Teagasc Technology Foresight 2030

Current situation and future prospects for Irish livestock production, focusing on future challenges and opportunities

In the coming decades mankind will be faced with the heretofore unparalleled dilemma of feeding an ever-growing global population from a decreasing land base, while concomitantly reducing the carbon footprint of agriculture and food production. The success of this endeavour will be heavily influenced by willingness of the broader agri-food industry to adopt current as well as future biotechnologies, which will underpin efficient food production. In particular, the ever-growing demand for meat and milk, together with increased competition between human and livestock populations for feed resources, will further exacerbate the challenges faced. Additionally, enterprise intensification, in conjunction with likely knock-on effects from climate change, will undoubtedly bring further challenges in terms of animal health and welfare, further increasing the risks of infectious diseases on farms. Indeed, optimal animal health underpins the successful capture of all other traits of economic interest, including growth, milk yield and fertility.

According to the United Nations (UN), the world's population is set to exceed 9 billion by 2050 from 7.3 billion in 2015. Therefore, food production must increase to meet this future demand. However, feeding crops to livestock will reduce the potential food supply for humans. At present, 60% of the world's crop supply is intended for people, while 35% is used for animal feed. Grass-fed beef and dairy cattle convert an inedible material for humans into a consumable form of protein, subsequently increasing crop availability for human consumption (Boval and Dixon 2012; Foley 2011). Additionally, targeting increased meat and milk yields from livestock with grass-based diets will require increased voluntary intake and enhanced feed conversion efficiency at the level of the individual animal.

Worldwide challenges associated with this increase in livestock production include: (i) the safeguarding of animal health in order to preserve human health and guarantee safe food products, (ii) animal welfare to be improved while the number of animals per farmer is increasing, (iii) environmental impact must be significantly reduced, (iv) the sustainability of the operator (farmer) must be protected in light of increasing labour demand and, finally, (v) production must be economically viable.

The livestock sector is the largest land-use system on Earth, occupying 30% of the ice-free surface (Herrero et al. 2013), and 26% the total land area is occupied by grasslands (Boval and Dixon 2012). Ireland's land area is 6.8 million ha, and in 2013 66% of this area was used for agriculture (Agricultural Area Utilised, AAU). Within the AAU, 81% was grassland (excluding rough grazing), 11% was rough grazing and 8% was total crops, fruit and horticulture (Central Statistics Office). Therefore, Ireland is ideally positioned to maximise livestock production efficiency of the individual animal in a grass-based system.

1. Genetic Improvement of dairy, beef and sheep

Animal breeding is currently undergoing a paradigm shift with the inclusion of genomic information in genetic prediction models; the stage of implementation is species dependent, with genomic evaluations being the norm in most dairy and pig populations, but predominantly still in the research phase in beef and sheep. Based on current genomic prediction models, genetic gain is expected to increase by at least 50%. Generation intervals of the sire-to-progeny pathways are being shortened and the farmer mind-set of using a small number of high-reliability sires is changing to using a larger number of individually lower reliability sires.

Adoption of genomic technology requires a total re-evaluation of modern day breeding programs for the national genetic evaluation bodies (if they continue to exist), breeding companies, breeders, farmers and research centres. Having the most pertinent (holistic) breeding goal will become even more crucial as the rate of genetic gain accelerates. The ability to generate moderately accurate genetic evaluations for a very low cost may intensify the (international) commercialisation of animal breeding in cattle and sheep, following a model similar to pigs and poultry – this has advantages and disadvantages. Long-term genetic gain must remain the cornerstone of breeding programs and Teagasc must continue to closely monitor genetic diversity. Access to low cost genetic evaluations can also facilitate the generation of multiple genetic lines for multiple purposes, which also has advantages assuming the direction outlined in the overall national breeding goal remains the foundation. Teagasc must remain the leader in the science of the development of breeding goals to ensure industry focus remains on the national breeding goals and, more importantly, must continuously monitor genetic gain in all traits from selection on the national breeding goals. It is likely that the national breeding goals will come under greater pressure from international companies attempting to sell germplasm to Irish breeders and farmers. The sale of "off-the-shelf" genomic products based on research undertaken in other populations is also likely to intensify in Ireland, and Teagasc must be in a position to comment on the scientific validity of these products. Irrespective of advances in genomics, phenotyping will still remain a crucial component of animal breeding programs and day-to-day herd/flock management.

Current genomic prediction algorithms are based on a statistically unsupervised approach exploiting only a fraction of the genomic information. The advent of low-cost sequencing technology will soon (i.e., ~5 years) alter the approach to genotyping and thus the computational requirements for generating high quality genotype information. The ability to detect the causal functional mutations will improve the accuracy of genomic prediction and applicability across breeds and generations. The availability of such information will require re-evaluation of the genomic prediction algorithms (will likely be a combination of supervised and unsupervised approaches), but also mating strategies among animals to generate the most profitable animal; these animals may not necessarily be the most elite in additive genetic merit. Breeding schemes (both at national and farm-level) will thus require a complete re-evaluation on what is the best strategy (e.g., straight breeding, crossbreeding, nucleus herds) to achieve long-term gains and this will have to be achieved with the exploitation of state-of-the-art reproductive technologies. Teagasc is well positioned, with its research, extension and education skillsets in animal breeding, molecular genetics and reproductive physiology; computational resources and associated information technology may soon become the greatest bottleneck.

Genetic change has the potential to increase by 50 to 100% (species dependent); it is crucial that such genetic change equates to long-term sustainable gains in profit at the farmer and sector level without compromising social or environmental principles. Teagasc must engage with (international) breeding companies to ensure scientifically sound and validated principles are applied in the generation and supply of germplasm to Irish producers. Teagasc research and extension must also continue to be based on scientifically sound advice. The current euphoria surrounding omic technology must not take from the basic principles underlying animal breeding; exploitation of omic technology is merely a means to reaching the destination faster, but curtailing (perceived) expectations and ensuring research results/product stand up to scientific rigour is probably going to be the greatest challenge.

