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The importance of European funding

For a research organisation, research funding is essential, and research funders are very important organisations in the research ecosystem. In the same way that parents will never say they love one child more than another, it is impossible to say funding from one source is more important than another, but each has its niche in the funding web. European funding has its own important role. This is far more than just being a source of non-exchequer funding. This is obviously important, but the main benefit is the international collaboration that comes with EU funding. Collaboration is a vital ingredient of successful research, with sharing of ideas and intellectual stimulation, pooling of expertise and resources, and provision of critique and feedback among the benefits. For a small country like Ireland with a relatively small research community, international collaboration is critically important. EU research collaboration allows our researchers to benefit from the knowledge and expertise of top European researchers, and of course our researchers contribute handsomely to the various research consortia, thus enhancing our reputation. While European research funding programmes are often criticised for being very competitive, Teagasc has shown that by putting in a focused effort, organisations from small countries can have a big impact. We were delighted with our successes in 2018, where Teagasc was the fifth most successful research organisation in Europe when success in Societal Challenge 2 (Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research and the Bioeconomy) was measured. This was greatly facilitated by the support from Irish National Contact Points. We look forward over the coming years to carrying out the research projects with our European collaborators, and to seeing the results implemented in the agri-food industry.

An tábhacht a bhaineann le maoiniú Eorpach

D’eagraíocht taighde, tá maoiniú taighde rithábhachtach, agus tá maoinitheoirí taighde ina n-eagraíochttaí an-tábhachtacha san éiceachóras taighde. An doigh chéanna nach ndéantar thúsadúil choichoí go bhfuil níos mó grá acu do pháiste amhain ná mar atá acu do pháiste eile, ní féidir a rá go bhfuil maoiniú ó fhoiseamh amhain níos tábhachtail ná ceann eile, ach tá a chuirte ag gach ceann diobh san eangach maoiniúcháin. Tá a ról tábhachtach féin ag maoiniú Eorpach. Tá i bhfad níos mó i gceist leis sin nach a bheith ina fhoiseamh nach ón stáitche é amhain. Is leir go bhfuil sé sin tábhachtachach ach is é an buntáiste is mó an comhar idirnáisiúnta a thagann le comhar AE. Comhghabh rithábhachtach de thaighde rathúil is ea comhar, agus i mbeadh na mbuntáistí tá smaointe agus spreagadh intleachtúil a chomhoirmint, saineolas agus acmhainní a chomhthiomsú, agus criticol agus aiseolas a sholáthar. Le haghaidh tír bheag ar nós Éireann ina bhfuil pobal taighde measartha beag, tá comhar idirnáisiúnta an-tábhachtach ar fad. Le comhar taighde AE is féidir lenáirear dtaighdeoirí taobhthe a bheith in aiceal agus saineolas a bflatruitheacht de maoiniú Eorpach. An ndéanann an dátaighdeoirí ar fáil aithne aithneachtaí inar gcumhruitheasc an eangsúla taighde, agus ar an tuisí sin treisíonn siad an gcáil. Cé go gcaítear cláir um maoiniú taighde Eorpach go minic as a bheith iomaíoch, tá sé léiríteach ag Teagasc gur féidir leis an díotha beaga tionchar nó a bheith acu m’i díantar iarracht fhócais teaghathe. Bhí réimsear órainn lenár rath in 2018, i gcás gur bheith Teagasc an cúigiú heagraíochta taighde is rathúla san Eoraip amach, i gcás gur tomhaiseadh rath i nDúshláin Sochaioch 2 (Taighde maidir le Slándáil an Bhia, Takmhoíocht agus Foraoisitheachta Inbhuanaithe, Usce Mara, Mhuíirí agus Intirí). Bhí sé sin eacachta go mór leis an tacaíocht ó Phointí Teagmhála Náisiúnta na hÉireann. Tá theagmháil ag tréadhar ná bhí a dílianta amach rómhainn leis na tionscadail taighde a dhéanann lenár gcomhoibriú Eorpach, agus torthaí a theicseáil curtha chun feidhme sa tionscadal a graiBH.
Researcher profile

Áine Macken-Walsh

Áine Macken-Walsh is a Senior Research Officer at Teagasc’s Department of Agri-Food Business and Spatial Analysis, Rural Economy Development Programme (REDP). She completed a BA (sociology and political science) at NUI Galway, which included a year in rural France. She was subsequently awarded a fellowship by the European Commission’s (EC) Directorate-General for International Cooperation and Development (EuropeAid) to study for an MA at the European Inter-University Centre in Venice, Italy, writing her thesis at the Department of Government at Essex University, UK. She developed an interest in EU enlargement and her thesis undertook a rights-based analysis of the EU Special Accession Programme for Agriculture and Rural Development (SAPARD). Following her MA, Áine almost accepted a position to work with the Department of Foreign Affairs and Trade (DFAT) in Geneva, but has never looked back after deciding to pursue a career in research. She joined an EC FP5 project to continue her research interest in EU enlargement (PhD, Sociology, NUI Galway) involving field research in rural Lithuania. Since joining Teagasc, with its integrated research, extension and education functions, Áine has an ideal laboratory for impacting policy and extension. Her primary research involves in-depth interviewing to understand human values, beliefs, routines, etc., analysis of which identifies patterns of behaviour and explains policy and extension outcomes (uptake of innovations, popularity of policies, etc.). On foot of sociological evidence, Áine facilitates farmers, advisors, diverse disciplinary scientists, industry, and policymakers to co-design extension approaches, communications, and technologies. Co-designed outputs, featured in Teagasc’s Research Impact Highlights, have informed EU policy formulation and are used widely by practitioners in Ireland and internationally.

Áine has been awarded over €2m in funding and has supervised 10 PhD students to completion. She has published extension manuals, policy reports and articles in top-ranking sociology and interdisciplinary journals. She is a member of the Social Sciences Committee of the Royal Irish Academy, and Adjunct Lecturer at NUI Galway. She is delighted to live and appreciate family life in her native Galway while networked through Teagasc in an EU-wide professional community. In her free time, Áine enjoys the arts and has recently become a leader with the Irish Girl Guides, where her two daughters are members.

FameLab 2019

Congratulations to Teagasc and Tyndall National Institute Walsh Fellow Luiza Wasiowska, who took first place at the Cork heat of the FameLab Ireland science communication competition recently. Luiza explained the difference between ‘good’ and ‘bad’ E. coli and the challenges connected to its detection. “Currently, we are able to detect pathogenic E. coli, which have already caused infections in the past, while the focus should as well be placed on detecting new possible types of the ‘bad’ E. coli in advance”, explains Luiza. “In my talk I have compared different types of these bacteria to the famous villains from the movies – Lord Voldemort [from the Harry Potter movies] and Cat from Shrek. I have chosen this topic because in my research I am working on a quick method of detection of the pathogenic E. coli”. The FameLab Ireland final took place on April 11 in the Science Galley in Dublin.

Luiza Wasiowska took first place at the Cork heat of FameLab Ireland with her talk on ‘good’ and ‘bad’ E. coli.

SFI funding

Government investment of €10.8 million in research funding for 20 projects, through Science Foundation Ireland’s (SFI) Starting Investigator Research Grant (SIRG), was recently announced by Minister of State for Trade, Employment, Business, EU Digital Single Market and Data Protection, Pat Breen, TD. One of the recipients of these awards was Sinead McParland, Teagasc, Moorepark (pictured above), for a project entitled ‘Development of tools to identify the most efficient cows in the national herd leading to benefits for producers, processors, and consumers nationally and internationally’. 
When moving strip-grazing fences at his family’s beef farm in Delvin, Co. Westmeath, continually kept Charlie Drumm late for football training, he decided to design a solution. Over the next three years, he developed the Freshgraze system – an automated cloud-controlled moving fence for livestock. The project was selected as the Teagasc Special Award winner by judges at the 55th BT Young Scientist and Technology Exhibition (BTYSTE) 2019, which took place in the RDS in January. Charlie was also awarded second place in the Technology Senior Individual category.

Charlie, a fifth-year student at Coláiste Mhuire, Mullingar, explains: “Using commercially available tumble wheels, I developed an automated moving fence system that allocated fresh grass to grazing animals on a continual basis using two robots on either side of a field that are controlled by a cloud-based user interface to allow for high accuracy grassland management”. Freshgraze is now patent protected and Charlie plans to develop and ultimately commercialise the product. According to Dr Laurence Shalloo, Teagasc, Moorepark: “We have met with Charlie on a number of occasions and are very excited about the concept of what he has developed”. The Teagasc Special Award is presented to the project that best demonstrates a thorough understanding of the science of agricultural or food production, or the use of science to improve technologies available to agricultural or food production. Teagasc volunteers kept visitors to the stand entertained with hands-on experiments throughout the event.

### Westmeath student wins Teagasc Award at BTYSTE 2019

Charlie Drumm receives the Teagasc Special Award from Teagasc Director Gerry Boyle.

### IJAFR papers

The *Irish Journal of Agricultural and Food Research (IJAFR)* is a peer-reviewed open-access journal published continuously online by Teagasc. The latest papers published in 2019 include: ‘Low-density genotype panel for both parentage verification and discovery in a multi-breed sheep population’ by Berry et al.; ‘First evidence of retained sexual capacity and survival in the pyrethroid resistant Sitobion avenae (F.) (Hemiptera: Aphididae) SA3 super-clone following exposure to a pyrethroid at current field-rate’ by Walsh et al.; and, ‘The impact of cattle drinking points on aquatic macroinvertebrates in streams in south-east Ireland’ by Madden et al. To read these, and for details on how to submit papers to the journal, see: https://content.sciendo.com/ijafr.
Standardised protocol for food digestion simulation – INFOGEST 2.0

Teagasc researchers have been involved in a large-scale EU-funded network to improve and standardise the scientific protocol for simulating food digestion. The protocol is a result of a long-term collaboration between more than 27 academic institutes from 18 different countries. A paper detailing the protocol has just been published in the prestigious journal *Nature Protocols*. The paper, ‘INFOGEST static in vitro simulation of gastrointestinal food digestion’, was co-ordinated by Teagasc scientist André Brodkorb (above), a Principal Research Officer in Teagasc Moorepark Food Research Centre.

