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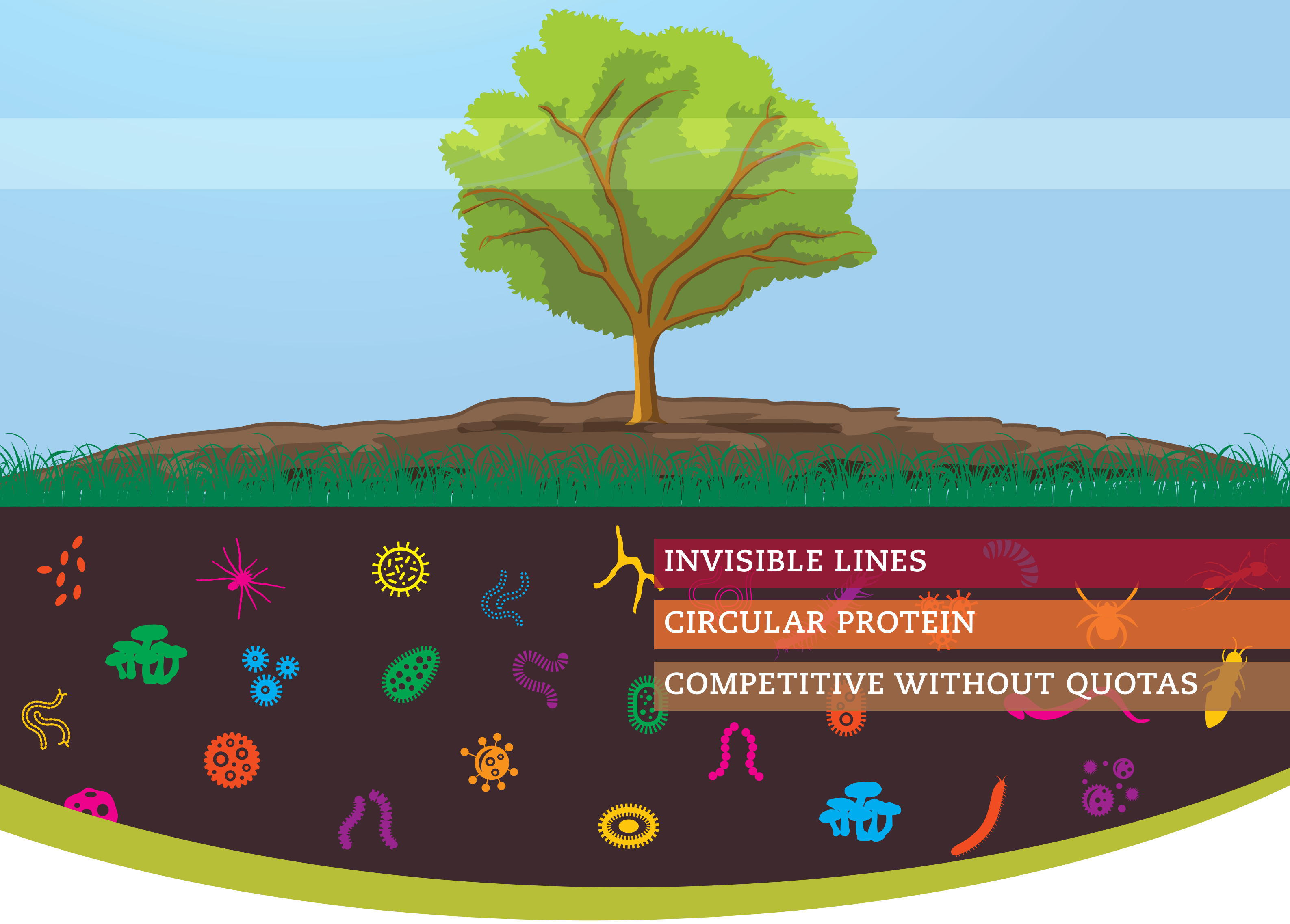
THE LIVING SOIL