2. Reproductive Technologies

After almost a half century of declining reproductive performance, global fertility trends in dairy cattle are now improving. In Ireland, this has arisen due to a combination of improved management (BCS management, better use of interventions, improved herd health status) and genetics (selecting for calving interval and survival, use of genomic selection for earlier and more accurate identification of bulls with good merit for fertility traits). It is likely that the next 20 to 30 years will see continued improvements in genetics for fertility traits, and this will coincide with new developments leading to better nutritional management and better reproductive management tools.

Development and routine use of sensors

In the genomic era, phenotype is king. Currently, selection for fertility traits in most countries is based on calving interval (or days open) and survival (or longevity), but these traits have low heritability. It is likely that new traits can be identified that will have greater heritability, but the challenge will be to routinely (and inexpensively) record these on a large population of cows and to capture the relevant phenotypic data in a central database.

Wearable sensor technologies have become commonplace for humans during the last decade, and are now starting to gain widespread use in cattle. Phenotypes that can be automatically recorded using accelerometer collars include: calving to first oestrus, oestrous cycle duration, oestrus intensity, oestrus duration, grazing time and rumination time. Tympanic or reticular temperature measuring devices can identify time of calving onset, time of oestrus and some health events (i.e., fever). A milking system with in-line progesterone measurement capability is commercially available; this automatically detects interval from calving to commencement of luteal activity, identifies oestrous cycle characteristics and provides heat alerts. A variety of approaches have been developed to automatically capture body condition score and bodyweight measurements.

As these collective technologies improve and become cheaper, it is likely that the use of many or all of these sensors will become commonplace on dairy farms within the next 30 years. A methodology needs to be developed to capture the data from the on-farm computer and store it in a central database. This will allow interrogation of genetic predisposition to favourable or unfavourable phenotypes, and hence facilitate selection based on these new phenotypes where appropriate. This will generate cows that better maintain BCS, promptly resume normal oestrous cyclicity after calving, and require fewer interventions for uterine health problems and anoestrous.

Development of improved synchronisation protocols

New developments to ovulation synchronisation protocols developed during the last decade have markedly improved phenotypic fertility performance in confinement systems. On pasture-based systems, it is possible to achieve very high heat detection efficiency and a compact calving pattern without use of exogenous reproduction hormones. On the other hand, even on well-managed farms, some cows will be anoestrous at the start of the breeding period. It is, and will likely continue to be, economically advantageous to treat these cows with an ovulation synchronisation protocol that allows fixed time AI at the start of the breeding period. The optimum timing and precise sequence of hormone treatments required for anoestrous cows will continue to be an active area of research.

Sexed semen

Sexed semen has been commercially available for over a decade. This technology provides a reliable gender bias of 90%, but fertility is generally reduced. For example, multiple large-scale studies in the US and Europe indicated that conception rates with sexed semen were approximately 75% of conventional. A field study in Ireland in 2013 indicated that frozen-thawed sexed semen achieved conception rates approximately 87% of conventional semen (i.e., if conception rate was 70% with conventional semen, it would drop to 61% (70*0.87) with sexed semen). Although fresh sexed semen performed poorly in that study, research from New Zealand with fresh sexed semen reported conception rates that were 94% of conventional semen. Hence, a sexed semen product with conception rates equal to (or perhaps better than) conventional semen should be a realistic target for the next 20 to 30 years. It is likely that the sex sorting procedure will become faster and will have improved fertility performance in the coming decade. Part of the improved fertility will come from increased numbers of sperm per straw (as a result of faster sorting speed) and part will come from better sorting procedures (hardware, software, media etc.). Substantial variability between bulls has been noted in response to the sex-sorting procedure; some bulls have no reduction in fertility after sorting, whereas other bulls have a marked reduction in fertility. If research to identify bulls suitable for sorting prove fruitful, it would obviously be hugely beneficial for sexed semen.

3. Developments in Grassland Science

At present on Irish dairy farms the level of grass utilisation is approximately 7.5 tonnes per hectare. The Food Harvest 2020 report has set an ambitious target to increase milk production by 50% by 2020. If this increase in milk production is to be produced profitably at farm level, then most of it will have to be produced from grazed grass. Grass utilisation at farm level will have to increase to approximately 10 tonnes per hectare if this is to be achieved.

To maintain Ireland's competitive advantage in grass-based systems of animal production, it is essential that the following developments in grassland technologies are put in place:

- In Europe grass breeders have increased DM yield by 0.5% per year as tested in cutting trials in the Netherlands and Northern Ireland. However, there is little evidence that new grass cultivars have made a significant contribution to increased animal production from grazed pasture. Considerably greater gain has been achieved in other crops such as maize breeding. There is considerable potential to increase the rate of genetic gain in perennial ryegrass, not only in annual yield, but also in other traits such as improved winter/spring growth, increased nutritional value, especially in mid-season and persistency. The recent development of the Pasture Profit Index (PPI) is a significant step towards linking breeding objectives, evaluation programmes and farmers' needs. The PPI provides a mechanism to enhance these linkages. Selecting grass varieties based on the PPI will result in increased profit at farm level. Additionally, there is the possibility that biotechnologies similar to those used in dairy cow genetics could increase the rate of genetic progress in grass breeding.

- The profitability of ruminant farming in Ireland is closely linked to the level of grass utilised per hectare. Greater adoption of pasture measurement and budgeting will be essential in lifting grass utilisation from its current level. Recent research has shown that at higher stocking rates both grass production and utilisation can be increased. This is based on the fact that availability of green leaf in the grazed horizon is increased. The development of web-based grassland management decision support tools such as PastureBase will be critical in increasing the adoption of best grazing management practices at farm level. The development of such reliable, easy-to-use decision support tools will encourage greater reliance on grazed grass and greater connection between researchers, advisors and grassland farmers.

- Since the late 1990s, the levels of phosphorous (P), potassium (K) and lime being applied to grassland in Ireland has reduced significantly. This has resulted in only 10% of the soils on dairy farms being optimal for soil pH, P, and K in 2013. It's not possible to produce optimum grass production with this level of soil fertility. Recent research has shown that a soil with optimum pH has a replacement value of 72 kg/ha of N fertilizer. Similarly, soils with optimum P can deliver an additional 1 t/ha of DM in spring period. While it costs money to increase fertility levels in low fertility soils, the return in grass production more than doubles the annual investment in fertilizer costs.