The paper describes a standardised step-by-step *in vitro* protocol for the study of gastrointestinal digestion of food. It is based on an international consensus developed by an EU-funded COST Action FA1005 INFOGEST (2011-2015). The method is now the academic and industry standard to simulate the digestion of food using standard laboratory equipment. It has been validated in several *in vivo* trials and is a particularly good approximation of the gastrointestinal digestion of dairy products. “The method is designed to be used with standard laboratory equipment and requires limited experience to encourage a wide range of researchers to adopt it. It is a static digestion method that uses constant ratios of meal to digestive fluids and a constant pH for each step of digestion”, says André. The publication is one of the very few food science papers ever to appear in *Nature Protocols*. This in itself is a sign of the importance of the work in this field. The publication consists of the paper itself, a supplementary information section describing all digestive enzyme assays, spreadsheets, videos, and links to online tools and a YouTube channel managed by André Brodkorb.

First perennial ryegrass variety makes Irish Recommended List

Oakpark, a new late diploid perennial ryegrass variety with a Pasture Profit Index of €118, has been added to the 2019 Recommended Grass Variety List in Ireland for the first time. This is the first variety to be commercialised from the marketing agreement signed between Teagasc and Goldcrop in 2013. The Oakpark grass variety has very good balance for spring, summer and autumn growth, and high silage values. It rates as the second highest late diploid variety in the recommended list. Oakpark was bred by Patrick Conaghan, who is the forage grass and clover breeder in Teagasc, based in Oak Park, Co. Carlow.

National Sheep Conference

Teagasc held a series of sheep conferences (Offaly, Donegal and Wicklow) in January and February. Tim Keady, Teagasc, Athenry, gave an update on an international sheep research project called SheepNet (Sharing Expertise and Experience towards sheep Productivity through NETworking), which is looking at relevant and practical lessons from international sheep farming. SheepNet aims to increase sheep productivity throughout the six primary sheep-producing countries in the EU including France, Ireland, Italy, Romania, Spain and the UK. Tim outlined the three primary areas of the project – reproduction, gestation and reducing lamb mortality – and gave an overview of the practical knowledge and advice that has been gathered from each of the participating countries.

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National Tillage Conference

Presenters at the 2019 National Tillage Conference include (from left): John Spink and Steven Kildea, Teagasc; Guy Smith (National Farmers’ Union, UK); Fiona Thorne, Teagasc; John Cullen (Irish Farmers Journal Tillage Farmer of the Year, 2019); Ewen Mullins, Teagasc; and, Andy Doyle, Irish Farmers Journal. *The theme of the conference was ‘Responding to Future Challenges’.*
Farming by Satellite Prize

The fourth Farming by Satellite Prize, promoting the use of satellite technologies in agriculture, was decided in December at EU Space Week in Marseille. The overall winner of €5,000 was Team Teagasc from Ashtown Research Centre, Dublin, with their idea for FODDERApp (Feed On Demand – wEddge & gRazing), a complete system and mobile app for grass and grazing management. Richa Marwaha (Walsh fellow PhD student), Azucena Jiménez-Castañeda (Walsh fellow PhD student) and Gabriela Afrasinei (Post Doc) were mentored by their Teagasc supervisor Stuart Green (Teagasc, Rural Economy & Development Programme, Ashtown, Dublin). According to the judges: “This team presented an idea with a strong focus on practical issues and use by farmers. During their final presentation we liked being asked to put ourselves in the shoes (or boots!) of the farmer. The idea has high market potential; the team already has a working prototype, and good examples of how it could work”.

Getting the right balance

Teagasc recently ran a Career Development Workshop and Networking event at Teagasc Moorepark to mark International Women’s Day. This year’s theme was ‘Balance for Better’. The day included an update by Jane Kavanagh, Head of Research Operations at Teagasc, on Teagasc’s involvement with Gender-SMART, a new EU-funded project on gender issues in agricultural and life sciences. Each organisation in the project, supported by two technical partners specialising in institutional change and appraisal, has committed to develop and implement a gender equality plan, centring on four shared issues: building a gender equality culture; developing equal career support measures; reshaping decision-making and governance; and, integrating gender in funding, research and teaching. For each organisation, the aim will be to adapt its action plan to its reality, taking existing inequalities and bias as its starting point, and building a research and training offering that covers gender issues. Teagasc also ran a social media campaign for the International Day of Women and Girls in Science featuring women in various roles and research programme areas to show the diversity of careers available to women in science at Teagasc (see campaign picture above).

MASTER launch

The MASTER project is an EU Horizon 2020 Innovation Action being co-ordinated by Paul Cotter, Head of the Food Biosciences Department at Teagasc, which has received EU funding of nearly €11m. This ambitious research project will be achieved over four years through the involvement of 31 leading European and international academic and industry teams.

Speaking at the first meeting, Paul Cotter said: “I am excited to be working with outstanding colleagues from so many different countries. We will harness exciting new microbiome knowledge and apply DNA sequencing technologies to significantly enhance the health and resilience of fish, plants, soil, animals and humans. This will be achieved by adding, or encouraging the growth of, health-promoting microbes, and detecting and eliminating spoilage- and disease-causing species. Through applying our cross-sectoral and transdisciplinary expertise, this research will bring these applications closer to market, thereby facilitating capacity building and supporting the creation of new jobs in the food sector and the bioeconomy”.

The overall aim of the MASTER project is to take a global approach to the development of concrete microbiome products, foods/feeds, services, or processes (including microbiology testing) with high commercial potential. Paul said: “This will benefit society through improving the quantity, quality and safety of food, across multiple food chains, to include marine, plant, soil, rumen, meat, brewing, fruit and vegetable waste, and fermented foods. This will be achieved through mining microbiome data relating to the food chain, developing big data management tools to identify inter-relations between microbiomes across food chains, and generating close to market products and applications that promote sustainability, circularity and contribute to waste management and climate change mitigation”.

Pictured at the launch of the MASTER project are (from left): Frank O’Mara, Director of Research, with researchers Sinead Waters, Paul Cotter and Fiona Brennan, Teagasc.
Brexit: The case for cheese research

The Irish cheese industry has been gearing up for big changes in preparation for Brexit. **TEAGASC** is supporting the industry with a world-class cheese research programme.

“We buy 78,000 tonnes of your cheese every year”, said Boris Johnson, former British Foreign Secretary, in response to RTÉ’s C atríona Perry, on his understanding of the need for a backstop in the context of Brexit. The backstop is a position of last resort, to maintain an open border on the island of Ireland in the event that the UK leaves the EU without securing an all-encompassing deal. That the UK actually imports about 115,000 tonnes of Irish cheese annually may also suggest a wider underestimation of the impact of Brexit by some. Irish cheese production has grown by over 250% since 1995 and exports were 225,000 tonnes in 2018, valued at €815m (CSO). Cheddar – a cheese consumed largely by English-speaking nations – accounts for over 65% of Irish cheese exports. The imposition of tariffs post Brexit at €1,671/tonne on a product valued at approximately €3,000/tonne reflects the gravity of the situation faced by the Irish cheese industry.

**Industry response**
The response from the Irish cheese industry in recent years has been to increase exports to other EU countries, the Middle East, North Africa, and Japan. The industry is also substantially investing in process facilities, including: siting by Tine of a new Jarlsberg (continental-type) cheese plant at Dairygold Mogeely, Co Cork; a €78m diversification project including development of mozzarella cheese production by Carbery; and, a joint venture between Glanbia and Leprino for a 45,000-tonne mozzarella cheese plant in Portlaoise, Co. Laois, and with Royal A-w are for a €140m continental cheese plant to process 450 million litres of milk annually at Belview in Co. Kilkenny. Ibec chief economist, Gerard Brady, recently said that “(Cheese) diversification is not a panacea. It is difficult, expensive work”. Notwithstanding the progress made in diversifying markets, and in non-Cheddar cheese type production, considerable technical challenges are posed in producing diverse, market-led products of consistently high quality within the context of an Irish seasonal milk production system.

**A complex subject matter**
Cheese differs from many other dairy products in that it is a highly complex and dynamic biological system produced from a raw material of continuously changing composition. While products such as powders are relatively stable, cheese contains a live and continuously evolving microflora and enzyme complement that remain active throughout ripening, chilled distribution, and ultimately to the point of consumption. Furthermore, cheese ripening and quality is the product of a complex interplay between the physico-chemistry of the cheese matrix (Figure 1) and the metabolic activity of pockets of bacteria dispersed throughout cheese blocks.

**Teagasc and cheese research**
Teagasc is well placed to provide a scientific platform to support the Irish cheese industry. Since 1988, Ireland has ranked seventh globally in publishing cheese science papers, although this drops to eighth when focusing on the most recent five-year term, where China has overtaken Ireland. When comparing similar timelines, Teagasc has increased its ranking as a cheese research provider from third to second globally (Web of Science, Thomson Reuters). Similarly, Teagasc has also been centrally involved in commercial innovation, such as through a public–private partnership with Ornua.

**Recent cheese research at the Teagasc Food Research Centre, Moorepark, includes:**

**Predictive modelling of in-vat curd moisture content**
Focused on reducing the effect of seasonal variation in milk for cheese making and increasing plant throughput, this research showed a marked interactive effect between coagulation temperature and protein-standardisation of milk on coagulation properties (Figure 1). Models have been derived that predict the interactive influence of these parameters on curd moisture loss kinetics during in-vat stirring of curds (Panthi et al., 2019).
Cheese structure-function
Knowledge of fracture properties of cheese is important for understanding breakdown properties of cheese during mastication, in designing bespoke cheese texture suitable for slicing, etc. (Lamichhane et al., 2018). Results have shown that modulation of hydrolysis of $\alpha_{\text{s}1}$-casein is an effective means for maintaining the strength of the cheese matrix during ripening, but maintaining higher levels of intact $\beta$-casein or insoluble calcium content results in reduced shortness or brittleness of cheese texture.

Cheese for China
Although desiring its nutritional properties, most Chinese consumers have limited experience of cheese, and its sensory properties may not appeal to them. Research underway will: profile Chinese consumer preference for cheese sensory traits; exploit colloidal and casein-polymer sciences to incorporate non-dairy ingredients familiar to Asian consumers into cheese formulations to achieve desired sensory (flavour and mouthfeel) properties; and, develop a platform technology for cheese innovation for emerging Chinese markets post Brexit.

Cheese from grass-fed milk
This research is focused on examining the influence of herd diet and particularly pasture fed (grass fed or grass and clover fed) compared to total mixed ration (TMR) on cheeses produced from milk derived therefrom. Grass-fed derived Maasdam cheeses (a continental-type cheese containing ‘eyes’) had significantly higher scores for colour, smooth texture, ivory colour and shiny appearance compared to TMR. A further metabolomics study showed herd diet to influence cheese metabolites from the lipid phase.