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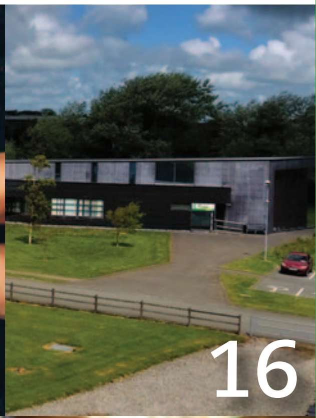

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Soil health – underpinning production and sustainability

Improving the productive capacity of Irish soils, through improving soil fertility and soil drainage, was the primary focus of agricultural research and extension from the 1950s to the 1980s. The challenge that Pierce Ryan (Head of the National Soil Survey) faced when soil science started in Johnstown Castle in 1951 was to understand the distribution of soil and how agricultural production could be improved. Over the intervening decades, through the national soil survey, soil testing and advisory support, Irish farmers improved the soils on their farms to drive food production and economic prosperity. More recently, combining agricultural production and environmental sustainability has become an important consideration for farmers. Once more soils have been highlighted as central to achieving both economic and environmental sustainability. It is now recognised that soil health or the ability of soil to deliver the ecosystem services is critical for sustainable land management. The importance of soil health has led to the EU proposing that one of the five Horizon Europe research missions is focused on Soil Health and Food, putting soil science on a similar footing to cancer and climate change research.

A series of articles in this issue highlights the pathway from production-oriented soils research in the 1960s, led by Pierce Ryan and his team, to the current soil research focused on the chemical, physical and biological health of Irish soils. The soil health doctor gives Irish soils a physical examination, illuminates the dark mystery of dirt and gives soil microbes a memory test. Never before has so much been asked of our soils. The tools, which would have been science fiction to the early soil scientists, now exist to delve deeply into soil health. These new tools can help us to better understand the functioning of soil, to explore the complex interactions, and how to optimise soil management to underpin sustainable agricultural production.

Karl Richards
Head of Environment, Soils and Land Use Department

Sláinte ithreach – tacú le táirgeadh agus le hinbhuanaitheacht

Ó na 1950í go dtí na 1980í ba é príomhréimse béime an taighde agus an leathnú talmhaíochta ná acmhainn tháirgeachta ithreacha na hÉireann a fheabhsú, trí thorthúlacht agus draenáil ithreach a fheabhsú. Ba í an dúshlán a bhí le sárú ag Pierce Ryan (Ceann an Suirbhéireacht Náisiúnta Ithreach) nuair a tosaíodh le heolaíocht ithreach i gCaisleán Bhaile Sheáin i 1951 ná dáileadh na hithreach a thuiscint chomh maith le conas a d'fhéadfaí táirgeadh talmhaíochta a fheabhsú. I gcaitheamh na mblianta ó sin, tríd an tsuirbhéireacht náisiúnta ithreach, tástáil ithreach agus tacaíocht chomhairleach, d'fheabhsaigh feirmeoirí na hÉireann na hithreacha ar a gcuid feirmeacha chun táirgeadh bia agus rath eacnamaíoch a spreagadh.

Níos deireanaí, tá meascadh an táirgeadh talmhaíochta agus an inbhuanaitheacht chomhshaoil tagtha chun bheith ina ábhar machnaimh tábhachtach d'fheirmeoirí. Arís eile tá aird tarraingthe ar ithreacha mar bheith ríthábhachtach chun inbhuanaitheacht eacnamaíoch agus chomhshaoil a bhaint amach. Tuigtear anois go bhfuil sláinte ithreach nó cumas ithreach na seirbhísí éiceachórais a sholáthar ríthábhachtach um bainistíocht inbhuanaithe talún. Mar gheall ar thábhacht na sláinte ithreach tá sé molta ag an AE go mbeadh ceann amháin de chúig mhisean taighde de chuid Horizon Europe dírithe ar Shláinte Ithreach agus Bia, agus an eolaíocht ithreach curtha ar comhchéim le taighde ar ailse agus athrú aeráide.

