

These projects had two main goals. These were to investigate:

- The effect of soil type and condition on the transport of microbial pathogens through soil, and the risk posed to underlying groundwater from landspreading practices.
- The effect of soil type and condition on the capacity of soil to act as a reservoir for enteric microorganisms, which can subsequently be leached to groundwater.

3. The experimental studies:

The research questions were addressed using a combination of field, intact soil columns (lysimeters) and laboratory studies. In field trials, the transport of model organism *Escherichia coli* was investigated *in-situ*, under artificial rainfall conditions, on different soil types and under different soil moisture regimes. Transport pathways were identified using a tracer dye. Under natural rainfall conditions the movement of *E. coli* from landspread dairy slurries was investigated in 1 m deep intact soil columns of different soil types. Environmentally persistent *E. coli* isolates were then characterized using molecular and physiological approaches to investigate their capacity for long term survival

4. Main results:

- Landspread microbial pathogens can travel rapidly through soil to depth in macropores which are large soil pores (Figure 1).
- Soil type has a significant impact on risk of pathogen transport with poorly drained (well structured) soils representing the greatest risk due both to their inherent capacity to support pathogen survival and their pronounced network of macropores, which facilitate transport.
- *E.coli* can become naturalised and survive long-term in Irish soils.
- Brilliant blue dye and Bromide were good predictors of *E. coli* transport pathways and distribution under certain conditions. *E. coli* was observed to leach deeper than both tracers in numerous profiles indicating that caution should be used in extrapolating tracer test results to pathogen movement in soil, as this could result in an underestimation of the depth of transport and risk to underlying water bodies.

5. Opportunity/Benefit:

The presence of *E. coli* in soils and waters may not be indicative of recent landspreading or other activities. This has implications for its use as an indicator of water quality.

6. Dissemination:

The findings of this research has been disseminated to stake holders by means of international peer reviewed papers, national and international conferences, popular and technical outputs, open days and radio interviews.

Main publications:

Brennan, F.P., Kramers, G, Grant, J., O'Flaherty, V., Holden, N.M. & Richards, K.G. (2012) Evaluating E. coli transport risk in soil using dye and bromide tracers, *Soil Science Society of America Journal*, 76, 663–673.

Brennan, F.P., Abram, F., Chinalia, F. A., Richards, K. G. & O'Flaherty, V. (2010a) Characterization of Environmentally Persistent Escherichia coli Isolates Leached from an Irish Soil. *Applied and Environmental Microbiology*, 76**,** 2175–2180.

Brennan, F.P., O'Flaherty, V., Kramers, G., Grant, J. & Richards, K.G. (2010b) Long-Term Persistence and Leaching of Escherichia coli in Temperate Maritime Soils. *Applied and Environmental Microbiology*, 76**,** 1449–1455.

Brennan, F.P. (2010c) The Role of Soil Type and Condition in the Fate and Transport of Landspread Microbial Enteropathogens in Soil. *PhD Thesis Microbiology*. National University of Ireland, Galway.

Popular publications:

Brennan, F. P., Richards, K., O'Flaherty, V., Bhreathnach, N., Moynihan, E., Ritz, K., Tyrrel, S., Jordan, P., Murphy, S. & Wuertz, S. (2010d) Protecting Environmental Water Quality from microbial pathogens. *TResearch,* 5**,** 26–27. http://www.teagasc.ie/publications/view_publication.aspx?publicationID=6

Brennan, F. P. (2010a) Fate and transport of landspread microbial pathogens in Irish soils. *Teagasc Environment Advisory Newsletter,* May**,** 4.

Radio interviews by Fiona Brennan on Galway Bay FM and Dublin City FM

Novel experimental designs and models for measuring agronomic effects of multi-species grassland swards

Project number:
5658
Date:
November, 2010
Funding source:
IRCSET
Project dates:
Dec 2006–Sep 2009

Key external stakeholders:

Researchers in sustainable agriculture, grassland agronomy and ecology, grassland farmers.

Practical implications for stakeholders:

- The outcome is that modest increases in sward diversity to four-species mixtures can increase yield and reduce weed invasion, compared to monocultures. These results are applicable at least up to fertiliser applications of 150 kg ha^{-1} of nitrogen per annum.

Main results:

- Applying our methodology to data from a common experiment across 34 European sites, we show that the above-ground biomass of four-species mixtures (two legumes and two grasses) in intensive grassland systems was consistently greater than that expected from monoculture performance, even at high productivity levels. The magnitude of this effect generally resulted in the performance of mixtures exceeding that of the best-performing monoculture. Mixtures very strongly reduced the incidence of weeds in the sward.
- A combined analysis (across all sites) of first-year results on aboveground biomass across sites showed that the additional performance of mixtures was strongly related to the evenness of the community.
- The effect of the mixtures on yield was consistent over a wide range of European environmental conditions, thus adding generality to our findings. It persisted over at least three harvest years and under relatively intensive management (>150 kg ha^{-1} of nitrogen fertiliser).

Collaborating Institutions:
UCD

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Technology

Opportunity/Benefit:

The use of simple agronomic mixtures with legumes offers potential further investigation of their contribution to ecosystem services from agricultural ecosystems, such as soil carbon sequestration, and mitigation of greenhouse gas emissions through the ability of legumes to fix atmospheric nitrogen.

1. Project background:

Recent ecological research provides evidence that an increased number of plant species in semi-natural grasslands is strongly associated with increased biomass productivity, and provides a wide range of other ecosystem benefits. This suggests that increases in species diversity in agricultural ecosystems may similarly lead to increased benefits.

Traditionally, agronomic science suggests that, compared to more species-rich mixtures, species-poor mixtures or even monocultures of high-yielding species will maximise yield under productive and highly fertilised conditions. Although the maximisation of yield is often the dominant reason for use of monocultures, other advantages of agricultural monoculture systems include the synchronisation of farm management and the simplified harvesting associated with a single crop type. The increasing cost of nitrogen fertiliser, agri-environmental legislation and efforts to reduce greenhouse gas emissions are all contributing to a re-evaluation of the use of fertiliser nitrogen on farms and a search for lower-cost and environmentally compliant alternatives. Forage legumes offer the potential to lower fertiliser costs on farms and may offer a more sustainable option for pasture-based production, not just economically but also in terms of other environmental impacts. Whether increased crop diversity in species-poor agronomic systems could improve the provision of ecosystem services remains largely untested due to the rarity of multi-species agronomic experiments that use more than two species.

Controversy has surrounded the statistical design and analysis of mixture experiments and the extent to which mechanistic explanations of relationships can be inferred from their results. We developed and implemented a new statistical approaches to better measure the benefits of multi-species mixtures. This work was based on data from the COST 852 Agrodiversity experiment, which was conducted at 34 sites across Europe.

The work was conducted following an IRCSET Postdoctoral Fellowship award to Laura Kirwan.

2. Questions addressed by the project:

- How to develop statistical models that describe ecological interactions in multi-species swards?
- How to quantify the general effect of sward diversity on agronomic outputs (e.g. yield) across multiple experimental sites?

3. The experimental studies:

We developed a modelling framework that explicitly quantifies and separates the effects of individual species from the synergistic benefits that occur when species are mixed. This new approach allowed us to test between alternative descriptions of how synergistic benefits occur i.e. do all species interact equally? do some species interact more strongly than others? and, if so, are benefits related to specific traits? As well as being applicable to agronomic experiments, this approach can be applied to a variety of ecosystem functions and organisms.

We tested hypotheses about species mixtures using data from a collaborative European multi-site agricultural experiment (n= 34 sites) that established gradients of agronomic forage diversity (from monoculture to mixtures that systematically varied the proportions of four species) at each site for at least 3 years (time factor) across a wide variety of European climatic conditions (climate factor). At each experimental site, adapted cultivars of two legume and two grass species were chosen such that one of the grass and one of the legume species was fast establishing and the other was slow establishing. Five species-groups were selected depending on the geographical region of the experimental site: north European, mid-European, dry Mediterranean, moist Mediterranean and a fifth group consisted of sites, each with its own group of species but all with the same four functional groups. The experimental layout followed a simplex design with four monocultures and eleven mixtures of the four species sown at two levels of overall sowing density (low being 60% of high). The eleven mixtures consisted of four mixtures dominated in turn by each species (sown proportions of 70% of dominant and 10% of each other species), six mixtures dominated in turn by pairs of species (40% of each of two species and 10% of the other two) and the centroid community (25% of each species). Species proportions at sowing were based on proportions of seed mass considered appropriate for monocultures for each species at a site.

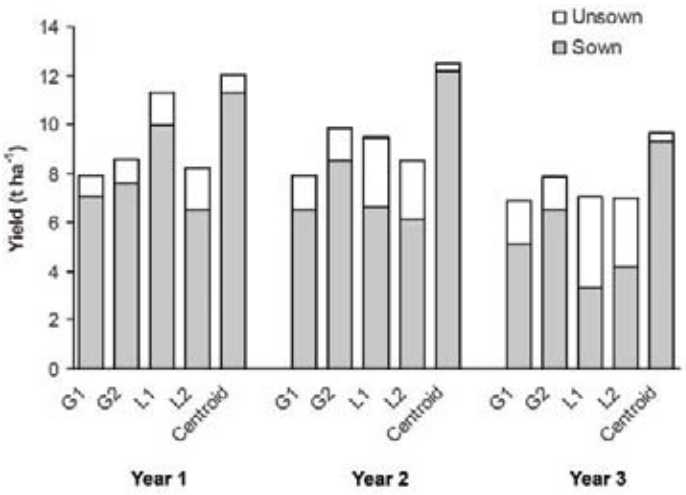


Figure 1 Predicted sown and unsown yield (t ha^{-1} of dry matter) for each monoculture and the centroid mixture for each year from the combined analysis across the 12 mid-European sites. The unsown yields in this diagram were calculated as the difference between estimated means of total yield and sown species yields. G1= Lolium perenne (perennial ryegrass), G2= Dactylis glomerata (Cocksfoot), L1= Trifolium pratense (red clover), L2= Trifolium repens (white clover). (From Helgadóttir et al. 2008.)

4. Main results:

We successfully developed a range of models that are relevant both to the design and analysis of yield from multi-species grassland experiments, but are also appropriate to address other functional effects e.g. yield stability, weed suppression, nitrate leaching, and nutrient dynamics.

Applying our methodology to data from a common experiment across 34 European sites, we show that the above-ground biomass of four-species mixtures (two legumes and two grasses) in intensive grassland systems was consistently greater than that expected from monoculture performance, even at high productivity levels. The magnitude of this effect generally resulted in the performance of mixtures significantly exceeding that of the best-performing monoculture (Fig. 1). A combined analysis (across all sites) of first-year results on aboveground biomass across sites showed that the additional performance of mixtures was greatest when the mixtures consisted of equal proportions of each of the four species. Mixtures very strongly reduced the incidence of weeds in the sward (Fig. 1). The effect of the mixtures on yield was consistent over a huge range of environmental conditions, thus adding generality to our findings. It persisted over at least three harvest years (in eleven sites that were analysed) and under relatively intensive management (~150 kg ha^{-1} per annum of nitrogen fertiliser).

Similar results were obtained for Irish sites that participated in this experiment, and virtually every mixture had a higher yield, and suppressed unsown species better, than monocultures of perennial ryegrass.

5. Opportunity/Benefit:

These multi-site results offer potential further investigation of the contribution of simple agronomic mixtures to soil carbon sequestration, and mitigation of greenhouse gas emissions through the ability of legumes to fix atmospheric nitrogen.

6. Dissemination:

Main publications:

Kirwan, L., Connolly, J., Finn, J.A., Brophy, C., Lüscher, A., Nyfeler, D. and Sebastià, M.T. (2009) 'Diversity-Interaction Modelling-Estimating Contributions of Species Identities and Interactions To Ecosystem Function.' Ecology 90: 2032–2038.

Connolly J., Finn J.A., Black, A.D., Kirwan L., Brophy C. and Lüscher A. (2009) 'Effects of Multi-Species Swards on Biomass Production and Weed Invasion at Three Irish Sites.' Journal of Agricultural and Food Research 48: 243–260.

Lüscher, A., Finn, J.A., Connolly, J., Sebastià, M.T., Collins, R., Fothergill, M., Porqueddu, C., Brophy, C., Huguenin-Elie, O., Kirwan, L., Nyfeler, D. and Helgadóttir, A. (2008) 'Benefits of Sward Diversity for Cultivated Fertile Grasslands' Biodiversity 9: 29–32.

Popular publications:

Kirwan, L., Finn, J.A., Brophy, C. and Connolly, J. (2007) 'Sward diversity in intensive grasslands – increased yield and reduced weeds' TResearch 2: 30–31.

Carnus, T., Finn, J.A., Kirwan, L. and Connolly, J. (2007) 'Does Plant Diversity Stabilise Ecosystem Function?' In: Ireland's Rural Environment: Research Highlights from Johnstown Castle by Finn, J.A., Richards, K. and Shortle, G. (Eds.).Teagasc IE 45–46. ISSN 18 4170 4776

Crops
Environment
& Land Use
Programme

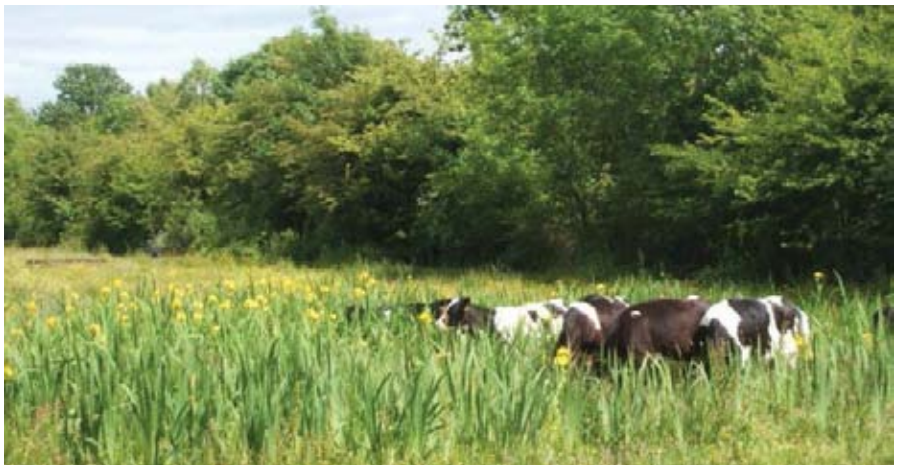
Surveying and modelling of semi-natural habitat cover on farmland

Project number:
5729

Date:
Nov, 2010

Funding source:
Teagasc

Project dates:
Oct 2005–Dec 2009



Key external stakeholders:

- Policymakers
- Participants in agri-environment schemes
- Extensive farmers
- Agri-environmental researchers and NGOs

Practical implications for stakeholders:

- Having failed to halt biodiversity loss by 2010, halting and reversing biodiversity loss by 2020 will undoubtedly be one of the specific public goods to be prioritised following CAP reform (e.g. as Ecological Focus Areas), and in the National Biodiversity Plan 2010–2015.
- Biodiversity conservation goals will not be achieved solely by protecting particular habitats or species (as under the Natura 2000 network of designated sites), and there is now a policy target to protect habitats and species in the wider countryside. To this end, High Nature Value (HNV) farming and forestry systems are prioritised in both EU and national policy goals for biodiversity. Member States are required to identify HNV farmland, and target agri-environmental payments toward them.
- Farmland can be a significant reservoir of biodiversity. In a survey of 32 farms in east Galway, there was an average of 2.6 semi-natural habitats per farm, with an average of 15% of the surveyed farms containing semi-natural habitats. The area of semi-natural habitat cover ranged from 0% to over 60%. All of the surveyed farms were dominated by grassland, but a total of 13 semi-natural habitats were recorded on the 32 farms.

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Technology

Main results:

- We found a widespread occurrence (43% of surveyed fields in east Co. Galway) of a 'semi-improved grassland' category that is not currently recognised in the Irish grassland classification system. Failure to identify semi-improved grassland can underestimate the biodiversity levels on farmland.
- Semi-natural habitat cover on lowland farms was best predicted using the variables 'stocking density', 'soil diversity' and 'river and stream length'. Such modelling approaches could be further developed and used to provisionally target areas with high percentage of semi-natural habitat. Farm-scale assessments may still be required for verification and local targeting of measures of greatest environmental merit.

Opportunity/Benefit:

- These results point to significant opportunities for the targeting of agri-environmental funding toward the protection and/or restoration of existing farmland habitats and species of conservation value.

1. Project background:

Public money from the proposed reform of the Common Agricultural Policy (CAP) will be more closely linked to support the delivery of environmental public goods. Having failed to halt biodiversity loss by 2010, halting and reversing biodiversity loss by 2020 will undoubtedly be one of the specific public goods to be prioritised.

Biodiversity conservation goals will not be achieved solely by protecting particular habitats or species (as under the Natura 2000 network of designated sites), and there is now a policy target to protect habitats and species in the wider countryside. To this end, High Nature Value (HNV) farming and forestry systems are prioritised in both EU and national policy goals for biodiversity (including the National Biodiversity Plan 2010–2015). These systems can be found in designated sites, but are also widespread in other (undesignated) areas of countryside. All Member States were required to identify HNV farmland, and target agri-environmental payments toward them by 2008. The national-scale spatial distribution of undesignated HNV farmland and farming systems is a significant knowledge gap and considerable work remains to fully incorporate HNV farmland into agri-environment policy and practice

This project involved whole-farm habitat surveying and mapping in a geographic information system (GIS). Grassland and hedgerow plant surveys also formed an important component of the field work. The project developed a model for predicting semi-natural habitat cover on farms in a region of western Ireland, suggested an improvement to the current grassland classification in Ireland and accurately describing farmland habitat heterogeneity as well as highlighting the implications of this for HNV farmland identification.

2. Questions addressed by the project:

We developed methods for identifying semi-natural habitat cover on farmland, and surveyed grassland habitats on lowland farms located outside EU-or nationally-designated sites in the west of Ireland (e.g. Natura 2000). We investigated habitat diversity of grasslands, diversity of linear habitats on selected farms, as well as the relationship between field vegetation diversity, field characteristics, management practices and topographic factors. We also identified field-based indicators of grasslands of conservation value that can be used to aid identification of HNV farmland at the farm scale.

3. The experimental studies:

The study was located in County Galway, in the west of Ireland. The east of the county was chosen as, unlike the west of the county, most farmland in this region is outside of European and national nature conservation designation sites (Special Areas of Conservation, Special Protection Areas, and Natural Heritage Areas). District Electoral Divisions (DEDS) were selected as the sites for this study, as the Irish Central Statistics Office compiles farming data per DED. Using stratified random selection, six DEDs were selected from the east of County Galway. These DEDs were representative of lowland farms in East Co. Galway and much of the midlands. Ten per cent of the farms in each of the six DEDs were surveyed, giving a total of 32 farms and an area of over 1200 ha. On each selected farm, all habitats were identified and all fields and field boundaries were surveyed in more detail. All vascular plant species and bryophytes observed were identified and assigned an abundance based on the DAFOR (D = dominant, A = abundant, F = frequent, O = occasional, R = rare) scale. The grassland habitat type in each field was identified based on existing classifications. Data were collected from 603 fields during the summers of 2006 and 2007.

	Group 1 (n = 61) Unimproved Grassland	Group 2 (n = 262) Intermediate Grassland	Group 3 (n = 280) Improved Agricultural Grassland
Total number of species	139	143	107
Mean (±sd) species richness per field	23.5 ± 8.2[a]	16.9 ± 5.6[b]	12.0 ± 3.9[c]
Max./min.species richness per field	49/9	36/6	27/3
Percentage of total number of fields	10	43	46

Table 1. Surveyed fields were categorised according to their average Ellenberg N value of the vegetation. Different superscript letters indicate significantly different groups (ANOVA, $p < 0.001$). The number of fields in each vegetation category is also represented as a percentage of the total number of fields. (From Sullivan et al. 2010.)

4. Main results:

A Generalized Additive Model (GAM) was used to model the relationships between landscape and farm management variables and farmland habitat diversity. Semi-natural habitat cover on lowland farms was best modelled using the variables 'stocking density', 'soil diversity' and 'river and stream length'. This approach could be adapted and applied in other discrete regions of Ireland and combined to create a national map of semi-natural habitat cover on Irish farms.

With specific reference to the lowland grasslands, using the Fossitt (2000) classification system the majority of the 603 fields classify into two grassland types, improved or semi-natural. However, multivariate analyses of these grasslands revealed a continuum between semi-natural and improved agricultural grassland categories, including an intermediate category of 'semi-improved grassland'. The fields in this intermediate grassland type are more species-rich (>10 species per field) and have lower Ellenberg N values (<6) than the more intensively farmed fields (Table 1). This gradation from improved to semi-natural grassland highlights the biodiversity variation that occurs on farms that are frequently considered to be of low nature value. Failure to identify semi-improved grassland could underestimate of biodiversity levels on these farms. The detailed description of the grasslands that occur on these lowland farms has the potential to provide a better assessment of the overall nature value of a farm, potentially aiding the identification of Type 2 High Nature Value farmland. There is a need to amend the Irish grassland classification system so that intermediate semi-natural grassland assemblages can be identified at the field level. Field surveys are necessary for this level of detail.

The average (± s.e.) farm size was 39.8 ha (± 4.6). The average number of habitats on any farm was 10.6 (± 0.6) and the average number of semi-natural habitats was 2.6 (± 0.3). The average cover of semi-natural habitats per farm was 15.2% (± 3.0). The proportion of semi-natural habitat cover on any one farm varied from 0% to over 60% with just 9% having no non-linear semi-natural habitat cover. All farms were dominated by grassland, but a total of 24 habitats were recorded on the 32 farms. Of those, 13 were semi-natural habitats (see Sullivan et al. 2011).

This research also investigated field boundaries as indicators of biodiversity. There was no correlation between non-linear semi-natural habitat area and either field boundary density or hedgerow density. We did find statistically significant variations in hedgerow quality and species-richness between sites and noted that more intensive farms had better quality linear semi-natural habitats and a lower area of non-linear semi-natural habitats. This has implications for any future agri-environment schemes that aim to adopt spatial-targeting of measures for field boundaries in more intensively farmed regions of the country.

5. Opportunity/Benefit:

These results point to significant opportunities for the targeting of agri-environmental funding toward the protection and/or restoration of existing farmland habitats and species of conservation value.

6. Dissemination:

The results of this project have been presented at a number of national and international conferences, and HNV farming systems have been included as part of a number of in-service training events for Teagasc advisory staff.

Main publications:

Sullivan, C.A., Bourke, D., Gormally, M.J., Sheehy Skeffington, M., Finn, J.A., Green, S. and Kelly, S. (2011) Use of generalised additive models to estimate area of semi-natural habitats on lowland farms in western Ireland. *Biological Conservation* 144: 1089–1099.

Sullivan, C.A., Sheehy Skeffington, M., Gormally, M.J., and Finn, J.A. (2010) The ecological status of grasslands on lowland farmlands in western Ireland and implications for grassland classification and nature value assessment. *Biological Conservation,* 143: 1529–1539.

Sullivan, C., Sheehy Skeffington, M., Gormally, M., Finn, J.A. and Kelly, S. (2007). Identifying High Nature Value Grassland in the West of Ireland. *High Value Grassland: providing biodiversity, a clean environment and premium products,* Conference Proceedings, University of Keele, Staffordshire, pages 325–328.

Sullivan, C.A. 2010. *Identification of High Nature Value (HNV) farmland on lowland farms in East County Galway, Western Ireland*. PhD thesis. National University of Ireland, Galway.

Popular publications:

Sullivan, C., Sheehy Skeffington, M., Gormally, M., and Finn, J.A. (2009) Conservation status of lowland grassland in western Ireland. In: *Ireland's Rural Environment: research highlights from Johnstown Castle.* Teagasc. p. 86–87. ISSN 1841705438.

Sullivan, C.A., Sheehy Skeffington, M., Gormally, M.J. and Finn, J.A. (2008) Characterisation of agricultural grasslands in the West of Ireland and implications for identifying High Nature Value farmland. British Ecological Society Annual Meeting, London, 3–5 September.

Crops Environment & Land Use Programme

Project number:
5508

Date:
Dec 2011

Funding source:
DAFF/RSF05/211

Project dates:
Oct 2005–Sep 2009

An evaluation of strategies to control ammonia emissions from the land – spreading of cattle slurry and cattle wintering facilities

The experimental slurry tanker and ammonia flux gradient mast

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Rothamstead – North Wycke
Westlakes Scientific

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Key external stakeholders:

- Livestock farmers
- Department of Agriculture, Food & Fisheries
- Environmental Protection Agency

Practical implications for stakeholders:

This research demonstrates the effectiveness of altered timing and application technique on ammonia emissions abatement. This will enable stakeholders to make informed decisions as to which strategy to adopt in order to reduce N losses to the atmosphere.

Farmers: This research demonstrates that N losses to the atmosphere can be reduced without any outlay in terms of new machinery simply by targeting application either early in the season or be evening application. This will increase the N-fertiliser efficiency of slurry (demonstrated in RMIS 5512).

Policymakers: This research has quantified the abatement benefits of adopting trailing shoe technology and altered timing. Results are also feeding into a revision of the national ammonia inventories which should lead to reduced estimates of housing emissions.

Scientific: This research quantifies ammonia emissions from out-wintering pads in Europe for the first time.

Technology

Main results:

- On average, 54% of total ammoniacal nitrogen (TAN) was lost when slurry was applied by splashplate. Emissions were highest on hot, dry days. Application was targeted for cooler periods, particularly during spring, reduced emissions by over 30%. Emissions were also reduced by application in evening.
- The adoption of trailing shoe technology reduced ammonia emissions by an average of 36%. Under low emission weather conditions, there was no significant difference between application techniques.
- Ammonia emissions from slatted sheds were lower than those used by the EPA in the national ammonia inventories such, indicating a substantial overestimation of cattle housing emissions within the inventory. By comparison, emissions from an outwintering pad (OWP) were higher, particularly dry periods. Emissions were substantially reduced (90%) if pads were regularly cleaned. However, OWP's are in general, *not* an effective ammonia abatement technique.

Opportunity/Benefit:

Application technique and timing are both effective measures for reducing ammonia emissions following landspreading. Therefore, farmers can reduce emissions without the requirement to adopt more expensive machinery. Ammonia emissions from slatted cattle housing is towards the low end of European figures and lower than default values derived from UK data. In addition, it was also demonstrated that whilst out-wintering facilities be advantageous in terms of animal welfare, ammonia emissions per animal were higher.

1. Project background:

Irish agriculture faces considerable challenges in reducing N inputs both in terms of financial sustainability and complying with future emissions targets. The loss of N via ammonia volatilisation represents a challenge both in terms of atmospheric pollution and a loss of resource for the farmer. Under the terms of the National Emissions Ceilings Directive (2001) ammonia (NH_3) emissions are limited to 116,000 tonnes by 2010; with further, more stringent, reductions currently under discussion. Agriculture comprises 98% of national ammonia emissions, with cattle accounting for 80% of this total. In terms of agricultural practices, the land spreading of slurry and animal housing comprise 47% and 34% of total emissions, respectively; whilst the remainder is split between manure storage and animal deposition. In terms of atmospheric pollution, ammonia is both a local and trans-boundary pollutant, and also indirectly contributes to greenhouse gas emissions. Ultimately, however, these emissions represent a considerable loss of N to the farmer. Indeed, the economic cost associated N loss via volatilization is c. €60 million. As a result, there is an urgent need to develop abatement strategies to reduce these losses.

2. Questions addressed by the project:

This project had two principle research goals. The first was to assess the effect of timing and application technique on ammonia emissions. The second objective was to assess the emissions from housing and to evaluate the efficacy of Out-Wintering Pads (OWP's) as a housing control measure.

3. The experimental studies:

Landspreading: Eight land-spreading experiments were carried out between July 2006 to August 2008 with slurry applied to grassland on a loamy soil using either splashplate or trailing shoe application methods. On all plots, application rates were 33 m^3 per hectare. All slurry used for application came from the slatted beef unit at Teagasc Environmental Research Centre, Johnstown Castle, was agitated in the shed 1–3 days prior to application and spread using the same purpose built tanker (Abbey Machinery Ltd, Nenagh, Co. Tipperary). The tanker had a capacity of 7 m^3 and had a valve which allowed slurry to be circulated inside the tank. The slurry was forced through the pipes to the 24 applicators. Each applicator had a valve to allow the selection of splashplate or trailing shoe application. In order to accurately assess the effect of timing and spreading technique on ammonia emissions, measurements were performed using the flux-gradient technique. This method measured ammonia emissions at various heights (from 0.1 to 2.2m) above the ground, with the sum of the all heights representing the emissions for an area of ground (dependent on the mast height and windspeed). Thus it provided a non-invasive technique and provided an integrated measurement over a large area (100m^2). The masts contained passive flux samplers which were coated with acid to trap the ammonia. This trap was subsequently washed and the ammonium content analysed. Experimental data was used to parameterize a statistical model.

Housing Systems: A comparative assessment of emissions from both slatted sheds and OWPs was undertaken using of direct measurements from acid traps placed at 1m intervals on each side and roof of the building. In addition, emissions plumes arising from housing sources were simulated using atmospheric dispersion models, which simulate the ammonia plume emitted from the housing system. This plume modelling was undertaken as direct emissions measurements from open out-wintering pads and lagoons were impractical.

4. Main results:

- On average, 54% of total ammoniacal nitrogen (TAN) was lost when slurry was applied by splashplate. However, there was significant variation in emissions depending on the prevailing weather conditions for the first four hours after application, with up to 78% of TAN lost on hot, dry days. However, if application was targeted for cooler periods, particularly during spring, emissions were reduced by over 30%. In addition, dusk application during summer halved emissions with only 24% TAN lost. The adoption of trailing shoe technology reduced ammonia emissions by an average of 36%. In addition the range of ammonia emissions across weather conditions was more consistent. However, under low emission conditions, there was no significant difference between application technique.
- Ammonia emissions from slatted sheds were 8 gNH_3–N LU^{-1} day^{-1}. This value is considerably lower than the values (38 gNH_3–N LU^{-1} day^{-1}) used by the EPA in the national ammonia inventories and as such, indicating a substantial overestimation of cattle housing emissions within the inventory. By comparison, OWP emissions were 62 gNH_3–N LU^{-1} day^{-1} with periods of higher emissions occurring during dry periods. Emissions were substantially reduced (90%) if pads were regularly cleaned. However, OWP's are in general, *not* an effective ammonia abatement technique.