Other current research
Other research being carried out includes: cheese manufacture from micellar casein concentrates; sustainability of Cheddar cheese manufacture; casein-polymer interactions to support development of ambient stable dairy products; and, process and technological factors influencing cheese matrix digestion and consumer health.

Future requirements
Future research needs to focus in depth on areas such as: enhanced sustainability of cheese manufacture and reduction in greenhouse gas emissions; application of sensor technology and development of algorithms to improve in-process control to make bespoke cheeses from milks of variable composition; and, developing flexible factories of the future to produce a broad range of cheese types. Overall, given the changing portfolio of cheese types, the need for sustainable manufacture processes, and the accelerating rate of change in the sector, maintaining a targeted cheese research platform is vital to provide a national competitive and innovative edge for Irish cheese products.

References and further reading

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Visions of research and innovation

Once again, the winners of the Teagasc Vision of Research and Innovation image competition have produced a stunning selection of images.

The Teagasc Vision of Research and Innovation image competition entered its third year in 2018. The competition opened in May 2018 and closed on September 28. It was judged by a panel comprising Mark Moore (Teagasc, editor of Today’s Farm), John Beeching (University of Bath, UK), and Marie Christie (Teagasc Corporate Web Editor).

Winners

The winners of the 2018 Vision of Research and Innovation image competition were announced on December 6, and the 12 winning images featured in a 2019 calendar delivered to Teagasc centres and offices before Christmas. The winning images were:

- ‘The Gruesome Guest’ by Shafique Matin;
- ‘Alginate: Polysaccharides with a Colourful Future’ by Antonio Lourenco and Laura Gómez-Mascaraque;
- ‘Top Dips for Mastitis Control’ by Sarah Fitzpatrick;
- ‘Playtime!’ by Jen-Yun Chou;
- ‘Grazing Working Group’ by Michelle Liddane;
- ‘Glowing Oats’ by Dheeraj Rathore;
- ‘Barley in Summer’ by Evelyn Zuniga;
- ‘Happy & Healthy’ by Emer Kennedy;
- ‘Fly Agaric’ by Ian Short;
- ‘Fight against Blight’ by Dheeraj Rathore;

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- ‘Happy & Healthy’ by Emer Kennedy;
- ‘Fly Agaric’ by Ian Short;
- ‘Fight against Blight’ by Dheeraj Rathore;
The overall winner was Shafique Matin. Shafique’s image, ‘The Gruesome Guest’, features a Cordyceps fungus invading its insect host, observed during his work on the Department of Agriculture, Food and the Marine-funded IDEAL-HNV project. The IDEAL-HNV project brings together researchers from Teagasc and IT Sligo to identify and describe high nature value (HNV) farmland in the Irish context. HNV farmland is extensively managed farmland with high biodiversity. HNV farms are mostly found in areas where natural constraints prevent intensification, and supporting this type of farmland helps to maintain biodiversity, sustain rural communities, and promote water, air and soil quality. EU member states are required to identify areas with HNV farming practices and support them through Rural Development Programmes (https://idealhnv.wordpress.com/).

Dr Frank O’Mara, Teagasc’s Director of Research, thanked the judges for their careful deliberation in selecting the winning images and congratulated all of the entrants for the extremely high standard of images submitted. Prints of selected images from the Vision of Research and Innovation image competition over the last three years will feature in an exhibition to be held in the Department of Agriculture, Kildare Street, in spring 2019.

The next Vision of Research and Innovation image competition launches in Spring 2019 and will close in September.

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Vitamin D levels in cattle – time to look again?

TEAGASC research is looking at whether recommendations on vitamin D supplementation need to change in light of new information on its role in immune function.

It’s not just humans that benefit from a day in the sun: cows do too. The role of vitamin D in improving bone development has long been established, but more recently its role in boosting immune function has also come to light (pun intended). Although sunshine was known to be beneficial for the treatment of TB back in the 19th century, it wasn’t until 2006 that scientists identified that the beneficial effects were due to increased vitamin D. It is now thought that vitamin D activates innate immune defences while minimising damaging inflammation. The principal source of Vitamin D comes via the skin from the sun, but supplementation is also routinely recommended in cattle diets – both in milk powder and in rations – without hard data on circulating levels in cattle under Irish conditions. Furthermore, supplementation guidelines were developed to avoid clinical deficiency symptoms but may need to be updated in light of the immune functions that this important vitamin is now known to have. Recent work in the USA contends that a blood concentration of 30ng/ml of 25(OH) vitamin D is required to meet calves’ developmental needs, as well as to provide immune support in times of disease challenge.

Results from recent research conducted in Teagasc, Grange, led by Dr Kieran Meade, have shown that Irish dairy calves don’t meet this threshold until about five months of age (Figure 1). This could mean that there is a window where calves could be susceptible to disease.

Teagasc research shows that the levels of vitamin D climb when the calves are out at pasture but reduce significantly once daylight hours lessen and cattle are housed, particularly under a low concentrate supplementation system such as is practised in Ireland.
Vitamin D for disease resistance

It is commonly known that prospective mothers isolate themselves from the herd or flock to give birth. This is thought to be an evolutionary strategy to avoid predation but it also reduces the exposure of the newborn to pathogens. This isolation is not always possible with modern farming practices.

The current focus of this work, in collaboration with other research institutes, is the investigation of how this level of vitamin D affects disease susceptibility, and whether supplementation can alter disease outcomes.

Therefore, in combination with disinfection measures at calving, we need to find alternative means to boost the disease resistance of the neonate.

Milk is also a poor source of vitamin D, so low vitamin D levels are not confined to the artificially reared dairy calf; our research shows that levels are low in suckled beef calves too. There are a number of factors that contribute to lower vitamin D levels such as indoor calving, extended periods of housing, and low levels of concentrate supplementation. Teagasc research shows that the levels of vitamin D climb when the calves are out at pasture but reduce significantly once daylight hours lessen and cattle are housed, particularly under a low concentrate supplementation system such as is practised in Ireland. This also has important implications for the season-related changes in disease susceptibility.

How much vitamin D?

Whereas vitamin D concentrations in US dairy cattle range between 50 and 80ng/ml, with significant changes due to geography and sun exposure, our research has shown that more than 87% of cows on one Irish farm were below this optimal threshold in the immediate post-partum period. This is likely to have important consequences for the physiology of the transition cow – from a reproductive, metabolic and immune function perspective.

Our work shows that vitamin D activates the innate immune defences in cattle, which includes host defence peptides – a natural suite of proteins that target both bacteria and viruses. We know that there is potential there to supplement animals via the diet; however, strict guidelines are in place under EU regulations for both milk powder and concentrates. This research, led by Teagasc, will help to establish if these levels are sufficient to meet the demands of cattle under Irish conditions or if new guidelines are required. The current focus of this work, in collaboration with other research institutes, is the investigation of how this level of vitamin D affects disease susceptibility, and whether supplementation can alter disease outcomes.

Given the pressure that the agricultural sector is currently under to find alternatives to antibiotics, identifying mechanisms like vitamin D to support natural immune defences has enormous potential to reduce the disease burden across livestock species.

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FIGURE 1: Measurement of circulating levels of 25(OH) vitamin D in serum from spring-born beef and dairy calves under standard management systems in Teagasc. The horizontal black line shows the levels of vitamin D recommended by research in the USA for optimal immune function.
Improving conception rates in dairy cows

TEAGASC research is looking how a range of factors involved in artificial insemination impact on conception rates in dairy cows.

In cattle, artificial insemination (AI) plays a vital role not only in the successful establishment of pregnancy, which is a prerequisite for initiation of the subsequent lactation, but also in accelerating genetic improvement and facilitating the distribution of semen from genetically elite sires. The latter has been greatly facilitated by the ability to successfully cryopreserve semen. The objective of an insemination is to ensure that there is an adequate reservoir of competent, capacitated, motile sperm in the caudal region of the oviductal isthmus, the site of the main sperm reservoir in the cow, at the time of ovulation, to ensure fertilisation. This is a prerequisite to achieving a high embryo survival and pregnancy rate. There are many cow and semen factors that affect fertilisation rate. Other factors that impact on fertilisation include: inseminator competency; handling of semen; site of semen deposition; heterospermic insemination; and, timing of AI. These are the focus of this review.

The deposition of semen near the uterotubal junction would be hypothesised to reduce sperm loss either by retrograde flow of uterine mucus or by phagocytosis and would, therefore, be expected to enhance the reservoir of sperm in the caudal region of the oviductal isthmus and potentially improve conception rate. The objective of this study was to test this hypothesis.

**Study of commercial inseminators**
This study was carried out over two years with six commercial inseminators involved in each year, four of which were involved in both years. All inseminators were chosen by the AI Centre and trained prior to the start of the experiment in each year. The inseminators chose the co-operating herds. Each alternate cow presented for AI in co-operating herds was inseminated either by placing all of the inseminate in the body of the uterus (Body), or by placing 50% of the inseminate beyond the curvature in each uterine horn (Horn) (Figure 1). Frozen-thawed semen in 0.25ml straws was used throughout. Records were kept and data collected on a total of 1,860 inseminations in 37 herds in Year 1 and on 1,586 inseminations in 24 herds in Year 2. Conception rate (CR) was determined by ultrasonography at 28-60 days after AI. Data were analysed, with terms for AI treatment, year, inseminator, and their interactions included in the model. Other factors that impact on fertilisation include: inseminator competency; handling of semen; site of semen deposition; heterospermic insemination; and, timing of AI. These are the focus of this review.

**Best practice for AI**
There were no AI treatment x inseminator x year, treatment x year, or inseminator x year interactions for CR (P>0.05). However, there was a significant effect (P<0.02) of AI treatment x inseminator on CR, with evidence of either an increase (+11.4%; P<0.05), decrease (-4 to -6%; P<0.05), or no effect (P>0.05) of Horn AI on CR for individual inseminators. Results are presented in Figure 2. A retrospective analysis of the data for each inseminator for each year showed that that there was an inverse relationship (P<0.005) between the improvement in CR recorded following Horn insemination and CR achieved.
follow ing Body AI (Figure 3). This study indicates that the effect of uterine horn AI on CR is not uniform, and may be inseminator dependent. For individual inseminators, there was an inverse relationship between the improvement in CR recorded following Horn insemination and CR achieved following Body AI. The results further suggest that non-return rates could be improved for individual inseminators by adopting the practice of placing half of the inseminate beyond the curvature of each uterine horn as opposed to body insemination, which is normal practice.