I sraith alt san eagrán seo tarraingítear aird ar an gconair ón taighde ithreach a bhí dírithe ar tháirgeadh sna 1960í, faoi stiúir Pierce Ryan agus a fhoirne, chuig an taighde reatha ithreach, atá dírithe ar shláinte cheimiceach, fhisiceach agus bhitheolaíoch ithreacha na hÉireann. Déanann an dochtúir sláinte ithreach scrúdú fisiceach ar ithreacha na hÉireann, caitheann siad solas ar mhistéir dhorcha an tsalachair agus déanann siad scrúdú cuimhne ar mhiocróib ithreach. Ní raibh éileamh chomh mór riamh ar ár gcuid ithreacha. Tá na huirlisí, a bheadh ina bhficsean eolaíochta do na heolaithe ithreacha luatha, ar fáil anois chun iniúchadh domhain a dhéanamh ar shláinte ithreach. Is féidir leis na huirlisí nua sin cabhrú linn feidhmiú ithreach a thuiscint níos fearr, an t-idirghníomhú casta a thuiscint chomh maith le conas bainistíocht ithreach a bharrfheabhsú le tacú le táirgeadh talmhaíochta inbhuanaithe.

Karl Richards
Ceann an Roinn Comhshaoil, Ithreacha & Úsáide Talún

Teagasc announces Peter Doyle as Walsh Scholar of the year 2021

PETER DOYLE is the Teagasc Walsh Scholar Gold Medal winner for 2021. Peter was awarded the medal by Frank O'Mara, Director of Research at Teagasc, at a special online ceremony hosted by broadcaster Jonathan McCrea.

Peter is a Teagasc Walsh Scholar based at the Teagasc Animal & Grassland Research and Innovation Centre at Grange, Co. Meath. He is investigating the production and quality attributes of grass-fed beef. Peter is a PhD candidate registered with University College Dublin and funded by Teagasc.

Speaking about his experience with the Teagasc Walsh Scholarship Programme, Peter said: "The Programme has provided me with great opportunities and experiences examining many aspects within the beef industry. The best advice that I can give to potential scholars is to do a research topic that you are truly passionate about".

There are currently 35 PhD scholarships available at Teagasc in association with national and international universities and institutes of technology.

Peter won the overall award after winning the Animal & Grassland Research and Innovation Programme category. The winners in the other categories were:

TARA O'CONNOR is the winner of the Teagasc Crops, Environment and Land Use Programme category. Tara is based at the Teagasc Crop Science Department in Oak Park, Co. Carlow. Her research looks at the strengths and weaknesses of the barley immune system and developing durable disease resistance in barley. She is a PhD candidate registered with Maynooth University and funded by Teagasc.

JIE HAN is the winner of the Teagasc Food Programme category. Jie is based at Teagasc Food Research Centre Moorepark, Co. Cork. Her project focuses on understanding and controlling dairy powder breakage during transportation and production to improve the functionality of dairy powders. Jie is a PhD candidate registered with University College Cork and funded by Teagasc. She also received a special award from the Institute of Food Science and Technology Ireland (IFSTI).

TRACY BRADFIELD is the winner of the Teagasc Rural Economy and Development Programme category. Tracy is based at the Agricultural Economics and Farm Surveys Department, Teagasc. She is investigating how land mobility and structure affect farms' economic performance. Tracy is a PhD candidate registered with University College Cork and funded by Teagasc.

LISA O'TOOLE is the winner of the Teagasc Knowledge Transfer Programme category. Lisa is a Teagasc Walsh Scholar based at the Portlaoise Advisory Office, Co. Laois. Her study focuses on developing an understanding of the relationships and methodologies to encourage contract cropping agreements. Lisa is a postgraduate student registered with University College Dublin doing an MSc in Agricultural & Extension and Innovation with Teagasc and UCD.

Announcing the awards, Frank O'Mara congratulated all the winners and the shortlisted Scholars and said: "Today's event showcased former and current Walsh Scholars and highlighted the high-calibre, talented Scholars coming through the Programme, who are about to embark on their careers in the agri-food industry".