5. Opportunity/Benefit:

This research demonstrates the effectiveness of both changing application technique and timing. In particular, statistical models generated in this study will provide a starting point for the construction of an Application Timing Management System for Ireland. This would allow farmers to reduce emissions without the requirement to adopt more expensive machinery.

In terms of housing, this research indicates that ammonia emissions from slatted cattle housing is towards the low end of European figures and lower than default values derived from UK data. In addition, it was also demonstrated that whilst out-wintering facilities be advantageous in terms of animal welfare, ammonia emissions, expressed on a per head basis were much higher than housing.

6. Dissemination:

The primary stakeholders for this research are both farmers and policy makers.

Main publications:

Dowling, C., Hill, R., Curran, T. & Lanigan, G.J (2010) Ammonia emissions associated with cattle housed on Out-Wintering Pads. Biosystems Engineering (accepted)

Meade, G., Pierce, K., O'Doherty, J.V., Muller, C., Lanigan, GJ and McCabe, T. (2010). Ammonia emissions following land application of high and low nitrogen manures to winter wheat at three growth stages. Agriculture, Ecosystems & Environment (in press).

Dowling, C., Hyde, B., Carton, O., Curran, T. and Lanigan G.J. (2010) Ammonia emissions associated with the landspreading of cattle slurry in Ireland. Atmospheric Environment (submitted).

Dowling, C., Curran, T. and Lanigan G.J. (2008) The effect of application technique and climate conditions on ammonia emissions from cattle slurry. In: 13th Int. RAMIRAN Proceedings, Albena, 4pages ISBN 978–954–9067671–6–3

Lalor, S. and Lanigan, G. (2010). The potential of application timing management to reduce ammonia emissions following cattle slurry application. In: 14th Int. RAMIRAN Proceedings, Portugal.

Popular publications:

Dowling, C., Curran, T. and Lanigan G.J. (2009) Reducing Ammonia Emissions. TResearch. 4(1): 40–43

The objectives and harvesting plans of Ireland's forest owners

Project number:
5504
Date:
Oct, 2011
Funding source:
Teagasc
Project dates:
April 2006–Dec 2012

Key external stakeholders:

- Teagasc Forestry Clients
- Forest Service, Department of Agriculture, Food and Marine
- Teagasc Producer Groups
- Forestry Commercial Companies

Practical implications for stakeholders:

The factors shown to increase the likelihood of a forest owner thinning their forests were

- They had previously thinned his/her stand;
- Having availed of extension activities; and
- Having a management plan for the forest.

Measures to promote increased Knowledge transfer of silvicultural information to growers will promote good forest management in the private sector.

Main results:

A recent survey of 120 private forest owners indicated that almost three-quarters (72%) of all forest owners surveyed planned to thin their forests in the future. The suitability of the area they planned to thin was assessed taking account of access, ground conditions and windthrow risk. Only one-half of this area was found to be suitable for thinning with poor ground conditions and/or excessive roading requirements the main constraints. The study found that while most forest owners hoped to produce timber from their woods many of them either planned to use the timber themselves or were unsure as to whether they would put it on the market. Availing of extension activities significantly increased the likelihood that an owner would their plantations. However, the study raised concerns as to whether owners were making the correct silvicultural decision regarding thinning.

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Technology

Opportunity/Benefit:

Growers who availed of extension services are more likely to thin their plantations. Targeted extension which assists in silvicultural decision making process will ensure correct decisions are made regarding thinning and forest management.

1. Project background:

Since 1980, an estimated 16,000 Irish landowners, mostly farmers have afforested 212,200 ha of new forests. Government projections for timber supply from Irish forests assume that private forests will be managed and harvested in a similar way to State forests. In order to understand more about the harvesting intentions of private forest owners and the suitability of their stands for thinning, a study was conducted to gather information from a sample of 120 forest owners and their forests.

2. Questions addressed by the project:

- The study characterised the private forest resource, in relation to growth rates and plantation details.
- The study quantified the area of forest that has already been thinned.
- The study determined the primary objectives of private forest owners.
- The study determine the factors influencing a private forest owner's decision to thin/or not thin their forest.
- The study assessed whether the stands that owners plan to thin are "suitable" for thinning.
- The study assessed the role of training and extension in influencing the owner to consider thinning.

3. The experimental studies:

A survey of a 120 private forest owners was conducted during the summer of 2007. A detailed questionnaire was completed by each owner during face-to-face interviews. It included questions regarding the owner's objectives, harvesting plans, and involvement in extension activities as well their awareness of silvicultural processes involved in forest management. A silvicultural audit of the forests owned by those surveyed was also conducted, and logistic regression analysis was used to determine which characteristics of the owners and their forests influenced whether an owner planned to thin his/her stand. An assessment of the area that owners planned to thin, based on ground conditions and access to the site, along with a consideration of windthrow risk was used to assess the area that was suitable for thinning.

4. Main results:

Three-quarters of those surveyed were farmers (full-time, part time or retired). Less than one-fifth were younger than 45 years. Only seven percent of stands visited (i.e. 31 ha), had been previously thinned. All thinning performed was for merchantable purpose, including firewood production. The primary objective of most forest owners was to produce timber from their woods. Landscape enhancement was an objective for 20% of respondents. Forty nine percent of forest owners had multiple objectives.

While most (79%) of the forest owners surveyed had employed a management company or contractor to establish their forest, most were now managing their forests themselves and planned to continue to do so in the future. Almost three-quarters of all forest owners surveyed planned to thin their forests in the future. Almost half of those planning to thin did not know how many thinning operations would be carried out.

Over one-half of respondents had attended training courses or demonstration days relating to forestry, while one-quarter attended more than one training event. Sixty-nine percent of all respondents believed that private forest owners need training in aspects of forestry, with training in thinning and harvesting most commonly suggested.

Logistic regression identified the key factors that influence the probability that a forest owner planned to thin his/her stand forest:. Forest owners who had attended forestry extension activities were 2.55 times more likely to have decided to thin their stands than those that had not. Those who had the production of timber as an objective were 2.7 times more likely to plan to thin their forests than those that did not have this objective. All owners who had a management plan planned to thin.

5. Opportunity/Benefit:

Training courses on forestry and attendance at extension events such as those run by Teagasc and the completion of management plans are key factors in motivating thinning in the private sector, these events should continue to be promoted and encouraged.

6. Dissemination:

Ní Dhubháin, A., Maguire, K., and Farrelly, N. 2010. The harvesting behaviour of Irish private forest owners and the suitability of the private estate for thinning. Proceedings from IUFRO Conference: 3.08. Small scale forestry. Bled, Slovakia 06–12 June 2010. pp 117–127.

Main publications:

Ní Dhubháin, A., Maguire, K., and Farrelly, N. 2010. The suitability of the private estate for thinning. Irish Forestry 2010: 21–37.

Ní Dhubháin, A., Maguire, K., and Farrelly, N. 2010. The harvesting behaviour of Irish private forest owners. Forest Policy and Economics (12). 513–517.

Farrelly, N. 2006. The farm forest resource and its potential contribution to rural development in Ireland. In: Wall, S. (ed.). Small-scale forestry and rural development, the intersection of ecosystems, economics and society. Proceedings Iufro 3.08 conference, Galway, Ireland. June 2006, Coford and Gmit, Ireland, pgs 41–50.

Thesis:

Maguire, K. 2008. The objectives and harvesting intentions of Ireland's private forest owners. MSc Thesis, University College Dublin. 128 pp.

Project number:
5519
Date:
August, 2011
Funding source:
EU FP6
'infrastructures'
Project dates:
Jun 2006– Mar 2011

Co-ordination of tree breeding in Europe

Key external stakeholders

Farmers, foresters, consultants, The Department of Agriculture and Food, forestry, EC, Coillte

Practical implications for stakeholders:

- The European community of tree breeders in 19 countries have created a vast data base of their field trials of genetic materials which are in the process of being genetically improved using a variety of conventional and new technologies.
- The infrastructure of tree breeders their resources and collective approaches has been assembled.
- A series of species monographs in relation to breeding has been prepared.
- The project concluded that tree breeders face many common challenges and they have prepared outlines for collaborative breeding.

Main results:

- Breeders of forest trees across the EU have collaborated to create a large meta-data base of all field experiments for nine of the major forest species in Europe, their location, design, and genetic constitution.
- A network of EU personnel with identifiable expertise and their facilities has been collated.
- A series of nine species monographs on the state of the art and the objectives for cooperative breeding at EU level has been prepared as well as many other position papers.
- Full proceedings of important conferences on mass propagation by seed and vegetative means are available.

Collaborating Institutions:
INRA, France
BFW, Austria
INBO, Belgium
SBS, Germany
METLA, Finland
(FR)FC, UK
ALTERRA, Netherlands
NFLI, Norway
SKOGFORST, Sweden

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Technology

Opportunity/Benefit:

End users can gain access to the work of the project via the project website: http://treebreedex.eu/ and they can interface with tree breeders via the e-mail discussion forum indicated below.

Many project outputs are available and all will be public in 2012 including a series of species monographs.

1. Project background:

Teagasc was a partner in the infrastructure project TREEBREEDEX. It consisted of 28 partners in 18 countries. They were either public-funded -national or regional-forestry research institutions or private agencies, covering major fields of R&D in forest sciences. The project focussed on the upgrading of genetic resources of trees available in Institutes throughout Europe. Over decades, huge collections of trees of economic species and vast networks of experimental trials have been established which are a unique infrastructure of biological materials. In addition, the methodologies in genetics and in related sciences to recombine, test, evaluate, analyse, select and mass-produce forest tree species have been developed but are scattered throughout the EU.

The main aim of the project was to develop a scientific and technical research framework in forest genetics and tree breeding at the European level to ensure:

- a better co-ordination and integration of tree breeding research activities.
- the enhancement of a more multidisciplinary approach to solve acute new challenges facing breeders through a closer co-operation with other fields of research such as physiology, climatology, molecular biology, pathology, and wood technology.
- an increase in scientific and technical excellence,
- a facilitated access to complementary national institutes research facilities and expertise, so as to optimise the use of technical resources,
- an improved linkage between research activities and economic outputs from forests,
- a greater interaction with policy-makers, stake-holders and the public,
- a strong support background for studies on the multi-functionality of European forests.

2. Questions addressed by the project:

- What trials are underway to test the performance of different sources of tree germplasm of different species in Europe?
- What are the most important forest species now and emerging species for the future throughout Europe?
- Which countries have significant trial networks, who are the personnel which can be contacted so that greater access and cooperation can be fostered?
- Can the scientific and technical excellence of R&D activities across Europe be enhanced by complementation among teams?
- Can R & D programmes in tree improvement, in member states, be progressively integrated into co-operative improvement programmes?
- Can specialist facilities and teams be opened to the wider scientific community in forestry, agriculture & horticulture (fruit, ornamental trees)?
- Can a Virtual Tree Breeding Centre for Europe be created?

3. The experimental studies:

The project was implemented through a set of Activity Tasks, one of which was coordinated by Teagasc. In collaboration, the partners developed sets of defined tools which would facilitate the building of the research infrastructure by :

- Creating and managing web-based co-ordination tools, mainly in the form of a common meta-database in which data on existing trials were entered. This together with position reports and species monographs forms the core of the 'Virtual Tree breeding Centre' in Activity Task 2.
- Enhancing the circulation of information, knowledge and expertise among tree breeders in their field of research by publications, seminars and workshops,
- Establishing scientific and technical methodological standards for common scientific work such as experimental trials, data storage and analysis,
- Identification of gaps in knowledge and new research needs for important forest species,
- Organising training through seminars in tree breeding,
- Preparing the scientific, technical and legal background for the development of true co-operative breeding programmes on some pilot-species.

4. Main results:

Many documents produced by the project are currently available at the main Treebreedex website: http://treebreedex.eu/ and all of them will be made public in 2012.

- In Activity Task 2, the project has created a large meta-data base of all field experiments for nine of the major forest species in Europe, their location, design, and genetic constitution. Specifically it provides information on 4111 genetic field trials comprising, nearly 107000 genetic units; that is 5632 provenances, 2012 synthetic populations, 44139 half-sib progenies, 10508 full-sib progenies and 44644 clones. These are in and 244 provenance trials, 283 progeny trials, 140 clonal trials, 12 variety trials, 112 seed orchards, 36 clonal archives, and 23 other trials types. The data base is searchable.
- Activity Task 3 dealt with the geographical structure of genetic resources and has produced Reports on the 'Principles of Seed transfer' and workshop reports on 'Adaptability and plasticity in relation to breeding'.
- Significant reports have been produced on: 'Defining access rules to genetic material collections and benefit sharing arrangements' and on the 'Principles of joint long term management and conservation of breeding populations' in Activity Task 4 'Assessing the Structure & Organisation of Breeding Material'.
- Activity Task 5 dealt with 'Optimisation of breeding strategies' and has established the EU network of breeders and reports on: 'Assessment of drought and frost hardiness of young trees', the 'Layout of field trails' and **'**Common protocols and reference standards for lab and field experimentation, assessment, and analysis'.

5. Opportunity/Benefit:

Teagasc was responsible for Activity Task 6, that is, the 'Optimisation of Improved Variety Mass-Production and Deployment in Forests'. The following outputs were developed:

- A discussion forum on tree improvement was established to elicit and share information on various subjects related to breeding. Contact with the network of 85 subscribers of European tree breeders can be assessed automatically by e-mailing TREEBREEDEX-SUBSCRIBE-REQUEST@ guava.ease.lsoft.com.
- A European 'expert group' of scientists on mass propagation by seed and vegetative means was collated with 52 names and contact details.
- A catalogue was prepared of web-links which identified and created links to relevant pages and contact personnel for the national data bases of forest reproductive materials as well as the national regulations. It also has web-linked documents on websites related to Breeding, Forest Reproductive Material Acts and National Lists.
- A workshop report on 'Concerns of the public in relation to tree breeding' was produced.
- To aid in the standardization of new varieties a report was prepared 'Guidelines on Genetic Quality of Forest Reproductive Materials, Plant Variety Rights, and a Proposal to define 'descriptors' for use in Certifying 'Tested' material and 'Trademarks' for tree varieties'.
- Important conferences and workshops were held on methods for mass-propagation; for the 'Seed Orchard Conference' in, Sept 2007 the publications details are given below.
- The conference on: 'Vegetative propagation and Deployment of Varieties-The Scope for Europe', was in April 2009 and the following themes emerged.
- Developing varieties for clonal forestry is practised in several places worldwide.
- Ensuring that deployed genetic material is adaptable to future, often unknown climate conditions ('future proofing') is a challenge to breeders.
- Although variety development is concentrated on short-rotation species, increasingly this is not the case (e.g. white spruce in Canada). Clonal forestry may not be the answer for all organisations. The economics may not justify such an approach and there are other issues such as certification and acceptance by stakeholders. Foresters may find that the next best option of 'family forestry' in which high performing families are vegetatively propagated is quite productive and acceptable for their own circumstances.
- Some countries are investing more money in tree breeding as a means of locking up more carbon from the atmosphere.
- Developing improved varieties can help tackle climate change by maximising carbon sequestration and producing better-grade construction timber to displace carbon-intense building products such as metal and concrete.

- The message from existing enterprises which deploy varieties was that the investment in people and facilities may not be prohibitive.
- More extensive demonstrations of clonal variety trials are needed for breeders to evaluate that the effort is worth while (i.e. to check whether realised gains match theoretical figures or not). This will help to convince budget holders and policy makers on the real potential based on production facts.
- The demand for clonal varieties is clearly already here and viable (Eucalyptus in Portugal, poplar etc) but its uptake and development will vary depending on the national / regional forestry objectives.

6. Dissemination:

The main vehicle for dissemination of the reports, conclusions and outcomes of this project is the web site: http://treebreedex.eu/ All information not currently present will be public in 2011.

Main publications:

- As indicated above two conferences and workshops were held on methods for mass-propagation: for the 'Seed Orchard Conference, Sept 2007. Summaries of all papers are available at : http://treebreedex.eu/IMG/pdf/Seed-Orchard-Summary–080812.pdf and on the Teagasc website.
- The full conference proceedings are available at http://pub-epsilon.slu.se:8080/151/01/ZProcFinalFeb08.pdf as well as on the Teagasc website.
- The project has generated a series of monographs on the breeding of important forest species for Europe such as Spruces (Sitka and Norway), Pines, Douglas fir, Larch, Wild cherry, poplar and Sycamore. Teagasc was responsible for the monograph on Ash (*Fraxinus excelsior*); all of these will be public in 2012.

Crops
Environment
& Land Use
Programme

Project number:
5086
Date:
March, 2011
Funding source:
COFORD
Project dates:
Sep 2001–Jun 2011

Birch and Alder – the development of a tree breeding programme and a seed supply for Irish forestry

Key external stakeholders:

Farm forest growers, commercial forestry companies, tree nurseries, COFORD & Forest Service, Department of Agriculture, Food and Fisheries

Practical implications for stakeholders:

The project is developing a sustainable supply of improved, adapted and healthy seed of birch and alder within the framework of the EU Forest Reproductive Material (FRM) regulations. The project has reached a key stage having produced improved material at the 'qualified' level of the FRM regulations.

Main results:

- Seed orchards for both birch (downy birch) and alder have been established. The clones included in the orchards have been selected on the basis of work carried out in the project.
- Grafts of downy birch, silver birch and alder plus-trees have been used to establish a living clonal archive that provides a resource for future breeding, research and conservation.

Opportunity/Benefit:

In the first instance parent material will be available to nurseries to produce and market improved planting material. And as the supply system is put in place, forestry owners can avail of improved material to increase the monetary and ecological value of their forests. The availability of improved birch planting material would enable the Forest Service to list birch as a grant-aided species providing more choice to forest owners.

Collaborating Institutions:
UCC
UCD

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Technology

1. Project background:

Two species of birch are native to Ireland; Betula pubescens and Betula pendula. Currently birch is not on the recommended species list for afforestation grants. Two factors have prevented the listing of birch as a recommended species; the poor stem quality of naturally regenerated birch and the poor survival and growth rates that has followed importation of seed from abroad. However, experience from abroad indicated that birch had improvement potential. The development of birch as commercial forestry tree species' supports government policy in the aspiration to increase forestry area in Ireland, to increase the broadleaf component of forestry in Ireland, to use more native species and to increase diversity in Irish forestry. The physiology of birch and alder means that they can be used on land that would not be suitable for oak or ash and birch has a short rotation period, about 40 years, in comparison to other native broadleaves.

The birch project began with an initial study 'Pilot project for the genetic improvement of Irish Birch' (1998–2000). This has been followed by a series of other COFORD funding including the current funding. The improvement of alder (Alnus glutinosa), a species that is on the Forest Service schedule, was initiated in 2005. In a 2007 COFORD review, alder and birch were confirmed as native species' of high potential for improvement in the Irish context.

2. Questions addressed by the project:

- Do better-quality provenances of birch and alder exist in Ireland and can they be recommended as suitable seed collection areas?
- Can superior individuals of birch and alder be identified to be used as a base population for an improvement programme?
- Do the characters of growth and stem form display heritability for cyclical and concurrent selection and improvement?
- Can superior families of birch and alder be identified in progeny trials, indicating high value parent trees to retain in the breeding populations?
- How do the selected clones respond to growing in a managed seed orchard and what is the annual seed yield?

3. The experimental studies:

The overall objective of the research is the development of a sustainable supply of improved, adapted and healthy seed of birch and alder within the framework of the EU Forest Reproductive Material (FRM) regulations. The approach to develop sources of improved planting stock has been;

- Locating the best examples of mature trees (plus-trees) of these species on which to base the improvement programme;
- Collecting scion wood from plus-trees and grafting the scion wood onto rootstock to generate clones of the plus-trees;
- Establishing clone banks to preserve the genotypes;
- Establishing seed orchards;
- Establishing progeny trials to assess the value of the trees as parents.

Ten year old birch progeny

For birch, a survey was conducted during 1998/1999 to identify good birch stands and individual plus-trees. Good stands of mature birch were rare and often the trees were in small groups or were scattered throughout an area. Most of the stands were unmanaged and downy birch was more common than silver birch (O' Dowd, 2004). Three Breeding Seedling Orchards were established in 2001 (O' Dowd, 2004) – plants generated from the seed collected from the plus-trees were used. Seedlots from thirty-three provenances (B. pendula and B. pubescens) and 37 controlled crosses of plus-trees (B. pubescens) and some overseas B. pendula material were included. These have been evaluated for height, diameter and stem form every other year. For alder, grafts of eighty-five plus-trees have been collected for use in an untested seed orchard. Open-pollinated seed from these plus-trees has been collected and a series of three progeny testing field trials have been established in 2008 and 2009. These have been evaluated for height and survival on an annual basis.

The location and collection of new material for the breeding programmes is ongoing. In spring of 2009 grafts from 16 new birch plus-trees and 26 new alder trees were successfully established.

4. Main results:

- The main result is the establishment of seed orchards for both birch (downy birch) and alder. The clones included in the orchards have been selected on the basis of work carried out in the project.
- The alder orchard is based on parents i.e. backward selection. This means that, in the future, the results from the alder progeny trials will allow the alder orchard to be modified so that only the clones that have shown good breeding values are included.
- The birch orchard is based on forward selection i.e. good trees from within the progeny trials will be selected for inclusion. At the moment, the birch orchard contains early selections and protocols to manage these indoor seed orchards are being developed.
- Grafts of downy birch, silver birch and alder plus-trees have been used to establish a living clonal archive that provides a resource for future breeding, research and conservation.
- The field trials established during the project continue to provide information as the trees mature.

5. Opportunity/Benefit:

In the first instance parent material will be available to nurseries to produce and market improved planting material and as the supply system is put in place, forestry owners can avail of improved material to increase the monetary and ecological value of their forests.

The availability of improved birch planting material would enable the Forest Service to list birch as a grant-aided species providing more choice to forest owners.

The collections provide a valuable resource for future breeding, molecular and physiology research and conservation. As there is very little information about birch growth in Ireland, in particular in a plantation situation. The progeny trials provide some information about birch growth in Ireland.

6. Dissemination:

Results were also presented at demonstration visits, conferences (including Treebreedex 2010) and project reports.

Main publications:

Hemery, G., Clark, J., Aldinger, E., Claessens, H, Malvolti, M., O'Connor, E., Raftoynnis, Y., Savill, P. and Brus, R. 2010 Growing scattered broadleaved tree species in a changing climate – risks and opportunities. Forestry 83: 65–81

O'Dowd, N. 2004. The improvement of Irish birch. Phase 1: Selection of individuals and populations. COFORD, Dublin. http://www.coford.ie/media/coford/content/publications/projectreports/Birch-improvement.pdf

Skovsgaard, J.P., O'Connor, E., Graversgaard, H.C., Hochbichler, E., Mohni, C., Nicolescu, N., Niemistö, P., Pelleri, F., Spiecker, H., Stefancik, I. and Övergaard, R. 2008 Procedures for forest experiments and demonstration plots. COST E42, Valbro. Online Publication and COST Action E42 (Valbro) final report. http://www.valbro.uni-freiburg.de/

Popular publications:

June 2010 Project up Date: BIRCH/ALDER: Selection and improvement of Irish birch and alder Forestry and Wood Update 10 (6): 3 at http://www.coford.ie/publications/newsletter/newsletter-vol10/#d.en.47373

O' Connor, E. 2007 Progress in the selection and improvement of Irish birch COFORD Connects: Reproductive Material 10. http://www.coford.ie/media/coford/content/publications/projectreports/cofordconnects/birch.pdf

O' Connor, E., Steer, M. and Bulfin, M. 2006 Growth and Stem Quality Variation In Irish Birch (Abstract). In Proceedings of the IUFRO Division 2 Joint Conference: Low Input Breeding and Conservation of Forest Genetic Resources: Antalya, Turkey, 9–13 October 2006. Edited by Fikret Isik. p 165. Available from http://www4.ncsu.edu/~fisik/IUFRO%20Antalya%20Conference-Proceedings.pdf

Characterising 'brown bud' – hybrid ash

Project number:
5699
Date:
February, 2012
Funding source:
COFORD
Project dates:
Apr 2007–Dec 2010

Key external stakeholders:

Farm foresters, forest nurseries, forestry advisors, DAFF

Practical implications for stakeholders:

Forest owners should be very careful about the geographic origins of all forest trees, especially ash, which they use to establish their forest plantations. Some imported ash trees from Europe in the period 1990–2002 have shown poor growth and stem form in plantations (see figure above). This is due to the deployment of plants which were not pure common ash (Fraxinus excelsior); rather they were complex hybrids of common ash with the continental species of narrow-leaved ash, F. angustifolia. Key morphological characteristics to identify F1 hybrid material are described.

Main results:

- In F1 hybrids, thirteen of the variables were statistically different between the two species but the main differences were a greater leaf area and a lower stomatal density in the leaves of F. excelsior compared to F. angustifolia.
- Useful characters to distinguish hybrid trees from our native F. excelsior were the characters of 'leaf width' and the character of 'number of teeth / leaflet'. In the case of teeth number per leaflet, the reciprocal F1 hybrids had an intermediate number of teeth (16–17) and these numbers were significantly different from either parent: F. excelsior (24) and F. angustifolia (12), Figure 1; similarly for total leaf area and leaf weight.
- The morphological characters described are useful in providing evidence for the potential presence of hybrid individual trees in the plantations of farmers who suspect they may have them.

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Technology

- Hybridisation of ash occurs in nature on continental Europe where the two species co-exist and where their geographic ranges overlap. Seeds collected from such areas are undesirable because they may consist of pure F1 hybrids and back crossed hybrids which are not suited for Irish plantations.

Opportunity/Benefit:

This research provided key morphological features which may be used to evaluate the material found in plantations that is suspected to be derived from hybridization. As Ash trees and seeds can be freely marketed across Europe forest nurseries are now aware of the dangers of importing germplasm and plants to Ireland from ash sources which are not pure F. excelsior and which may prove to be mal-adapted to Irish growing conditions. Forest owners can now make every effort to ensure that their source of ash seeds / plants is from the recommended list of countries and preferably from registered sources in Ireland and the UK.

1. Project background:

In the period 1997–2007 we have planted 1.3 million ash trees per year because ash is a hardwood crop with a good economic potential for farm forestry which also produces thinnings for firewood and hurleys. In some years, we have imported ash plants as home production failed to meet full demand. Although the imported plants appeared good, many plantations from this period have produced crooked stems and poor growth (see figure). Contact with European colleagues indicated that common ash (F. excelsior) can form hybrids with a related species (F. angustifolia), which shares its geographic territory on the continent. The poorly performing material may be progeny from the hybridisation of common ash (F. excelsior) with narrow leaved-ash, (F. angustifolia). It was observed that imported plant material in these plantations had brown coloured buds rather than the typical black buds of common ash and so, problematic plantations have become known as ‘brown bud ash’.

An important aim of this research was to find distinctive morphological characters which would aid in the identification of hybrid plant material, so pure F1 hybrids were analysed.

2. Questions addressed by the project:

- What are the main morphological characteristics of pure common ash, F. excelsior compared to pure narrow-leaved ash, F. angustifolia?
- What are the main morphological characteristics of F1 hybrids of F. excelsior x F. angustifolia when each species was used as mother or father species?
- Which morphological characteristics are most useful in the identification of F1 hybrids?

3. The experimental studies:

Measurement were taken from confirmed control plants of each species and compared with F1 hybrids of F. excelsior with F. angustifolia which were derived from reciprocal crosses with each species as female and male. Ash has compound leaves and measurements were made on whole leaves and component leaflets. We measured dimensional traits (and some computed ratios): leaflet length, width, leaflet area, apex angle of the terminal leaflet, internode length between the second and third leaflet, total leaf area, total leaf length, total leaf width, and total dry leaf weight, and discreet variables: number of leaflets per leaf, number of teeth on the second leaflet from the terminal leaflet and the density of stomata on the underside of leaves. Statistical analysis included both univariate and multivariate methods. Data analysis for basic statistics and data transformation were performed using R Foundation statistical computing software and Statistica v.6.0 .Some variables were log transformed for normalisation. One-way analysis of variance and Tukey HSD post-hoc tests (at 5% probability) were used to make comparisons among the different groups. Observations were also made on trees in plantations which have shown poor growth and crooked stems for the presence of brown buds and the presence of three buds at each node. The latter character is in short shoots on some trees of F. angustifolia whereas common ash (F. excelsior), has typically two buds per node.

4. Main results:

- Winter buds of common ash are typically black and opposite, there is variation in both traits in hybrids so characterization was concentrated on determining measurable traits. We compared F. excelsior with F. angustifolia and the F1 hybrids with either parent. Most of the measurements of

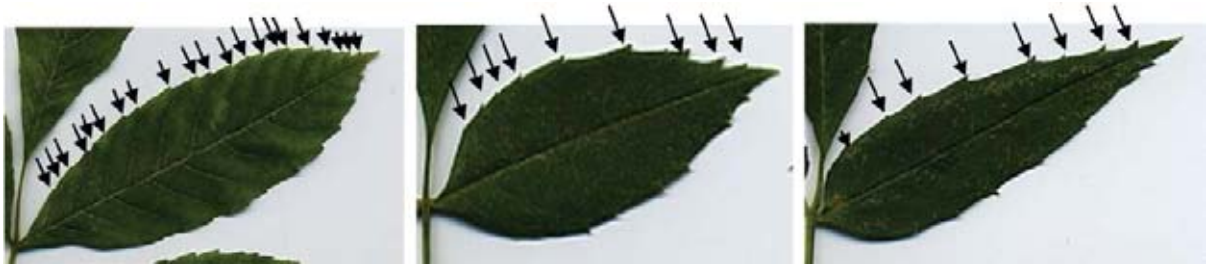

Figure 1. Illustration of teeth (number) on leaflet margins of: (Left to Right); Common ash, F. excelsior (20–30); F1 hybrids (7–15), Narrow Leaved ash, F. angustifolia (5–12)

the whole leaf and leaflets of common Irish ash F. excelsior were significantly larger for this species compared to continental narrow-leaved ash F. angustifolia; including: leaflet area, leaflet length and width, total leaf dry weight, total leaf area, total leaf length , the angle at the apex of terminal leaflet and the number of teeth per leaflet. For example the mean number of leaflets in F. excelsior was 11.95 and was significantly smaller in F. angustifolia, with 7.9.