**Improving conception rate**

From the foregoing, if inseminators are achieving consistently high conception rates following body insemination, there would appear to be little benefit in switching to uterine horn insemination. However, if conception rates are low, uterine horn insemination will result in a modest increase (almost 5-11%) in conception rate.

Extra care is required with deep uterine body insemination to avoid trauma to the uterine epithelium. One possible explanation for the benefits of uterine horn insemination may be the avoidance of cervical deposition of the semen, which has been shown to reduce conception rates by 10 percentage points compared to uterine body deposition.

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Bio-economic models describe the links between the components of economic and biological processes. They are used as tools to predict and understand system behaviour by investigating such links. Several models have been developed for pig production systems in countries such as Australia, France and Belgium; however, due to different structural and procedural practices between countries, it is important to develop a bio-economic model that is capable of simulating the particular Irish pig production and market conditions. The pig industry is the third most important Irish agri-food sector, after dairy and beef, accounting for 8% of gross agricultural output. There are around 290 commercial farms in Ireland, and the pig population is estimated at c.1.6 million pigs, including 149,900 breeding sows. This article describes the development of the Teagasc Pig Production Model (TPPM), the first bio-economic simulation model for farrow-to-finish Irish pig farms. The TPPM allows realistic scenarios to be tested before implementation, and thus we expect that it will be used as a decision tool in different aspects of production such as investment, nutrition, welfare and health.

TPPM development
The TPPM simulates the biological and economic performance of a farrow-to-finish commercial pig farm with weekly farrowing batches. To build the model, real Irish data was obtained from multiple sources including the Teagasc eProfit Monitor (ePM), Teagasc research data, and input from members of the Teagasc pig advisory team. The model simulates, on a weekly basis, the annual production of a farm. The model consists of a series of inputs (Figure 1), including biological parameters such as herd size, conception and farrowing rate, number of litters/sow/year, number of piglets born alive per litter, and mortality rate for each production stage. Also, as feed costs represent over 70% of production costs, nutrition was considered the main engine for the model. A growth curve was provided for the model, and net energy and standard ileal digestible lysine requirements, as well as feed intake, were calculated for each production stage based on the estimated weekly bodyweight. Additionally, the model has a built-in least cost feed formulator, which is used to formulate wheat- and barley-based diets with nutritional values appropriate for Irish pig diets. Information on reproduction (e.g., number of services and number of boars for heat detection), labour (e.g., number of employees and number of hours worked per week), infrastructure (number of spaces per stage, energy usage, manure handling, etc.), and income (e.g., finisher and culled sow sales), and their associated costs, are also inputs for the TPPM. These inputs are used to calculate physical outputs (e.g., feed usage and number of pigs slaughtered), and financial outputs (e.g., annual cash flow, profit and loss account, and a balance sheet) (Figure 1). Net profit is calculated on a total farm basis, as well as per pig produced and per kg of carcass sold.
TPPM validation
Two methods were used to validate the input values used in the TPPM. First, a group of experts (i.e., pig advisors and researchers) evaluated the methodology and values used for the model. Once the experts agreed, a second validation was carried out by comparing TPPM outputs with real farm data from 20 anonymous farms with complete records (e.g., production parameters and financial receipts) from the Teagasc pig ePM. Average biological parameters were calculated using 2016 data for the 20 ePM farms, and used to simulate a farm. Then, results from the simulation were compared to the average performance of the 20 ePM farms. Results from the validation using actual data showed the capabilities of the TPPM to realistically represent Irish pig farms. Physical outputs were almost identical between the TPPM and ePM farms; however, the TPPM produced 1,154 more pigs than the mean number of pigs sold from the 20 ePM farms. This discrepancy likely arose because the animals sold during the first five to six months of the year from the 20 ePM farms were born in the previous year (i.e., 2015), where annual mean number of litters produced per sow per year and number of piglets born alive per litter were lower than in 2016. The TPPM simulated lower variable costs, mainly due to costs associated with gestating and lactating sow feed. Feed usage was similar but the price per tonne for the sow diets formulated within the TPPM was cheaper than the prices reported by the ePM farms. It is possible that farmers provide nutrient values greater than those specified in the National Research Council (NRC) (2012), thereby increasing feed prices. Non-feed variable costs were greater for the TPPM than the average of the 20 ePM farms, mostly due to the on-farm replacement gilt cost, which is not recorded on the ePM system. Income per pig predicted by the TPPM (€27.5) was also similar to the average income per pig of the ePM farm (€27.5 ± 12.45).

TPPM future uses
TPPM simulated results could be used to facilitate decision making to address the challenges that Irish pig farmers face on a daily basis. It is expected that future uses of the TPPM will include investigation of the impact of weaner-finisher diets with different nutrient specifications, and the impact of respiratory diseases such as porcine reproductive and respiratory syndrome and swine influenza on farm performance and profit.

Acknowledgements
The project was funded by the Teagasc Walsh Fellowship Scheme. Julia A. Calderón Díaz was supported by the Department of Agriculture, Food and the Marine under the Research Stimulus Fund (grant no. 14/S/832). Michael McKeon (Teagasc), Ilias Kyriazakis (Newcastle University), Gerard McCutcheon (Teagasc) and Alan Bohan (Teagasc) are also collaborators on this project.

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Respiratory disease is one of the most important issues affecting pig production worldwide, including in Ireland. Infections by the bacteria *Actinobacillus pleuropneumoniae* and *Mycoplasma hyopneumoniae* are a major concern for Irish farmers. These organisms are associated with lung lesions such as pleuritis and pneumonia, causing major losses both at farm level (decreased growth rate), and at factory level (increased time for carcass processing). Besides the economic losses, the unpredictability of disease creates uncertainty regarding production outputs, and greatly affects the welfare of the animals.

To control respiratory disease, pig farmers typically monitor herd disease status using serology (testing blood samples), where positive results indicate that the animals were previously exposed to a specific pathogen of interest, either by natural infection or by vaccination. Alternatively, on-farm necropsies and slaughterhouse inspections of pluck lesions (by examining lungs, heart, and liver) allow an investigation of the effects of disease and provide a rationale to conduct further herd diagnostics.

Using these methods, Teagasc researchers investigated for the first time the prevalence of infection by four key respiratory pathogens: porcine reproductive and respiratory syndrome virus (PRRSv); swine influenza virus (SIV); *Mycoplasma hyopneumoniae* (Mhyo); and, *Actinobacillus pleuropneumoniae* (APP) primary lesions at slaughterhouse (pleuritis, pneumonia, lung abscesses, and pericarditis), and their effects on production performance and medicine use.

**How many pigs did we look at?**
A total of 9,254 pigs and 1,792 blood samples from one-third of the pig farms in the country were examined and collected, respectively. All farms were enrolled in the Teagasc eProfitMonitor, from which production performance indicators were retrieved.

**What was the prevalence of disease and lesions at slaughter?**
The prevalence of SIV, PRRSv, Mhyo and APP in Ireland is reported in Figure 1, and is similar to or lower than the prevalence in other European countries.

An average of 162 plucks (i.e., heart, liver and lung tissues) per farm were assessed and the national average prevalence for lesions observed is reported in Figure 2. Most of the lungs with pleuritis (>80%) had moderate to severe lesions, while the severity of pneumonia was mild, with an average of 6.2% (±3.88%) of lung surface affected.

**How do these results relate to on-farm performance?**
With the data collected at slaughter (serology and pluck lesions), and taking into account the vaccination protocols on each farm, the associations between disease status and key performance indicators for pig production were studied (Table 1).
Table 1: Effect of respiratory disease on farm performance of 56 farrow-to-finish pig farms.

<table>
<thead>
<tr>
<th>Production performance indicators</th>
<th>How much of it was explained by respiratory disease?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weaner mortality</td>
<td>26%</td>
</tr>
<tr>
<td>Finisher mortality</td>
<td>20%</td>
</tr>
<tr>
<td>No. pigs sold per sow per year</td>
<td>8.2%</td>
</tr>
<tr>
<td>Average daily feed intake</td>
<td>47%</td>
</tr>
<tr>
<td>Average daily gain</td>
<td>40%</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>14%</td>
</tr>
<tr>
<td>Age at sale</td>
<td>41%</td>
</tr>
</tbody>
</table>

Respiratory disease greatly impacted on average daily feed intake, average daily gain and age at sale (or age at slaughter; see Table 1). This indicates that pigs on farms that had respiratory disease issues ate less, grew more slowly, and took more time to reach slaughter weight. The effect of respiratory disease on feed conversion ratio was relatively small. This result suggests that disease clearly affects the growth rate and feed intake of pigs. It does not necessarily make production less efficient in terms of feed use, but effects on pig welfare might be expected.

Conclusions

- Respiratory disease and vaccination information were able to explain a large proportion of key production performance indicators such as average daily feed intake, average daily gain and age at slaughter.
- Monitoring and control of respiratory disease are essential for improved farm efficiency.
Ruminant animals play a key role in global society, converting human indigestible plants into high-quality meat and dairy products for human consumption. Within the rumen dwells an ecosystem, known as the rumen microbiome, consisting of various microbes including bacteria, archaea, protozoa and fungi, all of which contribute different functions that allow the ruminant to obtain nutrition from plant matter. The rumen microbial community is highly differentiated and functions in an orchestrated manner, the outcomes of which are mainly beneficial to the overall nutritional status of the host animal.

One group of rumen microbes belonging to the kingdom archaea, known as methanogens, are, however, responsible for ruminant animals contributing ~40% of global agriculture’s greenhouse gas (GHG) emissions through the production of methane. Methane as a greenhouse gas is 28 times more potent than carbon dioxide (CO₂), and is a major contributor to the quantity of GHG produced from agricultural-based activities. The production of methane, also known as methanogenesis, not only negatively impacts on the environment but is also an energy loss to the host animal, which ultimately directly impacts farm profitability. During the degradation of ingested feed particles in the rumen, hydrogen (H₂) is produced as a fermentation end product by some members of the rumen microbial community. The accumulation of an excess amount of H₂ hinders further rumen fermentation. Therefore, methanogenesis acts in a homeostatic capacity, resulting in the expulsion of excess H₂ from the rumen and promoting continued fermentation. While methanogens directly produce methane, various other bacteria, fungi and protozoa collude to produce a variety of fermentation end products, some of which act to supply the methanogens with substrate for methanogenesis, such as CO₂ and H₂. The methanogenesis process is energy inefficient, and has the capability to divert an estimated 6-12% of the animal’s gross dietary energy intake away from productive aspects of the animal’s performance, i.e., muscle growth or milk production.