A full report from the winning scholars will appear in the Autumn issue of *TResearch*.

Chorca Dhuibhne 2030: building sustainability on the ground

The Dingle Peninsula in the southwest of Ireland has become an important focus for innovative projects involving diverse Agriculture Knowledge and Innovation System (AKIS) actors. At the 25th meeting of the European Seminar on Extension and Education (ESEE) Conference (2021), a new docufilm was launched showcasing Corca Dhuibhne's (Irish for Dingle Peninsula) ambitious vision for 2030, and a profile of rural innovation projects that are achieving that vision on the ground. These projects illustrate how inclusive innovation approaches, anchored in integrated research, education and extension, can make impactful contributions to rural sustainability.

Teagasc is the Irish partner in three major projects working with local people in west Kerry to test and launch new innovations that provide sustainability solutions to farmers nationwide and across the EU.

Áine Macken-Walsh, the lead Teagasc researcher on the projects, began working in west Kerry with the SKIN Horizon 2020 EU project and, in co-operation with the Dingle Creativity and Innovation Hub, the Irish Farmers' Association and other local partners, extended the work through the Ploutos Horizon 2020 project and BiOrbic, Ireland's Science Foundation Ireland centre. Áine explains: "The imagination, commitment and huge appetite

for innovation and sustainability on the ground in west Kerry makes it an ideal living laboratory for developing new solutions. Benefits will be transferable to farmers and other rural development actors EU wide".

The docufilm, produced by filmmaker John Kennedy, and commissioned by the Dingle Creativity and Innovation Hub and Teagasc, can be viewed online at: https://youtu.be/ZkM2Z_Vy2sQ.

Fulbright-Teagasc awardee 2021

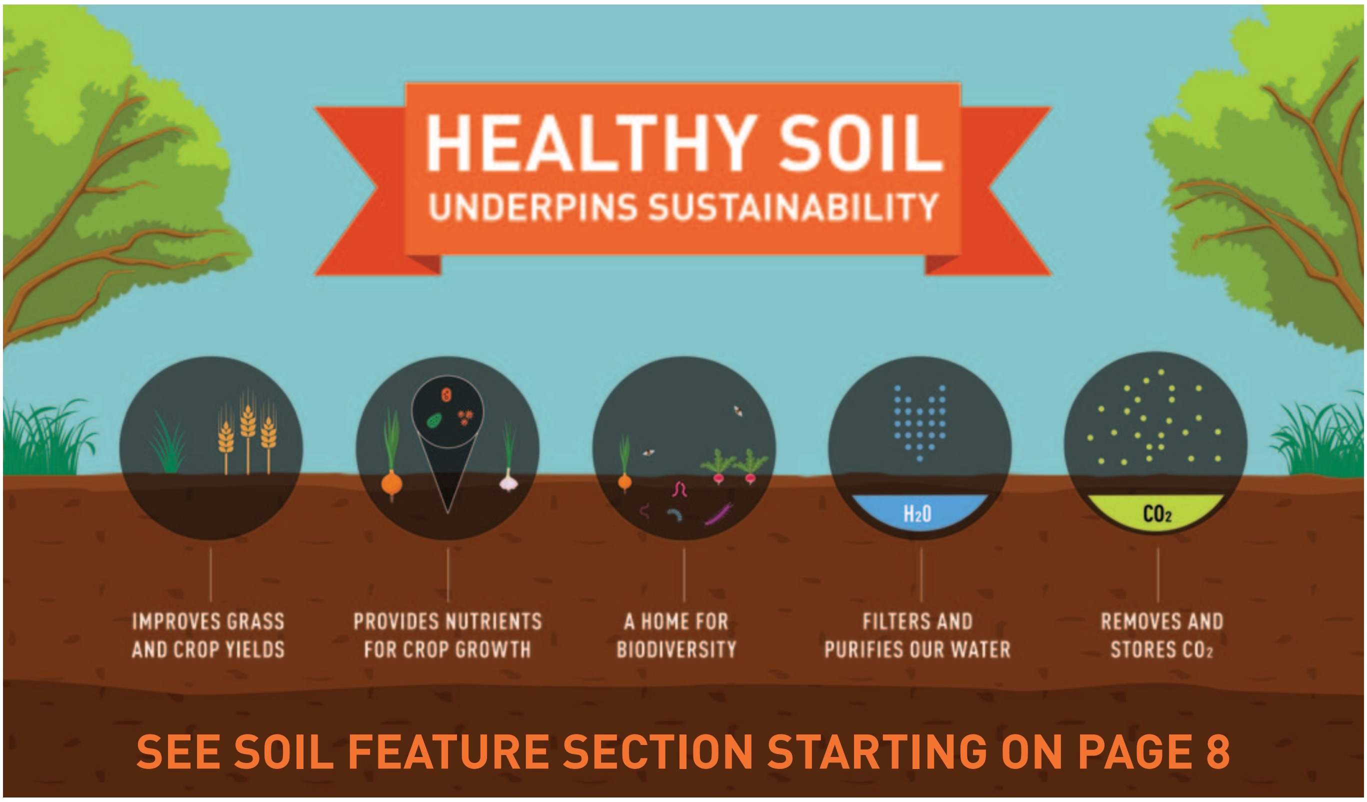
Rachel White is the Fulbright-Teagasc student scholar for 2021. Rachel received the award from Tánaiste Simon Coveney TD, Minister for Foreign Affairs and Trade, at an online ceremony recently. She will visit the University of Florida, Gainesville, USA, to explore the impact of infection and immunity in the female reproductive tract on fertility, under the guidance of Prof. John Bromfield.