- The density of leaf stomata on the underside of leaves was the only variable found to show significantly higher values in F. angustifolia, compared to F. excelsior.
- We compared details in offspring of two different types of F1 hybrid; one set had F. excelsior as mother, the other had F. angustifolia as mother. These offspring were morphologically intermediate between the two parental species for most characters, although the ranges of values for hybrids generally overlapped with those of one or other parental species. Only three of the variables were significantly different between the two types of F 1 progeny when compared to each of the parental species. In the case of teeth number per leaflet, the reciprocal F1 hybrids had an intermediate number of teeth (16–17) and these numbers were significantly different from either parent: F. excelsior (24) and F. angustifolia (12), Figure 1; similarly for total leaf area and leaf weight.
- For five of the characters there was no significant difference between F. excelsior and the F1 progeny from reciprocal crosses i.e. leaflet length, leaflet width, leaflet area, leaf length, and number of leaflets / leaf. However, for all of these characters in the F1 hybrids, they were significantly different (and greater) than in F. angustifolia.
- Hybrids which had F. excelsior as mother could be distinguished from those with F. angustifolia as mother only by the characters of apex angle of the terminal leaflet and the ratio of leaflet length to width. In each case these characters in the F1 hybrids followed the female parent.
- The ratio of leaflet length to width and the total leaf width were similar in each of the reciprocal hybrid types.
- Although Fraxinus excelsior had a significantly lower density of leaf stomata than F. angustifolia, the two hybrid types were not significantly different from each other for this character. Stomatal density in the hybrids derived from F. excelsior as mother, were more similar in number to pure F. angustifolia whereas those hybrids derived from F. angustifolia as mother were more similar to pure F. excelsior for the density of stomata.

A stepwise discriminant analysis was performed to identify those variables which could best discriminate among the four groups of: F. excelsior, F. angustifolia, F1 hybrids with F. excelsior as mother and F1 hybrids with F. angustifolia as mother. The variable characters of 'leaf width' and the character of 'number of teeth / leaflet' had the most discriminatory power to separate the four groups. The character of 'total leaf area' was also useful as indicated above.

5. Opportunity/Benefit:

End-users of this information are forest owners, COFORD, Department of Agriculture Fisheries and Food, Forestry Inspectors and advisors. Results have shown that pure common ash (Fraxinus excelsior) has different morphological features when compared to imported material of narrow leaved ash (F. angustifolia) and from hybrids derived from

these species. The key morphological features may be used to evaluate the material found in plantations that is suspected to be derived from hybridization. As forest reproductive material can be freely marketed across Europe. Forest nurseries are now aware of the dangers of importing seed germplasm and plants to Ireland from sources which may prove to be mal-adapted to Irish growing conditions and which may be not consist of pure common ash, F. excelsior.

6. Dissemination:

A communication in the series 'Coford Connects' has been submitted giving more detailed information covering morphology, flowering, further hybridisation and management suggestions.

Main publications:

Thomasset, M., Fernández-Manjarrés, J.F., Douglas, G.C., Frascaria-Lacoste, N., Raquin, C., Hodkinson, T.R. (2011) 'Molecular and morphological characterization of reciprocal F_1 hybrid ash (Fraxinus excelsior F. angustifolia, Oleaceae) and parental species reveals asymmetric character inheritance'. International Journal of Plant Sciences 172, 423–433.

Thomasset, M., Fernández-Manjarrés, J.F., Douglas, G.C., Frascaria-Lacoste, N., Hodkinson, T.R. (2011) 'Hybridisation, introgression and climate change: a case study for the tree genus Fraxinus (Oleaceae)'. In: Climate Change, Ecology and Systematics, ed. Trevor R. Hodkinson, Michael B. Jones, Stephen Waldren and John A. N. Parnell. Published by Cambridge University Press. © The Systematics Association 201 pp. 320–342.

Thomasset M. (2011) Introduced hybrid ash: Fraxinus excelsior X F. angustifolia in Ireland and its potential for interbreeding with native ash. Ph D. Thesis (2011), University of Dublin Trinity College, Ireland.

Popular publications:

Keeping ash trees pure. Science Spin, November 2008. http://www.sciencespin.com/magazine/archive/2008/11/keeping-irish-ash-trees-pure-/

Broadleaf silviculture

Project number:
5701
Date:
September, 2012
Funding source:
COFORD & Teagasc
Project dates:
Jan 2009–Jul 2010

Key external stakeholders:

Forest owners, forest industry

Practical implications for stakeholders:

- Most broadleaf forest owners are capable of selecting and marking Potential Crop Trees prior to a tending operation after some initial training.
- Guidelines for the tending and thinning of broadleaf forest crops have been published.
- There is a demand from owners of broadleaf forests for silviculture knowledge, as demonstrated by the number of downloads of Silvicultural Guidelines for the Tending and Thinning of Broadleaves.
- An alder tending intensity trial has been established for medium-to long-term research.

Main results:

Silvicultural guidelines for the tending and thinning of broadleaves have been published and proven to be in great demand. Teagasc, in conjunction with UCD and COFORD, continue to research broadleaf silviculture to maximise the potential that the growing broadleaf forest estate can attain.

Collaborating Institutions:
UCD Coillte
Private forest owners

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Technology

Opportunity/Benefit:

The broadleaf silviculture guidelines provide forest owners with the knowledge and methodology to ensure that their broadleaf crop can reach its potential. The establishment of a medium-to long-term alder tending intensity trial will add to the available knowledge.

1. Project background:

Approximately 32,000 hectares of broadleaves have been planted during the period 1990–2007 inclusive (Forest Service statistics, 2008). The demand from forest owners and the wider industry for advice on broadleaf tending and thinning, especially for ash but also for other species, has increased in recent years, as demonstrated by the increase in number of enquiries to Teagasc Forestry Development Officers. The introduction of the Tending and Thinning of Broadleaves grant in 2009 as part of the Woodland Improvement Scheme increased the awareness by forest owners of the need for management interventions in order to realize the full potential of their broadleaf crop. An ultimate aim of this project is to provide owners, and the wider industry, science-based best-practice knowledge on the tending and thinning of broadleaves.

2. Questions addressed by the project:

- To secure, maintain and monitor existing broadleaf silvicultural trials and demonstration sites established by the COFORD-funded BROADFORM project.
- To report on the final measurements of a concluded clonal poplar trial.
- To establish a new alder tending intensity trial.
- To disseminate broadleaf silvicultural best practice to practitioners.
- To provide comments and recommendations on a draft version of 'Growing Broadleaves', a broadleaf silviculture book that is currently being written and is planned to be published by COFORD.

3. The experimental studies:

Growth data (diameter and breast height; stem height) were collected at existing broadleaf tending demonstration and experiment sites. These will continue to add to our knowledge of tree response to tending and thinning.

Alder tending trial

The objective of this trial is to investigate the effect of thinning intensity on Potential Crop Tree (PCT) growth rate. A 1.4 ha trial located at a Coillte property (Kilbride Woods, Arklow) consisting of three treatments in a Latin Square Design, has been established. The three treatments are:

- Light thin (1 competitor removed per PCT);
- Heavy thin (2 competitors removed per PCT); and
- Control (no competitors removed).

Baseline measurements were captured during a previous funding period. The Light and Heavy tending treatment plots were tended between the 2008 and 2009 growing seasons. Data to enable the calculation of volume to 5 cm diameter of each thinned stem has been captured. Stem diameter was measured again after the 2009 growing season.

A number of demonstration days and field presentations were conducted during the project period to disseminate broadleaf silviculture information to forest owners and the industry. These are described below.

4. Main results:

Alder tending trial

A new tending intensity trial in alder has been established for medium-to long-term research. Results one growing season after the tending operation was conducted suggest that there is a positive relationship between intensity of tending and PCT stem diameter increment.

Review of 'Growing Broadleaves' book

The draft version of the 'Growing Broadleaves' book, authored by John Fennessy, Prof. Joyce and Prof. Huss, and due to be published by COFORD, was sent to reviewers during the reporting period. Dr Ian Short and Mr Toddy Radford reviewed the pertinent chapters of the draft publication and sent comments/suggestions to Mr John Fennessy.

Reporting of concluded poplar trial

The final data from the poplar clonal trial have been analysed. These have been written-up and submitted to a journal for peer-review.

5. Opportunity/Benefit:

Information created by the project is transferred to industry through various means, including presentations by project staff, articles, demonstration days and through technology transfer by the Teagasc Forestry Development officers.

It is apparent from the demonstration days that, after a short amount of training, the majority of forest owners are able to mark their own broadleaf plantation in readiness for a tending or thinning operation or have the knowledge required to check work carried out by a contractor.

6. Dissemination:

Ash tending demo days

Two ash tending demo days were held with approximately 200 attendees at each. Each demo consisted of three 20 m × 20 m plots. The first plot has the PCTs, competitors, extraction rack, wolves and diseased stem marked and this process and methods employed to do this are described to the participants. The second plot is where the participants gain some practical experience in identifying and marking PCTs themselves. The final plot illustrates the result of a tending operation and has the PCTs marked and all competitors, wolves, diseased stems and the extraction rack felled. The PCTs are also high-pruned. The first demo day was held on the 20th May at The Rower, Inistioge, Co. Kilkenny. Dr Ian Short and Toddy Radford also presented at the Forest Service in-house training held directly after the event. The Teagasc "Silvicultural Guidelines for the Tending and Thinning of Broadleaves", written by Dr Ian Short and Mr Toddy Radford, was launched at the demo day. The Guidelines are available on the Teagasc website and have subsequently been downloaded more than 20,000 times. Methods described in the Silvicultural Guidelines have also been transferred to growers by Teagasc Forestry Advisors through demonstrations and the provision of leaflets and Factsheets available on the Teagasc Forestry website e.g. "The 2–stick method for marking trees" and "Tending and thinning of broadleaf forests".

The second ash tending demo day was held at Four Mile House, Co. Roscommon, on 22nd October. Extraction methods for small-scale tending/ thinning operations were also demonstrated. There was also a stop to discuss chainsaw health and safety issues.

Sycamore tending demonstration day

A demonstration day on the tending and thinning of sycamore was held on 21st April 2010 in Summerhill, Co. Meath on a privately-owned site. This involved the establishment and measurement of three plots as above, including the felled volume of one plot. The procedure for selecting Potential Crop Trees, marking thinnings, diseased stems, wolves and racks was demonstrated. A couple of options for small-scale extraction were also demonstrated. Dr Michael Carey did a presentation on grey squirrel. The owner of the site chips the felled thinnings from his plantation and uses them for heat. This was also demonstrated. Approximately 150 people attended on the day. Two of the plots will be monitored into the future as per previous ash demonstration sites.

Presentations

Project staff were asked to present the tending and thinning of broadleaves at the National Forestry demonstration of Small Scale Harvesting and Extraction, held at St. Joseph's Abbey, Roscrea, Co. Tipperary on Wednesday 30th June 2010. In addition staff marked Potential Crop Trees and thinnings on 1.75 ha of ash in preparation for demonstrations of different methods of extraction by contractors. More than 400 participants took part on the day and good feedback has been received from the evaluation forms completed after the event.

Project staff were asked to attend and present at the Teagasc Farm Forestry Management Walk, Ballyfin, Co. Laois, held on 11th May 2010. The walk concentrated on the management of broadleaves, especially those that are at the age requiring tending and thinning. Over 50 participants attended this local event.

Dr Ian Short and Toddy Radford were invited to present the tending and thinning of broadleaves at the Small-Scale Harvesting demonstration day held at Teagasc Ballyhaise College on 27th May 2009, attended by more than 200 participants. The Irish Farmer's Association (IFA) also invited them to present the Silvicultural Guidelines at the IFA Forestry Section meeting on 18th June where the IFA county forestry representatives were present.

Main publications:

Short, I. and Radford, T. (2008) *Silvicultural Guidelines for the Tending and Thinning of Broadleaves*. Available at: http://www.teagasc.ie/forestry/docs/research/Teagasc_silvicultural_guidelines_Broadleaves.pdf

Short, I. and Radford, T. (2009) *The 2–Stick Method for Marking Trees*. Available at: http://www.teagasc.ie/forestry/docs/research/Teagasc%202–stick%20method%20– tending_thinning_broadleaves.pdf

Popular publications:

Photo and caption of launch of "Silvicultural Guidelines for the Tending and Thinning of Broadleaves". *The Nationalist* . May 29, 2009.

Teagasc publish broadleaf advice *Irish Independent Farm Supplement*. June 2, 2009. http://www.independent.ie/farming/news-features/teagasc-publish-broadleaf-advice–1757757.html

New guidelines for tending and thinning of broadleaves Donal Magner, *The Irish Farmers Journal*. August 15, 2009.

Teagasc/COFORD publish latest forestry research. *The Nationalist*. June 17, 2009. http://www.nationalist.ie/news/business/teagasc-coford-publish-latest-forestry-research–1–2244359

Characterisation and conservation of veteran hardwood trees

Project number:
5461
Date:
August, 2012
Funding source:
DAFF06/R&D
Project dates:
Oct 2006–Oct 2009

Key external stakeholders:

Landowners, foresters, Department of Agriculture Fisheries and Food, consultants, land use advisors, nurseries.

Practical implications for stakeholders:

- Veteran trees of oak, ash and sycamore may be viable for many decades and centuries when managed well. They have unique ecological value by providing habitats for plants, birds, mammals, fungi and many specialised invertebrates and microorganisms. They also produce seeds.
- Individual veteran trees of oak and ash have been successfully propagated vegetatively by grafting to extend the life of individual trees; they were returned to the original owners for planting out as shown in the figure above (veteran ash in the background with a young grafted copy in the foreground). Grafted copies of notable veteran trees such as the 'king oak' of Charleville estimated to be 450 years old were established in a living collection at JFK Arboretum Wexford.
- Seeds may be safely collected from veteran trees and used by nurseries because they were shown to be representative of the general gene pool for oak and ash in Ireland and they are capable of producing viable seed and progeny.

Collaborating Institutions:
TCD;
National Botanic Gardens, Glasnevin (NBG);
John F Kennedy Arboretum Wexford (JFK)

Teagasc project team:
Dr. Gerry C. Douglas (Teagasc, project leader)
Dr. Evelyn Gallagher (Walsh Fellow)

External collaborators:
Dr. Trevor Hodkinson (TCD)
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Compiled by:
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Technology

Main results:

- Veteran trees are valuable as hosts which provide unique habitats and other ecological functions in Irish landscapes. Individual veterans may be propagated by grafting. Prolonging the lifespan of individual veteran trees is best ensured by safeguarding the root zone around each tree.
- Genetic analyses revealed evidence that veteran trees of oak and ash were no less genetically diverse / unique when compared to the general populations of these species.
- Veteran trees of oak and ash are reproductively active, contributing viable pollen, ovules and seed.
- Progeny from veteran trees is viable and fit in Irish landscapes and seeds from veteran trees may be used by nurseries for establishing plantations.

Opportunity/Benefit:

- The provision of shoot material by scores of owners of veteran trees, for their propagation indicates a great interest among landowners for the preservation and prolongation of the life of individual veteran trees on their lands.
- Best practice for prolonging the life of veteran trees is to provide an exclusion zone around trees to avoid ground compaction.
- Veteran trees provide viable seed and these seeds should be collected from all sectors of the tree to capture the greatest genetic diversity in the progeny for use by forest nurseries.

1. Project background:

Many farms have veteran trees in pasture or cultivated fields. Typically they are large in girth (>5m oak, >3–4m ash and >3.5m sycamore) with hollowing trunks, cavities and some dead branches. They are living relics of former populations of trees and currently provide a unique ecological habitat. Concerning veteran trees, David Attenborough notes '*there is little else on earth that plays host to such a rich community of life within a single living organism*'. The decaying heartwood is a specialised habitat for a large number of threatened invertebrates and the fruiting bodies of fungi provide an essential breeding ground for insects: fungal gnats, flies and beetles. Decaying wood in branches and hollowing tree trunks is normal and is not a sign of ill health or imminent death. Specialised fungi digest and recycle the deadwood in the centre of trees (heartwood) and rarely colonise the outer rings of living sapwood. The pattern of tree growth is an annual increase in girth with the deposition of new wood on the outer rims of the trunks and branches; therefore, as long as the fungal advance is less than the new growth of wood the tree will remain alive. Notable veteran trees in Ireland have been catalogued: see the Irish Heritage Tree Database at http://www.treecouncil.ie/.

Specific genes conferring longevity of life have been identified in other organisms and may be important in veteran trees. The reproductive capacity of veteran trees is not well studied but their capacity to produce viable seed which gives rise to the next generation of trees is an important source of genetic diversity in forests and landscapes. Molecular markers can be used to trace seed dispersal from veteran trees by analyzing putative progeny among surrounding young trees in the same location. Markers in the chloroplast DNA are maternally inherited and are passed exclusively via seeds in ash and oak and are useful in identifying progeny. On the other hand, markers in nuclear DNA are dispersed via pollen and ovules. By using a combination of several nuclear markers and chloroplast markers it is possible to determine the dispersal patterns and gene flow characteristics of veteran trees.

The life span of individual trees such as notable veteran trees of oak, ash, and sycamore may be prolonged by means of their vegetative propagation and was tested in the project. Furthermore the genetic characterization of veteran trees in relation to their capacity to act as male and female parents for future generations of trees is poorly understood and was studied. The project was support by the Department of Agriculture programme 'Conservation of Genetic Resources for Food and Agriculture' and by a Walsh Fellowship for Dr. E. Gallagher.

2. Questions addressed by the project:

- Can veteran trees be propagated vegetatively by grafting to extend the lives of individual trees?
- Are veteran trees unique genetically?
- Do veteran trees pass on their genes and contribute to future generations of trees by producing viable seed?
- Are progeny derived from veteran trees viable in the landscape?

3. The experimental studies:

Vegetative propagation of veteran trees by grafting was undertaken over three Spring seasons, January–March. Scionwood (dormant shoots) was collected, or mailed to us from tree owners using selected tree sources listed in Irish Heritage Tree Database at http://www.treecouncil.ie/ At least 10 grafts were made per genotype. Seedlings of each species (2 year old) were used as rootstocks. A wedge graft was made in all cases by decapitating the rootstock and making an incision in the middle of the rootstock. Shoots with an apical bud were prepared by removing a sliver of stem tissue from two sides at the base followed by immediate insertion into the incision in the rootstock to align the cambial areas. Graft unions were tied with elastic bands and then painted with molten paraffin wax. After grafting, all buds that developed from the rootstock were removed and viability of veteran grafts was recorded after 6 months. For oak grafts we compared the effects of bare rooted rootstocks with container grown rootstocks. We also compared the viability of grafts using rootstocks which were primed into growth with graft viability using dormant rootstocks using four genotypes from 130 yr old trees.

For diversity assessment in oak, the study trees at Ballytobin estate Kilkenny were separated into four classes: seedlings, saplings, mature trees and veterans and three microsatellite markers were used to assess genetic differentiation by analysis of molecular variance (AMOVA). For analysis of progeny from veteran oaks, DNA was extracted from 70 trees including 25 mature and veteran oak trees and from 40 candidate offspring trees on the same lands. Five trees, including one veteran, were sampled outside the stand as they were considered large and close enough to be possible parent trees. All trees in the site were mapped and parentage was analysed using a likelihood assignment approach with the Cervus software programme.

For ash, DNA was extracted from 74 trees (including veterans) at Stradbally, Laois. Parentage analysis was undertaken using two approaches: a) paternity analyses of seed progeny from known mothers, (up to 20 seeds collected from each tree) and b) analyses of putative progeny trees by a parent-pair analysis with unknown sexes of the parent trees. For the former, the paternity analysis was on progeny from four veteran mothers and 13 candidate veteran father trees. For the latter, the analysis was on molecular data sets of 24 young trees, with 12 candidate veteran mother trees and 13 candidate veteran fathers. As with oaks all ash trees in the site were mapped and parentage was analysed using a likelihood assignment approach with the Cervus software programme.

4. Main results:

Over the course of the project we made 858 grafts of oak (87 genotypes), 180 of ash (18 genotypes) and 223 of sycamore (22 genotypes). Overall, genotype viability for oak was 63%; ash 100% and sycamore 90% giving viable plants of 209 oaks, 163 of ash and 95 of sycamore, some of which were established as a conservation collection at JFK Arboretum Wexford and others were returned to the owners and planted out in their fields. The figure on page 1 shows a veteran ash tree in the background with a viable grafted copy in the foreground, protected against sheep in Co. Offaly. In oak experiments, dormant rootstocks were superior to rootstocks which were growing; bare rooted oak rootstocks gave 39% viable grafts whereas containerized rootstocks gave only 8% viable grafts.

The microsatellite markers used on ash and oak were highly variable and useful to determine estimates of genetic diversity. Lower levels of genetic diversity were found in veteran oak and ash compared to the much larger general populations of each of these species. Veterans may be remnants of earlier populations and may be genetically less rich than younger generations which may have acquired their diversity from long distance wind pollination and from introduced populations of trees from abroad or diverse regions in Ireland.

Genetic diversity and parentage of mature and veteran oak trees (*Quercus robur*) at an estate in Kilkenny were assessed. The markers used were sufficiently variable with 9–14 alleles / locus and all samples were heterozygous. Diversity analysis showed that only 2% of the variation was partitioned among different age classes of the analysed trees, indicating there was a lack of genetic differentiation between age classes and supporting the view that the diversity of the gene pool was maintained in the regenerating younger population of trees, over time.

Overall, veteran oaks were found to be reproductively successful giving rise to viable progeny. Parent-pair analysis revealed that out of 24 trees that were potential parent trees, 15 of them were assigned as a parent to at least one offspring

tree, and out of these, five different veteran trees were assigned as parents for a total of four offspring trees. In addition, one veteran tree outside the main study stand was identified as the parent of two offspring found within the strand. Using offspring for which two parents could be assigned, we estimated that the distances among parent trees ranged from 22–150m with an average pollination distance of 47.8m and seven out of 12 parent pairs were within 50m of each other.

The three nuclear microsatellite molecular markers used on ash were highly variable with 19–29 alleles per locus. This allowed estimations of paternity of 37 ash seeds collected from four veteran mother trees. There were 13 candidate father trees in the analysis. Resolving power was not sufficient to assign the father trees for each progeny from each of the veteran mothers. However, paternity was assigned with statistical confidence to four seeds taken from one veteran mother. In this case at least three other veteran trees were male pollen donors while the fourth was a mature ash. Some evidence was found of self pollination, i.e. where the mother tree, on which seeds were collected, was also the most likely pollen donor.

The parentage of 17 young ash trees in woodland surrounding the veteran trees was determined by parent-pair analysis. Of these 17 trees, 12 were assigned parentage, leaving five, which were either the offspring of trees outside the stand or for which genotypic data was insufficient to assign parentage. Of the 12 trees which were assigned parentage with statistical confidence, only one was assigned as both first and second parent, suggesting a lower level of selfing among the woodland trees than the result of the seeds (above) would suggest. The average pollination distance was found to be 172m for ash trees.

5. Opportunity/Benefit:

- It is feasible to extend the life span of individual veteran trees of oak, ash and sycamore by grafting shoots from them onto young rootstocks.
- The value of veteran trees in Irish landscapes is that they are living ecological systems which are host to rare and threatened organisms which live within and on them.
- Genetic results have shown that veteran oak and ash trees are representative of the general gene pool of each species in Ireland and do not represent either a unique gene pool by virtue of their character of age-longevity.
- Veteran trees provide the valuable ecological function of contributing seeds and pollen to future generations of trees thereby contributing to the maintenance of genetic diversity of the Irish gene pool for each species.
- We demonstrated the presence of viable progeny derived from veteran trees, among saplings and young trees for both oak and ash. This indicates the ecological fitness of progeny from old trees. Therefore they should not be ignored as sources of seeds by seed collectors and nurseries for use in afforestation and amenity planting.
- Landowners can prolong the life of individual veteran trees by safeguarding their root systems from compaction and cultivation. This will help to maintain their viability for many further decades, even centuries. Typically, veteran trees lose large branches as part of the natural process in which the crown volume reduces gradually overtime. Larger pieces of deadwood may be used to protect trees and roots from stock. Most biologically active roots are in the top foot or two of soil and they spread outwards to a distance that is twice the radius of a tree's canopy. An exclusion zone around veteran trees by a living or wire fence offers best protection to exclude and / or manage access by animals / machines. This zone should extend to at least five meters beyond the limit of the tree's canopy.

6. Dissemination:

Main publications:

Gallagher E. (2011) Conservation and molecular characterisation of Irish veteran oak (*Quercus* spp.) and ash (*Fraxinus excelsior* L.) Ph D. Thesis University of Dublin Trinity College, Ireland.

Gallagher E, Douglas GC, Kelly DK, Barth S, Kelleher CT, Hodkinson TR (2012) Old age sex: a parentage study on different age cohorts in a native veteran pedunculate oak (*Quercus robur* L.) woodland using nuclear microsatellite markers. *Biology and Environment*. (accepted and in press).

Douglas GC (2006) Final report to Department of Food and Agriculture, 'Conservation of veteran Irish Hardwood trees'.

Popular publications:

E.Gallagher, T.R.Hodkinson, D.L.Kelly, G.C.Douglas (2005) Conservation and molecular characterisation of veteran oak (*Quercus spp.*) and Ash (*Fraxinus* L.) European Vegetation Conference. 20th–23rd June 2005. Conference programme page 48

Gallagher, E., Hodkinson, T., Douglas, G. and Kelly, D. (2006) Conservation and molecular characterisation of veteran oak (*Quercus* spp.) and Ash (*Fraxinus* L.) Irish Plant Scientists' Association Meeting IPSAM. 10th–12th April 2006, Galway. Conference programme page 39

E.Gallagher, T.R.Hodkinson, D.L.Kelly, G.C.Douglas (2005) Conservation and Molecular characterisation of veteran Oak (Quercus spp.) and Ash (Fraxinus excelsior). In: "Plants 2010" The Global Partnership for Plant Conservation. National Botanic Gardens in Dublin 23rd–25th October 2005. http://www.botanicgardens.ie/gspc/gppc/posters/oakash.jpg

G.C.Douglas, E.Gallagher, D.L.Kelly, T.R.Hodkinson (2005) Conservation of veteran trees by grafting and cuttings In: "Plants 2010" The Global Partnership for Plant Conservation. National Botanic Gardens in Dublin 23rd–25th October 2005. http://www.botanicgardens.ie/gspc/gppc/posters/veteran.jpg

Crops
Environment
& Land Use
Programme

Project number:
5700
Date:
Oct, 2012
Funding source:
COFORD
Project dates:
July 2007–July 2009

A Cluster based approach for identifying farm forest resources to maximize potential markets

Collaborating Institutions:
None

Teagasc project team:
Dr. Niall Farrelly (PI)
Mr Brian Clifford
Mr Stuart Green

External collaborators:
None

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Key external stakeholders:

- COFORD, Council for Forest Research and Development Forest Service, Department of Agriculture, Food and Marine Teagasc Forestry Producer Groups
- Forestry Companies and Stakeholders

Practical implications for stakeholders:

- The potential of Geographic Information Systems (GIS) as a tool to derive forest clusters has succeeded in identifying large geographic concentrations of private forestry in Ireland.
- GIS technology can assist in the rapid cost-effective assessment of timber resources.
- Forest clusters provide many advantages for small scale forestry including provision of economies of scale, in supply, reduced costs and increased competitiveness of the private forest sector.
- Such concentrations of forests and growers may enable the establishment of Forestry producer groups within defined geographic locations, and enabling a more targeted knowledge transfer and extension service.

Main results:

A GIS based cluster analysis of private forestry in Ireland succeeded in locating 16 forest clusters greater than 10,000 hectares. The sixteen cluster areas contain 88,000 hectares (Table 1). A survey to examine the potential timber supply and constraints of private forestry was undertaken in one forest cluster near Ballaghaderreen in Co. Roscommon. The use of GIS methods and field survey data enabled a rapid assessment of forest resources to be performed. The methodology employed offers a cost-effective solution to the assessment of private forest resources which could be used to assess national wood supply targets.

Technology

Opportunity/Benefit:

This research has demonstrated a cost-effective solution to the assessment of private forest resources. Significant opportunities for developing a local forestry infrastructure, using innovative solutions to identify forestry resources, presents economies of scale and scope, indicating that there are grounds for co-production and integration of harvesting activities. Secondly, the boundaries or extent of a cluster, also present opportunities exists to pool resources from geographic concentrations of farm forest plantations and knowledge gained thus optimising the value of first thinning.

1. Project background:

The project aimed to quantify the potential of clustering as a technique suited for identifying geographic concentrations of private forest plantations approaching first thinning, specifically to address the following issues:

- Quantification of the resource
- Identifying markets for produce
- Creating economies of scale
- Reducing the costs associated with harvesting
- location of potential end users close to the resource
- Creation of harvest and forecasting schedules for cluster areas

2. Questions addressed by the project:

- Allows identification of large concentrations of private forestry in defined geographic locations with significant harvest potential.
- It provides a cost effective methodology for assessing private forest resources.
- It allows a rapid assessment of thinning potential in local defined areas.
- It provides a methodology for the establishment of forest grower 'producer groups' who may wish to collaborate in the sale and harvesting of forest products and in the grouping of forest operations together to achieve economies of scale.

3. The experimental studies:

All private forests in receipt of grant aid in Ireland were identified from a spatial database provided by the Forest Service, Department of Agriculture, Food and Fisheries. We performed a GIS cluster analysis which identified 16 national forest clusters. A cluster study area was chosen in the counties of Mayo, Sligo and Roscommon. Within the study area, we developed a forest inventory database covering 4,597 ha using remote sensing technologies (including LIDAR) together with a detailed field survey. A sample survey of 92 forest owners was conducted covering 932 ha to compile forest growth data. We simulated various management regime practices on forests using growth data and windthrow risk. This allowed a forecast of production from c. 5,000 ha covering the period 2009–2028.