- Marginal land occupies a large proportion (approx. 50%) of Ireland's total land area. This land is limited principally by its poor drainage status, and farm profitability on such land is highly weather dependent. The Heavy Soils research programme has demonstrated site-specific land drainage design methods to ensure that efficient drainage can be achieved regardless of variations in soil/site conditions. Land drainage and infrastructure improvement strategies will be critical in reducing income volatility and sustaining viable farm enterprises on heavy soils.

- There is renewed interest in forage legumes, particularly white clover, as it offers important opportunities for sustainable grass-based animal production systems by increasing herbage yield, increasing herbage nutritive value and raising the efficiency of conversion of herbage to animal protein, substituting inorganic nitrogen (N) fertiliser with symbiotic N fixation, and mitigating and facilitating adaption to climate change. Herbage intake and milk production have been shown to be higher in mixed perennial ryegrass-white clover swards compared to pure perennial ryegrass swards; this has been substantiated by recent results from research. Despite the clear advantages of incorporating white clover into ryegrass pastures, its adoption on Irish grassland farms is low. Given its significant advantages, this requires significant research over the coming years.

4. Ruminant Nutrition

Ruminant production involves the conversion of feed to product. In the context of an increasingly, resource-challenged planet, the objective is to enhance the nutrient utilisation of consumed feedstuffs by ruminants, which are, economically and environmentally, sustainable to produce. Overall sustainability of Irish ruminant production systems will likely depend on optimising the contribution of grazed grass/legumes to the lifetime intake and utilisation (i.e. digestion and metabolism) of feed and on providing and utilising conserved forage (grass, maize and legume silages) and concentrate (by-products rather than cereals) as efficiently and at as low a cost as feasible, in order to produce a high yield of animal product specific to market requirements.

Grass grazed currently underpins Irish dairy, beef and sheep production systems, because of its lower cost. Due to the considerably lower comparative cost of grazed grass as a feedstuff, ruminant production systems should aim to increase animal output from grazed grass/legume (clover) swards. Nevertheless, animal performance is limited from grazed grass: for example, cow milk yield and cattle growth on well-managed, high nutritive value, grassland is only ca. 0.75 that achieved on a nutrient-dense diet. This begs the question as to what prevents an animal from performing to potential on grazed grass and what can be done to change this? Additionally, because of the seasonal growth of grass herbage, conserved forage is required for the indoor winter period: currently the duration of this indoor period varies substantially. In seasonal spring calving systems of milk production, conserved forages are generally fed as a dry cow feed, while in some beef finishing very high performance is required from conserved forages. Therefore, consistently, achieving high intakes of grass and legume silages and consequently, supporting high and efficient rates of ruminant performance, will become much more important. We require the management guidelines to reliably achieve this and crop growth and quality and animal response prediction systems to enable this improved management.

Organic matter digestibility (OMD) is closely related to metabolisable and net energy supply as the main factors that affect metabolisable and net energy are those that influence digestibility. Grass quality is however a very difficult parameter to measure in a large-scale fashion on-farm. One area of research should be to harness new technologies (sensors, Cloud technology, mobile apps, etc) to enable grass quality to be measured on-farm real-time (i.e. in the grazing sward). This will enable better support and advice to be provided to farmers in terms of (i) advantages of increasing grass quality and (ii) ways of increasing grass quality. The effects of season, climate, geography, soil fertility, grass cultivar, management decisions, etc on grass quality will then be analysable using a large dataset of on-farm data. The second area of research is to measure grass digestion in more detail. The mechanisms and products of grass digestion have important implications for product output, the environment and overall animal performance and well-being. Much is known about the way in which ruminants utilize nutrients in indoor feeding systems based on several decades of research. There are, however, large gaps in the knowledge of the digestion and utilisation of feed in pasture-based systems, such as data on the passage rate of herbage from the rumen and nutrient flow rates associated with herbage. The objective of this research area should be to characterise the degradation, digestion, retention time, passage rate and nutrient flow to the omasum of grass-based diets.

Additionally, variation in the ruminal fermentative process is mediated through the composition and activity of the ruminal microbiome. Research is required to examine the interactions and functional capacity of these microbes to facilitate strategies on improving feed efficiency and methane abatement without compromising animal performance. Collectively, this will result in improved animal efficiency, productivity and health, whilst simultaneously reducing the environmental footprint of ruminant production systems and, additionally, creating more value-added, economically sustainable forage-based systems.

5. Animal Health: Non-Regulated Infectious Diseases

The World Health Organisation has estimated that 20% of livestock production losses are directly related to poor animal health. Enormous production gains can be made, therefore, by improving the health status of livestock including cattle, sheep and pigs. At present, livestock farmers and their veterinary practitioners rely solely on their stockmanship and clinical expertise to make an immediate diagnosis of an infectious disease condition. While this proves highly effective for easily recognisable conditions in individual animals, such as pneumonia, it does not yield information on the causative agent of a particular condition. Rapid identification of the causative agent is critical for herd protection and prevention of costly herd/flock outbreaks, especially for highly contagious diseases.

Examples of economically important non-regulated diseases that currently impact Irish adult livestock are outlined in the following table. To highlight how these pathogens can impact not only on animal health, but on farm income, it has been estimated that the total annual profit in an unvaccinated dairy herd will be reduced by €112 per cow (i.e. over €11,000/year in a 100-cow Spring calving herd) at a milk price of 34.5 cent per litre as a result of exposure to Salmonella. Costs of an infectious disease outbreak in an intensive pig system would be significantly higher due to the intensive nature of the system.

The mainstay of disease control for non-regulated diseases in Irish livestock currently is administration of antibiotics or anthelmintics. This often occurs without application of a diagnostic regime to allow identification of the exact pathogen to be targeted. As such, these valuable products are applied in a non-specific manner, leading to overuse, misuse, and development of product resistance. In a manner similar to the use of grass measuring to determine the availability of nutrients at farm level, routine disease monitoring is required to highlight the pathogens circulating at farm level, thereby allowing design of the most appropriate disease control plan.