Climate change crossroads
The need to supply nine billion people with high-quality animal-derived proteins by the year 2050 coincides with a somewhat conflicting requirement to mitigate climate change, and has therefore positioned global livestock production at a crossroads. However, an increasing body of research indicates that animals that are more efficient at utilising ingested feed for productive purposes also typically produce less methane and, in addition, have increased retention of dietary nitrogen. Increasing the nitrogen retention of ruminants is a very valuable concept, as excreted nitrogen is converted to nitrous oxide, a gas that has a global warming potential 265 times that of CO₂. Also, protein often forms one of the most expensive components of animal diets, so increasing the retention of nitrogen, a key constituent of protein, has potential to benefit farm profitability and ultimately meet human dietary protein requirements. In addition, previously conducted research from our own group and others has shown that the genetics of the host animal influence the composition and activity of its constituent rumen microbiome, with differences in the composition of the latter varying both between breeds and indeed between individual animals within a particular breed.
RumenPredict

RumenPredict, an international research consortium, aims to further advance our understanding of the association between the feed efficiency capacity of the host animal and GHG emissions, with particular focus on how the host shapes its constituent rumen microbiome. As part of RumenPredict, over 400 beef cattle located at the Irish Cattle Breeding Federation (ICBF) cattle performance test facility in Tully, Co. Kildare, will be recruited to the study and undergo detailed study of: level of feed intake and efficiency; growth; GHG and nitrogen output; and, ultimately, meat yield and quality. To estimate the methane output, two GreenFeed systems have been installed at the ICBF progeny test centre in Tully. The GreenFeed system allows for the quantification of individual animal emissions within a normal production setting. To entice animals to use the machine, a small amount of bait feed is dropped when the animal approaches the unit, with all animals fitted with a unique radio frequency identification (RFID) tag for identification purposes.

Contrary to popular belief, the majority of methane emissions are exhaled in the breath of ruminants and are not the product of flatulence. As such, while the animal consumes the feed, the air surrounding the animal’s head, including that which is exhaled, is extracted via a fan, whereby it is passed by sensors and a subsequent value for each animal’s methane emissions is determined.

In conjunction with this work, the composition of the rumen microbiome of each animal will be determined to identify differences between high- and low-emitting animals. Finally, in an effort to provide insight into linkages between the genetics of the host and its constituent rumen microbiome, a genome-wide association study (GWAS) will be conducted. Another aim of RumenPredict is to produce guidelines to encourage best practice for researchers investigating the rumen microbiome. These guidelines will include the development of a rumen-specific sequencing standard, containing known quantities of microbial DNA, and developing standardised laboratory procedures enabling across-country comparisons and amalgamation of data sets. At present, a rumen-specific microbiome sequencing standard is not available to assess the quality and accuracy of rumen microbiome DNA sequencing and analysis. Therefore, it is envisioned that the developed standard will be utilised as a quality control metric to assess the performance of future rumen microbiome sequencing projects.

It is envisaged that DNA-based biomarkers identified from this work will help to identify animals with a greater genetic propensity to efficiently utilise feed while minimising their impact on the environment. This will assist in meeting our aims of breeding animals that are both economically and environmentally sustainable to produce, and is wholly consistent with the goals of Food Wise 2025, the Government’s roadmap for the future direction of the Irish agri-food industry.

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A review of soil sample results over 2017 and 2018 analysed by Teagasc indicates that soil fertility levels on Irish farms may be turning a corner, with some positive signs of overall improvement. Soil fertility had been in decline since the mid 2000s, linked closely with lower lime and compound fertiliser use, and had reached very low status between 2013 and 2015, with just 10% of soil samples showing good overall fertility in terms of pH (>6.2), phosphorus (P) and potassium (K) (≥ index 3) status. Over the last decade in particular, a worrying trend of continuous mining of the native fertility of some soils may have eroded their grass and crop production potential, limiting their ability to maximise grass as our main fodder source and to maximise the yield potential from new cereal varieties. The Teagasc soils database now indicates large improvements in soil pH levels and early signs of improvements in both soil P and K levels on farms, although the rates of these improvements are enterprise specific.

**Soil pH**
In 2017 and 2018, c.90,000 soil samples were analysed by Teagasc and this large database of soil analysis results has been shown to generally reflect national soil fertility trends. Over this period 49% of soil samples came from dairy farms, 44% from drystock farms and 7% from tillage farms. Notably, in 2018 the number of soil samples taken on dairy farms increased (by 29%) compared to the previous five-year average. Across all farm enterprises the only soil fertility indicator showing significant signs of improvement was soil pH (Figure 1). Increased research and advisory emphasis on the importance and benefits of lime application to our naturally acidic soils since 2013 has helped to raise awareness among farmers. This is reflected in current national lime use (approximately 1 million tonnes), which has increased by on average 211,000 tonnes per year since 2013 compared to the previous five years. The optimum soil pH for grassland mineral soils is ≥6.3 and in 2014-16, on average, 37% of soils tested were in this range. In 2017-18, an average of 54% of soils had optimum pH levels. When soils from tillage farms were examined separately, the improvements in soil pH were greater, with up to 83% of samples having optimum soil pH in 2017-18. This large improvement in soil pH will have significant positive effects on nutrient uptake efficiency from applied fertiliser and organic manures, and also on the longevity of reseeded grassland swards, in particular the maintenance of clover. Soil pH levels on dairy farms have shown improvement since 2015 and increased annual lime applications have contributed to a dramatic change in soil pH status over the last five years, with 64% of soils below optimum pH in 2014-15, and just 39% in 2017-18.

**P and K levels**
Examining soil P and K levels across all farming systems, just 38% and 45% of soil samples, respectively, had sufficient P and K for optimal grass and crop production (≥ index 3). The 2018 soil results show some positive signs, but a large proportion of soil samples still have low fertility (i.e., index 1 and 2), with 59% low in P and 50% low in K.

These data show very little difference between grassland enterprise (dairy vs drystock) in terms of soil P and K fertility levels, with 40% and 50% of soils with sufficient P and K (≥ index 3), respectively. Increased N-P-K compound fertiliser use on grassland farms over the last four to five years has not yet been reflected in soil P, which is naturally slow to respond; however, it appears that soil K levels are beginning to respond positively with a reduction of 10% in low K soils in 2018. This is a positive result, as it indicates a halt to the steady decline in soil K, some of which may have been a result of...
increased grass utilisation and the removal of high-quality baled silage from paddocks being routinely grazed. These paddocks need to have adequate K fertiliser returned to balance the high K offtake. The samples from tillage farms show a slow but steady improvement in both soil P and K levels over the past four years, with approximately 46% and 57% of soils with sufficient P and K for crop production (≥ index 3), respectively.

Soil pH levels on dairy farms have shown improvement since 2015 and increased annual lime applications have contributed to a dramatic change in soil pH status over the last five years, with 64% of soils below optimum pH in 2014-15, and just 39% in 2017-18.

Good progress
Overall, all farm enterprises have made progress in relation to soil fertility over the last couple of years (Figure 2). Soil fertility on tillage farms had the largest increase, with approximately 20% of soil samples with the optimum mix of pH, P and K for crop production. Dairy farms were next with approximately 15% of soils with good overall soil fertility. Drystock farms showed the least improvement, with just 11% of samples with good overall soil fertility. These poorer results on drystock farms may be influenced by a number of factors such as lack of profitability, lower fertiliser use, lower feed demand and need to maximise grass production, especially where stocking rates are low. While the majority of these overall soil fertility improvements have resulted from positive changes in soil pH across all farming enterprises, there are also indications that soil K, and possibly P, are also improving.

These positive trends in national soil fertility represent a foundation to build on. While they represent a snapshot at national scale, the real focus is needed at farm, and even field, scale to develop a balanced fertiliser programme and to utilise organic manure resources where they are most beneficial on low P and K soils. Soil fertility is a cornerstone of our grass-based animal production systems and critical for enhancing crop yields and quality into the future.

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A precious resource
Soil is a precious resource that supports essential functions, including: food, feed and fibre production; nutrient cycling; carbon sequestration and climate regulation; water purification; and, as a habitat for biodiversity. The sustainable management of agricultural soils is critical for achieving the growth targets set out in Food Wise 2025, and for protecting soil resources (post 2020 EU-CAP). Grass-based animal production systems rely heavily on soil quality to deliver profitable and sustainable production. But what is soil quality or soil health?

Soil quality has been described as the soil’s ability to provide ecosystem services through its capacity to perform the functions mentioned above under changing management and climatic conditions (Toth et al., 2007). Recently this term has been replaced by ‘soil health’, which really focuses more on the soil biological community as a key driver of soil functionality. In light of this, monitoring of soil health is required to better manage and protect our agricultural soils and their viability for future generations.

Selecting suitable soil health indicators
Not all soil attributes are suitable indicators of soil health. However, certain soil properties play a major role in maintaining soil health, making them suitable indicators. A final matrix of key indicators of soil functionality was compiled for Irish grassland soils, including their ability to inform the delivery/supply of at least two out of five soil functions. Three classes of indicators (physical, chemical, and biological) were identified to provide holistic assessment of soil health (Table 1) (Bünemann et al., 2018).

What soil quality indicators are important for grassland soils?
Of the physical indicators identified, structure was considered a key factor that supports all soil functions. The decline in soil structural quality, which leads to soil degradation and compaction, is often the consequence of more intensive management practices. The chemical indicators provide much information in relation to nutrient cycling, primary production and carbon sequestration functions in soils. In particular, soil pH and soil organic matter were identified as key factors, which regulate nutrient availability in soil, and were considered highly relevant in the delivery of all the different soil functions, including carbon sequestration and macro/micronutrient cycling. The biological indicators provide the greatest information on the delivery/supply of all soil functions. This indicates that soil biodiversity and the soil microbiome is at the centre of soil functioning. However, some biological indicators were more difficult to measure and were impractical for soil health assessments.