4. Main results:

The GIS based cluster analysis succeeded in locating 16 forest clusters occupying 88,000 hectares. The use of a cost-effective solution to assessing private forest resources was in one forest cluster near Ballaghaderreen in Co. Roscommon enabled c. 5,000 ha of forest to be identified which offered a realistic thinning potential. A follow up ground survey indicated that although average individual plantation sizes were small (5.14 ha – 47% were less than 8 ha), the majority of stands assessed had good public road access, a key factor influencing the availability of forest thinnings. In fact thinning has been carried out in 30% of the forest area examined but is confined solely to productive forests. These forests are predominately pure stands of Sitka spruce, where exceptional yields (>24m^3 ha^{-1} yr^{-1}) of on difficult to farm wet mineral soils offer short term harvest potential. The species accounts for 75% of the area and 90% of the total standing volume (754,146 m^3) and stands are suitable for thinning on average at 14 years of age. Total standing volume for a cluster of c. 4,500 ha is 840,698 m^3 with 365,990 m^3 available as small sawlog, 324,796 m^3 as pulp and 149,913 m^3 as large sawlog. These results indicate the significant potential of farm forestry to meeting local and national supply targets.

5. Opportunity/Benefit:

Significant opportunities exist with which to accelerate timber output from small-scale forest plantations through clustering the geographic concentrations of forests. The primary stakeholder for this research is COFORD and Government policy makers, who can use information to formulate policy regarding the supply of raw material from the private forestry sector in order to meet timber forecasts and renewable energy targets. The benefits of the project are already being realised in the setting up of forestry producer groups throughout the country They study has provided a

No.	Location	Forest area (ha)	Cluster Area (ha)	Forest as % of Cluster
1	Limerick, Kerry, Cork	28,400	296,314	10%
2	Galway, Limerick, Tipperary	13,455	163,220	8%
3	**Mayo, Sligo, Roscommon**	**9,576**	**130,409**	**7%**
4	Leitrim, Sligo, Cavan	8,901	105,277	8%
5	Clare	8,922	80,825	11%
6	Donegal	4,287	54,044	8%
7	Westmeath, Laois	3,506	48,646	7%
8	Kilkenny, Laois	2,041	26,474	8%
9	Donegal	2,219	22,569	10%
10	Mayo	1,440	18,184	8%
11	Waterford, Tipperary	1,104	13,753	8%
12	Donegal	1,200	12,477	10%
13	Longford, Westmeath	768	10,991	7%
14	Wicklow	715	10,896	7%
15	Cork	881	10,893	8%
16	Mayo	728	10,593	7%
	Total Area	88,143	1,015,565	

Table 1: The location of forest clusters, forest area and forest cover in percent. Study area is highlighted in bold.

template for assessing forest resources. It is hoped it may facilitate local cooperation between growers and industry to achieve economies of scale in harvesting.

6. Dissemination:

Farrelly, N. 2008. Fuelling Your Future – The Growing Forest Resource. Proceedings from the Teagasc/COFORD/SEI Wood Energy Conference, Westport 10 September 2008.

Clifford, B., Green, S. and Farrelly, N. 2008. A cluster-based approach for the identification of private forest resources. 2nd Annual Irish Earth Observation Symposium, Cork, 6–7 November 2008.

Clifford, B. 2009. A cluster-based approach for identifying thinning material for wood energy users. Proceedings from the Teagasc/COFORD/SEI Wood Energy Conference, Wednesday 17 June 2009, Kilkenny.

Farrelly, N. and Clifford, B. The Potential of Cluster Analysis to aid the Private Forest Sector in Ireland. National Forestry Producer Group Conference, September 9, 2009.

Main publications:

Farrelly, N., Clifford, B. and Green, S. 2008. Unlocking Farm Forest Potential. TResearch 3 (1): 22–25.

Farrelly, N., Clifford, B. and Green, S. 2008. Using GIS Cluster Analysis to Quantify Timber Production from farm forestry plantations. Irish Timber and Forestry 17 (5): 30–33.

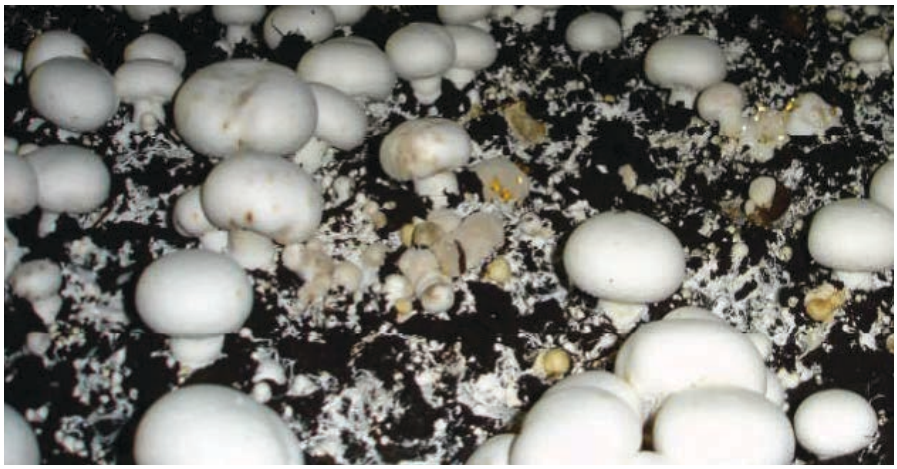
Farrelly, N. and Clifford, B. 2010b. A preliminary evaluation of the application of multi-return LiDAR for forestry in Ireland. COFORD Connects Research Communication.

Popular publications:

Farrelly, N., Clifford, B. and Green, S. 2008. Forest Focus Unlocking Farm Forestry. Irish Farmers Monthly July 2008. p42–44.

Detecting dry bubble disease on mushroom farms

Project number:
5695
Date:
February, 2012
Funding source:
Teagasc
Project dates:
Sept 2007–Sept 2010



Key external stakeholders:

Mushroom growers, Teagasc commercial clients (Commercial Mushroom Producers, PO), mushroom industry

Practical implications for stakeholders:

The dry bubble pathogen, *Lecanicillium fungicola,* can cause crop losses of from 5–20% so any reservoirs of the pathogen on a farm pose a serious threat to the profitability of the grower.

The main outcome of this research is that the pathogen can be found at many locations on mushroom farms, especially concrete areas and surfaces both inside, and outside of the growing rooms.

The main recommendation generated from this project is that in order to minimise the risk of spreading the disease, all surfaces and concrete areas should be disinfected daily, especially outside growing rooms, where picking staff and other farm staff intermingle.

Main results:

- A modified *L. fungicola* selective medium has been developed which allows for easier detection of the dry bubble pathogen in organic-rich mushroom farm samples.
- *L. fungicola* has been detected at most locations on farms but levels were much higher inside and outside growing rooms where 2nd and 3rd flush mushrooms were being harvested.
- *L. fungicola* was detected most frequently on mushroom-picking trolleys, picking equipment, growing room floors, door handles, packing crates stored close to growing rooms and canteen areas.

Collaborating Institutions:
NUI, Maynooth
PRI, Netherlands
CMP, Monaghan

Teagasc project team:
Dr. Helen Grogan (PI)
Justyna Piasecka (Walsh Fellow)

External collaborators:
Dr Kevin Kavanagh, NUI, Maynooth.
Dr. Carolien Zijlstra, Plant Research International b.v., Wageningen, The Netherlands.
Grower members of Commercial Mushroom Producers (CMP), Monaghan

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Technology

Opportunity/Benefit:

Mushroom farms can have their growing facilities tested for the presence of the dry bubble pathogen. Teagasc advisors can inform clients of best practice to control the spread of this disease.

1. Project background:

Dry bubble disease is caused by the pathogen *Lecanicillium fungicola* and it is the most widespread disease of commercial mushroom production world wide. If the disease gets out of control it can cause crop losses as high as 20% or more, but 1–5% losses are common. A poor understanding of how the disease spreads within and between mushroom crops has been a contributing factor in the persistence of dry bubble problems. There is currently only one approved fungicide – prochloraz – for the control of dry bubble disease and the pathogen population has developed a degree of tolerance to this active ingredient. With fewer chemicals available or approved for use, growers must adopt integrated disease control strategies if they are to achieve successful disease control. This requires them to have a greater knowledge and understanding of disease epidemiology and the importance of constantly monitoring for disease presence. Disease outbreaks are often traced back to poor farm hygiene.

2. Questions addressed by the project:

- Can a real time PCR-based detection method accurately detect the dry bubble pathogen, *Lecanicillium fungicola*, in mushroom farm samples that may contain a high level of organic matter?
- Can an existing *L. fungicola* selective medium be improved in order to increase the successful and rapid isolation of viable propagules from mushroom farm samples?
- Can these two diagnostic methods identify locations on mushroom farms where reservoirs of infective *L. fungicola* propagules occur and how do the detection methods compare?
- What are the principal locations on mushroom farms where *L. fungicola* propagules occur?

3. The experimental studies:

A number of experimental studies was conducted. Two methods to detect *L. fungicola* in mushroom farm samples were compared. DNA extraction methods and reaction conditions for real time PCR were evaluated and for use with organic-rich mushroom substrates. A range of antifungal, antibiotic and nutrient compounds in an agar base medium were evaluated for their ability to suppress the growth of non-desirable moulds and bacteria while allowing the selective growth of *L. fungicola*. Both detection methods were optimised and then used to test a variety of mushroom farm samples obtained during a series of mushroom farm visits in 2008–10. The results from the two methods were compared and analysed statistically. Each sample was categorized according to the location on the farm as well the stage of crop development in order to identify reservoirs of infection on farms where hygiene measures should be targeted.

4. Main results:

- A modified *L. fungicola* selective medium was developed which allowed for easier detection of the pathogen in organic-rich samples.
- The real time PCR method, as developed, detected *L. fungicola* in three times more samples compared to the selective medium and it may be picking up non-viable pathogen propagules in the samples.
- Live *L. fungicola* was detected at almost all farm locations but was most abundant inside and outside growing rooms when the 2nd & 3rd flush of mushrooms were being harvested.
- *L. fungicola* was detected most frequently on mushroom-picking trolleys, picking equipment, growing room floors, door handles, packing crates stored close to growing rooms and canteen areas.
- To minimise the risk and spread of dry bubble disease the utmost attention should be given to daily disinfection of all surfaces and concrete areas, especially those areas around growing rooms and where picking staff and farm staff intermingle.

5. Opportunity/Benefit:

Mushroom farms can have their growing facilities tested for the presence of the dry bubble pathogen, which will highlight areas of weakness in the farms hygiene procedures. Teagasc advisors can provide their clients with the latest research results regarding the best practice to control the spread of this disease.

6. Dissemination:

The outcomes of this research have been disseminated to mushroom growers and their key staff through a series of Disease Control Seminars in 2011 and 2012, organised by stakeholders CMP in conjunction with Teagasc (venues in Cavan, Monaghan, Westmeath and Tipperary). In addition the key results were presented to a wider audience at the 2011 All Ireland Mushroom Conference in the Hillgrove Hotel in Monaghan (21 October 2011) via a presentation, poster display and informal contact with growers during the event. The Mushroom conference is a biennial event sponsored by Bord Bia in conjunction with Teagasc and key stakeholders. Teagasc advisory staff deal with grower queries on this topic and when necessary, farm visits are made to provide one to one advice tailored for specific farms. A technical service can be provided to detect *L. fungicola* in farm samples.

Formal links with Industry: Work with both the national and international mushroom industry continues on this subject via FP7 Project MushTV (6270) 2012–2014.

Main publications:

Piasecka J, Grogan H., Zijlstra C, Baars J.J.P and Kavanagh K. (2009) 'Detection of *Verticillium fungicola* in samples from mushroom farms using molecular and microbiological methods' Agricultural Research Forum, 2009, p131 (http://www.agresearchforum.com/publicationsarf/2009/proceedings2009.pdf)

Piasecka J, Kavanagh K. and Grogan H. (2011) 'Detection of sources of *Lecanicillium* (*Verticillium*) *fungicola* on mushroom farms' http://wsmbmp.org/proceedings/7th%20international%20conference/1/vol1/ICMBMP7–Oral–4–20%20Piasecka.pdf

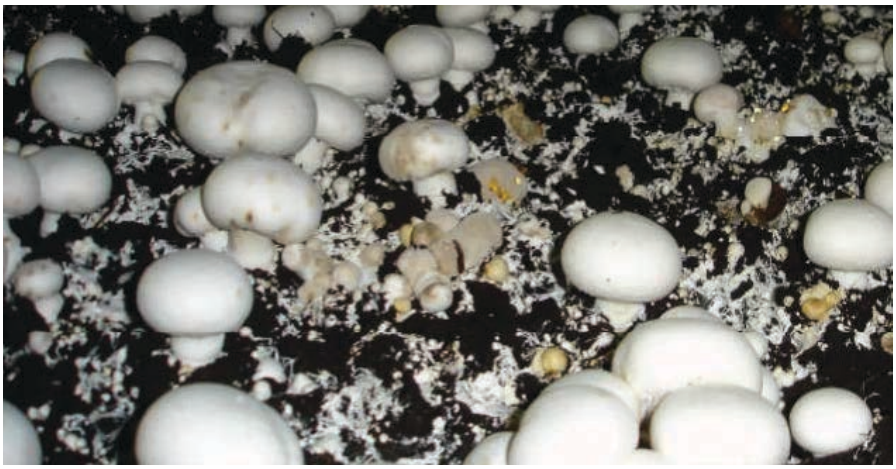
Grogan, H. (2011) 'Research Update – Teagasc Kinsealy' Proceedings of the 2011 All Ireland Mushroom Conference and Trade Show, Hillgrove Hotel, Monaghan, Ireland

Popular publications:

TResearch, Autumn, 2012: Detecting bubble trouble in mushrooms.

Project number:
5850
Date:
October, 2012
Funding source:
DAFF RSF (07 547)
Project dates:
Dec 2007–Nov 2010

Understanding Mushroom Virus X disease



Key external stakeholders:

Irish Mushroom Industry, Compost Companies, Research community

Practical implications for stakeholders:

There is a poor understanding of how Mushroom Virus X (MVX) induces the brown, off-coloured, poor-quality mushrooms associated with this new complex disease. The project aimed to advance our understanding of the disease and to develop diagnostic tests to facilitate its detection.

- Mushroom crops can be infected with MVX at any stage of the crop cycle but symptoms, and consequent financial losses, generally only develop when infection occurs at the end of the compost incubation phase (Phase 3).
- In order to prevent MVX symptoms developing, composters and growers need to ensure that there is no MVX-contamination of the compost (or casing) when incubated (Phase 3) compost is being filled into mushroom growing rooms.
- MVX can be reliably detected in mushrooms using a molecular diagnostic test.

Main results:

- **Critical infection time identified.** A low rate of MVX-infected material (0.01%) that is incorporated into compost or casing at the end of the compost incubation period gave the most consistent symptom expression. Thus it is imperative that mushroom compost and casing does not come into contact with any infective material (from previously infected crops) at this time.

Collaborating Institutions:
AFBI, Northern Ireland
DIT, Dublin
Mushroom composters, growers and Allied Trades

Teagasc project team:
Dr. Helen Grogan (PI)
Dr. Caoimhe Fleming-Archibald
Ms Angela Ruggiero

External collaborators:
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Dr Jesús Frías, Dublin Institute of Technology, Cathal Brugha St, Dublin 1
Commercial Mushroom Producers P.O. (CMP), mushroom composters, mushroom growers and Allied Trades

Compiled by:
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Technology

- **MVX moves through compost very rapidly.** Following a point-infection of MVX into mushroom compost it was found to move at least 4 m (length of compost studied) within a single cropping period. This contrasts with a <1 m spread for fungal diseases following a point-infection.
- **Agronomic factors do not influence MVX symptoms expression.** Crops grown under stressful environmental conditions were no more likely to develop brown mushroom symptoms than crops grown under non-stressful conditions. MVX does not appear to be "triggered" by environmental factors.

Opportunity/Benefit:

The improved understanding of the epidemiology of Mushroom Virus X informs growers, composters, advisors and researchers of possible routes of transmission on facilities and allows for preventative measures to be taken.

1. Project background:

Mushroom virus X (MVX) is a relatively new disease affecting the production of the commercial white mushroom, *Agaricus bisporus*, causing a range of disruptive symptoms within crops. The most predominate symptom in Ireland is the occurrence of 'brown' and off-coloured mushrooms in white strain crops. These mushrooms are rejected upon picking, after a period of cold storage, or by the retailer, and result in financial losses to growers. Other symptoms include crop delay, bare patches and poor quality or malformed fruit bodies. The epidemiology of the disease is not well understood but symptoms are associated with the presence of double-stranded RNAs (dsRNAs) in mushrooms of crops with symptoms. DsRNAs are indicative of replicating viral nucleic acids. A number of dsRNAs have been identified in mushrooms with symptoms. A range of low molecular weight dsRNAs (0.6–2.2 kb) are associated with the 'brown' symptoms, while a larger 3.6kb band is commonly found in mushrooms from crops experiencing delay and bare patches.

Anecdotal evidence has pointed to poor hygiene and/or crop management as critical factors in disease expression. While some control of the disease has been gained by increased hygiene measures, outbreaks continue to occur regularly but they are transient and inconsistent in nature.

2. Questions addressed by the project:

- What are the optimum conditions for MVX symptom expression?
- Does the source of MVX-infective material, i.e. the dsRNA band pattern of the infective material affect the range and severity of symptom expression?
- Can environmental and agronomic factors cause or influence symptom expression?
- Can the effect of symptoms on mushroom quality be quantified pre-and post-harvest?
- Can a reliable and effective molecular diagnostic be developed to test for MVX?

3. The experimental studies:

MVX-infected *Agaricus bisporus* isolates, containing different dsRNA banding patterns, were used to prepare MVX-inoculum for the various cropping experiments conducted by Teagasc, Kinsealy and AFBI, Loughgall. Cropping experiments at Kinsealy looked at the effects of different rates and times of MVX-infection on symptom expression, as well as the influence of different MVX dsRNA band profiles. Point inoculation cropping experiments were also conducted to see how rapidly MVX could move through incubated compost.

Studies at Loughgall examined the effect of agronomic factors, such as ruffling, and environmental factors such as humidity, evaporation and watering management, to provide "stressful" conditions that might trigger or influence the expression of MVX symptoms. Mushroom "colour" was measured quantitatively using a colorimeter to quantify the level of brown and off-coloured mushrooms observed in all crop experiments. Measurement of post harvest quality was done at DIT using a wide array of analytical tools, techniques and methodologies such as Colorimetry, RGB image acquisition, hyperspectral imaging, Fourier Transform Infra Red microscopy (FT-IR). External quality indexes (colour, density, weight loss) were analysed using wet lab and image analysis together with biochemical quality indexes (enzyme activity, browning pigments). Finally, in order to confirm MVX presence in both mushrooms and compost, reliable diagnostic tests were developed using standard and newly-reported molecular biology techniques for nucleic acid extraction, purification, electrophoresis, and PCR.

4. Main results:

- **Critical infection time identified.** The critical infection time and conditions that lead to consistent appearance of MVX brown mushroom symptoms were identified. A low rate of infected material (0.01%) that is incorporated into compost or casing at the end of the compost incubation period gave the most consistent symptoms. Thus it is imperative that mushroom compost and casing does not come into contact with any infective material (from previously infected crops) at this time. Composters and growers should enhance hygiene measures to minimise any cross-contamination at this critical time.
- **MVX moves through compost very rapidly.** Following a point-infection of MVX into mushroom compost it was found to move at least 4 m (length of compost studied) within a single cropping period. This contrasts with a <1 m spread for fungal diseases following a point-infection.
- **Agronomic factors do not influence MVX symptoms expression.** Crops grown under stressful environmental conditions were no more likely to develop brown mushroom symptoms than crops grown under non-stressful conditions. MVX does not appear to be "triggered" by environmental factors.
- **Effective molecular diagnostic test to detect MVX in mushrooms.** A PCR based diagnostic test for mushrooms was effective and reliable, detecting MVX in infected mushrooms. MVX was also detected in mushrooms and crops that showed few/no symptoms. An industry-wide survey also detected MVX at a level higher than the occurrence of symptoms suggested. This would explain the persistence and transience of the symptoms within the Irish industry since the late 1990's. Although a test to detect MVX in compost was developed it was only not entirely reliable due to the humic acid content of compost.
- **FT-IR detection of MVX in post-harvest mushrooms shows promise**.Detection of MVX in post-harvest mushrooms using spectroscopic methods and its discrimination from other causes of browning proved difficult but the FT-IR micro-imaging method shows promising results. This technique may be useful to rapidly detect MVX within a few hours in mushroom samples and might develop into a complementary technique to the molecular diagnostic.

5. Opportunity/Benefit:

The research results from this project have provided both the Irish and International mushroom community with a substantial body of information on how MVX infects and affects a mushroom crop. The most critical infection time has been identified, highlighting the need for excellent hygiene measures to be in place to prevent crops becoming contaminated. The research also highlighted the fact that non-symptomatic MVX infections are common, which is likely to be the reason why the disease is so persistent and has been so hard to control. This increase in understanding has paved the way for future research to focus on how to monitor for, detect and eliminate MVX-infected material on mushroom farms and compost facilities. Industry stakeholders across Europe have acknowledged Teagasc's expertise in this area leading to a major International collaborative EU FP7 project being funded in 2012 (www.MushTV.eu).

6. Dissemination:

The outcomes of this research have been disseminated to mushroom composters and key staff through a series of Internal Seminars on individual premises during 2011. Mushroom growers and their staff were reached via Disease Control seminars in 2011 and 2012, which were organised by CMP, in conjunction with Teagasc, at venues in Cavan, Monaghan, Westmeath and Tipperary. In addition the key results were presented to a wider audience at the 2011 All Ireland Mushroom Conference in the Hillgrove Hotel in Monaghan (21 October 2011) via a presentation, posters and informal contact with growers during the event. (http://www.teagasc.ie/publications/2011/1056/index.asp). The Mushroom conference is a biennial event sponsored by Bord Bia in conjunction with Teagasc and key stakeholders. Teagasc advisory staff deal with grower queries on this topic and, when necessary, farm visits are made to provide one to one advice tailored for specific farms. A technical service can be provided to detect MVX in mushroom and compost samples.

Formal links with Industry: Work on MVX epidemiology and control continues with national and European industry and scientific partners via EU FP7 Project MushTV (6270) 2012–2014 (www.MushTV.eu)

Main publications:

Grogan, H. (2011). Mushroom Virus X disease: Understanding the factors which trigger "brown mushroom" symptom expression as a means to improved diagnosis and control. Final Report RSF 07547. DAFF. http://www.agriculture.gov.ie/media/migration/research/rsfallfundedprojects/2007projects/RSF07547310712.pdf Fleming-Archibald, C., Ruggiero, A., Kilpatrick, M. & Grogan, H.M. (2010). Mushroom Virus X Disease: A Whiter Shade of Pale Brown? T Research, 5: 14–15. http://www.teagasc.ie/publications/view_publication.aspx?publicationID=51

Fleming-Archibald, C., Ruggiero, A, & Grogan, H.M. (2009). Identifying factors which influence the expression of "brown mushroom" symptoms in crops infected with Mushroom Virus X. Agricultural Research Forum, 2009, p 124. http://www.agresearchforum.com/publicationsarf/2009/proceedings2009.pdf

Rural Economy & Development Programme

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Rural Economy & Development Programme

The aim of the Teagasc Rural Economy and Development Programme is to support the decision making of Teagasc stakeholders through research and knowledge transfer activities.

In particular, the objectives of the Programme are to:

- Collect timely, quality information in an efficient manner to support decision making by our stakeholders.
- Undertake research to interpret trends and changes in markets and policy to enable each of our stakeholders to make better decisions.
- Provide advice, training and tools to support our stakeholders in making decisions that enable their business to be more effective.
- Understand who adopts technology, why potentially beneficial technologies are not adopted and how adoption can be increased.
- Provide specific skills to stakeholders to enable them to exploit income generating opportunities both on and off farm.

Its mission is to produce high quality social science research and advice to improve the competitiveness and sustainability of the Irish agri-food sector and to enhance the quality of life in rural Ireland, thus contributing to the achievement of Teagasc's key goals. An important focus is placed on policy relevant research that will help policy makers to design and implement better public policy.

The Programme is divided into three Departments:

- Agricultural Economics and Farm Surveys
- Agri-Food Business and Spatial Analysis
- Farm Management and Rural Development

People

Teagasc is a knowledge intensive organisation which relies on its expertise, innovative capacity and research infrastructure for success. In total there are 49 staff involved in the Rural Economy and Development programme, comprising 13 permanent researchers, 10 knowledge transfer staff, 22 technical staff, and 4 administrative staff. In addition there are 5 contract research staff and 20 Walsh Fellows.

The programme's main research locations are at Teagasc Ashtown and Teagasc Athenry, while knowledge transfer specialists and farm survey recorders are based at various locations around the country.

1. Agricultural Economics and Farm Surveys Department

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Introduction

The focus of this research department primarily relates to the objectives of collecting timely, quality information to support decision making by our stakeholders and to undertake research to interpret trends and changes in markets and policy to enable each of our stakeholders to make better decisions. The core skills and technologies of the department are agricultural production economics, economic modelling and data collection.

National Farm Survey

Underpinning much of the analysis and modelling of the programme, is the Teagasc National Farm Survey (NFS) which has collected detailed financial and farm management data for a nationally representative sample since 1972. It is the Irish component of the EU Farm Accountancy Data Network, which is harmonised across Europe facilitating an international comparison of the performance of agriculture. As the official statistical source on the economic performance of farms, the data collected by the NFS have been used extensively over the years for many purposes.

Economists in Teagasc and other institutions have used the data to chart the performance of farms, measuring productivity, efficiency, farm investment and the adoption of technology. NFS data has also been used for policy analysis and the capability to demonstrate the impact of a policy reform on the full population of farms has been critical in informing debate. Recent methodological improvements have improved the efficiency of delivery and management of the data and have allowed for linkages to administrative, geographic and environmental data.

FAPRI-Ireland Partnership

A significant amount of the research of the department is policy focused within the banner of the FAPRI-Ireland Partnership, which was established in the mid-1990s between Teagasc and the University of Missouri Food and Agricultural Policy Research Institute (FAPRI) to develop economic models to quantify the effect of policy reform on agricultural markets and farm income in Ireland. Teagasc developed the FAPRI-Ireland aggregate and farm-level models.

The FAPRI-Ireland models have been used to examine numerous policy questions including the decoupling of direct payments, WTO trade agreements, expansion of the EU milk quota, national strategy planning such as Food Harvest 2020 and more recently environmental policy. The FAPRI-Ireland models play a central role in the policy formation process by providing timely, evidence based information.

2. Agri-Food Business and Spatial Analysis Department

Introduction

The department is divided into three groups, each with a different focus, but built on a base of social science and computer based analytical tools:

- **Spatial and Environmental Analysis**. The primary focus of this team is to collaborate with the Crops, Environment and Land Use Programme and Knowledge Transfer Directorate rural development initiatives by providing research expertise built around the disciplines of environmental economics, rural geography, spatial analysis and remote sensing.
- **Food Market and Consumer Research**. The primary objective of the Food Market and Consumer Research group is to contribute to the improved strategic marketing performance of the Irish agri-food sector by addressing the need for more future-oriented consumer and market insights. Within Teagasc, the team's role is to undertake social science based food marketing research to support the needs of the Food Programme and to coordinate cross-supply chain research within other Programme areas.
- **Agri-Innovation and Learning.** The main objective of this team is to support Teagasc in making its knowledge transfer activities within the agricultural programmes more effective. Drawing on the disciplines of economics and sociology, it uses quantitative and qualitative social science tools to understand how farmers make decisions, learn and innovate, and study the effectiveness of alternative knowledge transfer methodologies.

Spatial Analysis

Spatial analysis research, comprising Geographic Information Systems (GIS) and earth observing (EO) remote sensing (RS) technologies provides a powerful platform for the comprehensive analysis of all land–based activities at the interface between the agri-food sector, economy and environment.

- A key strength of GIS/EO is the potential for integrated analysis across all scales from the field to farm right up to national level.
- New methods of analysis and the collection, archiving and distribution of spatial data on issues affecting the agri-food industry and the rural economy are being developed and applied.

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- Current research using RS technologies in space and on board aircraft is seeking to integrate real measurements of farm performance and output into Teagasc farm models, to map areas of high biodiversity and to make 3D-derived measurements of biomass contained in hedgerows and woodlands.
- Spatial analysis seeks to equip stakeholders with the knowledge to achieve high farm output and excellent agri-environmental quality while providing evidence-based knowledge to support policymakers in designing, implementing and evaluating programmes.

Food Marketing

Food market and consumer research is conducted using qualitative and quantitative research techniques to support new product development and market orientation by food companies, and the design of food sector support services and policy measures by public bodies.

- In consumer research there is a focus on examining consumer behaviour and attitudes in relation to health and novel food technologies.
- Regarding market insights, the agenda covers such areas as innovation management, strategic market planning, marketing channels, and supply chain and relationship management.

Much of this research is fundamental to the Teagasc Food Programme ensuring such research is market oriented and providing a foundation for research commercialisation.

Agri-Innovation and Learning

Developing capabilities and use of best practices and technologies is critical to increasing employment, income, and profitability. Through national and EU funding, Teagasc examines innovation at farm and firm level.

- At farm level, it focuses on the agricultural knowledge and innovation system (AKIS) and seeks to understand the innovation systems that support farmers' capability building and their technology adoption, as well as the extension mechanisms and activities through which Teagasc interacts with its clients.
- At firm level, the focus is more on technology transfer and understanding barriers to interaction between researchers and industry, and on understanding how companies organise themselves to support innovation.

Rural Development Research

Rural Development Research is concerned with improving our understanding of economic development in rural Ireland. It primarily focuses on:

- Changes affecting farm enterprises and farm households and exploring their implications for the broader rural economy.
- It applies spatial analysis and microsimulation methods to capture the interconnections between farms, farm households and whole sectors of agriculture. It does so in the context of the societal process of change operating at local, regional and global levels in order to simulate the impact of socio-economic and policy changes at the local level.