1. Important non-regulated infectious diseases of Irish livestock			
Dairy	Beef	Sheep	Pigs
Mastitis pathogens	Bovine respiratory disease	Parasitic diseases e.g. liver fluke, teladorsagia	Post weaning multi-systemic wasting syndrome (PMWS)
Salmonella species	Parasitic diseases e.g. liver fluke, ostertagia	Ovine respiratory disease	Porcine reproductive and respiratory syndrome(PRRS)
Bovine herpesvirus-1	Johnes' Disease	Infectious causes of	

		lameness	
Johnes Disease		Caseous lymphadenitis (CLA)	
Parasitic diseases e.g. liver fluke, ostertagia, neospora			

Future challenge and opportunities

A significant challenge over the next 20 years for livestock farmers and veterinarians will be reducing the reliance on antibiotics and anthelmintics. While achieving this reduction in the use of veterinary medicines, farmers and veterinarians will need to employ additional strategic controls to maintain, and indeed improve, the health status of the national herd and flock. Therein lies the challenge, and a novel set of tools will be required at farm level to support decision-making with regard to non-regulatory infectious diseases; therein also lies the opportunity. Reliance on laboratory-based methods slows down the diagnostic process and leads to uncontrolled spread of disease or mis-diagnosis of disease until diagnostic confirmation is received. This can lead to disastrous consequences in many farming systems, especially high volume intensive systems such as pig units. Consequently, at both an Irish and a global level, there is a significant need for new low-cost, on-farm diagnostic approaches that increased accessibility to test results, thereby delivering rapid and early identification of infectious pathogens. This will provide farmers and veterinarians with the data necessary to make informed decisions with regard to application of disease control strategies, be that improved biosecurity, requirement for vaccination, or administration of an appropriate treatment.

Key areas that should be focused on to give Irish livestock holders a competitive edge with regard to non-regulated infectious diseases include;

- Rapid, low-cost, multiplex diagnostic tools enabling real-time detection to support informed decision-making at farm level.
- Development of novel vaccines (for pigs most importantly), novel vaccine combinations (e.g. BVD, Leptospirosis, IBR, PI3, RSV, Mycoplasma, Salmonella, Neospora, liver fluke) and novel vaccine delivery methods (slow release over the lifetime of an animal) to support correct and appropriate vaccination protocols.
- Promotion of additional national eradication/control programmes e.g. Bovine herpesvirus-1, Salmonella, PMWS, CLA.
- Further investigation in selective treatment for parasites used in combination with natural control methods such as anti-parasitic feed supplements.
- Adaptation of human health technologies to the field of veterinary medicine e.g. use of blood gas analysis for improving calf health.
- All strategies mentioned will need to be supported by educational and awareness programmes. It is essential that these programmes extend to farmers, veterinarians and advisors.

Targeted and appropriate control of non-regulated diseases in Irish livestock is critical to reducing antibiotic and anthelmintic use. The increasing trend of drug resistance must be reversed in order to prolonging the life of these vital tools. Teagasc has a key role to play in improving implementation of biosecurity, reducing the inappropriate use of veterinary medicines, developing new methods of informed decision-making at farm level such as rapid diagnostics, and investigation of both new and old human health technologies for adaption to livestock systems.

6. Animal Welfare

Pigs

Intensive farming poses many threats to animal welfare. This is particularly true in the case of pig production where large numbers of animals are kept indoors all year round in barren, concrete floored houses and in unnatural, densely stocked social groups. These issues are exacerbated by genetic selection for fast growth rate, leanness and large litter sizes which places pigs under intense metabolic pressure. Indeed, there are concerns that when it comes to growth rate, pigs are close to their biological limit in terms of genetic selection. In Ireland, these issues are further compounded by very large herd (+600 sows – largest in EU) and very low profit margins (highest costs of production in the EU).

Aggression is major cause of poor welfare in pigs, but while selection against aggressiveness is possible, there are concerns about modifying the animal to suit its environment rather than vice versa. Tail biting is a behavioural abnormality performed by growing and finishing pigs which are also known as a production disease, as it is only seen in intensive production systems. It causes poor health and welfare and considerable economic losses due to ill-thrift and carcass condemnation, and poses major challenges to the industry as tail docking, the primary method of addressing tail biting, is limited under EU legislation. Yet, almost 100% of Irish slaughter pigs are docked. In countries where there are outright bans on tail docking, it has proved difficult to produce pigs with long tails in the absence of dramatic changes to the housing environment (increased size and complexity of the pigs' environment).

Developments in sow housing such as the inevitable advent of loose or 'free farrowing' systems for farrowing and lactating sows means that the need for clipping piglets teeth is likely to be reduced. Such systems allow sows to escape from the attentions of their piglets and thereby reduce the risk of damage to their teats caused by the piglets' teeth. However, the Irish pig industry has proved slow to adopt such costly changes to housing systems, even as is likely to be the case with free farrowing systems, they are enforced by legislation. Nevertheless, novel and innovative management tools can also ameliorate certain risks to animal welfare. For example, co-mingling of piglets prior to weaning reduces stress at weaning and, correspondingly, disease and the need for use of antimicrobials. Indeed it is probably this last issue which will drive the greatest change in our animal production industries considering the global threat to human and animal health posed by antimicrobial resistance.

In pigs, the increasing prolificacy of sows will inevitably be associated with increases in piglet morbidity and mortality, although projects are underway to ensure that increases in the numbers of piglets born alive is achieved sustainably (i.e. combined with piglet viability). Stereotypies (repetitive, meaningless behaviours) in sows reflect chronic food deprivation (sows are fed to just 60% of appetite) and pose serious challenges to sow welfare because they reflect feelings of hunger. Additional research is required to investigate high fibre diets to improve gut fill without compromising sow performance.

Dairy and beef cattle

In Ireland, dairy and beef farming is typically seen as being less intensive as animals have access to pasture for a large proportion of the year. Indeed, the scientific literature supports the welfare advantages of pasture access for cattle and imparts a marketing advantage to dairy and meat products produced in Ireland.