Are Irish grassland soils healthy?
Overall, the health status of Irish grassland soils is relatively good; however, we identified potential weaknesses under certain soils by weather or management situations where soil health may be negatively impacted. Our assessment of physical, chemical and biological indicators of soil health across grassland soils identified differences in the delivery of soil functions according to soil type, climatic region and grassland management system (i.e., grazing vs silage). While all soils have the capacity to deliver all functions, some soils were better at delivering particular functions compared to others. We found that well-drained soils were more resilient in terms of soil compaction and had high capacity to support the primary production function once balanced nutrition was supplied. However, these soils presented higher risk in terms of water purification and
Table 1: Soil health key indicators selection. Indicator categorisation matrix and evaluation of their explanatory power for each soil function.

<table>
<thead>
<tr>
<th>Key indicators</th>
<th>1. Type</th>
<th>2. Suitability of indicator across different scales</th>
<th>3. Feasibility of indicator measurement</th>
<th>4. Relevance to delivery of soil functions*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static</td>
<td>Dynamic</td>
<td>Soil pedon/ biota</td>
<td>Field</td>
</tr>
<tr>
<td>Physical indicators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil texture</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Soil structure</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Bulk density</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hydraulic conductivity</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Chemical indicators</td>
<td></td>
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*Soil functions: PP = primary productivity; WP = water purification; CS = carbon sequestration; BIO = biodiversity; NC = nutrient cycling.

Climate regulation. In contrast, poorly drained soils were more prone to structural compaction and less resilient for production, especially with high trafficking intensity. On the other hand, these soils have high capacity to sequester carbon, to provide a habitat for an active microbiome under low to moderate management intensity.

What next?
Thus far the results of the SQUARE project have led to the production of on-farm tools for a first quick assessment of soil health (Bondi et al., 2018; Emmet-Booth et al., 2018). These tools can now be used by farmers and practitioners to check the health status of their land. In addition, we need a long-term soil quality monitoring network to detect changes in soil health over time, and further research to find practical management solutions for its protection. This knowledge can be integrated with knowledge transfer services to provide advice to farmers and farm advisors. We have made a start but we have a long way to go!

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References


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What is 3D printing?
At its simplest, 3D printing is a process for successive deposition of thin layers of a material or printing formulation, sometimes referred to as an ink, into a self-supporting 3D structure of a desired shape and dimensions using a printing machine. Essentially, the feed stream is subjected to conditions that induce controlled aggregation (sticking/fusion) of the material following deposition, to enable the formation of the desired structure with functional characteristics, using a wide range of materials (e.g., plastic, metal, wax, food, biomaterials). In modern large-scale manufacturing industries, production of customised products generally implies an increase in production costs. However, 3D printing enables economical use of ingredients and manufacture of customised products in small quantities.

Types of 3D food printers
In the 3D printing process, a digital template of the desired 3D shape is produced by digitally slicing the design/shape into layers (<2mm), from which the 3D structure is built, layer by layer. There are different techniques for how the layers of the 3D structures are printed. These are based on the physical state of the printing formulation (solid or liquid) and the technique to aggregate it. Generally, in the food field, the most common 3D printing techniques are selective sintering, binder jetting, inkjet, and extrusion-based printing. Selective sintering and binder jetting printing fuse powder particles, layer by layer, into a 3D structure. The former applies a laser or hot air, and the latter a liquid, to bind the individual particles of the powder (e.g., sugar or sugar-rich powders) into complex structures. In extrusion printing, the printing formulation is typically an aqueous dispersion of food components (e.g., proteins, polysaccharides and fat); it is extruded through a moving nozzle, or series of nozzles, which trace its deposition at a controlled rate onto a platform, which may be temperature regulated. Depending on the materials used, the transition from a liquid to a solid may occur as a result of the aggregation of one of the food components (e.g., protein), cooling-induced solidification (e.g., fat), or hydrogel formation (e.g., polysaccharide- or protein-induced swelling). Inkjet printing is applied as a means of dispensing a stream of droplets of decorative liquid or molten materials (e.g., chocolate, jams, sauces) to specific surface regions of the food structure for decoration purposes.

A milk-jet printer?
TEAGASC researchers are examining how 3D food printing could revolutionise dairy-based foods and snacks.
Adapting 3D printing in the dairy industry

In a food context, 3D printing enables the printing of structures from specific formulations comprised of proteins, fats, carbohydrates, and other materials. Recently, the food sector has begun to examine the potential of 3D food printing as a means of creating customised food designs, and personalised and digitalised nutrition. Dairy ingredients are potentially very amenable to 3D printing, owing to the presence of proteins (caseins and whey proteins) whose aggregation behaviour can be manipulated by alteration of the printing formulation.

Critical factors in the development of 3D dairy structures are the provision of ingredients which, on reconstitution, have the desired viscosity and aggregation behaviour that support uniform printing characteristics, i.e., controlled flow through printer nozzles, ideally forming self-supporting structures within the timeframe of printing, and forming a product with the desired functional attributes (e.g., texture and mouth-feel attributes). Developing dairy printing formulations requires evaluation of the aggregation behaviour of dairy ingredients (e.g., milk protein concentrates, micellar caseins, whey protein concentrates/isolates, and caseins) or mixtures when subjected to different conditions or variables, such as:

- ingredient concentration and solvent quality (e.g., pH, ionic strength, type of ions), in which the ingredients are dispersed;
- the method used to induce aggregation (e.g., enzymatic cleavage, acidification, heat, enzymatic-induced cross-linking);
- additives (e.g., hydrocolloids, modified starches); and,
- printing conditions (e.g., nozzle diameter, flow rate, time, temperature, pressure).

Potential applications/innovations

The commercial adoption of 3D printing provides the dairy industry with an increased opportunity to supply ingredients with specific functionalities that enable the development of novel foods and snacks. 3D food printing offers the means of creating products with personalised nutrition requirements. Food printing can personalise nutrition in two ways: by controlling the amount of food to be printed; and, by regulating nutritional ingredients used in the printing formulation. Customised 3D printing of dairy snacks designed specifically for seniors, athletes, and expectant mothers, allows tailored foods that encompass the macro and micronutrients required for the individual’s health status and body type by altering the types and levels of nutrients in the printing formulation. Moreover, the customisation of 3D-printed foods can be synchronised with online information from motion sensors (e.g., pedometers and accelerometers) and heart rate monitors, thereby allowing the printing of a food to meet the nutritional requirements according to the outputs from these devices.

The current project, entitled ‘Exploitation of dairy ingredients in the development of 3-dimensional structured dairy snacks’, has recently received funding from the Department of Agriculture, Food and the Marine (DAFM). The goals of the project, which continues until 2022, are to establish the technological properties of dairy ingredients to generate the ideal printing material and their ability to form 3D structures, develop a high-quality food-grade 3D printer designed specifically for processing dairy-based formulations, and characterise the composition, functionality, sensory characteristics, and consumer acceptability of the end 3D snacks.

Acknowledgements

This project is a collaboration between Teagasc Food Research Centre Moorepark, Teagasc Food Research Centre Ashtown (Dr Eimear Gallagher (Principal Investigator), Dr Emily Crofton, and Dr Sinéad McCarthy), Cork Institute of Technology (CIT) (Dr Caroline Vaughan and Dr Craig Murphy), Medical Engineering Design and Innovation Centre CIT (MEDIC-CIT) (Mr Patrick McGowan), National University of Ireland Galway (NUIG) (Dr Charles Spillane and Dr Galina Brychkova) and Dairy Concepts Irl (Mr Tom Brennan).

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With the abolition of milk quotas in 2015, the dairy sector has expanded significantly. The Food Harvest 2020 target of a 50% increase in milk production was reached two years ahead of schedule in 2018. With further expansion expected in the coming years, more land will be required to facilitate the growing dairy herd. However, Irish farmland markets are notoriously thin, with little land changing hands outside of inheritance, and rental markets dominated by short-term conacre transactions. Given the high capital cost of purchasing farmland, it is likely that land rental will be the more accessible source of land for Irish farmers in the coming years. This research aims to estimate the value of land attributes to farmers in terms of renting in and renting out land. One difficulty in studying Irish farmland markets is the lack of information concerning the structural drivers that drive land prices. This study aimed to fill this information gap by using discrete choice experiments (DCEs) to estimate farmer preferences for land mobility. The objective was to gain insight into Irish agricultural land rental markets by estimating farmers’ willingness to pay (WTP) and willingness to accept (WTA) compensation for differing land attributes.

Methodology
Four attributes were settled upon for the choice experiment: type of land access; distance of land from farmyard; the soil quality of the land; and, the rental price of the land. Type of land access describes the type of rental contract the land would be rented under and had two levels: conacre; and, lease. The distance from farmyard attribute has three levels: adjacent; one kilometre away; and, five kilometres away. Each level denotes how far the land in question was from the main farmyard. The soil quality attribute has three levels: good; medium; and, poor. To avoid subjective interpretation of these levels by participants, each soil quality level was accompanied by a description of the soil’s characteristics. The attribute describing the price for one hectare of land has six levels: €100; €200; €300; €400; €500; and, €600 per hectare.

The sample frame for this study consists of Irish farmers in 2014 and 2015. A total of 846 farmers were surveyed across the 26 counties of the Republic of Ireland. Of these, 425 farmers took the survey containing the ‘Rent In’ version of the choice experiment while 421 took the ‘Rent Out’ version. Each choice task consisted of two land rental choice alternatives and one ‘status quo’ (SQ) option where the farmer indicated a choice for no change to their current land holding position.

Results and conclusions
The results of the DCE indicate that all the examined land attributes (contract type, distance, soil quality, and price) significantly affect farmers’ WTP and WTA amounts for land, and that WTA amounts are larger than WTP amounts for identical land attributes. The model revealed a significant preference for leasing land rather than renting.
under the conacre system. Farmers are willing to pay €123/ha more for a long-term lease of at least five years compared to an 11-month conacre contract. Farmers prefer land adjacent to their farmyard compared to land further away. Farmers are prepared to pay €221/ha more for land adjacent to the farmyard compared to 1 km away, and €155/ha more for adjacent land compared to land 5 km away. Interestingly, farmers are prepared to pay €66 more for land 5 km away compared with land 1 km away. A significant preference is found for good soils over poor soils. Farmers are willing to pay €251/ha more for land with good quality soil compared to land with soil of poor quality.

A total of 846 farmers were surveyed across the 26 counties of the Republic of Ireland.