3. Farm Management and Rural Development Department

Introduction

The objectives of this department are to:

- Provide advice, training and tools to support our stakeholders in making decisions that enable their business to be more effective.
- Provide specific skills to stakeholders to enable them to exploit income generating opportunities both on and off farm.

The activities of this department are closely integrated with the Teagasc Knowledge Transfer Directorate and are delivered through three teams:

Farm Management and Technology

The activities of the farm management and technology team are focused on:

- Supporting farmers to become more profitable, efficient and viable into the future through improved financial management skills and more efficient use of technology.
- Providing support to farmers on farm expansion strategies, farming structures, succession planning and meeting the requirements of the Single Farm Payment and other direct payment schemes.

Rural Development and Organics

The activities of this team are focused on:

- Adding value to existing on and off farm enterprises as well as new diversification activities to ensure that clients have a hybrid mix of income generating activities to sustain the farm household.
- The Rural Development Options Programme provides mentoring, guidance and business related training programmes for those who are in a position to develop new services and businesses and links clients with specialist internal or external expertise to assist them in developing a successful business.
- The organics sub-programme focuses both on the technical aspects of conversion, as well as financial and direct selling of organic products and aims to encourage and support the conversion of farms to organic status, enabling farms generate extra income.
- Utilising the low cost input model of farming, this team is involved in delivering programme objectives to part-time farmers.

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Equine

- The equine team's objective is to provide technical advice and training to the sport horse industry, with a particular focus on improving breeding, horsemanship and equine business skills.

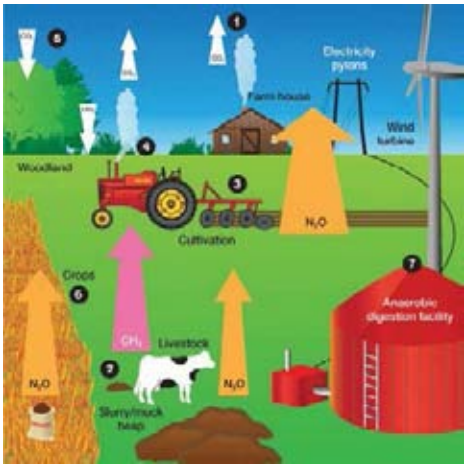
Teagasc eProfit Monitor

A key objective of the department is the development and maintenance of decision support tools to assist farm clients in making financial decisions. The Teagasc eProfit Monitor (ePM) is a farm business financial analysis system and decision support tool. This allows farmers and their Teagasc adviser to identify strengths and weaknesses in farm business performance and allows benchmarking of key financial measures. The ePM also allows users to link with data from other sources such as the Irish Cattle Breeding Federation (ICBF).

Teagasc Farm Options Programme

With about 40% of Irish farmers classified as economically vulnerable, a key objective of the department is to encourage the development of alternative income sources. The Teagasc Farm Options Programme aims to facilitate farm households to exploit the full potential of their farm resources by focusing on the financial position of their farm and exploring on and off-farm opportunities.

Market and non-market based strategies to reduce Greenhouse Gas Emissions on Irish Farms



Project number:
5816
Funding source:
DAFM Stimulus No: 07 555
Date:
March, 2012
Project dates:
Dec 2007– May 2011

Key external stakeholders:

Policy Makers, Food Companies and Agricultural interest groups

Practical implications for stakeholders:

To date research into GHG emissions from Irish agriculture has focused on two main themes (i) projecting future emission levels and (ii) devising abatement strategies at the farm level. This project will link these two areas of research and increase our level of understanding on the most cost efficient means of reducing GHG emissions.

Main results:

The project has produced projections of emission at the farm level, for various farm enterprises. These farm level projections have facilitated the estimation of the cost-benefit of adopting various abatement strategies. These projections are then aggregated to estimate the ability of the abatement strategies to allow us to meet potential future emissions limits for the sector. One of the more innovative aspects of the project includes an analysis of the impact of market based mechanisms, tradable emissions permits and emission charges, in reducing emissions from agriculture. This project constitutes the first such analysis with Irish farm level data.

Opportunity/Benefit:

The project results will be of interest to policy makers in the main, since it offers the capacity to contrast the abatement potential and associated costs of market based and non-market (technical) abatement strategies.

Collaborating Institutions:
University College Dublin (UCD)
University of Missouri, Columbia, Missouri, USA

Teagasc project team:
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James Breen

External collaborators:
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Compiled by:
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Technology

1. Project background:

Previously it has not been possible to model the impact the market and non-market based options for reducing GHG emissions. The impact of emissions reducing scenarios on farm numbers, farm income and enterprise mix will be measured using the farm-level model.

2. Questions addressed by the project:

- What is the level of GHG emissions produced by various farm enterprises in Ireland?
- What is the marginal cost of emissions abatement on these farms?
- What is the wider economy impact of agricultural GHG emission abatement strategies?

3. The experimental studies:

A linear programming farm–level model is developed utilizing data from the Teagasc NFS and from the FAPRI-Ireland partial equilibrium agricultural model. In particular the project develops a capacity to model a market for emissions permits. This model utilizes livestock numbers as measured by the NFS along with GHG emissions coefficients to project farm-level GHG emissions from Irish agriculture under alternative scenarios. The model allows us to determine the impact of changes in enterprise on emissions at the farm level. Also it will allow us to determine the marginal cost of emissions abatement for different farm types.

The emissions reduction scenarios and the emissions abatement strategies examined will also have an impact on the local or regional economy; however the size of the impact is likely to vary considerably. This task therefore will conduct a case study to determine the impacts on the regional economy of various strategies to reduce GHG emissions.

4. Main results:

It is possible to cost different levels of emissions reductions at farm level. The least cost emission reduction strategy at farm level can be determined. The beneficial effect of a market for emissions permits over a simple emissions cap can be demonstrated.

5. Opportunity/Benefit:

The research that has been conducted is of interest to a variety of stakeholders including farmers, government authorities and other academics both nationally and internationally.

6. Dissemination:

Main publications:

Breen J., Donnellan T. & Westhoff P. 2010. EuroChoices, The Agricultural Economics Society and the European Association of Agricultural Economists, vol. 9(3), pages 24–29, December.

Breen J., Donnellan T., Hennessy T., Wallace M. and Westhoff P. (2010). A Comparison of the Marginal Cost of Greenhouse Gas Emissions Abatement on Irish Farms. Rural Economy Working Paper Series, Teagasc.

Breen J., Donnellan T., Hennessy T., Wallace M. and Westhoff P. (2010). Estimating the Marginal Cost of Greenhouse Gas Emissions Abatement for Irish Agriculture. Rural Economy Working Paper Series, Teagasc.B

Breen J., Donnellan T., Hennessy T., Wallace M. and Westhoff P. (2010). Simulating a Market for Tradable Greenhouse Gas Emissions Permits in Irish Agriculture. Rural Economy Working Paper Series, Teagasc.

Breen J., Donnellan T. and Wallace M. (2010). Cutting Irish Agricultures Greenhouse Gas Emissions: A Carrot and Stick Approach. Rural Economy Working Paper Series, Teagasc

Breen J., Donnellan T. and Johnson T. (2011). Economic Impact of a Greenhouse Gas Emissions Policy for Agriculture on the Border, Midlands and Western Region of Ireland. Rural Economy Working Paper Series, Teagasc

Breen J. and Donnellan T. (2009). A Review of Alternative Technical and Policy-based Greenhouse Gas Emissions Abatement Strategies in the context of Irish Agriculture Rural Economy Working Paper Series 09– WP-RE–16

Breen, J., T. Donnellan and T. Johnson (2011) Regional economic implications of cutting GHG emissions from Irish Agriculture. Paper presented at the Agricultural Economics Society 85th Annual Conference Warwick University UK April 18th and 19th.

Breen J., Donnellan T. and Wallace M. (2010) Cutting Irish Agricultures Greenhouse Gas Emissions: A Carrot and Stick Approach. Paper presented at the Agricultural Economics Society 85th Annual Conference Edinburgh University March 30th–31st.

Breen, J. P., Donnellan, T. and Wallace, M. (2010) Estimating the marginal cost of greenhouse gas emissions abatement using Irish farm-level data Joint meeting of the British Society of Animal Science and the Agricultural Research Forum, Belfast, 13th–14th April 2010.

Breen, J. P., Donnellan, T. and Wallace, M. (2010) Measuring the Impact of Alternative Greenhouse Gas Emissions Policies on Irish Farmers A Climate for Change, Dublin, 24th–25th June 2010.

Breen, J. P., Clancy, D., Donnellan, T. and Hanrahan, K. (2010) Cost Implications of a Carbon Tax on Fuel Used in Agricultural Production in Ireland A Climate for Change, Dublin, 24th–25th June 2010.

Breen, J. P., Donnellan, T., Hennessy, T., Wallace, M. and Westhoff. P., (2010) Comparison of the Marginal Abatement Cost for Greenhouse Gas Emissions across Irish Farms 1st Annual Conference of the Irish Environmental Economist's Network, Athenry 2nd September 2010

Breen, J. P., Clancy, D., Donnellan, T. and Hanrahan, K. (2010) Estimating the impact of the carbon tax on Irish agriculture and the ability of farmers to adjust their production activities in response 1st Annual Conference of the Irish Environmental Economist's Network, Athenry 2nd September 2010

Breen, J. P., and Donnellan, T. (2009) "Simulating a market for greenhouse gas emissions permits amongst Irish farmers" Agricultural Research Forum, Tullamore, Ireland, March 12th 2009

Breen, J. P., Donnellan, T. and Hanrahan, K. (2009) "Greenhouses gas reduction targets: An economic assessment of the challenges for Irish agriculture" Agricultural Research Forum, Tullamore, Ireland, March 12th 2009

Breen, J. P., and Donnellan, T. (2009) "Estimating The Marginal Costs Of Greenhouse Gas Emissions Abatement Using Irish Farm-Level Data" Agricultural Economics Society, Dublin, Ireland, March 31st 2009

Breen, J. P., and Donnellan, T. (2009) A Review of Alternative Technical and Policy-based Greenhouse Gas Emissions Abatement Strategies in the context of Irish Agriculture Rural Economy Research Centre, Working Paper Series, Athenry, Ireland, 2009. 09–WP-RE–16.

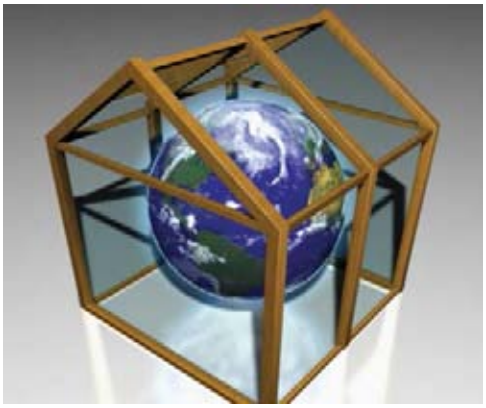
Breen, J. P. (2008) Controlling Greenhouse Gas Emissions by means of Tradable Emissions Permits and the Implications for Irish Farmers 107th EAAE Seminar "Modelling Agricultural and Rural Development Policies" Sevilla, January 29th–February 1st, 2008

Breen, J. P. (2008) Simulating A Market for Tradable Greenhouse Gas Emissions Permits Amongst Irish

Farmers Agricultural Economics Society 82nd Annual Conference Cirencester 31st March to 2nd April 2008

Project number:
5724
Funding source:
EPA (via ESRI subcontract)
Date:
March, 2012
Project dates:
Jun 2007–May 2011

Environmental economic model for agriculture



Collaborating Institutions:
Economic and Social Research Institute (ESRI)

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Key external stakeholders:

Policy makers, state agencies, agricultural interest groups

Practical implications for stakeholders:

The research has produced an updated model capable of projecting greenhouse gas (GHG) emissions from Irish agriculture. This model is integrated as part of the ESRI's Sustainable Development Research Model for Ireland (ISUS).

Main results:

The model is capable of undertaking analysis to project emissions of greenhouse gases and ammonia from agriculture over a ten year forward basis and the results can be integrated with the wider ISUS model.

Opportunity/Benefit:

The model's scenario capacity will be of interest to policy makers and other researchers working in this area.

Technology

1. Project background:

The political desire to reduce our impact on the climate has now come to the fore both in Ireland and in the EU generally. GHG emission reduction targets have been established for Ireland and other Member States as part of the effort sharing agreement reached in Brussels in December 2008. For Ireland, at a minimum, the target is a reduction of 20% by 2020 in overall GHG emissions from all sectors of the economy, relative to the 2005 level. The reduction target would increase to 30% if a successor agreement to the Kyoto protocol is achieved.

This study addresses the issue of agricultural greenhouse gas (GHG) emissions from an economic standpoint. A range of policy strategies to abate emissions are examined. The capacity of technical abatement strategies is examined against the possible reduction requirements that could emerge. Detailed consideration is given to the economic impact of reducing the level of agricultural activity in order to further reduce GHG emissions from agriculture.

2. Questions addressed by the project:

- How could policy makers approach the issue of GHG abatement in agriculture ?
- What are the types of economic GHG abatement policies that could be used ?
- How much of a limit on agricultural activity would be required to deliver a 30% reduction in GHG emissions from the agricultural sector?

3. The experimental studies:

The GHG model was developed in a manner consistent with the EPA GHG emissions inventory and projections model. The model was then used to run particular GHG reduction scenarios.

4. Main results:

Agricultural policy and market returns will give rise to reduction in GHG emissions from agriculture over the next decade. However, even with such reduction, the level of emissions from agriculture in 2020 is likely to be well off a 30% GHG emission reduction target. The results from this project illustrate the dramatic impact which meeting a 30% GHG emission reduction target could have on the Irish beef production. Ireland's 2020 GHG emission targets are onerous, given the limited extent to which the country has moved towards meeting the relatively benign GHG emission targets that were set under the EU Burden Sharing Agreement for the Kyoto Protocol.

5. Opportunity/Benefit:

This research is of benefit to stakeholders seeking a better understanding of the implications of potential future constraints on agricultural GHG emissions in Ireland.

6. Dissemination:

Main publications:

Breen J., Donnellan, T. and Hanrahan, K. (2009) 'Greenhouses gas reduction targets: An Economic Assessment of the challenges for Irish Agriculture' Plenary paper in the Proceedings of the Agricultural Research Forum: 162–167.

Popular publications:

Donnellan T. and Hanrahan K. 'Competing on a World Stage', TResearch, Summer 2009, Teagasc http://www.teagasc.ie/publications/2009/15/15_tresearch200905.pdf [accessed on 5th March 2012]

Project number:
5934
Funding source:
Teagasc
Date:
March, 2012
Project dates:
Jan 2009–Dec 2011

Meeting national targets for organic farming in Ireland

Key external stakeholders:

Policy Makers, Organic Farming Bodies, Conventional Farmers, Organic Farmers

Practical implications for stakeholders:

- This study examines the factors that determine whether producers adopt organic farming and estimates the likely future level of adoption that will take place.

Main results:

This study examined the factor influencing the take up of organic farming in Ireland. It found that under current circumstances, large-scale conversion to organic farming by drystock farmers within the next five years is unlikely.

Opportunity/Benefit:

The study points to an information deficit amongst farmers and a general lack of knowledge and awareness of organic farming. Policy makers may wish to consider modifying the means by which they communicate with farmers on issues associated with organic farming.

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Technology

1. Project background:

Despite the considerable interest in organic farming the Irish organic sector remains small. Therefore, to target support for the sector, it is important to understand why farmers make decisions in favour or against organic farming as well as to identify drivers and barriers of that decision. The adoption of organic farming is assumed to be driven by a variety of different drivers such as economic, socio-economic, structural and institutional factors.

2. Questions addressed by the project:

The project had a number of objectives. It asked: Which factors influence the diffusion and adoption of organic farming in Ireland? Which factors influence entry to and exit from organic farming?

3. The experimental studies:

The project looked at the economics of organic production, and use a quantitative approach to examine the decision making that takes place on farms with a particular focus on economic and policy factors as well as the role of producer networks and social and family influences in the advancement of organic production. A survey of conventional drystock farmers was conducted to elicit farmers attitudes to a range of issues including the environment, conventional organic production, information sources and attitudes to risk. This data was then applied to social psychology models in an econometric framework to better understand the motivation of producers.

4. Main results:

The results suggest that under current circumstances large-scale conversion to organic farming by drystock farmers within the next five years is uncertain, but nevertheless 6% of farmers state considerable interest in conversion to organic production.

5. Opportunity/Benefit:

It appears that farmers do not have strong opinions about organic farming but equally the results here suggest that they do not have a good level of knowledge about organic farming. Therefore an increase in the provision of information mainly focused on promoting organic farming as a profitable alternative to conventional farming could have a positive impact on the tendency for conversion. Future conversion to organics is most likely to be financially driven, but this may be hampered by the farmers' perception that only rich people can afford to buy organic food.

6. Dissemination:

Main publications:

Laepple D. and Donnellan T. (2009) Adoption and Abandonment of Organic Farming

An Empirical Investigation of the Irish Drystock Sector. Paper presented at the 83rd Annual Conference of the Agricultural Economics Society.

Project number:
5935
Date:
September, 2012
Funding source:
Teagasc
Project dates:
Jan 2009–Dec 2011

Economic analysis of the impact of policy on Irish agriculture using the FAPRI-Ireland model

Key external stakeholders:

Policy makers including Department of Agriculture, Food and the Marine (DAFM) officials, agricultural and agri-food representative organisations, Environmental Protection Agency (EPA) and Teagasc research and advisory colleagues

Practical implications for stakeholders:

The FAPRI-Ireland aggregate sector modelling research programme builds and maintains the analytic capacity required to quantitatively evaluate the impact of policy and market developments on Irish agriculture.

- The capacity to produce an annual Baseline projection of agricultural activity, commodity supply balances and agricultural output, input and income tables.
- Allowed the analysis of policy issues of interest to the Irish agri-food sector including CAP reform, WTO issues and Food Harvest 2020.
- Allow the annual analysis of the contribution of Irish agriculture to Ireland's future GHG emission inventories.

Main results:

The key results were the:

- Economic analysis on Irish agriculture of the WTO Doha Round proposals for agricultural trade liberalization.
- Economic analysis of the impact of the achievement of the Food Harvest 2020 targets.
- Provision of projections used to produce Irish agricultural GHG inventories by the EPA.
- Economic analysis of the impact of policy developments on the level of Irish agricultural GHG emissions.

Collaborating Institutions:
Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri-Columbia, USA
Agri-Food and Biosciences Institute – Northern Ireland (AFBI-NI)
The EPA.

Teagasc project team:
Dr Kevin Hanrahan (PI)
Trevor Donnellan

External collaborators:
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Agri-Food and Biosciences Institute – Northern Ireland (AFBI-NI), United Kingdom (Myles Patton)

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Technology

Opportunity/Benefit:

The analysis conducted and published supported agricultural policy making in Ireland, is a key input into the provision of projections of GHG inventories by the EPA and results of analysis are used by other researchers in related projects in Teagasc and other institutions.

1. Project background:

The policy and market context within which Irish agri-food industries operate is complex and characterised by a) a high degree of interdependence across agricultural sectors, b) the very high dependence of Irish agriculture and food industries on export markets and c) the continued importance of public policy (at Irish, EU and international levels) in influencing the market environment within which farms and agri-food businesses operate.

The research undertaken in this project provided the basis for the quantitative future orientated analysis of the impact of developments in agricultural, trade and environmental policy on the Irish agri-food industry.

2. Questions addressed by the project:

- What would the impact of a WTO Doha Round Agreement be on Irish agriculture and its various component subsectors?
- What is the likelihood of the Food Harvest targets being achieved and what would the consequences of achieving the targets be for the Irish agric-food sector?
- What contribution is Irish agriculture likely to make to inventories of GHG emissions in the medium term?
- What impact would the achievement of the FH2020 output growth targets have on Irish agriculture's GHG emissions?

3. The experimental studies:

In this project a set of dynamic partial equilibrium models of Irish agriculture and the Irish agricultural economy and its GHG emissions were developed, maintained and used to conduct baseline and policy scenario analysis. These models were econometrically estimated using time series data obtained from the CSO, Eurostat, DAFM and other sources. The models are currently simulated in a MS Excel environment over a ten year horizon.

The models developed cover all of the principal sub-sectors of the Irish agricultural economy and include a model of Irish agriculture's input use and expenditure, which, when combined with the sectoral sub-models, will allow for the projection of the full economic accounts for the Irish agricultural sector. The models developed and maintained in this project will form the core tools used in the provision of future orientated economic analysis by Teagasc.

Annual baseline projections were produced using the models developed and these were used to provide projections of agricultural activity levels to the EPA. Scenario analysis undertaken using the models over the course of the project focused on WTO issues, environmental policy (specifically climate change policy) and the challenge to the Irish agri-food industry of the Food Harvest Committee's output growth targets for the sector.

4. Main results:

Economic analysis of the WTO Doha Round proposals for agricultural trade liberalization. The analysis highlighted the negative impact of the potential trade reform on Irish agriculture and the importance of sensitive product status in mitigating some of the potential negative impacts of a WTO agreement on Irish agriculture.

Economic analysis of the impact of the achievement of the Food Harvest 2020 targets versus a baseline where policy continues as currently structured. The analysis highlighted the magnitude of the challenge faced by the sector in meeting the FH2020 targets and the consequences of achieving the output growth targets for the sector's emissions of GHG.

5. Opportunity/Benefit:

The primary stakeholders for this research are policy makers in Ireland both within government (DAFM, DEHLG) and other state organizations such as the EPA, farm and agri-food industry representative organizations and colleagues within Teagasc. The research conducted has informed policy on issues of great importance to the future of the industry.

The models developed form the basis for ongoing research that analyses the impact of policy change and market developments such as the increasingly volatile input and output price environment within which the agri-food sector operates.

6. Dissemination:

Main publications:

Donnellan, T. and K. Hanrahan (2009) "WTO Doha Round: Impact of an Agreement on Agriculture and the Importance of Sensitive Products." Paper presented to the 83d AES Annual Conference http://purl.umn.edu/50936

Donnellan, T. and K. Hanrahan (2009) "Issues in examining the impact of WTO reform on the Beef and Dairy Sectors in the European Union" Paper presented at the IAAE Conference http://purl.umn.edu/51752

Clancy Breen Hanrahan Donnellan Cost Implications of a Carbon Tax on Fuel Used in Agricultural Production in Ireland, http://www.teagasc.ie/publications/2010/11/11_Briefing_Note_Carbon_Tax_050510%20Final.pdf

Donnellan, T. and K. Hanrahan (2011) Hanrahan Teagasc "Greenhouse Gas Emissions by Irish Agriculture: Consequences arising from the Food Harvest Targets." Teagasc Briefing Note No. 2011 / 1 http://www.teagasc.ie/publications/2011/67/67_FoodHarvestEnvironment.pdf

Donnellan, T. and K. Hanrahan (2011) "Implications of Measures to Reduce Greenhouse Gas Emissions from Irish Agriculture by 30 percent by 2020: Achievement of the target through a reduction in animal numbers." Teagasc Briefing Note No. 2011 / 2 http://www.teagasc.ie/publications/2011/68/68_GHG30percentcut.pdf

Popular publications:

Donnellan, T. and K. Hanrahan (2009) Competing on a world stage. T-Research, Vol 4(2):30–31

Donnellan, T. and K. Hanrahan (2011) Food Harvest and greenhouse gas emissions. T-Research, Vol 6(2):34–35

Extension of the AGMEMOD model to Turkey

Project number:
6039
Date:
December, 2010
Funding source:
EU FP6 (SSPE-CT–2005–021543)
Project dates:
Jan 2009–Dec 2010

Key external stakeholders:

European Commission, national governments, policy makers.

Practical implications for stakeholders:

The potential accession of Turkey to the EU represents a significant challenge in terms of aligning existing domestic agriculture policy and monitoring and evaluation frameworks to EU standards. The extension of the AGMEMOD model to include Turkey facilitated the development of common approaches to data collection and reporting and enabled analysis of the implication of Turkey's membership of the EU.

Main results:

- A dynamic agricultural commodity market model for the EU27 and Turkey, that is capable of generating baseline and scenario projections to a ten year horizon, was developed.
- The project has also contributed to the development of expertise in Turkey in the economic analysis of agricultural commodity markets.
- The accession of Turkey to the EU would have limited impacts on Irish agricultural production due to differences in each country's comparative advantage.

Opportunity/Benefit:

The model developed as part of this project will be used to conduct baseline and policy analysis relating to the ongoing CAP reform processes and other EU accession analyses.

Collaborating Institutions:
Agricultural Economics Research Institute (LEI)
Johann Heinrich von Thünen-Institute (vTI)
Association Alessandro Bartola, Akdeniz University

Teagasc project team:
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Petra Salamon, Johann Heinrich von Thünen-Institute (vTI)
Roberto Esposti, Association Alessandro Bartola
Andrea Bonfiglio, Association Alessandro Bartola
Antonello Lobianco, Association Alessandro Bartola
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Gülden Bölük, Akdeniz University

Compiled by:
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Technology

1. Project background:

Enlargement is an important policy issue for the EU. The Union saw its biggest enlargement in 2004 when ten new countries acceded, while Romania and Bulgaria became the newest members of the EU in January 2007. The EU enlargement process took a further step forward in October 2005, when formal accession negotiations were opened with Croatia and Turkey. More than half of Turkey's total land area is devoted to agriculture. A Turkish accession to the EU would add about 41 million hectares to the agricultural area of the EU, and Turkey would account for one fifth of the agricultural area of a future EU28. In 2008, more than one quarter of the Turkish workforce was employed in agriculture, while the sector accounted for 9.2% of Turkish GDP. Vegetables and fruits (with tomatoes ranked first) account for the majority of Turkish crops output value. Cow's milk is the most important product accounting for 36% of livestock product output value.

The research conducted in this project, by extending the scope of the AGMEMOD model builds on earlier research projects supported by the EU 5th and 6th Framework Programmes (FP5 QLRT–2000–00473 and FP6 SSPE-CT–2005–021543) and research contracts from the European Commission Joint Research Centre's Institute for Prospective and Technological Studies (DG JRC-IPTS).

Given the importance of Turkey's agricultural sector and its intensive domestic agricultural support system, Turkish accession to the EU, and the concomitant adoption by Turkey of the CAP, will influence Turkish and EU agricultural commodity markets. This project provides an in-depth model based quantitative assessment of the possible implications of the accession of Turkey for these markets.

2. Questions addressed by the project:

What would the impact of a hypothetical Turkish accession to the EU in 2015 be on Turkish and EU agricultural markets?

3. The experimental studies:

The research project was broken into six principal phases:

- The development of the modelling structure for the Turkish AGMEMOD model.
- Turkish agricultural commodity supply and use and agricultural output database construction and development.
- Estimation and validation of the Turkish country model.
- Integration of the Turkey AGMEMOD model within the AGMEMOD model structure.
- Solving of the European composite EU27 and Turkish AGMEMOD models and generation of baseline projections (assuming no Turkish accession to the EU).
- Solving of the European composite EU28 model and generation of Turkish accession scenario projections assuming Turkish accession to the EU in 2015.

4. Main results:

- A dynamic agricultural commodity market model for the EU27 and Turkey, that is capable of generating baseline and scenario projections to a ten year horizon, was developed.
- This modelling system was used to analyse the impact of a Turkish Accession to the EU in 2015 on EU and Turkish agricultural markets. Some of the key outcomes from an Irish perspective were that:
- Generally the impact of Turkish accession on EU and Turkish markets depends on whether levels of protection afforded to Turkish agriculture are reduced or increased following accession.
- The magnitude of the impacts on Irish agricultural output prices is projected to be minor. This is because of the limited degree to which Irish and Turkish agricultural output are substitutes and the fact that for many agricultural sectors the level of prices in Turkey will be lower following accession to the EU.
- Of those agricultural commodities produced in Ireland that are affected by Turkish accession the largest impacts occur on lamb and poultry meat markets.
- As a result of Turkish accession to the EU, by 2020, producer prices for lamb are projected to be 5% lower than under the Baseline.

- The principal impacts of Turkish accession to the EU are on Turkish agriculture rather than EU agriculture. Generally producers of cereals and fruits and vegetables will see reduced incomes while producers of livestock and livestock products gain from accession.

5. Opportunity/Benefit:

The model developed as part of this project will be used to conduct baseline and policy analysis relating to the ongoing CAP reform processes and other EU accession analysis. The project has also contributed to the development of expertise in Turkey in the economic analysis of agricultural commodity markets.

6. Dissemination:

The results of the project have been presented at a seminar in Brussels for the European Commission and the wider academic and policy making community.

Main publications:

Leeuwen, M. v., Tabeua, A., Salamon, P., Esposti, R., Bonfiglio, A., Lobianco, A., Donnellan, T., Hanrahan, K., Koç, A. and Bölük, G. 2010. Extension of the AGMEMOD model towards Turkey – Final Report.

Submitted to the Institute for Prospective and Technological Studies (IPTS-JRC), Sevilla, Spain. July 2010.

Rural Economy & Development Programme

Project number:
5623

Date:
February, 2010

Funding source:
DAFF (RSF/06/316)

Project dates:
Jan 2006–Feb 2010

The impact of climate change on Irish farming

Key external stakeholders:

Policy makers, national government, farm bodies, farmers, industry

Practical implications for stakeholders:

- Climate change impacts will vary both spatially and between farm systems.
- Tillage producers are, potentially, most exposed to the negative implications of climate change.
- Pasture based systems may experience an increase in productivity as a consequence of improved growing conditions, particularly in the north and west of the country.

Main results:

- Results show that cereal production, in all regions, would be negatively affected under the climate change scenario used in this research.
- Production of maize silage is, however projected to increase in all of the regions.
- The effect of climate change differs across farm types and regions. However, the most common feature is that all livestock farms could increase profitability by exploiting the increase in grass production.

Opportunity/Benefit:

The primary benefits arising from this research relate to, firstly, providing indications as to the sectoral implications of climate change and, secondly, spatial implications. The research also highlights future policy issues that will arise as a consequence of changing patterns of agricultural production in response to climate change.