In the beef industry, concern for the welfare of finishing cattle during the winter finishing period, particularly in relation to housing conditions (space allocation and floor type), has been expressed at National, EU and OIE level (2011). There is the view that conventional slatted floors without access to lying-areas should be replaced by more animal-friendly systems. Currently, there are more than 60,000 slatted floor units in operation in Ireland. As individual animal performance is central to livestock profitability and sustainability, any factor limiting performance is a central issue. At farm level, there is a need to balance input costs, which may be associated with a change in farming practice, with its impact on revenue. There is a requirement to examine the interactions between the economics of livestock production and animal welfare in Ireland with a view to making recommendations to government and policy makers on relevant actions to safeguard and promote our production practices.

With dairy cows, lameness is the major welfare problem. Chronic discomfort while walking, standing and lying is a major risk factor for lameness, and is related to a complexity of issues among which poor roadways, inadequate bedding, prolonged standing, injurious/slippery floors play a role. In spite of much concerted research on mastitis from the point of view of milk quality, the incidence of the disease has not diminished, and is likely to worsen with intensification in the dairy industry. Although the welfare implications of mastitis are likely to be significant, because of the associated pain, the area has received little or no research attention.

Technology offers the greatest opportunity to address some of the current and future animal welfare challenges arising from further intensification in the dairy and pig industries. The recently developed bovine SNP genotype panel offers great potential for breeding polled dairy cattle and would greatly contribute to Ireland's cow welfare friendly image. Breeding could be a very useful tool to develop cows better suited to the adverse weather associated with extended grazing. Automatic monitoring and controlling techniques are becoming more and more important to support the farmer in managing animal production processes. Although biological processes involving living organisms have always been considered as too complex to be monitored and controlled in an automatic way, today new emerging technologies offer possibilities to develop full automatic on-line monitoring and control of many of these processes. Therefore, electronic identification and monitoring devices can be very helpful to support the management skills of the dairy and pig farmer.

7. Labour, Energy and Water Efficiency

The need to respond to climate change, energy security challenges and sustainable food production is the backdrop to the development of the energy and water research programme in Teagasc. A number of external factors are currently acting on farming businesses that may increase the electricity costs associated with food production, thereby affecting overall farm profitability and, therefore, economic viability. First, the electricity price for European farmers increased by 32% in the last five years, due to increases in global energy prices. Second, government policies in countries such as Ireland encourage increases in milk output after the abolition of European Union (EU) milk quotas in 2015. Increased milk production may lead to increases in electricity costs for farmers, because increased mechanisation and more industrial equipment is required to manage larger enterprises. And third, European-wide directives encourage the use of smart metering as a means of driving demand side energy efficiency, which might increase farm electricity costs if not anticipated by the farmer. All of these components will combine to create an unprecedented level of uncertainty around electricity costs on farms.

The European Energy Services Directive 2006/32/EC was enacted to drive improvements in energy efficiency through the implementation of improved metering of electricity coupled with incentivised demand side management (DSM) of electricity for the consumer. By the end of 2009, the Energy Services Directive was transposed into Irish law. Also in 2009, the Irish Government adopted the National Energy Efficiency Action Plan 2009-2020 in order to help achieve Ireland’s energy efficiency targets. One of the principal measures contained within this action plan was the encouragement of more energy efficient behaviour by electricity consumers through the introduction of smart meters. Compared with traditional electricity pricing systems, dynamic pricing systems may entail more uncertainty for end-users with respect to the frequency and timing of high peak prices. However, exposing electricity users to hourly real time prices is known as the most efficient tool that can urge consumers to consume more wisely and efficiently.

Therefore the following research issues will be addressed as priority in the future energy research program.

- The advent of smart metering will change the electricity tariffs to a time of usage system rather than a flat day and flat night rate system. There will be a strong price signal for farms to change their load pattern to use more electricity at night. Smart meters have the potential to change significantly the way in which many of the activities of electricity supply are undertaken. Research will focus on ways to exploit this new tariff system. Dynamic modelling of the interaction between varying electricity tariffs and farm electricity load profiles will be carried out
- Load shifting to off-peak electricity rates will be an important feature of an energy efficient farm in the mid-term, making instant milk cooling using a reserve of ice water built during periods of low electricity prices look much more favourable. Trials on ice water systems, heat recovery and solar systems will be prioritised with load shifting in mind, as these systems lend themselves ideally to suit this distributed use model.
- Control systems to optimise electricity usage in response to modulating electricity price will be a critical feature of an energy efficient farm. The lowest cost electricity will be available at varying times during the day and night. Control systems to interface farm equipment with the national

distribution grid will intelligently keep cost to a minimum while meeting all heating and cooling requirements on the farm. Development of these control systems has already begun and will continue over the next five years.

- Integration of renewable technologies into agricultural enterprises will be of importance in the long term. While the political environment around incentivised renewable energy schemes is uncertain, Teagasc can contribute by providing advice and techno-economic modelling and performance evaluation of renewable systems. This will be accomplished though the development a suite of models to i) forecast energy demand using remote sensor networks and trending algorithms ii) compute dynamic energy costs and CO_2 output per litre of milk produced in multiple electricity tariff scenarios iii) automatically provide optimised feedback information to the farmer relating to the performance of the farm infrastructure by employing demand side management (energy storage and load shifting) techniques iv) advise on the feasibility of specified renewable energy technologies for Irish farms from technical and economic viewpoints. These tasks will be completed with minimal capital infrastructure by leveraging existing datasets (i.e. energy consumption data, wind turbine performance data, PV performance data and solar thermal performance data).

Moreover, agricultural production contributes to 92% of the global water footprint, of which cereals account for 27%, meat 22% and dairy 7%. Understanding the distribution and demands for freshwater in the agri-food sector is of particular importance due to increasing global populations, food security concerns, climate change and changing patterns of dietary demands. Limits in freshwater availability could become the main limiting factor in the growth of the agri-food sector. Quantifying the water footprint of agricultural outputs and identifying hot spots of water consumption along the food production and processing chain is the first step in reducing the pressures on freshwater systems caused by agricultural production.