The Fulbright Programme supports academics, professionals and students from Ireland to travel to institutes in the USA for research and collaboration with their US counterparts. Established by Senator J. William Fulbright in 1946, it is the largest US international exchange programme in the world and aims to build connections across research institutions and universities, and increase mutual respect and understanding between different nations.

Rachel is a research MSc student based in Teagasc Moorepark. Her supervisors are Stephen Butler at Teagasc and Pat Lonergan, University College Dublin. Rachel graduated with a first-class honours BSc in Animal Science from UCD in 2017 and subsequently joined the graduate programme of Ornua. There, she worked across procurement, international sales and marketing for the Kerrygold brand in their Dublin and Dubai offices. Rachel then secured a Teagasc Walsh Scholarship to undertake her MSc in Dairy Reproduction, which is focused on uterine disease in lactating dairy cows. Rachel's study examines the risk factors and incidence of such

disease, as well as treatment efficacies to mitigate associated fertility loss. As part of her undergraduate degree, Rachel spent a semester at Cornell University, where she gained an insight into US dairy farming practices and reproductive management.

The next round of applications for Fulbright Irish Awards will open on August 31, 2021. Interested candidates should visit for more information.



Researcher profile

Fiona Brennan

Fiona Brennan is a Senior Research Officer in Soil Microbiology at the Department of Environment, Soils and Land Use in Johnstown Castle, where she leads a research group focused on the soil and plant microbiome. She completed a BSc in Environmental Biology (University College Dublin) and an Irish Research Council-funded PhD in Soil Microbiology (NUI Galway) based at Johnstown Castle prior to holding postdoctoral research positions within Teagasc and INRA (The French National Institute for Agricultural Research). Prior to her current appointment, she was a permanent research scientist in the James Hutton Institute, Scotland, and a lecturer in Microbiology in NUI Galway.

As part of her role Fiona holds an adjunct lecturer position in NUI Galway and is a researcher within the VistaMilk, APC Microbiome Ireland, and Plant and Agricultural Biosciences research centres. She is an associate editor with the both the *European Journal of Soil Science* and *CABI Agriculture and Bioscience*, and is on the editorial board of the *European Journal of Soil Biology*. As an active member of the Microbiological Society, Fiona was recently the chairperson for an international conference on ‘Microbiomes underpinning Agriculture’. She is also a member of the scientific and local organising committees of the Global Soil Biodiversity conference to be held in Dublin in 2023. She is a past recipient of the Scottish Society for Crop Research Massalski award for meritorious research on the basis of her early research on the naturalisation of *E. coli* in soils.