Collaborating Institutions:
Met Eireann
Department of Agriculture, Fisheries and Food
Environmental Protection Agency

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Technology

1. Project background:

There is growing concern about the potential impact of climate change on the viability of farming in Ireland. In relation to livestock agriculture, there are concerns that climate change will affect production directly through animal health, reproduction and productivity. For example, a rise in temperature may induce heat stress in animals that can lower productivity by decreasing appetite and increase susceptibility to parasitic diseases. However, this direct effect on livestock production is expected to be minimal in comparison to the potential indirect effects, namely the implications for grass growth. Many studies suggest that due to the carbon dioxide (CO_2) -fertilization mechanism, increased levels of atmospheric CO_2 concentration can increase grass yield by 20–30%. Similarly, a higher rainfall will be beneficial for grass growth in regions where water is currently a limiting factor, but it will have detrimental effects on grazing and grass conservation in areas with poor water drainage.

Profit maximizing farmers adapt their farm practices to changing circumstances. Previous research has shown that studies that do not allow for this farmer adaptation tend to overestimate the impact of climate change on farming. Hence it is important to consider how farmers may best adapt in response to the challenges and opportunities that climate change may bring. The main objectives of this study were initially to explore how climate change might affect the growing conditions for Ireland's major crops, and subsequently to quantify how farmers could best respond to these changes.

2. Questions addressed by the project:

Three key issues were addressed in this project:

- How is climate change likely to affect the yields of major arable crops (cereals), yields of grass and field time availability?
- How are these changes likely to affect farming practices?
- What are the best strategies that farmers can adopt in response to the challenges and opportunities that climate change may bring?

3. The experimental studies:

The research project was broken into two principal phases:

(1) To determine crop and grass yields under climate change

The objective was to project crop and grass yields under a climate change scenario for different Irish regions. For this purpose, growth models, DSSAT for crop production and Johnstown Grass Growth model for grass production, were used. The growth models used the National Farm Survey data, 2007 (NFS) and weather data to project the crop and grass yields. Farm survey data was separated for each of the 7 NUTS region. The weather data was 30-year averaged data for each of the regions for a baseline scenario and a climate change scenario. Besides crop and grass yields, another parameter, field time availability, was also determined for the baseline and climate change scenario under this task by using a soil moisture deficit simulator (JSMD).

(2) To determine the impact of climate change on farms and farmers responses to the change

An optimising linear programming model was developed for this study. The model is a farm level model which maximises farm profits within restricted farm resources. The model consists of a choice set of all possible farm activities a farmer may adopt to maximize profit. The major component of the model contains three livestock enterprises; dairy, beef and sheep production as well as tillage production systems. These systems are constrained by fixed endowments of land, feed and labour. Land is fixed on a farm but feed and labour can be brought in if profitable. There are two major data inputs for the model; (i) farm level data, which is taken from the National Farm Survey (2007) and (ii) climate data taken from growth models generated under the first phase outlined above. Where data was not available from these two sources, such as livestock coefficients and costs and prices of some of the farm variables, are taken from various published sources.

4. Main results:

(1) Summary results from the growth models

Results show that cereal production would be affected substantially under the climate change scenario in all regions of the country. Yields are estimated to reduce significantly; yields for winter wheat decreasing up to–11 % in the South East

region, spring barley yields decreases by up to–10% in both East and South East regions. Maize silage however, had a substantial increase in yields in all of the regions. The highest increase in the yield (+98%) was projected in the Border region. Grass yield also increases ranging from a maximum (+56%) in the South East region to a minimum (+49%) in the South West region. There is also an increase in field time availability especially during summer when grass is conserved. The availability of grassland for grazing also increases in all regions except the Border region where grazing period remained the same under the climate change.

(2) Summary results from the farm level model

The effect of climate change differs across farm types and regions. However, the most common feature is that all livestock farms can increase profit by exploiting the increase in grass production. On all farms it is optimal to reduce the use of concentrate feed. However, in the South East the increase in grass yields is not sufficient to decrease production costs. Tillage farms suffer from reduced yields in all regions. It is optimal for tillage farmers to increase livestock production to maximise profit. There is little benefit to be gained from the earlier (by one month) turn out of stock as the grass yield in the extra month is insufficient. The viability of miscanthus as an alternative crop, was explored, however, it was not optimal for the vast majority of farms. The main conclusion from this study is that there is no big difference in farm adaptations adopted by farms in different regions. Farms in all regions would benefit under climate change if they exploit the increase in grass yield under climate change. Generally livestock farms are capable of minimising loses in farm margins by changing their feed regime alone, where as tillage farms in all regions loose out.

5. Opportunity/Benefit:

The primary benefits arising from this research relate to, firstly, providing indications as to the sectoral implications of climate changes and, secondly, spatial implications. The research also highlights future policy issues that will arise as a consequence of changing patterns of agricultural production in response to climate change.

6. Dissemination:

Shrestha, S. (2010). Optimising Irish Farms Under Climate Change: A Farm-Level Study. Paper presented at the Seminar on Climate Change, Stuttgart-Hohenheim, Germany. June 2010

Dillon, E. and Hennessy, T. (2010). Modelling Farm-level Sustainability. Paper presented at the annual Agricultural Economics Society Conference, Edinburgh, Scotland. March 2010.

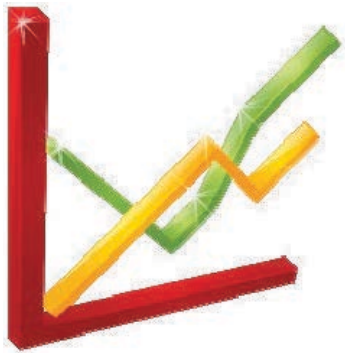
Shrestha, S. and Hennessy, T. (2010) The Impact of Climate Change on Irish Farming. An End of Project Report. Teagasc.

Main publications:

Abdalla, M., Kumar, S., Jones, M., Burke, J. and Williams, M., Testing DNDC model for simulating soil respiration and assessing the impacts of climate change on CO_2 effects from Irish Agricultural soils. Working Paper, School of Botany, Trinity College Dublin.

Modelling the effect of policy reform at the farm-level: the FAPRI – Ireland farm-level model

Project number:
5496
Date:
November, 2011
Funding source:
Teagasc
Project dates:
Jan 2006–Dec 2010



Key external stakeholders:

Policy makers, farmers, farm bodies, industry, national government.

Practical implications for stakeholders:

This project examined the impact of a number of policy issues that are of critical interest to the agri-food sector, including milk quota elimination and reform to international trade policy (World Trade Organisation through a conclusion of the WTO Doha Round negotiations).

Main results:

- Results from the FAPRI-Ireland farm level model on the implications of a proposed WTO reform conducted in 2007 concluded that if such a WTO reform was implemented the future of milk quota policy would need to be considered. They report also concluded that with an expected rationalisation in the dairy sector combined with significant restructuring in the tillage and beef sectors it was imperative for the future of the farming sector that resources like land and labour could move freely between farmers through leasing and other resource sharing initiatives.
- Results from the medium term outlook from the FAPRI-Ireland farm level model published in 2008 highlighted the dependence on off-farm income that existed on many Irish farms. Given the economic downturn in the national and global economy this presents concerns over the future availability of this off-farm income to supplement many of Ireland's non-viable farms.
- A number of reports from the FAPRI farm level model during the reporting period have indicated that a significant number of farmers have chosen to use their decoupled payments to subsidise unprofitable production. The implications of this finding is that it raises the question as to whether or not the SFP scheme be considered a green box policy if unprofitable production is subsidised.

Collaborating Institutions:
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UCD
TCD

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Technology

Opportunity/Benefit:

This project clearly quantifies the implications of various policy options on some key economic and social indicators for the agri-food sectors. The specific benefits of the farm-level model are measures of the effect of a proposed policy or market development on the following factors, changes in the farming population, in terms of the effect on entry to and exit from the farming sector, the proportion of full and part-time farms, the number of dairy farms, farm production plans, farm incomes, and the viability and sustainability of farm households.

1. Project background:

This project, in conjunction with other RMIS projects in the FAPRI-Ireland Partnership, examined the effects of market and policy developments on the Irish agri-food and farming sector. The objective of the FAPRI-Ireland Partnership is to provide timely, evidence-based policy advice to policy-makers. The objective is to show the farm-level effects of a policy reform, in terms of the implications for farm numbers, farm incomes, the intensity and diversification of farm plans and the general viability of farm households. The project plays a major role in contributing to policy decisions in the national interest and involves interaction at a senior level with government departments, state agencies and farm and food organisations.

2. Questions addressed by the project:

What are the possible effects of two policy reform scenarios:

- The elimination of milk quotes; and
- A WTO trade reform agreement as proposed in the so-called Falconer text?

3. The experimental studies:

The project used the FAPRI-Ireland farm level model to examine a number of specific research questions. First, a set of profit maximising farm level linear programming models is solved annually for each farm participating in the Irish National Farm Survey. The linear programming models are supplemented with three exogenously estimated econometric models which are used to model the structural change aspects. The first model estimates the effect of policy on the rate of entry and exit from farming and thus farm numbers. The second model assesses the effect of policy on the allocation of farm labour and in turn on the proportion of full and part-time farmers and finally, the third model examines the distribution of milk quota following a policy change. The three exogenous models are linked to the LP models in the integrated modelling system.

4. Main results:

A number of reports from the FAPRI farm level model during the reporting period have indicated that a significant number of farmers have chosen to use their decoupled payments to subsidise unprofitable production. The implications of this finding is that it raises the question as to whether or not the SFP scheme be considered a green box policy if unprofitable production is subsidised. Results from the FAPRI-Ireland farm level model on the implications of a proposed WTO reform conducted in 2007 concluded that if such a WTO reform was implemented the future of milk quota policy would need to be considered. The report also concluded that with an expected rationalisation in the dairy sector combined with significant restructuring in the tillage and beef sectors it was imperative for the future of the farming sector that resources like land and labour could move freely between farmers through leasing and other resource sharing initiatives.

Results from the medium term outlook from the FAPRI-Ireland farm level model published in 2008 highlighted the dependence on off-farm income that existed on many Irish farms. Given the economic downturn in the national and global economy this presents concerns over the future availability of this off-farm income to supplement many of Ireland's non-viable farms.

5. Opportunity/Benefit:

This project clearly quantifies the implications of various policy options on some key economic and social indicators for the agri-food sectors. FAPRI-Ireland appreciates the need to be proactive in bringing its results to end users and a strong emphasis will be placed on the dissemination of the output.

The specific benefits of the farm-level model are measures of the effect of a proposed policy or market development on the following factors:

- changes in the farming population, in terms of the effect on entry to and exit from the farming sector
- the proportion of full and part-time farms
- the number of dairy farms
- farm production plans
- farm incomes
- the viability and sustainability of farm households

6. Dissemination:

The primary stakeholders for this research are the policy making community and research peers.

The results of the project have been presented at numerous seminars and press conferences, attended by key stakeholders, and the wider academic and policy making community.

Main publications:

Hennessy, T., Breen, J and Thorne, F. (2007). FAPRI-Ireland Baseline 2007: Farm Level Analysis. DAFF

Breen, J, Hennessy, T. and Thorne, F. (2008). Medium term outlook for the beef, tillage and dairy farm sectors. Teagasc

Hennessy, T. and Thorne, F. (2006). The effect of a WTO Reform on Farming In Ireland. Irish Department of Agric 1 1–45

Popular publications:

Donnellan, T. and Hennessy, T. (2007). The Effect of Milk Quota Expansion on EU/Irish Production. In: Proceedings of the Teagasc National Dairy Conference, Kilkenny, 21–Nov–2007

Hennessy, T. (2006). The Outlook for the Agricultural Land Market in Ireland. The Property Valuer 1–25

Hennessy, T. (2007). Prospects for Dairy Expansion. In: ICOS National Conference, CityWest Hotel Dublin, 05–Nov–2007, 1–5

The Irish hedge map – version 1.0

Project number:
5690
Date:
November, 2011
Funding source:
Teagasc
Project dates:
May 2007–Dec 2010

Collaborating Institutions:
N/A

Teagasc project team:
Stuart Green (PI)

External collaborators:
None

Compiled by:
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Key external stakeholders:

Policy makers, agri-environment researchers

Practical implications for stakeholders:

This is the first national map showing the location and extent of mature hedges.

- There is now a sound estimate of the amount of non-forest woody biomass in the country. This allows for accurate assessment of the carbon sink potential of Irish Agriculture.
- The map will aid in the identification of valuable high nature value "hotspots" in the agricultural landscape.

Main results:

- All mature hedgerows in the State, wider than 2m, have been mapped.
- Approximately 450,000 Ha or 6.4% of the country is covered by hedgerows, individual trees and small woodland patches and scrub-nearly the equivalent area of Co. Tipperary.

Opportunity/Benefit:

This map database will be freely available via the Teagasc web mapping portal, when the portal becomes live at the end of 2012.

Technology

The Image processing takes the "raw" image on the left and eventually produces the yellow map of hedges and scrub you can see on the right

1. Project background:

Over the last decade there has been a concerted effort, undertaken by various state agencies, to map land-cover/land-use in Ireland. For forestry and trees, commercial plantations are well mapped and larger native woodlands have been surveyed. However the largest reservoir and most distinct element of the Irish arboreal landscape, its hedgerows, remain largely unmapped. Preliminary work in Teagasc estimated that up 6% of agricultural land could be under hedgerow.

Hedgerows are important as facets of the Irish Landscape, as important reservoirs of biodiversity and potentially valuable sinks within the national agricultural carbon budget.

2. Questions addressed by the project:

- Is it possible to train a computer to automatically identify and extract hedges from colour Arial photography?
- What area of Ireland, not already in the national forest database, is covered by hedges and small areas of natural woodland?

3. The experimental studies:

The work here is essentially image processing which involves taking a digital photograph and programming the computer to automatically detect hedges in the image. (We talk of "hedges" and not "hedgerows", as traditionally hedgerows refers to the whole structure of the field boundary, not just the vegetation but the bank and ditch associated with it – in this project we just map the area extent of the vegetation as seen from above). When we look at a picture we identify objects through their colour but also the texture we can see, the location and the context. Computers can't "see" the image, it sees a series of numbers– the job in image processing is to interpret and manipulate these numbers in such a way that the computer can apply thresholds and say that if a pixel has a particular range of numbers it is a hedge-otherwise it is not.

This project developed image processing techniques that exploited the colour but also the texture and shadows associated with hedges to classify the photographs. The project had to develop bulk processing techniques to process the 20,000 photographs that make up the national colour orthophotography database for 2005.

The process can be broken down into a number of steps.

1. Transform the colour image to its Intensity, Hue and Saturation components.
2. Create a vegetation/shadow index from the Intensity and Hue information.
3. Run a specially designed "wedge filter" over the Index to enhance the hedge structure in the image.
4. Classify presence of hedge with a predefined threshold.
5. Clean using standard GIS techniques and exclude upland and built areas.

4. Main results:

The results are the map, with 1m pixel size showing all mature hedgerows, individual trees and non-forest woodland/scrub with an 80% estimate accuracy. The map cannot be displayed at a visible scale in this document. The table below gives the estimate area under hedge/woodland in each county.

County	Area of HWS (Ha)	% of National HWS* Stock	% of County under HWS
Galway	30,000	6.7	4.9
Leitrim	11,000	2.4	6.9
Mayo	23,000	5.1	4.1
Roscommon	19,000	4.2	7.5
Sligo	11,000	2.4	6.0
Carlow	8,000	1.8	8.9
Dublin	5,000	1.1	5.4
Kildare	14,000	3.1	8.3
Kilkenny	19,000	4.2	9.2
Laois	12,000	2.7	7.0
Longford	8,000	1.8	7.3
Louth	8,000	1.8	9.8
Meath	24,000	5.3	10.2
Offaly	13,000	2.9	6.5
Westmeath	17,000	3.8	9.2
Wexford	20,000	4.4	8.5
Wicklow	10,000	2.2	4.9
Clare	22,000	4.9	7.0
Cork	57,000	12.7	7.6
Kerry	23,000	5.1	4.8
Limerick	25,000	5.6	9.3
Tipperary	35,000	7.8	8.1
Waterford	12,000	2.7	6.5
Cavan	20,000	4.4	10.4
Donegal	20,000	4.4	4.1
Monaghan	16,000	3.6	12.4

*HWS, Hedge, Woodland and Scrub

5. Opportunity/Benefit:

The main opportunity from this research lies with policy makers and researchers. Researchers now have a valuable layer of information when trying to map and predict high nature value farmlands. More importantly we can now estimate the carbon sink potential of "non-forest woody biomass" in agricultural grasslands. This important sink resource will potentially be worth millions of euro to the State in the context of reporting Land use change in post 2012 Phase III Kyoto agreements.

6. Dissemination:

The maps will be available per county via download on the Teagasc map viewer.

Audit of housing policy in rural areas

Project number:
5577
Date:
February, 2011
Funding source:
Teagasc
Project dates:
Jan 2007–Jan 2010

Key external stakeholders:

Policy makers, Local Development Companies (LEADER), Department of Agriculture, Fisheries and Food, Department of Social Protection, Department of Environment and Local Government.

Practical implications for stakeholders:

- This research provides critical insights to policy makers in relation to planning for rural housing.
- The project clarifies for rural social housing providers and funders, mismatches between rural social housing demand and supply.
- Through methodological advances, the project shows how existing vital data on rural house building can be optimised for policy analysis purposes.
- The project provides, for the first time, research findings on many previously unexplored rural housing issues in an Irish context.
- Findings on LEADER focused research could contribute towards mid and end term evaluations.

Main results:

- Conceptualisations of innovation and displacement used in LEADER companies' evaluation forms for enterprise funding, could be considered contradictory. If a traditional view of displacement is taken, innovative enterprises might be refused funding.
- The analysis raises the possibility that a more strategic interpretation of the displacement rule by LEADER might be appropriate if stimulating an innovation outcome is the goal of LEADER policy towards enterprise.
- The research undertaken as part of this study crosses a number of policy areas that impacts on rural housing policy. This highlights critical issues in terms of the mismatch between housing supply and demand for rural social housing providers and funders.

Collaborating Institutions:
NUI Galway
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QUB

Project team:
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Technology

Opportunity / Benefits:

A range of new analysis is available to policy makers concerned with a number of key rural development issues including innovation and development, land use and community development.

1. Project background:

The aim of this project was to assess the impact of selected critical policies on rural areas. Initially the project focused on how various aspects of housing policy impacted on rural areas. For the final eighteen months of the project, the project focused on enterprise policy and innovation in rural areas, specifically focusing on the LEADER programme.

2. Questions addressed by the project:

1. What are the housing issues that are not adequately addressed in the Irish literature on housing in rural areas?
2. How are new methodologies being applied to identify the spatial aspects of Irish rural housing?
3. Do the criteria used by LEADER in evaluating applications for funding by rural enterprises ensure the maximum contribution from such enterprises to rural economic development?

3. The experimental studies:

Drawing on a multidisciplinary team of internal and external collaborators, a variety of methods were employed to answer individual research questions. The methods included statistical analysis, GIS, sociological analysis, case studies, interviews and legislative reviews.

4. Main results:

There were seven main pieces of analysis carried out in relation to rural housing.

1. The first, provided an overview of the state of the art in rural housing research both internationally and in Ireland is outlined. This identified a lack of Irish research on rural social housing, rural homelessness, rural second homes and estate management in rural towns and villages.
2. The second, written from a legal perspective, focused on the impact of housing rights on Irish rural housing issues. It found that policymakers have been hindered from integrating the plethora of housing rights norms and standards which Ireland has signed up to, largely from lack of awareness of these obligations and the Constitutional barriers to their domestic enforcement in some cases.
3. The third, informed by a planning perspective, examined the factors that have influenced planning policy at national and local level in Ireland over recent decades. It concludes that the opportunity to plan strategically for rural places has not been grasped, although the framework for a national to local level planning system to facilitate such strategic planning existed. The introduction of national rural housing guidelines perpetuated this failure.
4. The fourth, inspired by an economic perspective, reviews the demand for, and supply of, social housing in rural areas. This identified that the provision of social housing in rural areas does not directly correlate with the level of need.
5. The fifth, combines GIS methodology and aerial photography to identify the exact pattern of housing development in rural county Galway over the period 1995–2008. By combining these two methods, this research shows how the shortcoming of the An Post Geo-Directory (a construction date for each building) can be overcome. If developed further, this tool will be invaluable to policy makers and researchers interested in using it to identify spatial aspects of residential and commercial development, economic geography and the distribution of various types of buildings in Ireland over time.
6. The sixth, written from a social geography perspective, explores the process underpinning estate management in private housing estates on the edges of towns and villages. It concludes that rather than providing opportunities for including residents in management functions, the tendency has been to create barriers to participation, with attendant negative consequences for the development of social capital and wider norms of civic engagement.
7. The seventh, drawing on sociology and using holiday homes in rural areas as the context, examines the type of interaction between local and 'outsider' though the nexus of social and cultural activities. Comparing the situations in rural Ireland and France, this analysis shows that local attitudes towards the development of the village, norms of extending houses rather than building new ones, and integration of local people with outsiders all contribute to the form of development that takes place in these rural areas.

There was one main piece of research carried out in relation to rural enterprise, innovation and the LEADER Programme.

This analysis showed that the conceptualisations of innovation and displacement used in LEADER companies' evaluation forms for enterprise funding, could be considered contradictory. If a traditional view of displacement is taken, innovative enterprises might be refused funding. The analysis raises the possibility that a more strategic interpretation of the displacement rule by LEADER might be appropriate if stimulating an innovation outcome is the goal of LEADER policy towards enterprise.

5. Opportunity/Benefit:

A range of new analysis is available to policy makers concerned with a number of key rural development issues including innovation and development, land use and community development.

6. Dissemination:

Main publications:

Heanue, K. (2008) (Ed) Embracing Change, National Rural Development Conference Proceedings, Teagasc Rural Economy Research Centre, Athenry, Co. Galway, ISBN 1–84170–503–9.

Popular publications:

Social Housing Estimates May Fall Short, by Lorna Siggins. Irish Times, January 15th 2007. http://www.irishtimes.com/newspaper/ireland/2007/0115/1168460530169.html

Presentations

Rural Services Research at the Rural Economy Research Centre, *Irish Rural Link Conference, Access to Services-Who Decides?*, Cavan, May 10–11th 2007 (with Karyn Morrissey) (Invited Presentation)

Rural Housing, Sense of Community and Social Capital: An Exploratory Framework for Analysing Sustainability, *Housing Studies Association Annual Conference, Housing and Sustainability*, April 11–13th, 2007, University of York, England (with David Meredith) http://www.york.ac.uk/inst/chp/hsa/spring07/Papers.htm

Rural Social Housing Need and Provision, *Irish Rural Link Seminar – Where to Now for Rural Housing?*, Moate, Co. Westmeath, April 9th 2008 (Invited Presentation)

Traditional farm landscapes

Project number:
5737
Date:
March, 2011
Funding source:
Teagasc
Project dates:
Oct 2008–Oct 2010

Key external stakeholders:

Departments of Agriculture Fisheries and Marine; Rural Community and Gaeltacht Affairs; Environment and Local Government.

Practical implications for stakeholders:

- The general public had a high willingness to pay for measures aimed at protecting traditional farm landscapes.
- Individuals were found to have a higher willingness to pay for measures aimed at protecting landscape features associated with biological and cultural diversity of the countryside (such as woodland, bogland, wild flora and fauna, water quality and features associated with cultural heritage) than what can be thought of as more obvious and scenic landscapes associated with farming activities (such as open grass covered fields, grazing farm animals and well maintained traditional farm buildings).
- For the most part, individuals had a positive view in relation to farmers' current management of the landscape and were supportive of financial incentives being given to encourage farmers to farm in an environmentally friendly fashion.

Main results:

This study suggests that there is a significant role for policy to help farm enterprises to actively move to meet demands from society with respect to the environment and wider rural development.

Collaborating Institutions:
NUI Galway

Teagasc project team:
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External collaborators:
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Technology

Opportunity/Benefit:

A significant body of research has been accumulated providing evidence to support payments to farmers for public goods i.e. the landscape.

1. Project background:

Since the early 1990s, there has been a new found interest in the multifunctional aspects of agriculture and attitudes towards the rural landscape and its conservation have changed. In particular, society increasingly utilises the rural landscape for a variety of purposes and its protection is now seen as much more important than heretofore by modern consumers. Agriculture, in addition to supplying market goods, jointly produces a number of public goods such as landscape elements and services that are valued by society. Within this context this project sought to analyse the publics' perceptions of the different functions of agriculture, the environmental aspects of the countryside and finally the behaviour of farmers. Facilitating a deeper understanding of individuals' preferences in relation to multifuntionality can provide information from which policymakers can ascertain if recent policy measures are in line with citizens' views and expectations.

2. Questions addressed by the project:

- What are the general public willing to pay for policy measures designed to protect the traditional farming landscape?
- What are the general public's attitudes towards the different functions of agriculture, the environmental aspects of the countryside and the behaviour of farmers?
- What are the general public's preferences in relation to a number of possible agricultural landscapes that may exist in Ireland in 2030 depending on the future direction of the Common Agricultural Policy (CAP)?

3. The experimental studies:

The data source utilised to examine individuals' preferences regarding the different functions of agriculture, the environmental aspects of the countryside and the behaviour of farmers was a nationally representative survey of 1000 individuals. Respondents in the survey were asked a series of questions as to their attitudes towards the environment and the countryside in general and their willingness to pay for agricultural activities aimed at protecting the traditional farm landscape.

4. Main results:

The general publics' willingness to pay (WTP) for protecting the traditional farm landscape

The average WTP for protecting the traditional farm landscape was estimated at €44 per person per year. The welfare estimates derived here are lower than a number of other national and international studies that have estimated the value of protecting traditional rural landscapes. The difference between these welfare estimates and those in this study may in part be a reflection of the downturn in the economic fortunes of Ireland prior to the collection of the survey which would have resulted in a lower WTP additional taxation on the part of the Irish public.

In terms of explanatory variables, results indicate that both income and education have a significant and positive effect on individuals' willingness to pay (WTP) to support agricultural activities aimed at protecting the traditional farm landscape. Respondents who had siblings involved in farming and those with children were found to have a relatively higher WTP. In addition, those who live in the countryside were found to have a much higher WTP for the protection of the traditional farm landscape. The analysis also suggests that landscape features have a differential impact on individuals' WTP for the conservation of the traditional farm landscape. More precisely, individuals have a higher WTP for measures aimed at protecting landscape features associated with the wider biological and cultural diversity of the countryside (such as woodland, bogland, wild flora and fauna, water quality and features associated with our cultural heritage) than what can be thought of as more obvious and scenic landscapes associated with farming activities (such as open grass covered fields, grazing farm animals and well maintained traditional farm buildings).

Attitudes towards the multifunctional aspects of agriculture

The analysis in this project suggests that producing high quality and affordable food is still viewed as the most important function of Irish agriculture but this is closely followed by environmental requirements such as ensuring the countryside is in a good environmental condition. This indicates that citizens view the role of agriculture as encompassing much more than just its traditional role as a provider of food and fibre.

Respondents do feel, however, that there are a number of negative externalities associated with

agriculture that are a significant problem. This includes nutrient leakages to the water system, pesticide residues in the soil and negative impacts on animal welfare and on wildlife habitats. That said, while reporting that they felt that there were a number of significant problems associated with the agricultural sector, respondents generally had a positive view in relation to farmer's behaviour. For instance, 46 percent disagreed with the statement "farmers are poor caretakers of the countryside" with only 23 percent of respondents agreeing with it. Furthermore, for the most part, individuals felt that farmers should receive financial incentives to farm in an environmentally friendly fashion. This lends support to policy measures under the second pillar of CAP and in particular agri-environmental measures aimed at protecting and enhancing the countryside. More generally, the results suggest that there is a significant role for policy to help farm activity move to meet wider demands from society with respect to the environment, food quality and safety and wider rural development.

Preferences for alternative future landscape scenarios

This study evaluated the non-market value of possible agricultural landscapes that may exist in Ireland in 2030 depending on the future direction of the CAP. Given the close linkages between the landscape and the agricultural sector and the significant shifts in agricultural policy that are occurring it is important to have research to determine if the resulting changes to the landscape accruing from changes to the CAP are in line with the general publics' needs and preferences. A number of hypothetical future agricultural landscape types that may exist in Ireland were examined in this analysis. Based upon expert judgment, the authors developed five different possible 'Irish farming futures' that may arise in 2030. These were entitled 1, the food island, 2, globally competitive farming, 3, energy squeeze fuels agriculture, 4, European agriculture and 5, the sustainable rural environment. Choice experiments were utilised to estimate the changes in welfare associated with each of these agricultural landscapes. The Sustainable Rural Environment was found to be the highest valued of all the future agricultural landscape scenarios which could be an indication that the Irish public wants something more from agriculture than just a sector that produces food and fibre for human consumption. They also appear to be aware of, and value, the range of other agri-environmental products and services that Irish farming delivers such as the biodiversity services from species conservation and the protection of traditional rural landscapes. In addition, a policy option that both allows for an increase in drystock production and an improvement in biodiversity was also associated with a positive impact on welfare (food island). On the other hand, the remaining three landscape scenarios (globally competitive farming, energy squeeze fuels agriculture and European agriculture) were associated with a negative change in welfare suggesting that the general public prefers landscapes associated with more traditional extensive farming practices as opposed to landscapes associated with more modern intensive farming activities.

5. Opportunity/Benefit:

This study is of particular relevance to policy formulators at both national and EU levels. The results provide evidence to support payments to farmers for the production of public goods i.e. the landscape and preservation of natural and cultural heritage.

6. Dissemination:

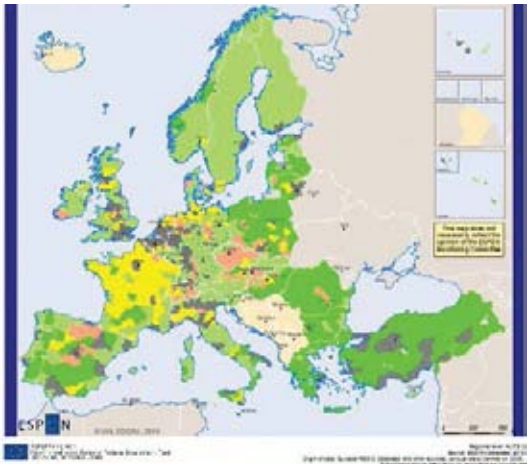
The results of the project have been presented at a variety of both national and international conferences as well as academic seminars and workshops.