The water footprint is a consumption-based indicator and is defined as the sum of water used in the production of goods and services consumed by a nation, organisation or individual. The water footprint addresses blue, green and grey water. The blue water footprint measures the volumes of groundwater and surface water consumed. The green water footprint is the volume of water lost through evapotranspiration of rain water stored as soil moisture during periods of plant cultivation. The grey water footprint refers to pollution, and is defined as the volume of freshwater that is required to absorb the load of pollutants, and is based on ambient water quality standards. Blue and green water represent consumed water whereas grey water represents an emission which can be better represented through life cycle assessment impact factors.
Therefore, the following research issues will be addressed as priority in the future water research program.

- Understanding the upstream effects of on-farm practices on blue and green water consumption will be at the core of the Teagasc research agenda.
- Methodologies for water footprint analysis are converging to an agreed approach which will allow the development of an enterprise specific water footprint model encompassing green and blue water requirements.
- Defining relevant end-point impacts, such as land use change or impact on human health, for water consumption across studies and countries will take a high priority. Likewise, the inclusion

of a relative water stress index in the water footprint model will illustrate the benefits of producing food in a water rich environment.

- It is possible that the total water footprint of Irish agricultural outputs can be reduced through system adjustments. However, a water footprint model for each farm enterprise is required before such analysis can be carried out.
- The effects of various system adjustments will be quantified using the water footprint model, especially feed origin, farm size, feed utilisation and production system.

8. Precision Farming Technologies

Improving productivity per cow within grazing systems will rely upon management strategies extrinsic and intrinsic to the animal. Extrinsic to the cow and critical to improving production is grazing management, which involves the optimisation of fertilizer application, use of legumes, stocking rate, herbage allowance (Boval and Dixon 2012), post-grazing residuals and grass budgeting. Intrinsic to the cow is her genetic make-up, fertility, health status, voluntary grass intake, feed conversion efficiency and energy utilisation/budgeting, for example. Apart from selecting for high genetic merit cows, the primary management strategy to deal with the majority of intrinsic cow factors affecting production is visual assessment of each cow in the herd. This can be a tedious on-going evaluation process for the farmer, an issue that will be amplified if the average Irish herd size increases post-quota, as predicted.

Precision farming is an emerging field of agricultural research with huge commercial potential and application which implements smart technologies to (i) monitor and record physiological parameters of vegetation and animals, and (ii) to carry out physically demanding tasks to reduce labour costs. Numerous smart technologies or sensors have been developed and are commercially available to monitor and record a variety of physiological parameters for individual cows and also to measure grass quantity and quality. Consequently, there is an expectation that precision farming smart technologies can address the fundamental challenges associated with increasing the productivity of livestock in grass-based systems.

Emerging technologies may assist with the management of individual animals in grassland systems through the low-cost acquisition of real-time quantitative data, which may also aid our understanding of pasture, environment and animal interactions. However, data are non-informative unless they accurately and precisely relate to the phenotypic state of the vegetation and animals at the instantaneous moment of data creation. This transition from data to information relies on (i) high quality experimental design and implementation and (ii) correct selection of accurate gold standards in order to calibrate and validate algorithms which relate the data to the phenotype.

In the era of digital technology, data have become a valuable commodity whose worth is based on trends, behaviours and associations defined through analysis that impact the individual and population. It is the pipeline from high quality, meaningful data acquisition to subsequent transformation of data to concise information, wherein lies the future challenges and opportunities for Irish livestock production. The instantaneous application of this pipeline from data acquisition to concise information would achieve a highly impacting situation for the end-user. However, data integrity and information quality are reliant upon high standards of data curation and applied scientific knowledge. Once overcoming the challenge of extracting accurate and precise information from smart technologies associated with animal and grass phenotypes, this information needs to be integrated to enhance a whole systems level understanding of pasture, environment and animal interactions.

The farmer is the most valuable stakeholder in terms of guaranteeing healthy livestock production, and precision farming technology can support this through real-time monitoring and management. However, the technology has to be robust and work well in harsh conditions. Such technology requires collaboration between a number of scientific disciplines and strong engagement from the industry, including SMEs, in order to implement innovative technology suitable for operation in the livestock field.

The potential value of a precision farming technology application is based on three elements: (i) the development costs of the application, (ii) the net economic benefit of the application and (iii) the preference of the farmer. The first aspect that needs to be examined is the development cost of the precision farming technology application. The cost can often be under-estimated and, depending on the complexity of the problem, can be quite high. Ideally these costs should become part of the price of the precision farming technology. Thus, a realistic estimation of the required steps in development of the precision farming technology application is needed in order to estimate the costs of development (and thus the cost price of the final product).

The economic value of a precision farming technology system depends on the type of application. Many new developments are aimed at improving disease situations. Therefore, cost of disease is an important first element, because in the cost of disease lies the potential economic value of the precision farming technology. Other benefits may include, for example, improved production efficiency (e.g., greater grass utilization) and reduced labour (e.g., automatic milking). The benefits of improved disease levels, reduced labour, reduced feed costs per kg milk should be weighed against the investment costs of the precision farming technology system for the farmer.

Alternatively, some precision farming technologies may actually generate economic advantages in the dairy production chain. The methodology by which milk is produced is now becoming increasingly important and can, in positive instances, secure premium payments. Thus, transparency in the dairy chain on items such as grazing time and animal welfare are gaining in value. Precision farming technology has a role in supplying dairy processors with such information. Furthermore, information from precision farming technology may also benefit animal breeding organizations, whose aim is to optimize the cow to her environment.

Even if a precision farming technology application is cost-effective, adoption of the technology is also dependent on other factors. Significant heterogeneity exists among farmers (micro-level behaviour) with regard to the adoption of technology. In addition to economic factors, risk preference and variation in the availability of labour, are factors that influence adoption of new technology. Different farmers have different goals and this has also been shown to have an effect on farmers' entrepreneurial behaviour and behaviour with regard to precision farming applications. However, indications are that farmer attitudes are becoming more favourable towards precision farming technologies.

Development of precision farming technology applications for dairy farms is costly and not all applications marketed have been successful. Innovations in the field of precision farming technology often come from an engineering perspective and a prototype hardware is developed not necessarily involved with dairy farming at all. However, this is only the first step and substantial investments need to be made to develop algorithms that translate data collected by sensors to information relevant for the decision maker. Moreover, the precision farming technology applications need integration with other farm data sources and decision support to add value to them. Finally, information delivered by precision farming technology application should be clearly linked to useful actions by the farmer.