Similar to the ‘Rent In’ model, farmers prefer to rent out land through a long-term lease compared to a short-term conacre contract. Farmers would require €648/ha more to accept a conacre contract over a lease agreement. Farmers prefer to rent out land that is further away from their farmyard, requiring €445/ha more to rent out adjacent land over land 5 km away and €314 more to rent out land 1 km away compared to 5 km away. Farmers also prefer to hold on to better quality land compared to land with poor soil. Farmers require €495 more to rent out good land compared to land with poor quality soil, and €576 more to rent out medium quality land compared to land with a poor soil type.

The results of the models revealed that farmers have a preference for long-term lease rental contracts over short-term conacre contracts in both the ‘Rent In’ and ‘Rent Out’ choice experiments. This shows a greater appetite for long-term leasing among Irish farmers than the current dominance of conacre rental would suggest. Preferences in relation to distance conformed to expectations for the ‘Rent Out’ choice experiment as farmers’ willingness to rent out land increased the further the land was away from their farmyard. When renting in land, farmers prefer land with good soil compared to poor soil. However, farmers have no significant preference for medium quality soil over poor soil. This may reflect the importance of soil quality to farming in Ireland. With regard to renting out, farmers prefer to rent out poor land compared with land of medium and good quality. It must also be said that although many farmers were open to land transactions, nearly 68% of choices in each choice experiment were for the status quo option of farmers not changing their current land holdings. Given the significant cultural attachment to agricultural land in Ireland, it may be the case that there are a large number of farmers who would never transact land at any realistic price.

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Irish dairy farmers are facing increasing uncertainty and risk with respect to their farm incomes. This increase in income uncertainty can be largely attributed to the volatility of global dairy markets, and related to this a general convergence of world dairy prices with EU dairy market prices. Another key factor has been volatility in input expenditure due to price movements and weather variability. A recent report by economists from Teagasc, Cork Institute of Technology (CIT) and University College Cork (UCC) addresses the issue of income volatility. The report contains a detailed quantitative assessment of a range of risk management tools, including milk price forward contracts, farm income taxation measures, direct payments and gross margin insurance.

The research highlights the pattern of rising farm income volatility, which is reflected in the average family farm income on specialist dairy farms in Figure 1. In recent years there are examples where income has almost halved (2009) and doubled (2010) in consecutive years.

**Forward contract milk pricing agreements**

Milk price forward contracts in Ireland typically involve an agreement between a dairy farmer and a milk processor to exchange a stated volume of milk at a fixed price over a specified period of time. As of 2018, the vast majority of Irish dairy farmers can enter into forward contracting agreements with their milk processor. The weighted average of specialist dairy farms in the Teagasc National Farm Survey (NFS) having forward sold in 2016 was found to be 37%. The availability of forward contracting agreements has increased somewhat since 2016. In the report, econometric analysis indicates that in 2016 Irish dairy farmers who used forward contracting tools were younger and produced more milk per cow than farmers that did not adopt such tools. Dairy farmers from the south east were also more likely to have used milk forward pricing mechanisms than dairy farmers located elsewhere, likely reflecting the fact that Glanbia has been the market leader in offering milk price forward contracts in Ireland. In addition, the report describes a new simulation model, which can be used to estimate the impact of forward contract adoption on farm income variability over time.

**Taxation measures**

The report contains analysis of the income tax system. The analysis examines the smoothing effect on taxable incomes of the ‘income averaging’ system, as well as the proposed ‘5-5-5 risk management tool’. The proposed 5-5-5 income stability tool is a risk management tool involving savings accounts to encourage a long-term approach to risk management. There are three components: five years’ income averaging; 5% of annual milk receipts; and, five years’ draw down period.

The research highlighted a key limitation of the income averaging system, as the scheme eligibility rules relating to off-farm employment meant that approximately 55% of all specialist dairy farms were automatically excluded from participation in the system as defined in 2018. In Budget 2019, the eligibility rules were altered and farm households with off-farm employment became eligible for income averaging. The report finds that, when managed in the right way, the proposed 5-5-5 income stability tool looks promising, but notes that if the tool does become available, farmers may seek advice from a professional (such as their accountant) in order to understand how best to effectively use the tool for their farm.

**Direct payments**

The research uses Teagasc NFS data to examine the important role of direct payments in providing farmers with a buffer from price volatility, but the research cautions that the effectiveness of the buffer is likely to be watered down as dairy farm output increases,
and also notes that the nature of the direct payment supports could change in the context of Brexit and the impending CAP reform.

**Insurance**
The report contains analysis of the gross margin scheme in the United States, which has been relatively unsuccessful to date, due to low levels of farmer participation.
The research concludes that in a grass-based dairy system such as Ireland’s, creating this type of insurance product would be challenging, as the estimation of a dairy farm’s gross margin is less straightforward in Ireland than in the predominantly feed-based system in the United States.

In an Irish context, the report also notes that gross margin insurance could be costly, and that tiered levels of cover with different associated premia would be required. Public support, to at least cover part of the farmer’s premium payment, would also be necessary, in order to persuade private insurers to offer such insurance products.

**A toolbox of risk management tools**
The report concludes that Irish dairy farmers require a risk management toolbox, as multiple risk management tools are required in the management of income variability. There is essentially no silver bullet in the effort to reduce the variability in farm incomes, and a farmer’s choice of tools will change from year to year as circumstances change. This means that farmers require education regarding the adoption and application of tools, in terms of how and when to apply them.

The full report is available at:

**Acknowledgements**
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**FIGURE 1:** Average family farm income on specialist dairy farms 1984 to 2017.
Source: Teagasc National Farm Survey.
Milk recording – a winning formula for dairy farmers

TEAGASC research shows that milk recording is a beneficial activity, which should be adopted by more farmers.

The benefits of milk recording in the post-quota expansion era
Irish milk production has increased by over 50% in the last decade, facilitated by the abolition of EU milk quotas in 2015. However, due to current uncertainty in export markets and ongoing policy reforms, economically sustainable dairy farming relies on competitiveness in international markets. Farm-level adoption of new technologies is an important component in this regard.

This research provides empirical evidence that farmers who adopt milk recording see clear benefits in terms of economic performance and animal health. More specifically, our findings indicate that, on average, milk recording increases gross margin by €42 per cow and milk yield by 406 litres per cow. Moreover, milk recording reduces herd-level somatic cell count (SCC) by 38,860 cells/ml on average. When translating these figures into percentages, milk recording results in a mean improvement of 4% in gross margins, 7% in milk yields, and 25% in herd-level SCC. Therefore, through dairy efficiency gains and reduced bacterial contamination of the milk produced, milk recording simultaneously decreases risk of mastitis incidence, improves product quality, increases output, and thereby gross margins.

Data and methodology
The data utilised to quantify the impact of milk recording is a subsample of 296 dairy farms from the 2015 Teagasc National Farm Survey (NFS) dataset. The survey is collected on a yearly basis on a nationally representative sample of Irish farms. Econometric techniques are applied to estimate the impact of milk recording by comparing adopters and non-adopters with similar profiles. More specifically, controlling for differences in farm and farmers’ characteristics – such as herd size, degree of specialisation in dairy production, soil quality, level of agricultural education, age, and access to family farm labour – allows for like-on-like comparisons and the isolation of the effect of milk recording alone.

Based on milk recording information, farmers can make informed management decisions about breeding and culling, and thereby improve overall herd production performance and animal health.

Milk recording uptake low despite benefits
Milk recording provides farmers with detailed information about milk yields, constituents, and bacterial contamination for each cow. Reports generated from milk recording also outline the Economic Breeding Index (EBI) of each dairy cow. Based on this information, farmers can make informed management decisions about breeding and culling, and thereby improve overall herd production performance and animal health. Moreover, data on individual SCC levels allows for the monitoring of mastitis at early stages of infection, even before symptoms become visible. It is important to note that milk recording organisations provide support to help farmers analyse the resulting information. From a practical perspective, milk recording is easy to implement. It is carried out during milking, either directly by the farmer with an electronic DIY meter (which does not require any technical skills), or by an external recorder who visits the farm.
technology does not require any upfront investment and costs around €12 per cow to milk record six times per year. Despite clear benefits, low costs and ease of use, uptake rates are quite low in Ireland, and have almost remained static over the last several years. For example, when compared to other European countries, only 51% of Irish dairy cows were milk recorded in 2017 compared to 85% in Germany (ICAR, n.d.; ICBF, 2018). Reasons for low uptake rates in Ireland are not fully understood, but one potential explanation is that non-adopters perceive milk recording to be too time consuming, or are not aware of the benefits. In fact, Dillon et al. (2018) found that Irish dairy farmers tend to adopt a reactionary versus precautionary response to elevated SCC. Their findings suggest that while cost is surprisingly not the main barrier to adoption of best herd management practices, time and labour constraints, as well as lack of perceived need to improve herd management routine, explain why dairy farmers do not engage with more effective management practices.

Implications for knowledge transfer
Given relatively low and stagnated adoption rates of milk recording in Ireland, it is important to explicitly highlight the advantages of the technology, mainly by focusing on three aspects. First, milk recording helps farmers to select a better-performing herd, which will lead to an extra 400 litres of milk per cow per annum (approximately). Second, it decreases avoidable costs due to poor udder health by detecting cows that are at risk of mastitis and reducing herd-level SCC by about 25%. Third, improvements in milk quality contribute to increasing the value for milk paid to the farmer, resulting in improvements in gross margins of at least 4%. As such, disseminating the findings of this study can help in providing farmers with information about the benefits of milk recording so they can make informed decisions on whether or not to adopt.

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Photography: Ryan Burger
The social network

Network diagrams can be valuable statistical tools for analysing short food supply chains.

Social networks
In popular culture the term ‘social network’ has become ubiquitous. The field of social network analysis (SNA) has its origins in the social sciences, and involves using network representations to model the pairwise relationships or exchanges between individuals, groups, or organisations (Newman, 2010). Visualisations, in the form of network diagrams, are often used to support the interpretation of network data, and can be particularly illuminating where food chains are concerned. Short food supply chains (SFSCs) are defined by policy as chains “with no more than one intermediary between farmer and consumer” (EC, 2014), which means that only one change of ownership of the product can occur. However, successful SFSCs involve multiple and diverse collaborations between primary producers and collaborators without a change of ownership occurring.

Social network analysis in SKIN
The SKIN project, funded by the European Commission’s Horizon 2020 programme, has collected over 100 ‘good practices’ in SFSCs, which are tested and validated innovations that are transferable to other contexts. Teagasc’s role in SKIN was to develop a methodology for the identification and collection of best practices EU wide, which included network analysis.