Main publications:

Howley, P., Hynes, S. and O Donoghue, C. (2010) The citizen versus consumer distinction: an exploration of individuals' preferences in contingent valuation studies. *Ecological Economics*, 69(7), 1524–1531.

Hynes, S., Campbell, D. and Howley, P. (2011) A holistic versus an attribute based approach to agri-environmental policy valuation: Do welfare estimates differ? *Journal of Agricultural Economics*, 62(2), 305–329.

European development options for rural areas



Project number:
5913
Date:
January, 2011
Funding source:
ESPON (EU)
Project dates:
Jan 2009–Dec 2010

Key external stakeholders:

European Spatial Planning Observatory (ESPON), DG Regio, DG Agriculture.

Practical implications for stakeholders:

- EU policies need to be tailored to regional challenges and opportunities. This necessitates greater coordination between sectoral policies through integrated development plans.
- EU policies need to reflect diverse local contexts within which 'common' policies are implemented.
- The territorial cohesion policy is critical to enabling rural regions develop their potential. It is important that the potential of linkages to other types of regions is also developed.

Main results:

- Climate change within the context of increasingly neo-liberal systems of governance is considered the primary driver of change within the EU in the period 2010–2030.
- Of four scenarios developed by this project the one that envisages gradual climate change + deregulated market economy is considered the most likely to come to pass.
- Assessment of this scenario by a panel of rural and policy experts suggests that it will give rise to greater levels of regional differentiation.

Opportunity/Benefit:

This research developed a new typology of rural regions in Europe highlighting the diversity of opportunities and challenges facing the communities in these areas. The study also formulated series of scenarios that outlined the potential implication of medium term trends, particularly policy responses to the challenge of climate change.

Collaborating Institutions:
NORDREGIO

Teagasc project team:
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Technology

1. Project background:

The over-arching aim of the project was to develop a better understanding of the economic development opportunities and challenges facing diverse types of rural areas in Europe. The European Spatial Planning Observatory (ESPON) funded this research as a means of developing the knowledge base used to support policy stakeholders. The underlying demand for such knowledge is to facilitate targeted policy development, relating (inter alia) to job creation and social change. Understanding gained during this project contributed to the evolution of the Territorial Cohesion Green Paper, the Fifth Cohesion Report, discussions on forthcoming reforms of the CAP post–2013, and the pursuit of the Lisbon and Gothenberg agendas.

Three key issues were identified at the outset that were fundamental to the project specification;

- The need to better understand patterns of differentiation between different kinds of rural area,
- The nature of the different opportunities for development which each of them faces,
- The way in which such opportunities depend upon, and may be strengthened by, interaction between rural and urban areas.

These issues were pursued through the development of a work programme comprising:

- A detailed review of key drivers of rural change.
- The development of three key narratives of rural change.
- The production of a spatial typology of rural change.
- The development of future perspectives of rural change.
- An assessment of the policy implications of the research findings.

Teagasc was allocated responsibility for the development of the future perspectives work package. The aim of this research was to develop future perspectives of rural regions through the use of foresight techniques. These perspectives were used to assess the implications of likely future developments for the rural regions defined in the EDORA typology.

2. Questions addressed by the project:

- What are the key drivers of change that will impinge on the future development of rural regions in Europe?
- Given these drivers of change, what future scenarios for rural regions might be envisaged?
- Which scenario is most likely to shape rural development trajectories in the period 2010–2030?
- What are the implications of this scenario for regional cohesion in Europe?

3. The experimental studies:

The purpose of this research, taking a 20 year perspective, is to look ahead and consider how current trends and emerging issues pertaining to globalization and climate change might shape rural regions and their potential for development. Further to this, we seek to assess, using expert evaluations, the consequences for balanced regional and rural development of such developments.

This type of research falls firmly into the area of future studies and, more specifically, foresight activities. With growing appreciation of the risks associated with uncertainty, policy stakeholders are increasingly looking to future orientated studies to provide a framework to guide strategic development initiatives. Foresight initiatives are generally used as part of strategic business planning and, increasingly, policy development as a means of considering the longer-term implications of contemporary trends and issues.

There are a variety of approaches to foresight. This research applies a foresight approach based on systematic methods incorporating a progressive perspective by which we refer to identifying ways of overcoming the challenges presented by contemporary issues such that the future prospects for rural regions are not constrained.

4. Main results:

- Policy responses to the potential negative impacts of climate change combined with increasingly neo-liberal systems of governance are considered by a group of rural policy experts to be the primary drivers of future change within the EU.

- Of four scenarios of the future developed by this project, the one that envisages gradual climate change + deregulated market economy is considered the most likely to come to pass.
- There is an expectation within this scenario that agriculture will shift towards the para-productivist model of production wherein food production systems are structured around natural or environmental potential.

5. Opportunity/Benefit:

The primary benefit of this research to the key stakeholder is support for the development of initiatives and policy in the area of territorial cohesion.

6. Dissemination:

Copus, A. Meredith, D. Dax, T. and Shucksmith, M. (2011) Development Opportunities for European Rural Regions. Paper presented at What Future for Cohesion Policy? An Academic and Policy Debate. Sava Hoteli Bled, Slovenia, 16th–18th March 2011, Regional Studies Association.

Meredith, D. (2010) The Future for Rural Areas of Europe. Paper presented at Rural Regions in Europe: Territorial Potentials and Main Challenges. December 13th–14th 2010, Maison de l'Europe, Luxembourg, ESPON.

Meredith, D. (2010) Scenarios and policy requirements for future development of rural regions. Paper presented at Rural Policy for the globalized post-recession European Countryside, 3rd December 2010, Norway House, Rue Archimede 17, Brussels.

Main publications:

Meredith, D (2011) Rural Development in the European Union: Scenarios for Change IN Kahila, P and Hörnström, L. (Ed) Development Opportunities in Rural Europe. Nordregio, Oslo.

Meredith, D (2010) Future Perspectives of Rural Development Opportunities in the European Union. IN Copus, A. (Ed.) Final EDORA report to ESPON. University of Highlands and Islands: Inverness. http://www.espon.eu/main/Menu_Projects/Menu_AppliedResearch/edora.html

Meredith, D (2009) Future Perspectives on Rural Development in the European Union. Rural Economy Working Paper.

Rural Economy & Development Programme

Project number:
6050

Date:
August, 2011

Funding source:
European Commission DG

Project dates:
Dec 2009–Oct 2010

Evaluation of direct aid in the beef and veal sector

Key external stakeholders:

European Commission, national governments, policy makers, agricultural industry representative bodies

Practical implications for stakeholders:

An ex post evaluation of the impact of the 2003 Reform of the Common Agricultural Policy on EU beef producers. The results of the study should be of interest to the European Commission, national policy makers, as well as economic actors in the EU beef processing and agriculture industries.

- Decoupled direct aids to the EU cattle sector have had a positive impact on EU producer incomes.
- Decoupled direct aids and their implementation have afforded EU producers important flexibilities.
- In the upcoming reform of the CAP the decoupled orientation of EU policy should not be changed and should be reinforced.

Main results:

The main results of the evaluation study undertaken were that the decoupling of direct aid should, in light of the upcoming agricultural policy reform process (CAP +2013), be maintained and reinforced because of its overall positive impact on producer incomes and the flexibility it is found to have afforded cattle farmers in the EU.

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Technology

Opportunity/Benefit:

This research adds to our understanding of the impact of previous reforms of the CAP and will be important in light of the ongoing reforms of the CAP that will determine agricultural policy for the period 2014–2020

1. Project background:

The European Commission DG Agriculture has an ongoing ex post policy evaluation programme that seeks to examine in particular the impacts of the measures of the Common Agricultural Policy on market equilibrium, farm incomes, production structures, the environment, and rural development. The evaluation projects are are carried out by independent experts, with contracts established through tendering procedures by the European Commission.

The reform of the Common Agricultural Policy in 2003 significantly altered the way in which the CAP affects EU beef industry. The objective of the study undertaken was to examine the impact of the changes to direct aid policy on the EU beef and veal sector.

2. Questions addressed by the project:

This ex post evaluation sought to answer the following questions:

1. What would be the evaluation of the impact of the 2003 CAP reform on EU beef production?
2. What would be the evaluation of the impact of the 2003 CAP reform on the market orientation and competitiveness of the EU beef sector?
3. What would be the evaluation of the effect of the reform on EU beef producer incomes?
4. What would be the evaluation of the effect of the reform on rural areas?

The objective of the evaluation studies commissioned and the overall DG AGRI evaluation programme is to provide information to decision makers within the EC and the Member States on the effectiveness, efficiency, relevance and overall coherence of the policy measures applicable to agriculture.

3. The experimental studies:

The methodology utilized in the study encompasses 4 phases:

1. Structuring: detailed planning of the study, identification of sources, theoretical analysis of decoupling, empirical analysis of the sector, identification of judgement criteria and indicators to answer the evaluation questions;
2. Observing: data collection;
3. Analysing: based upon the data collected, the analysis is organised around the 6 evaluation questions raised by the European Commission;
4. Judging and recommending: the studies qualitative and quantitative analysis relies on various data and other information sources:
   - Statistical data: DG AGRI, Eurostat, Farm Accountancy Data Network (FADN), national/regional statistics, data collected from technical institutes (Institut de l'Elevage, Teagasc, vTI, CRPA);
   - Case studies conducted in 10 MS/regions (Bavaria, Brandenburg, Scotland, England, Limousin, Veneto, Catalonia, Ireland, Poland, Finland), including interviews with the main stakeholders: National and Regional Authorities, professional organisations, economic operators (slaughterhouses, trading companies);
   - A mail survey targeting livestock farmers: about 400 valid questionnaires received across the 8 MS.

4. Main results:

The main results of the evaluation study undertaken were that, based on the 8 MS studied (Germany, Finland, France, Ireland, Italy, Poland, Spain and the UK), that decoupling of direct aid should in light of the upcoming agricultural policy reform process (CAP +2013) be maintained and reinforced because of its overall positive impact on producer incomes and the flexibility it is found to have afforded cattle farmers in the EU. The study found however that the role of the suckler cow premium as a coupled aid in some MS was effective at maintaining the size of suckler cow herds and that given the importance of specialized beef production in some areas and Member States that there was justification for the maintenance of

a coupled direct aid to livestock production into the future. The study recommended that the suckler cow premium be replaced with a "breeding activity premium" with the objective of the new premium to maintain employment linked to grassland exploitation in sensitive areas and to enhance regional cohesion within the EU. The receipt of the premium would not be exclusively conditional on the maintenance of suckler cows, farmers who satisfied minimum stocking density requirements of ruminant animals per hectare would qualify. Such a scheme it is argued would allow producers to react to the external market environment (and this would not interfere with the evolution of a competitive EU beef sector) but also support livestock production in regions and where it is particularly vulnerable

5. Opportunity/Benefit:

This research adds to our understanding of the impact of previous reforms of the CAP and will be important in light of the ongoing reforms of the CAP that will determine agricultural policy for the period 2014–2020.

6. Dissemination:

Main publications:

The main publication associated with this project is the final evaluation report delivered by the project consortium to the European Commission DG Agri Evaluation Unit. This report (in French) is available at http://ec.europa.eu/agriculture/eval/reports/directaidbeef/index_fr.htm.

An English summary of the final project report is available at http://ec.europa.eu/agriculture/eval/reports/directaidbeef/exec_sum_en.pdf

Rural Economy & Development Programme

The relative competitiveness of Irish agriculture

Project number:
5652
Date:
December, 2010
Funding source:
Teagasc
Project dates:
Jan 2007–Dec 2009

Key external stakeholders:

Policy makers, national government, farm bodies, farmers, industry.

Practical implications for stakeholders:

- A serious viability issue at farm level was highlighted whereby both cash and economic costs were significantly in excess of market based returns for the beef sector.
- In a decoupled policy environment the operation of non-economically viable enterprises cannot be considered sustainable in the longer term.
- Given the importance of economies of scale found in the research, these results present a serious challenge for policy makers and for those involved in planning the future of Irish agriculture, which at present is characterised by relatively small scale operations (internationally).

Main results:

- Findings from this research have shown that while all the sectors of Irish agriculture examined may have had a relative advantage compared to competing EU countries examined based on a short term planning horizon, this competitive advantage has deteriorated somewhat in the new era of decoupled payments.
- The longer term competitive position of Irish agriculture is less positive given the large amount of owned resources employed in Irish agriculture and the relative small scale of operations compared to international standards.

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TCD

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Technology

Opportunity/Benefit:

- Facilitation of informed decision making at farm level. The analysis of the annual situation and outlook for Irish farming using a representative farm approach which reflects the levels of technical efficiency at farm level provides information that facilitates economically rational production decisions.
- Understanding of the key determinants of competitiveness and productivity.
- Facilitate informed decision making by policy makers and stakeholders.
- To facilitate other Teagasc staff in the dissemination of timely reporting on the competitiveness and productivity of Irish agriculture.

1. Project background:

As a result of successive reforms of the CAP, the ability of Irish producers to compete at or near world prices is of paramount concern, thus providing an immediate rationale for the completion of this project. The lack of sufficient consistent data on the competitiveness of Irish agriculture was previously highlighted by the report of the 2010 Committee (DAFRD, 2000) which stated that 'The Committee is... of the view that there is insufficient up to date evidence on competitiveness in the agricultural sector. The action programme should therefore include provision for the collection and publication on a regular basis of key competitiveness indicators, with appropriate international comparisons'. This project is a direct response to this finding. Furthermore, the report of the 2015 Committee (DAF, 2004) recommended that research be carried out on the socio-economic determinants of the productivity performance of Irish agricultural production so as to inform our understanding of the sector's competitive potential. Such research should be in addition to research on benchmarking the competitive performance of Ireland's key agricultural enterprises against international competitors. The recommendation above provides a rationale for the continuation of this research on the competitiveness of Irish agriculture. Furthermore, the extension of this research to examine the impact of alternative policy reform scenarios on the future competitiveness of Irish agriculture is consistent with the recommendations of the 2015 Committee report.

2. Questions addressed by the project:

The principal question addressed by this project was; what is the relative competitiveness and productivity of Irish agriculture?

3. The experimental studies:

The main objectives of this project were to:

- Examine and discuss indicators of competitiveness of Irish agriculture using data from the European Commission (FADN) and the International Farm Comparisons Network (IFCN).
- Examine the potential future competitiveness of Irish agriculture under alternative policy scenarios, by linking the results from stage one with projections from the FAPRI-Ireland aggregate model.

4. Main results:

- Findings of the research have shown that while all the sectors of Irish agriculture examined may have had a relative advantage compared to competing EU countries examined based on a short term planning horizon in a coupled policy environment, this competitive advantage has deteriorated somewhat in the new era of decoupled payments. In both the previous coupled policy environment and the current decoupled policy environment the longer term competitive position of Irish agriculture is less positive given the large amount of owned resources employed in Irish agriculture and the relative small scale of operations compared to international standards.
- In addition to the results from the competitiveness analysis highlighting a competitive issue in the longer term, it also highlights a serious viability issue whereby both cash and economic costs are significantly in excess of market based returns for the beef sector. In a decoupled policy environment the operation of non-economically viable enterprises can not be considered sustainable in the longer term.
- From a productivity perspective, recent data are not available to compare productivity performance with other EU countries on the basis of total factor productivity measures. In absolute terms, however, the overall

productivity performance of Irish agriculture between 1996 and 2006 was poor. For example, reports rates of technical change in England and Wales for arable farms in the range 3.7 to 5.2 per cent annually, and for livestock farms (excluding pigs and poultry) of between 2.0 and 3.3 per cent. Based on these comparative findings it is unlikely that productivity growth rates of the magnitude found in this study will be sufficient to maintain farm incomes in the face of inflationary increases in costs suggesting that more rapid structural change in the sector is inevitable.

- Given the importance of economies of scale found in the research, this finding presents a serious challenge for policy makers and for those involved in planning the future of Irish agriculture, which at present is characterised by relatively small scale operations (internationally).

5. Opportunity/Benefit:

- Facilitation of informed decision making at farm level. The analysis of the annual situation and outlook for Irish farming using a representative farm approach which reflects the levels of technical efficiency at farm level provides information that facilitates economically rational production decisions.
- Understanding of the key determinants of competitiveness and productivity.
- Facilitate informed decision making by policy makers and stakeholders.
- To facilitate other Teagasc staff in the dissemination of timely reporting on the competitiveness and productivity of Irish agriculture.

6. Dissemination:

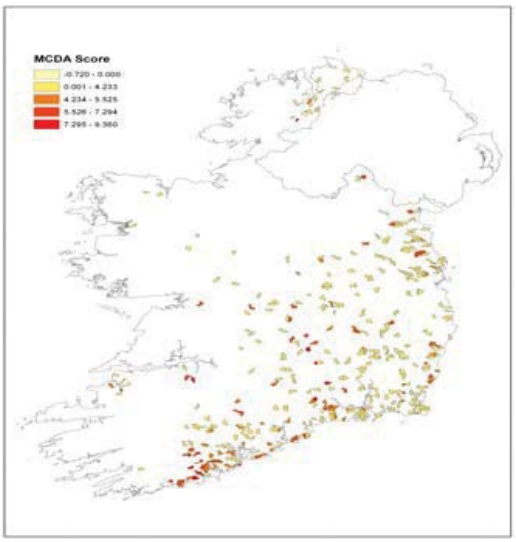
Main publications:

Donnellan, T., Hennessy, T. and Thorne, F. (2009) Perspectives on the Competitiveness of EU Dairy Farming, Volume 8, No.1, Eurochoices.

Annual (2007–2009) IFCN Dairy Report, International Farm Comparisons Network.

Project number:
5866
Date:
July, 2011
Funding source:
DAFF
Project dates:
Dec 2007–Jan 2009

A novel GIS-based approach for catchment selection in the Irish Agricultural Catchments Programme



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Key external stakeholders:

Dept. of Agriculture, Food and Marine, Dept of Environment, Community and Local Government, European Commission, research community

Practical implications for stakeholders:

The developed technique has established a technical framework for identifying experimental catchments and enabled a selection process that is cognisant of agricultural and environmental stakeholder interests.

Key outcomes of this chosen approach for stakeholders include:

- Development of capacity to incorporate expert judgment into a geographical information system (GIS) based selection/classification procedures.
- Provision of a mechanism whereby key aspects of a decision/selection problem in an agri-environmental context can be organised in a hierarchical manner.
- Facilitation of a better understanding of the participating elements in a complex decision making setting enabling transparency in the process.

Main results:

- GIS based application used to ensure compliance with European environmental legislation.
- Innovative GIS-multi criteria approach used for optimised catchment selection.
- Facilitation of the establishment of the Agricultural Catchments Programme.

Technology

Opportunity/Benefit:

The main research findings have been used to underpin the Agricultural Catchments Programme by identifying suitable catchments in a scientifically robust, transparent manner. The outcomes have been subject to external peer review and have been approved by the project steering committee as providing a comprehensive, justifiable selection of catchments appropriate to the requirements of the European Commission for establishing monitoring programmes under the framework of the Nitrates Directive.

1. Project background:

The European Union Water Framework Directive and Nitrates Directive are the primary legislative initiatives in place to mitigate the potential for agricultural activities impairing water quality in river basin districts. As part of the requirement for evaluating the Nitrates Directive National Action Programme (NAP) and an associated derogation for intensive grassland farming, Ireland is monitoring environmental and economic effectiveness at the catchment scale. As in other countries, issues around maintaining a high capacity, productive agricultural sector while ensuring a sustainability-based farming approach remain a focus for all stakeholders.

In partnership with farmers and other stakeholders, the Irish Agricultural Catchments Programme (ACP) is mandated to support productive agriculture while protecting water quality. It is funded by the Irish Department of Agriculture, Fisheries and Food and run by Teagasc. ACP advisers provide an intensive advisory and planning service to farmers in small river catchment areas (500 to 2,900 hectares). They help the farmers improve their profitability and implement the necessary agri-environmental measures contained in the NAP.

Prior to establishing a specific experimental design to evaluate the dynamics of agriculturally-derived nutrient transfers, it was necessary to define a landscape scale series of experimental river catchments that are representative of the existing range of principal agricultural enterprises and intensities, and in a variety of environmental settings.

In the work phase described here, which contributed to the main project, a method was developed to select experimental catchments using national spatial datasets in a multi-criteria decision analysis (MCDA) approach implemented in a Geographical Information System (GIS).

2. Questions addressed by the project:

The selection of catchments was subject to EU guidelines that indicated that monitoring efforts be concentrated in "areas of intensive crop and livestock production...with elevated nitrate concentrations...adjacent to existing or projected eutrophication areas...with similar land use, soil type, or agricultural practice."

Specific questions addressed by this project included:

- Could a database of environmental variables of relevance to the catchment selection guidelines be developed?
- Could we develop and implement a method for selecting small catchments (from 400 to 1,200 hectares) with specific criteria? Catchments that were: farmed intensively; either predominantly grassland or arable; and at risk of high phosphorus or nitrogen losses from land into the rivers that drain them.

3. The experimental studies:

Given the spatial and environmental context of the task of candidate catchment selection, the role for a GIS-based methodology was immediately obvious. ArcInfo GIS (ESRI Inc.) was used to build a geodatabase to hold and manage the range of datasets that were required for the task and which were supplied by a diverse group of government departments and agencies.

In beginning the selection process, Spatial Analysis Unit staff first examined a national catchment boundary dataset of approximately 6,000 catchments to generate a list of 1,300 possible small river catchments based on size and Strahler stream order. These were further divided into two broad categories—grassland and arable cropping. The data analysed included land use, forestry, area of peat, livestock density, non-agricultural land use, arable cropland, forage areas, housing density, geology, and soil types. A Multi-Criteria Decision Analysis (MCDA) approach was employed in the analysis using the onboard attribute table tools already available in an ArcInfo processing environment.

After detailed consultation with a broad range of experts from scientific, policy and farm sector backgrounds, various selection criteria were chosen and given weightings, reflecting the suitability of the catchments for monitoring by ACP. The internal attribute tables of each of these input parameters

were reclassified into appropriate ranges and these too were ranked according to selection suitability. A weighted summation provided an ordered list of catchments ranked by their suitability. GIS raster modelling software was used to model the risk at catchment-level of nitrogen or phosphorus moving from land to water. This model implemented a risk assessment procedure devised at national level for formal reporting to the European Commission on Water Framework Directive implementation. The ACP programme had at its disposal the most detailed national scale datasets and the risk model developed for the programme is the most highly resolved available nationally.

The model is primarily based on soil drainage and subsoil hydrological characteristics. Generally, more poorly drained soils have a greater risk of phosphorus loss through overland flow or runoff, while the more freely drained soils have a greater risk of nitrogen loss through leaching down through the soil. Of the 1,300 eligible catchments initially identified, a short list of 50 top-ranking arable and grassland catchments was drawn up. These catchments were visited by ACP staff and assessed for their physical suitability as study sites. Six catchments were subsequently selected for detailed study by ACP; 4 that were predominantly grassland and 2 with a high proportion of arable farming. The GIS-MCDA approach was shown to be particularly suitable to the selection task and its implementation in ArcInfo proved highly efficient in handling the large number of input datasets and processing requirements.

4. Main results:

The selection of six catchments in line with EU requirements and involving engagement with catchment stakeholder communities was a first stage in the evaluation of the NAP in Ireland. The MCDA approach was used to select four working catchments with data-mining of the individual layers to define a fifth in a karst landscape. MCDA was also used to aid in pre-selection of the sixth, grassland-based catchment. Combined, the catchments represent the range of intensive grassland and arable agricultural interests in Ireland across a soil and physiographic gradient that defines potential risk of P and/or N transfers, including regions availing of derogation under the Nitrates Directive. This range includes heavy clay and gleyed soils developed on glacial tills and marine clays; free draining brown earths on poorly productive aquifers; and base rich shallow soils developed on karst limestone plateaux. The hydrological susceptibility and inferred nutrient transport risks used in the process were based on measures of soil and geological permeability and were only applied as P or N risk in the context of a landuse pressure being present.

Four of the finally selected catchments are grassland based with differences in inferred P and N risk depending on the permeability of the soils and range of stocking densities. The two arable catchments are also distinguished by soil permeability with the extent of arable enterprises in each ranging between 30–50% of catchment area.

5. Opportunity/Benefit:

The main research findings have been used to underpin the Agricultural Catchments Programme by identifying suitable catchments in a scientifically robust, transparent manner The outcomes have been subject to external peer review and have been approved by the project steering committee as providing a comprehensive, justifiable selection of catchments appropriate to the requirements of the EU for establishing monitoring programmes under the framework of the Nitrates Directive.

6. Dissemination:

Main publications:

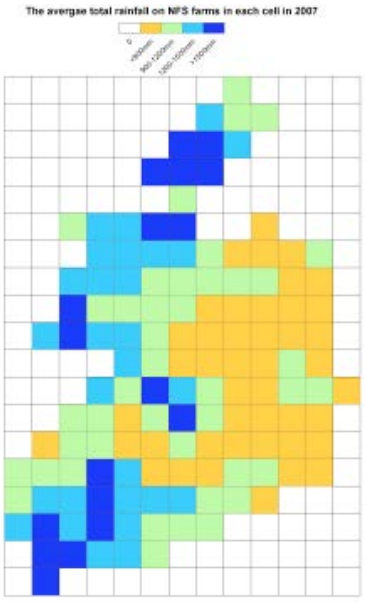
Fealy, R.M., Buckley, C., Mechan, S., Melland, A., Mellander, P-E., Shortle, G., Wall. D. and Jordan, P. (2010).The Irish Agricultural Catchments Programme: catchment selection using spatial multi-criteria decision analysis. Soil Use and Management 26: 225–236

Main Popular publications:

Mechan, S., Burgess, E. & Fealy, R.M. (2010). *Irish Agricultural Catchments Programme Protects Water Quality While Supporting Productive Agriculture.* ArcNews 3293): 34

Shortle, G. (2009). The Agricultural Catchments Programme – innovation for farming and the environment. *TResearch* 4(2) 38–39

Mapping the National Farm Survey



Project number:
5838
Date:
July, 2010
Funding source:
Teagasc
Project dates:
Feb 2008–May 2009

Collaborating Institutions:
N/A

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Key external stakeholders:

Farm Accountancy Data Network (FADN), Department of Agriculture, Fisheries and Food, Teagasc staff.

Practical implications for stakeholders:

REDP researchers can now ascribe geographic data, not collected in the survey, to NFS correspondents allowing us, for instance, to:

- Examine the effect of past weather on present agricultural output, economic performance and farmer decision making.
- Or see now how the geographic location of farms, including environmental conditions and physical infrastructure like the road network and distance to processing plants, effects performance.

Main results:

This project has successfully assigned a geographic coordinate label to farms in the 2007 national farm survey database.

Opportunity:

With a coordinate, spatially referenced environmental, economic and geographic data can now be assigned to each farm within the NFS thus expanding the data attributes of the NFS dataset.

Technology

1. Project background:

The National Farm survey (NFS) is designed to represent the major agricultural enterprises in Ireland. Its approach on collection and dissemination of data has always been by farm sector and enterprise type. The only geographic information collected was the address of the correspondent. Delivering results on a sectorial basis satisfies the national FADN reporting requirements and also guarantees the confidentiality of the correspondents.

Since the establishment of the NFS methodology there have been major developments in mapping technology such that the majority of agri-environmental data is managed and stored as computer map geo-databases. In the last decade the use of explicit geo-spatial analysis within agri-economics has grown in importance.

Retrospectively spatially-enabling the NFS allows the collected records to be used more easily within this new geospatial environment. Allotting each farm correspondent in the NFS with a geographic coordinate (an x-y coordinate) allows for the allocating of data to each farm from other map sources (for example calculating actual road distance to the nearest mart for all beef farms in the NFS). With a Geo-spatially enabled NFS (GNFS) we can allocate historical weather records to each farm or see how decisions year-on-year are influenced by weather. The geospatial NFS allows us to examine new FADN proposal to publish national surveys as maps.

2. Questions addressed by the project:

The aim is to try and associate a geographic X-Y point (in Irish National Grid coordinates) to each participant in the NFS for 2007 in order to attribute new environmental, geographical or meteorological data to each farm that is not ordinarily captured in the survey (local rainfall for instance) using address matching techniques against the GeoDirectory (an An Post/OSI geographic database with the location and address of every building address in Ireland).

3. The experimental studies:

There are three parts to the problem of spatially enabling the National Farm Survey for allocation of environmental attributes:

1. Matching addresses in the NFS to possible addresses in the GeoDirectory Database.
2. Allocating a geographic point that represents the matched GeoDirectory Database addresses that deals with the one-to-many matching possibilities and retains the confidentiality in the data.
3. Ascribing a representative sample of the environmental attribute to the point.

Addresses in the NFS 2007 database (names were not used or supplied) were matched against the 1.5 million addresses in the GeoDirectory. The method has to deal with the many alternate place name spellings (as well as accidental misspellings) that exist.

The NFS contained 1,350 records. Detailed examination of this list revealed a number of further data capture issues. The NFS address is allocated to a point in the Geodirectory if the address matched or nearly matched.

Only 6% of NFS addresses match one-to-one with a GeoDirectory building the rest match with numbers of buildings, the average is a NFS address to match to 10 GeoDirectory buildings. This *one-to-many* matching is normal in rural Ireland where all the houses in a townland will have the same address and post is delivered based on the name of the addressee.

4. Main results:

NFS Farm addresses were matched to addresses contained within the 2007 Geo-Directory. The wide variety of alternate spellings in Irish and English make rural address matching in Ireland difficult. Only 6% of NFS addresses matched with a single GeoDirectory point, the average match was 10 points to each NFS address.

- This project has successfully assigned a geographic coordinate label to farms in the 2007 national farm survey database.
- With a coordinate, spatially referenced environmental, economic and geographic data can now be assigned to each farm thus expanding the data attributes of the NFS dataset (as in the illustration showing average rainfall for NFS farms).

5. Opportunity/Benefit:

This is an internal Teagasc research enabling project. A service is now available to Teagasc researchers wherein they can request a geospatial dataset is ascribed to NFS farms, e.g. classification of farms in the NFS according to their height above sea level or proximity to contractors.