9. Livestock Systems

Producing more food from the same land area, while reducing environmental impacts, requires what has been referred to as 'sustainable intensification' of agricultural production. In a grazing systems context, this is based on new innovative blueprints of production based on increased herbage production and quality, and improved utilisation under grazing. Sustainable intensification relies more heavily on the use of natural resources and the functionality (or ecosystem services) they provide and places less emphasis on the use of external inputs. The challenge for such systems is to improve the efficiency of natural resource use in order to increase food production from existing farmland while minimising pressure on the environment *by achieving high grass production and utilisation per hectare using appropriate animals and developing resource efficient and sustainable production practices.* There are four 'pillars' that define resilient farm systems in the Irish dairy farming context (Figure 1), irrespective of region, rainfall, or farming philosophy.

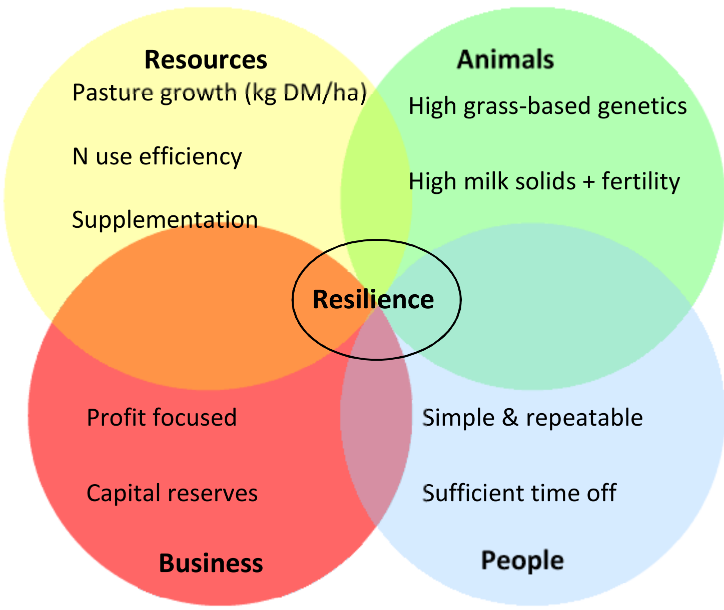

Figure 1: The 'pillars' of a resilient farm system

The challenge for primary producers is to increase the competitiveness of their businesses through innovation, productivity gain and increased operational efficiency to withstand market volatility by developing more resilient businesses. Resilience denotes the capacity of a system to absorb and thrive in a changing and uncertain production environment. Based on the triple bottom line of profitability, socially and environmentally responsible production, our farming systems must continue to be heavily reliant on the production of milk and meat from grazed grass. Resilient businesses are technically and financially efficient, generate surplus cash, consistently achieve financial expectations and are simple to operate. Resilient grass-based farming businesses must produce milk and meat in an economically and environmentally sustainable manner, while producing a product which is acceptable to increasingly discernible consumers from a quality, social and ethical perspective.

In addition to the economic and animal welfare benefits associated with grazing, Irish pasture-based ruminant production systems are highly regarded internationally for their environmental sustainability. Only 10% of global dairy production originates from grassland and, in comparison with cropping, grassland is an important biological filter and is associated with a better conservation of soil against erosion and reduced runoff and leaching of nutrients into surface and ground water (Briemle and Elsasser, 1997; Jankowska-Huflejt, 2006). Grassland also acts as an important carbon sink for GHG emissions, due to its high organic matter content relative to arable land (Leip et al., 2010). Recent international studies have indicated that by virtue of our high reliance on grazing and reduced need for mechanisation, Irish ruminant production systems have one of the lowest carbon footprint within the EU. Notwithstanding these benefits, the efficiency of Nitrogen (N) and Phosphorus (P) use within Irish pasture-based systems is variable and can potentially result in nutrient loss to water resources. In future, on-farm management practices must be tailored to achieve excellent nutrient management. Intensive production systems require grazing and nutrient management practices that increase slurry-use-efficiency, optimise fertiliser N use within allowable levels, and minimise the cultivation of grasslands and nutrient overloading associated with external feed supplementation. Recent evidence from both Ireland and New Zealand suggests that where intensification is fuelled by increased grazed pasture utilisation and conversion to product, intensified grazing systems will continue to deliver the highest standards of water quality even within highly vulnerable free draining soils.

With increasing worldwide demand and the globalisation of food markets, the competitive landscape for producers has intensified and become increasingly complex. In addition to the significant climatic risks which frequently impact upon production, increasing global supply and demand competition, changing international trade policies, input price variability, changing consumer preferences, increasing environmental regulations and geo-political instability in emerging markets have all contributed to a significant increase in milk and meat price variability (Boehlje et al., 1995; Boehlje, 2004; Gray et al., 2008). In an EU context, the abolition of milk quotas in 2015 and reducing market support mechanisms further heightens market volatility. Successive reforms of European Union (EU) Common Agricultural Policy (CAP) have resulted in reduced internal market price supports, reduced milk supply control and payment of the decoupled Single Farm Payment (SFP) to dairy farmers to directly compensate for the expected reduction in farm gate milk prices arising from reduced internal market supports. Fortunately for primary producers, world market milk prices have generally strengthened since 2006; with the exception of 2009, world market milk prices have remained above EU intervention levels. As a consequence of these reforms, Irish milk prices have become increasingly volatile in recent years due to global market turbulence arising from tight supply/demand conditions. Before 2004, the average yearly milk price was 30 cents/litre with little variation (+/- 2 cents/litre). Since 2004, average milk price has been 31.2 cents/litre, but with much greater variation (+/- 8 cents/litre). Such turbulence destabilises the risk/return profile of capital intensive primary production and increases the variability in the financial performance of the dairy farm business (Shadbolt, 2012).