In the project, we use SNA both as a data visualisation tool, and also to provide insights into the interactions and flow of resources (e.g., information, equipment sharing) between actors and institutions. In these networks, actors involved in the chain are represented as ‘nodes’ (circles), and the relationships/exchanges between actors are conveyed by ‘edges’ (lines connecting pairs of nodes). The flow of resources in these networks are naturally weighted and directed. In our visualisations, edge weights are indicated by the thickness of edges, while the visual curvature of edges denotes the direction of resource flows.

Results
From the overall set of networks that were created, the example networks presented in this article focus on ‘food hubs’, which are critical components of SFSCs’ “logistical and organisational platforms for the aggregation and distribution of source-identified food products” (Berti and Mulligan, 2016). We can use network diagrams to visually represent the operation of hubs, illuminating at a glance how they connect producers with consumers. As an example, Figure 1 shows the functionality of Ireland’s Larder 360 hub, represented as a network of 32 nodes, where the purple nodes denote primary producers. The anticlockwise direction of the edges from the farms signifies inward flows of produce to the central Larder 360 node, while the clockwise direction of the edges from Larder 360 to consumers denotes the flow of produce to consumers.

Another advantage of using network representations in this context is that it allows us to make use of a wide variety of existing measures and metrics that exist for characterising networks. Figure 2 shows a network representing DistriKempen, a Belgian food hub involving a co-operative of primary producers, which comprises 29 nodes and 55 edges. Table 1 provides a corresponding set of results for analyses performed using a set of standard network measures. The average degree of 3.8 edges indicates the level of flow of resources through the network. The density of the DistriKempen network is low, which reflects a function of SFSC hubs where actors are few but strategic, rather than widely involved (unlike networks
on social media platforms). Relationships are ranked as highly important by the actors involved. Despite an average path length of 2.6 “hops” between nodes, most nodes are closely connected to the central hub. Again, this is an intrinsic function of hubs, where efficiencies are generated by concentrating interactions and flows within a strategic node.

Implications and discussion
Social network diagrams have the potential to visually demystify organisational innovations. Furthermore, network analysis can act as a valuable statistical tool, identifying strategic relationships and ‘good practices’, as well as areas for growth and development.

References

Table 1: A statistical overview of the DistriKempen network.

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<th>Score</th>
<th>Description</th>
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<td>Total number of nodes in the network</td>
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<tr>
<td>Number of edges</td>
<td>55</td>
<td>Total number of edges in the network</td>
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<td>Average degree</td>
<td>3.8</td>
<td>How many edges there are compared to the number of nodes</td>
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<td>Average weighted degree</td>
<td>9.1</td>
<td>Average of the sum of the weights of the edges for all nodes in the network (network-specific criteria – subjective perception of ‘indispensability of relationship’ ranked 1-5)</td>
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<td>Network diameter</td>
<td>4.0</td>
<td>Total network diameter between farthest nodes in the network</td>
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<td>Graph density</td>
<td>0.1</td>
<td>Number of edges in the network, divided by the total number of possible edges (i.e., where all nodes are connected)</td>
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<tr>
<td>Average path length</td>
<td>2.6</td>
<td>The average of all shortest possible paths between any pair of nodes (e.g., via intermediary nodes)</td>
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**EVENTS**

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<td>The application of ICT and precision technologies is transforming not just agriculture but the development of supplies and services supporting agriculture, and therefore the production of food globally. Through accurate measurement of a wide variety of parameters and data management we are now better able to account for the variability that nature brings to agriculture, leading to more sustainable, environmentally friendly and profitable farms, and the creation of the nutritious foods consumers are demanding. Teagasc is leading Ireland’s large-scale efforts in the area of collaborative innovation in partnership with industry in the AgTech sector. This event will showcase Teagasc’s AgTech capabilities and platform technologies in areas such as crops, pasture-based farming, dairy, remote sensing, and sustainability. Hear from international experts about emerging trends in AgTech, new market opportunities and investment strategies.</td>
</tr>
<tr>
<td><a href="https://www.teagasc.ie/news--events/">https://www.teagasc.ie/news--events/</a></td>
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<tr>
<td>Contact: <a href="mailto:sean.mulvaney@teagasc.ie">sean.mulvaney@teagasc.ie</a></td>
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<tr>
<td><strong>May 22-24</strong></td>
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<tr>
<td><strong>Teagasc Conference Centre, Ashtown, Dublin</strong></td>
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<td><strong>ONE HEALTH – EJP ASM 2019</strong></td>
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<td>The first One Health EJP Annual Scientific Meeting is being jointly hosted by Teagasc and NUI Galway. The One Health European Joint Programme (OHEJP) is an EU Horizon 2020 co-funded scientific collaborative research programme. The OHEJP aims to strengthen co-operation between its 39 partners and to help prevent and control food-borne and environmental contaminants that affect human health, through joint actions on foodborne zoonoses, antimicrobial resistance and emerging microbiological threats. The conference is open to OHEJP members and delegates outside of this consortium.</td>
</tr>
<tr>
<td><a href="https://www.ohejp2019.com">https://www.ohejp2019.com</a></td>
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<tr>
<td>Contact: <a href="mailto:geraldine.duffy@teagasc.ie">geraldine.duffy@teagasc.ie</a></td>
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<th>JUNE</th>
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<td><strong>June 12-13</strong></td>
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<td><strong>Hudson Bay Hotel, Athlone</strong></td>
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<td><strong>SHEEPNET TRANSNATIONAL WORKSHOP</strong></td>
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<td>SheepNet (funded by the European Union’s Horizon 2020 research and innovation programme) is an innovative thematic network, which has brought together a wide range of stakeholders from the six main sheep-producing countries in Europe (Ireland, France, Italy, Romania, Spain and the UK), and from Turkey, to improve ewe productivity (number of lambs reared per ewe joined). SheepNet uses a multi-actor approach that engages farmers, farmer organisations, scientists, advisors/consultants, veterinarians, etc., involved in the sheep industry. SheepNet is holding its next Transnational Workshop focusing on solutions evaluated by producers in the SheepNet countries and prime lamb production from grass-based systems. The conference is open to delegates outside of this consortium, who can register online.</td>
</tr>
<tr>
<td><a href="http://sheepnet.network/node/352">http://sheepnet.network/node/352</a></td>
</tr>
<tr>
<td>Contact: <a href="mailto:tim.keady@teagasc.ie">tim.keady@teagasc.ie</a></td>
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<th>JUNE 14</th>
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<tr>
<td><strong>Teagasc Food Research Centre, Ashtown, Dublin 15</strong></td>
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<tr>
<td><strong>TEAGASC FOOD INNOVATION GATEWAYS – ASSURING FOOD SAFETY AND MAXIMISING SHELF LIFE</strong></td>
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<td>Shelf life is an essential requirement for all food products. An acceptable shelf life that satisfies consumer expectations, facilitates export and minimises wastage is reliant on excellent food safety and consistent quality. Moreover, recent consumer demand coupled with legislative requirements prevents the application of chemical preservatives, thus requiring excellent hygiene during primary production and processing. This event will present the latest concepts and technologies to help food companies meet the triple challenge of food safety, shelf life and consistent quality.</td>
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<tr>
<td><a href="https://www.teagasc.ie/news--events/">https://www.teagasc.ie/news--events/</a></td>
</tr>
<tr>
<td>Contact: <a href="mailto:mary.reilly@teagasc.ie">mary.reilly@teagasc.ie</a></td>
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<tr>
<td><strong>Wexford County Council</strong></td>
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<tr>
<td><strong>WATERPROTECT INTERNATIONAL WORKSHOP – SCIENCE, WATER GOVERNANCE AND POLICY IMPLEMENTATIONS: UP-SCALING TO EUROPEAN LEVEL</strong></td>
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<td>The EU Horizon 2020 project, WaterProtect, will host a workshop on ‘Science, water governance and policy implementations: Up-scaling to European level’. Stakeholders will present Ireland’s approach in reaching water quality targets with the emphasis on drinking water protection from pesticides and nutrients. There will also be examples presented by project partners from Denmark and Belgium. This event is being hosted by Teagasc and Wexford County Council.</td>
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<tr>
<td><a href="https://water-protect.eu/">https://water-protect.eu/</a></td>
</tr>
<tr>
<td>Contact: <a href="mailto:per-erik.mellander@teagasc.ie">per-erik.mellander@teagasc.ie</a></td>
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<th>JUNE 25-27</th>
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<tr>
<td><strong>Institute of Technology Carlow and Teagasc Oak Park Crops Research Centre</strong></td>
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<tr>
<td><strong>IPSAM 2019 – HARNESSING PLANTS FOR A BETTER SOCIETY, ECONOMY, AND ENVIRONMENT (INCLUDING TEAGASC CROPS OPEN DAY)</strong></td>
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<td>This year, the Irish Plant Scientists’ Association Meeting (IPSAM) will take place in the Institute of Technology Carlow. The Meeting is being jointly organised by enviroCORE at IT Carlow and the Crop Science Department at Teagasc. The meeting is being organised to coincide with the biennial Teagasc Crops Open Day at Oak Park (June 26) and participants will be invited to spend an afternoon at Oak Park and explore the Open Day.</td>
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<tr>
<td>Contact: <a href="mailto:susanne.barth@teagasc.ie">susanne.barth@teagasc.ie</a></td>
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<tr>
<td><strong>Teagasc Moorepark and University College Cork</strong></td>
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<td><strong>EUROPEAN CONFERENCE ON PRECISION LIVESTOCK FARMING</strong></td>
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<td>The ECPLF brings together the worldwide specialists in precision livestock farming. It will provide a forum to exchange knowledge and experience through an open discussion and to support progress in precision livestock farming. The conference will incorporate: an industry forum; networking event; farmers’ workshop; business models seminar; and, specific parallel conference sessions. Scientists and industry participants from several sectors – pharma, nutrition, technology, ICT, etc. – are expected to attend. This event is being hosted by Teagasc Moorepark.</td>
</tr>
<tr>
<td><a href="https://www.ecplf2019.com/">https://www.ecplf2019.com/</a></td>
</tr>
<tr>
<td>Contact: <a href="mailto:bernadette.obrien@teagasc.ie">bernadette.obrien@teagasc.ie</a></td>
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For a full list of Teagasc food industry training events see: https://www.teagasc.ie/food/research-and-innovation/research-areas/food-industry-development/.

For presentations from previous Teagasc events see: www.teagasc.ie/publications.