6. Dissemination:

The direct outputs of this project are confidential and have not been published – however the service has already been used in a number of projects that have produced reports and research papers.

Accurate income measurement for the assessment of public policies

Project number:
5562
Date:
February 2012
Funding source:
European Commission
Project dates:
Feb 2006–Jan 2009

Key external stakeholders:

European Commission, Euromod, Institute for Social and Economic Research (Essex), European government agencies

Practical implications for stakeholders:

This project supports the capacity of researchers to overcome data limitations and generate richer datasets for the analysis of key economic and policy changes.

This project enhances the ability of researchers to evaluate integrated tax and welfare policy at the European level and assess methodological issues relating to the most appropriate methods of analysis across a range of countries, policy and data contexts.

The methods can be used to match spatially disaggregated data such as the Small Area Population Statistics to household and farm level datasets. As a consequence, there will be more scope for Teagasc researchers to spatially illustrate social and economic data within Ireland.

Main results:

We evaluated different methods to link different datasets, so as to increase the available information for analysis. A relatively simple method based upon parametric regression was found to be the best of five methods.

Opportunity/Benefit:

REDP researchers will be able to pose a wider set of research questions as fewer constraints will emerge due to a lack of data availability. The codes used for the policy simulations can be used elsewhere e.g. identify the welfare effects of changes to environmental taxes and shocks to farm incomes.

Collaborating Institutions:
See Below

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Technology

1. Project background:

Research questions in quantitative economic research are typically designed with data availability in mind. Since the mid 1990s, there has been a significant improvement in the availability of household and individual level data on incomes, employment and other socio-economic variables. This has allowed economists and other social scientists to conduct research on topics such as the earnings distribution and the impact of inflation and taxation on household welfare. The Quarterly National Household Survey (QNHS), the Survey of Income and Living Conditions (SILC) and the familiar National Farm Survey (NFS) are examples of such micro level datasets.

All of these datasets are constructed with particular research questions in mind. For example, the calculation of the national unemployment rate is largely based upon the results of the QNHS while the NFS is concerned mainly with agricultural incomes, production costs and closely related issues. For the purposes of examining issues connected with Rural Development, there is a need to analyse changes to the social and economic wellbeing of households not just within agriculture but within wider rural communities. A sole dependence upon either the NFS or the SILC datasets does not provide us with the necessary infrastructure to carry out such research. This is not an unusual constraint faced by researchers. In many cases, there is no single data source available that includes all of the variables that the researcher requires in order to address a particular research question.

The absence of one single data source does not however, preclude researchers from achieving ambitious research objectives. This is due to the availability of statistical matching methods that can be used to impute information from one dataset to another. There exists a good deal of variation in the complexity of these methods. Some of these methods involve the simple ranking of records in each dataset according to the responses to questions that are common to both datasets. The more complex methods involve the use of regression-based econometric techniques. The aim of this AIMAP project was to provide an assessment of five different matching methods. The testing of these five methods involved the imputation of household expenditures from the Household Budget Survey into the Living in Ireland Survey of 2000, a household income survey. These methods can however, be used to match farm household data such as the NFS to a household income survey such as the SILC and therefore contribute to a better data infrastructure within Teagasc.

2. Questions addressed by the project:

- Identify the best generic method of matching a household expenditure survey to a household income survey for a selected set of EU-countries. The Household Budget Survey and the Living in Ireland Survey were the expenditure and income surveys in the case of Ireland.
- Estimate the incidence and distributional outcomes of a policy relevant simulation involving a shift from personal income taxes to indirect taxes or environmental taxes using the matched datasets. Identify who pays and gets how much in different forms of taxes and benefits under the new and old tax-benefit policies.

3. The experimental studies:

Five alternative methods were used to impute expenditures from the household expenditure dataset to the household income dataset. In all of these methods, the expenditure survey is considered to be the source dataset as it contains the original expenditure information. The household income survey is considered to be the target dataset as the expenditure values must be imputed into the household income dataset.

Two of the five methods involved the use of regression based techniques. The other three techniques were based upon the matching of each household in the income survey to a household in the budget survey using ranking methods. These rankings were based upon the responses from households to questions common to both the expenditure survey and the income survey. These included variables such as education level of the household head and the number of adults and children in the household.

The relative matching quality was evaluated by means of two criteria: a goodness of fit measure, and tests of the equality of the distributions of the imputed and the observed budget shares. The goodness of fit tests summarized the discrepancy between the expected and observed values of the imputed variables in terms of the average household in the income distribution. The tests on the equality of distributions were used to analyse the ability of the matching process to make accurate imputations for households at different points of the income distribution. The best matching method was chosen on the basis of these tests.

This was followed by a two-step simulation process involving a combined set of policy instruments: direct taxes and indirect taxes. The first step in the simulation involved a 25% decrease in the social security contributions of the employees in the matched dataset and the second step involved an increase in the standard VAT rate in order that revenue neutrality can be achieved.

4. Main results:

Overall, the parametric and non-parametric methods generated the best fit of the imputed values with respect to the observed values. The parametric match outperformed the non-parametric match in terms of imputing the distribution of expenditures. The parametric method is much less computational intensive to implement relative to the non-parametric method. The authors therefore selected the parametric regression method as the best method.

The results of the matching process show that indirect taxation is an influential, regressive component in the total tax system. It is therefore important to include it in microsimulation studies. The regressivity is due to the regressivity of the savings rate. Households earning more save more, and this compensates for the fact that they buy goods with higher indirect tax rates.

Decreasing the social security contributions of the employees and financing this by an increase in the standard VAT rate is a very regressive measure in all countries studied. This is the consequence of replacing a progressive taxation scheme by a regressive one.

5. Opportunity/Benefit:

REDP researchers will be able to pose a wider set of research questions as fewer constraints will emerge due to a lack of data availability. The codes used for the policy simulations can be used elsewhere e.g. identify the welfare effects of changes to environmental taxes and shocks to farm incomes.

6. Dissemination:

Main publications:

DeCoster, A., J. Loughrey, C. O'Donoghue and D. Verwerft, 2011, Microsimulation of Indirect Taxes, *International Journal of Microsimulation*

Decoster, A., Loughrey, J., O'Donoghue, C. and Verwerft, D. "How Regressive Are Indirect Taxes? A Microsimulation Analysis for Five European Countries" Journal of Policy Analysis and Management, March 2010, 29(2), 326–350

Agricultural member state modelling for the EU and eastern european countries – AGMEMOD 2020

Project number:
5529
Date:
July, 2011
Funding source:
6th EU Framework Programme, Project no. SSPE-CT–2005–021543
Project dates:
Jan 2006–Dec 2008

Key external stakeholders:

European Commission, national Governments, policy makers, agricultural industry representative bodies.

Practical implications for stakeholders:

- Teagasc Rural Economy Research Centre was a core member of the AGMEMOD Partnership which, with the support of the European Union's (EU) 6th Framework Programme, developed a dynamic, multi-country, multi-commodity partial equilibrium model of the European Union agricultural commodity markets.

Main results:

The AGMEMOD model developed in this project is capable of analysing the impact of changes in agricultural policy in each of the EU 27 Member States and the aggregate EU. The model's country by country structure facilitates the analysis of future EU enlargement and provides country level detail that distinguishes the model's analytic capacity from that available from other modelling systems.

The AGMEMOD model was used to analyse the impact of the Common Agricultural Policy (CAP) Health Check (2008). Analysis of the impact of possible outcomes of the ongoing CAP +2013 reform process was also undertaken.

Opportunity/Benefit:

The modelling system developed can be used by researchers and European institutions (European Commission) to analyse the impact of potential policy reforms at a detailed member state level.

Collaborating Institutions:
BOKU
UCL
IEABG
UNWE
UZEI,FØI
EMU
MTT
INRA
vTI
CUB
UNIVPM
LSIAE
LAEI
SGGW
UNL
IEARO
SAU
LJUB
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Technology

1. Project background:

Agricultural policy remains a key determinant of agricultural production in Ireland and the EU. Agricultural policy in Ireland and the EU is largely synonymous with the European Union's (EU) Common Agricultural Policy (CAP). Since the 2003 CAP reform (commonly known as the Fischler reforms) the CAP has become increasingly heterogeneous in its implementation across the EU. The expansion of the EU in 2004 and 2007 added to this heterogeneity, since the single payment system (SPS) that operates in the EU15 member states in general is not applied in those member states that acceded to the EU in 2004 and 2007 (they apply what is known as the simplifies area payments system of SAPS).

Nevertheless, despite the increased heterogeneity of policy, policy reforms are still determined at an EU level. Given the absence of barriers to trade within the EU what happens in response to a policy change in one member state can affect the market prices of agricultural production in another member state. These two pan-European dimensions of EU agricultural policy and its implementation at member state level called for the development of a policy analysis tool capable of analysing the impact of changes in agricultural policy at the individual member state and aggregate EU levels.

The research conducted in this project, in developing such a EU agricultural policy modelling tool, built on earlier research projects that were supported by the EU 5th Framework Programme (FP5 QLRT–2000–00473) and research contracts from the European Commission Joint Research Centre's Institute for Prospective and Technological Studies (DG JRC-IPTS).

2. Questions addressed by the project:

- Can a partial equilibrium, non-spatial, economic model of the EU27 and eastern European agricultural commodity markets be developed through a collaborative project involving economists from across the EU?
- Can the model developed be used to generate baseline (no policy change) projections for EU agricultural commodity markets?
- Can the model developed be used to analyse the impact of the CAP Health Check reform of 2008?
- Can the model developed be used to analyse the impact of changes to the CAP envisaged for the period 2014–2020?

3. The experimental studies:

The research project was broken into 5 principal phases:

- The development of the modelling structure for individual country models and for the EU27 model.
- Database construction and development.
- Estimation and validation of country models.
- Solving of the European composite EU27 model and generation of baseline projections.
- Simulation and analysis of alternative policy scenarios using the composite EU27 model.

4. Main results:

- The development of a dynamic, multi-commodity, multi-country partial equilibrium agricultural commodity market mode for the EU27 that incorporates current agricultural policy instruments prevalent in each member state that is capable of generating baseline and scenario projections to a ten year horizon.
- CAP Health Check analysis conducted using the model found that the recently agreed reform is likely to have very little impact on agriculture across the EU. The agreement reached on the phasing out of the EU milk quota represents the principal agricultural policy change agreed. The analysis suggests that the increase in the rate of modulation agreed by the Council will have only very modest impacts on agricultural production. The freedom to retain coupled suckler cow and ewe premium under the terms of the CAP Health Check Agreement will limit the extent of any adjustment in the cattle and sheep sectors.
- The second set of policy change scenarios analysed the impact of a mandatory move to national flat area payment systems and the impact of the implementation of an EU wide flat area payment in conjunction with the full decoupling of all remaining coupled policy instruments. The results suggest that the retention of coupled payments continues to support agricultural production in the EU. The introduction of an EU flat area payment leads to increased production in those member states with lower direct payments per hectare than the EU average and declines in agricultural activity and agricultural commodity production in those member states with above average direct payment receipts per hectare. Under the EU flat rate scenario there are no dramatic changes in the pattern of EU agricultural production.

- The third set of policy change scenarios were two EU Budgetary Review scenarios that examined the commodity market impacts of policy changes that would significantly reduce the budgetary resources devoted to CAP Pillar I measures. While these two scenario's impacts are the largest of the alternative CAP policies analysed the impacts on commodity markets and on agricultural output prices are relatively modest. The greatest impacts, as anticipated by Bureau and Mahé in their 2008 paper, are on the specialised beef and sheep sectors.

5. Opportunity/Benefit:

The primary stakeholders for this research are the European Commission, Member State national governments, the policy making community and research peers.

The results of the project have been presented at seminars in Brussels for the European Commission and at academic seminars, workshops, symposia and conferences organised by the Agricultural Economics Society of Ireland (AESI), Agricultural Economics Society (AES), European Association of Agricultural Economists (EAAE) and the International Association of Agricultural Economists (IAAE).

The model developed as part of this project will be used to conduct baseline and policy analysis relating to the ongoing CAP +2013 reform process. The project has also contributed to the development of expertise across the expanded EU in the economic analysis of agricultural commodity markets and has contributed to the development of the agricultural economics community within the European Union.

6. Dissemination:

Main publications:

Hanrahan, K., Chantreuil F., van Leeuwen, M. (eds.) (2012) *The Future of EU Agricultural Markets by AGMEMOD*. Springer, 128 pages. Go to http://dx.doi.org/10.1007/978–94–007–2291–0

Erjavec, E. Chantreuil, F, Hanrahan, K, Donnellan, T., Salputra, G., Kožar, M, van Leeuwen, M. (2010) Policy assessment of an EU wide flat area CAP payments system. *Economic Modelling*, 28(4): 1550–1558. Go to http://dx.doi.org/10.1016/j.econmod.2011.02.007

Hanrahan, K, Donnellan, T. and Chantreuil, F. (2010) Agricultural Policy Change in the EU: Analysing the Impact at Member State and Aggregate EU Levels. *Journal of International Agricultural Trade and Development*, 6(1): 83–100. Go to http://purl.umn.edu/96778

Chantreuil, F., Donnellan, T., van Leeuwen, M., Salamon, P., Tabeau, A. and Bartova, L. (2008) "EU dairy quota reform – AGMEMOD scenario analysis". Paper presented at the XIIth EAAE Congress, Ghent Belgium, August 29–29, 2008. http://purl.umn.edu/43655

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Assessing Rural Potential in the Western Balkans

Project number:
5223
Date:
February, 2008
Funding source:
EU RED
Project dates:
Jan 2006–Feb 2008

Key external stakeholders:

- Vakakis International, Ministry of Agriculture, Forest and Water Management, Serbia.
- Ministry of Foreign Trade (Agriculture Section), Bosnia Herzegovina.

Practical implications for stakeholders:

The outcome of this research includes:

- Increased capacity of Ministry staff / policy support staff in Bosnia Herzegovina and Serbia to undertake geo-statistical analysis, monitoring and evaluation of rural development policy.
- Development of a policy initiative linking clearance of mines (Bosnia Herzegovina) with rural development payments.

Main results:

Based on the skills developed within two projects funded by Teagasc, an EU funded initiative sought to provide training and analysis in geo-statistical techniques to public sector staff responsible for the design, implementation and monitoring of rural development initiatives in Bosnia Herzegovina and Serbia. The first examined restructuring of agriculture in Ireland whilst the second explored socio-economic development reshaping rural economies in Ireland. Both of these studies applied spatial typologies to summarize the differentiated geographic impacts of a variety of trends. Geo-statistical analysis was undertaken and a typology of rural regions in both Serbia and Bosnia Herzegovina was developed with the use of expert input.

Regions in both Bosnia Herzegovina and Serbia were identified for the future development of pilot rural development programmes based on the 'LEADER Approach'.

Collaborating Institutions:
Ministry of Agriculture, Forest and Water Management, Serbia
Ministry of Foreign Trade (Agriculture Section), Bosnia Herzegovina

Teagasc project team:
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External collaborators:
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Compiled by:
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Technology

Opportunity/Benefit:

Training was provided to local Ministry / University staff in the use of geo-statistical approaches and techniques to enable them to apply this approach to design and monitor rural development programmes.

1. Project background:

This project initially set out to explore the implications of the patterns of economic development that were emerging in Ireland's rural economy, including the decline of traditional rural industries (agriculture, fisheries and manufacturing) and the growing prevalence of commuting to urban areas. The project was part of the Rural Ireland 2020 foresight study undertaken in conjunction with the UCD School of Agriculture and Food Science and the Geography Department, NUI Maynooth. This initial objective was completed at an early stage in the project. The skills developed during this phase of the project were subsequently applied to two projects in the Western Balkans. These projects sought to establish a Rural Development Programming and Monitoring capacity in the Ministry of Agriculture, Forest and Water Management (Serbia) and a similar programme and capacity in the Ministry for Foreign Trade (Agriculture Section) in Bosnia Herzegovina.

In both instances, a rural programming approach was developed that was not based on administrative regions but rather on "functional rural regions" identified through statistical analysis and expert input. The objective of this analysis was to move from a purely (political) administrative approach to rural development programming to one which highlighted the commonality of socio-economic development challenges facing rural areas and their associated communities. The research also sought to introduce the EU 'LEADER Approach' which involves mobilising local authorities and rural stakeholders in the development of locally appropriate responses ("integrated" and "bottom-up") to rural development challenges.

2. Questions addressed by the project:

- Identify an appropriate and culturally acceptable definition of rural areas within the context of post-socialist economic transition and recovery from the Balkan wars.
- Establish the degree to which there are differences in the level of socio-economic development between rural regions.
- Identify a rural region that will provide an appropriate test site to the implementation of a pilot integrated rural development programme.

3. The experimental studies:

Main components of this methodology are:

a. The definition of rural areas in Serbia/Bosnia with criteria and indicators that consider prevailing structures in rural areas but which also are used at European level so to allow comparability of their socio-economic characteristics.
b. The preparation of a typology of rural areas in Serbia/Bosnia, with the use of statistical methods (factor and cluster analysis), that take into consideration differences or similarities existing among municipalities, identify major factors of heterogeneity and main clusters of rural areas.
c. The selection of pilot "rural regions" among the clusters identified, by applying criteria such as priorities in rural development, representativeness in socio-economic conditions, environmental conditions, etc.

4. Main results:

Teagasc were assigned specific tasks that sought to construct basic indicators and a methodology for identifying and selecting "rural regions" for the purpose of rural development programming. Whilst such research is normally pursued using a standard quantitative approach combining Principle Component Analysis with Cluster Analysis, a variant to this approach was required due to severe data limitations. Expert groups comprising policy makers, policy stakeholders and technical experts familiar with agricultural and rural economic development were convened. The experts provided an evaluation of the historic data available for the analysis. As there is an absence of up-to-date regional level data in both countries, the experts were asked to give their assessment of current regional level trends and conditions. This model of expert informed evaluation facilitated the achievement of the project objectives, namely;

1. The definition of rural areas through the combination of policy, administrative and statistical variables with expert input.

2. Identification and selection of a pilot rural development programme area using statistical analysis.
3. Training of Ministry of Foreign Trade (MOFTAR) /University of Belgrade staff in the use of geo-statistical techniques in the area of policy analysis and programme evaluation.

5. Benefit:

Training of 6 MOFTAR staff (Bosnia) and 2 staff members in the University of Belgrade staff in the use of geo-statistical techniques in the area of policy analysis and programme evaluation.

Implementation of a rural development initiative in Bosnia Herzegovina that linked the clearance of land mines from high quality farm land to the receipt of rural development payments.

6. Dissemination:

Main publications:

Meredith, D., N. Bogdanov & S. Efstratoglou (2008) A typology of rural areas in Serbia. Economic Annals, 177, 7–29.

Meredith, D. (2007) Report on the current status and potential of rural regions in Bosnia Herzegovina. MOFTAR, Sarajevo.

Meredith, D. (2006) Report on selecting pilot rural regions in Serbia for rural development programming purposes. Office for Economic Policy and Regional Development, Belgrade.

Rural Economy & Development Programme

Project number:
5260

Date:
November, 2011

Funding source:
EU FP6

Project dates:
Jan 2004–Apr 2007

Estimating the environmental performance of agri-environment schemes

Key external stakeholders:

Policymakers, participants in agri-environment schemes, farmers, environmental NGOs

Practical implications for stakeholders:

- Increased allocation of Common Agricultural Policy (CAP) payments to environmental objectives will be matched by increasingly demanding requirements to demonstrate their environmental effectiveness.
- Due to a lack of available environmental data, we devised a methodology (based on experts' judgements) to estimate the environmental performance of agri-environment schemes, and we implemented this in several EU case study areas.
- This methodology can help support efforts to learn how to improve decision-making about the appropriate design and implementation of agri-environment schemes.

Main results:

- Lack of assessment of the environmental effects of agri-environment schemes is a key obstacle to improving their implementation, and ensuring their value-for-money.
- In the absence of relevant environmental data, we developed a methodology based on a harmonised framework for characterising environmental objectives and the use of experts' judgement to help assess environmental performance of agri-environmental measures.
- This study demonstrates the potential practical application of this methodology as a tool to assist the design and evaluation of agri-environment schemes.

Collaborating Institutions:
https://w3.rennes.inra.fr/internet/ITAES/website.html

Teagasc project team:
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Eight partners of the EU FP6 ITAES project
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Technology

Opportunity/Benefit:

The structured use of experts' assessments can help identify and understand specific causes of deficiencies in the design and implementation of agri-environment schemes. Such understanding can enhance evaluation and judgements about priorities for corrective action in the future design of a scheme. Although the methodology is used to conduct an ex post assessment here, it could also be used to conduct an ex ante assessment and thereby improve technology transfer from environmental sciences at the design phase of policy formulation.

1. Project background:

This work was conducted as part of the EU FP6 ITAES project 'Integrated Tools to design and implement Agri Environment Schemes'. The main aims of the project were: 1) the construction of an integrated tool to analyse the interaction between the institutional process and the environmental outcome, and; 2) the construction of an integrated tool to analyse and simulate farmers' environmental practices depending on a range of alternative types of policy implementation. (https://w3.rennes.inra.fr/internet/ITAES/website.html)

Agri-environment schemes in the EU are now one of the most important policy mechanisms for the protection of environmental quality (public goods), and offer payments to farmers in return for undertaking management practices (measures) that are intended to maintain, enhance or restore the rural environment. EU Member States are obliged to monitor and evaluate the environmental, agricultural and socio-economic impacts of their agri-environment programmes (Article 16, EC Regulation No. 746/96). Most of the recent evaluations of agri-environment schemes have strongly criticised the over-reliance on data on levels of uptake and expenditure as measures of scheme performance (Court of Auditors 2000) as opposed to their environmental impact. Thus, the environmental performance of many schemes is not clearly known.

A number of challenges arise when attempting to evaluate the performance of agri-environment schemes. Most significantly, there is a lack of environmental monitoring data to objectively assess scheme performance. In addition, agri-environment schemes tend to have complex inter-linkages among measures and objectives. Schemes are usually comprised of multiple measures and are expected to deliver multiple objectives. Single measures may contribute to more than one environmental objective, and objectives may be achieved via multiple measures. The EU-wide application of schemes also poses a challenge for any methodology to be sufficiently generic to permit widespread application, but be sufficiently detailed to distinguish performance along relevant environmental objectives. Here, we report on one of the outcomes of the ITAES project that aimed to develop a policy tool that could be sufficiently harmonised to be applicable in different European regions, but capable of being customised to reflect local priorities and actions within a given European region.

2. Questions addressed by the project:

Could a methodology be devised that,

- identified a harmonised framework for characterising environmental objectives;
- rationalised the complexity of agri-environment schemes to assessable elements;
- defined criteria to reflect design and implementation characteristics of agri-environment schemes that would be expected to be the main drivers of environmental effectiveness, and;
- used these criteria to rate the performance of the scheme elements to be assessed?

3. The experimental studies:

We developed a methodology to estimate the environmental performance of agri-environment schemes, and applied it in nine EU case study areas that were participants in the project: Czech Republic, Finland, Ireland, Belgium, France, England, Italy (Veneto), Italy (Emilia Romagna) and Germany. The methodology combined: a harmonised framework for characterising environmental objectives; a reduction of the complexity of scheme structure into assessable elements; experts' judgement of the performance of agri-environment measures, and; multi-criteria analysis (MCA) techniques, aimed at producing an aggregated judgement about single objectives or measures. Expert panels assessed the link between environmental measures and the environmental objectives by scoring a set of specific criteria that reflect important factors for the delivery of environmental effectiveness. This study was based on agri-environment schemes implemented during the period 2000–2003.

An environmental assessment of multiple EU Member States with different environmental conditions and priorities required a common and extensive set of descriptors of environmental objectives. To this end, we used the hierarchical set of environmental objectives as described in the EU Common Evaluation Questionnaire. We also defined a set of criteria which assessed the contribution of environmental measures (farm-level management prescriptions) to specific environmental objectives (measure-objective pairs), and used these to estimate environmental performance of a specified measure toward a specified environmental objective. The criteria used were: strength of cause-and-effect relationship, quality of implementation by institutions, degree of farmer compliance, extent of participation and degree of targeting.

In each of nine European case-study regions, five to eight local agri-environmental experts were selected (see Finn et al. 2009 for details). For each agri-environmental measure in the case study area, the experts agreed on which environmental objectives were directly addressed by the measures. Using a scoring scale for each of the five assessment criteria, the experts assessed the measure-objective pairs. Within each case study area, a group meeting of the experts (of about one day) allowed sharing of knowledge that helped achieve consensus, as well as elaborating on the justification for their decisions.

4. Main results:

The methodology was successfully implemented, and proved to be a useful (based on feedback from the experts and project partners) support tool for quickly estimating the environmental performance of agri-environment schemes, and learning how to improve their design and delivery for achieving environmental objectives. The main results from this work have been published elsewhere (see Viaggi et al. in press, Finn et al. 2008, 2009 below).

There were considerable differences in overall environmental performance across different case study areas, and the experts' scores identified scope for improvement in one or more criteria in most measures. Higher priority environmental objectives (as assessed by stakeholders) did not necessarily demonstrate highest environmental performance.

Across the different European case study areas, environmental objectives were generally addressed by multiple measures that can vary widely in their performance. The ranking of environmental priorities across case study regions was quite different, highlighting a different strategic approach in each area that complicates direct comparison across case study areas.

This study clearly highlighted a number of information deficits about important elements of agri-environment schemes. Environmental assessment could be greatly improved by clearer statements in scheme descriptions about: the environmental objectives and their relative priority; the relative priority of different measures that contribute to a single objective; and the expenditure associated with individual measures.

This methodology could help prioritise resources for monitoring and evaluation by identifying where there is most to be learned about how to improve the environmental performance of a scheme – in this way, most benefit may be gained by focussing the costs of environmental monitoring and evaluation where they are most needed. For example, where experts' judgements indicate a very effective measure, then sufficient monitoring could be conducted to simply confirm effectiveness on this factor. Where experts indicate doubt about the environmental effectiveness of a measure, then monitoring can best support evaluation to identify strengths and weaknesses. For measures that experts clearly identify as failing (e.g. due to a deficient cause-and-effect relationship), then it may be best not to invest in monitoring until the design is changed.

In the Irish case study, the experts considered that compliance by farmers appeared to least affect the environmental performance of the Rural Environment Protection Scheme (REPS 2) i.e. the experts believed that the measures are implemented wholly or almost wholly in accordance with the management prescriptions in their farm plans (contracts). Overall, the experts agreed that REPS has strongly contributed to an improvement in nutrient management and water quality, and they cited the reductions in stocking density on many commonages as a general success. Overall, their views were more mixed about the role of REPS in protecting or enhancing farmland biodiversity. The REPS 2 measure contributing to genetic diversity of animal breeds received the highest score; however, the experts also commented on how the objective should be widened to protect the genetic diversity of rare arable plant and crop varieties. (See Finn et al. 2007, 2009 for details.)

5. Opportunity/Benefit:

Demonstration of the environmental impacts of agri-environment schemes (REPS and AEOS in Ireland) is important for the long-term justification of expenditure on such schemes. Importantly, the positive environmental effects of schemes can be identified and communicated to farmers, and to the public that pays for these schemes. Monitoring can identify whether agri-environment schemes are environmentally effective or not, but the methodology presented here can also complement environmental monitoring to help identify and rectify any weaknesses. The structured use of experts' assessments can help identify and understand specific causes of deficiencies in the design and implementation of agri-environment schemes. Such understanding can enhance evaluation and judgements about priorities for corrective action in the future design of a scheme. Although the methodology is used to conduct an ex post assessment here, it could also be used to conduct an ex ante assessment.

There will be an increased need for improved tools to verify environmental benefits, and learn how to improve the delivery of public goods. It appears likely that environmental requirements and greening measures will become more prevalent in the post–2013 CAP reform. If so, they will also require validation of their environmental effects, to justify the allocation of CAP budgets toward environmental objectives. A recent European Court of Auditors assessment of the design and management of EU agri-environment schemes strongly emphasised the future need for increased targeting of measures, clearer distinctions between 'deep and narrow' (targeted and more demanding) and 'broad and shallow' generally applied and less demanding) measures, and verification of environmental impacts. It is likely that these recent recommendations will appear in the implementation of agri-environment schemes in the post–2013 CAP.

6. Dissemination:

This work has been presented at a number of national and international workshops and conferences, e.g. Brussels workshop attended by DG Agriculture, DG Environment, and DG evaluation (Sept 13th, 2005); end-of-project conference in Venice (Dec 14th 2006); REPS Conference 2007; invited briefing session with DAFF 2007; AgForum, 2009. There have also been four journal articles, several conference papers and abstracts,two book chapters, and multiple popular articles.

Main publications:

Finn, J.A., Bartolini, F., Kurz, I., Bourke, D. and Viaggi D. (2009) '*Ex post* environmental evaluation of agri-environmental schemes using experts' judgements and multi-criteria analysis' *Journal of Environmental Planning and Management* 52: 717–737.

Finn, J.A., Kurz, I. and Bourke, D. (2008) 'Multiple factors control the environmental effectiveness of agri-environmental schemes: implications for design and evaluation' *Tearmann: Irish Journal of Agri-Environmental Research* 6: 45–56.

Finn, J. A., Bourke, D., Kurz, I. & Dunne, L. (2007) '*Estimating the environmental performance of agri-environmental schemes via use of expert consultations*' Final report of the ITAES project. https://w3.rennes.inra.fr/internet/ITAES/website/Publicdeliverables.html

Popular publications:

Finn, J.A., Dunne, L. and Ó hUallacháin, D. (2009) 'Agri-environment schemes for the delivery of public goods: a European perspective' TResearch 4: 28–29.

Bourke, D., Kurz, I., Dunne, L. and Finn, J.A. (2009) 'Experts' estimates of the environmental effectiveness of the Rural Environmental Protection Scheme' Agricultural Research Forum, Tullamore, 12th March, p. 74.

Finn, J.A., Bourke, D., Kurz, I. and Dunne, L. (2007) 'Estimating the performance of agri-environmental schemes' Teagasc IE 59–60. ISSN 18 4170 4776 In: *Ireland's Rural Environment: research highlights from Johnstown Castle.* Teagasc 85 pp. ISSN 18 4170 4776.

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NDP
National Development Plan 2007 - 2013

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