10. New Biotechnologies

The advent of genome sequencing for the major livestock species, together with the future cost-effective availability of this technology on an individual animal basis, will undoubtedly dramatically improve the accuracy of selection of genetically superior animals for a host of economically important traits. However, the impact of this technology will hinge upon the equal availability of accurate complementary phenotypes. Although widely available for more easily accessible traits (i.e. growth, carcass characteristics, milk yield etc.), the adequate availability of appropriate phenotypes for other key traits including those relating to feed intake, greenhouse gas emissions, fertility, health and welfare, will have a major bearing on future sustainable genetic progress. Thus, in addition to advances in genomic research, equal emphasis must also be placed on the development of accurate and cost effective methodologies to efficiently capture the key phenotypes essential to the development of future livestock breeding programmes

Definition: Animal biotechnology is a branch of biotechnology in which molecular biology or improved intervention techniques are used to engineer (i.e. modify the genome of) animals in order to improve their suitability for pharmaceutical, agricultural or industrial applications. Animal biotechnology has been used to produce genetically modified animals that synthesize therapeutic proteins, have improved growth rates or are resistant to disease.

Of specific interest to Teagasc are the agricultural (rather than biomedical) applications of new Biotechnologies. Potential health applications are listed below.

1. **GMO/Transgenic livestock**: Transgenic or genetically engineered livestock were first produced almost 30 years ago, but there are still no approved GE animals for use in agriculture. The delay in adoption of this technology is likely to have a significant impact on the world's ability to feed an ever-increasing population. Teagasc will need to lead the conversation nationally regarding an information campaign around GMO technology.
a. Animals as 'bioreactors' to produce therapeutically important molecules in milk or blood.
b. *Reduced environmental impact*: Transgenic pigs reduced phosphate in waste by 75% .
2. **Cloning/Reproductive technologies:** Although in existence for many decades, further advances in reproductive technologies including synchronisation of ovulation, fixed time artificial insemination, sex sorting of semen, MOET and cloning are warranted if introgression of genes from genetically superior animals are to make maximal impact in livestock populations.
3. **Genome engineering**: the next genomic revolution: With the development of systems like the CRISPR/Cas and TALEN, there is now the ability to precisely edit genomes on a population scale.
a. Simulations suggest a 3-fold increase in response to selection when genome editing is used in conjunction with genomic selection compared to genomic selection alone, with even greater responses predicted for lowly heritable traits. Cheap, whole genome sequencing will almost

definitely contribute to the identification of genomic loci suitable for editing - and this will not be restricted to SNP identification as current technologies are. Teagasc needs to be aware and prepared for this emerging area as it promises to be legal minefield, with the likelihood of the ability to patent any created genomic profiles - for example see the Fahrenkrug patent application claiming rights to any animal whose genes are edited to remove their horns.

4. **Tissue Engineering –** the production of *in vitro* meat.

5. **Phage technology**: The use of viruses to kill or modify target bacteria (i.e. shift the microbiome more favourably) or to introduce plasmids that will confer particular properties to target bacteria (reduce ruminal methanogenesis).

6. **Epigenetics technologies**: The vast majority of the heritability of most economic traits of interest is not directly genetically determined and is influenced by factors which alter how genes are expressed without altering the underlying DNA sequence. For example:

a. Using epigenetic technologies to help inform the role of the environment on the expression of a specific trait will be key to the future capture of that trait, e.g. the influence of early life events – pre-natal nutrition, post-natal infection on future productivity (meat and milk quality) as well as lifetime health etc.

b. Understanding genotype × environment interactions will help design improved management strategies. Of particular interest from an Irish ruminant production perspective is assessment of the genotypes predominantly developed under conditions which may not be aligned to our forage-based production systems. Epigenetics will also be important for tissue-specific expression of traits as well as the design of next generation vaccines.

7. **Metagenomics:** We can only currently culture ~3% of known microbes. Next-generation sequencing technologies are culture-independent, meaning that we can now shed light on the enormous complexity of the microbial world. Understanding the interactions between these microbes and host immunity will revolutionise our understanding of animal nutrition and immunity. Under normal forage-based ruminant production systems, such as that prevailing in Ireland, the vast majority of animals' dietary energy is derived from ruminal fermentation of ingested feed. This however, comes in tandem with significant wastage in the form of ruminal methane synthesis, a potent greenhouse gas.

a. Current and future advances in metagenomic technologies will greatly advance our understanding of the biology and dynamics of key microbes and microbial ecosystems of fundamental importance to livestock production. This, in turn, will facilitate the development of prophylactic and therapeutic intervention approaches to promote beneficial or eliminate pathogenic organisms

b. Probiotics for health – calves or piglets can be orally administered beneficial probiotics which can beneficially modify or restore gastrointestinal microbes following, for example, necessary antibiotic administration, diarrhoea, or in preparation for stressful events such as weaning.

8. **Next-Generation Sequencing, Functional Genomics and Systems Biology**: A thorough understanding of the regulation of inter-animal variation in key economically important traits will be fundamental to future progress in the development of health, economically and environmentally sustainable livestock.

a. Understanding the factors contributing to inter-animal variation in immunity will be critical to designing improved and better targeted management regimens (i.e. nutrigenomics, personalised nutrition, vaccines) and overcoming future disease challenges.

b. Furthermore, we still investigate diseases almost exclusively on a disease-by-disease basis. There is undoubtedly interplay between susceptibilities to multiple infectious diseases and improved disease models combined with a systems level appreciation of the complexity would help us gain deeper insight into the key susceptibility parameters.

c. Understanding the role of other intermediates – including microRNAs for example, will help us get a comprehensive grasp on the factors controlling a phenotype.

9. **RNA interference, synthetic biology**: Artificial molecules can be made to interfere (or direct) biological systems to knock down genes that confer an undesirable phenotype or disease susceptibility, for example. RNAi has been used to produce virus-resistant livestock for example.

10. **Nanotechnologies - drug delivery devices and biosensors.**

a. Administered nanosensors that can detect intestinal inflammation, for example (calves with MAP).

b. In dairying, in-line sensors that will identify the chemical composition of milk, presence of specific bacteria in milk (mastitis), cow oestrus, ovulation or pregnancy status, determination of foetal sex etc.

c. Hand-held (animal-side) sensors that will enable veterinary practitioners to identify viral or bacterial infectious agents.

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