Fiona is involved in multiple international projects focused on understanding the role of the soil microbiome in soil health and climate change, and leads a workpackage in an EU-funded network of scientists that is assessing the potential to increase the suppressiveness of plant microbiomes to human pathogen contaminants in horticultural crops.

The Soil and Environmental Microbiology Group, which is currently comprised of a technologist, four postdoctoral researchers and nine PhD students, aims to harness knowledge of the soil and plant microbiome towards the development of sustainable, resilient agricultural systems.

The Group is currently assessing the impact of agricultural practice on soil health, microbial-soil-plant interactions and microbial functioning, particularly with respect to the role of microbial communities in soil nutrient cycles, greenhouse gas emissions and plant health.

Increased vulnerability of upcoming wheat varieties to Irish Septoria strains confirmed

Researchers in Teagasc have confirmed that Irish strains of Septoria are able to overcome a source of genetic resistance present in a range of near-market winter wheat varieties. This is the conclusion of a significant study led by Steven Kildea, Teagasc crops researcher, and accepted for publication in the journal *Plant Pathology*.

Septoria blotch is the primary disease of the Irish wheat crop and requires judicious chemical treatment to ensure that the crop's yield potential is realised. In 2020, unexpected levels of the disease were observed on a selection of winter wheat varieties in a number of locations, each with the variety Cougar in their background, which has reported levels of Septoria resistance.

As part of the Teagasc cereal disease surveillance programme, initial results confirmed that the strains of Septoria isolated from these varieties were able to cause significant levels of disease on Cougar when tested under glasshouse trials.

Steven explains: "Cougar-derived resistance has been included in commercial breeding programmes for a number of reasons, including its initial resistance to Septoria. However, our work has now confirmed that this source of resistance is vulnerable to Irish strains of Septoria. With upwards of 20% of the Irish winter wheat seed available for autumn 2021 expected to be made up of varieties bred from Cougar, the implications of these findings are immediate".

As four of the six winter wheat varieties up for recommendation for inclusion on the Irish winter wheat recommended list in 2021 have been bred from Cougar, the detection of virulence prompted the crops research team at Teagasc Oak Park to conduct a rapid and detailed investigation.

This work confirmed that in addition to being able to overcome Cougar, these strains are also able to infect and cause high levels of disease on a range of varieties bred from Cougar, including those under review. There is no evidence to suggest that the Septoria strains identified are more aggressive on other commercially available varieties, including SY Graham, which is now most widely grown.

Steven confirmed that further investigations are ongoing to determine how widespread this virulence is within the Irish Septoria populations. Fortunately, following intensive sensitivity analysis, these Septoria strains are similar in fungicide sensitivity to the wider Irish *Z. tritici* population.

As varietal resistance forms a key pillar in cereal disease control, the emergence of virulence to Cougar-based resistance removes this key layer of integrated pest management (IPM), and as such growers must be aware of the risks associated. This risk is greatly increased in regions where Septoria pressure is traditionally high, such as the south of the country. Here, even with well-timed fungicide programmes, there is a concern that adequate disease control would not be achieved and growers should consider alternative varieties.

In areas of lower Septoria pressures, such as the north-east, growers should be aware of the increased risk associated with these varieties and develop disease control programmes accordingly. This must include: keeping to a minimum the area in which these varieties are grown; delaying their sowing as late as feasibly possible to reduce disease pressures; matching disease risk to fungicide choices; and, ensuring the correct application timings for Septoria control.

The full scientific paper can be viewed at:
https://bsppjournals.onlinelibrary.wiley.com/doi/abs/10.1111/ppa.13432.

Research pioneer: Pierce Ryan

Pierce Ryan spent decades advancing agri-food research in An Foras Taluntais and later TEAGASC. Here we look back at his life and achievements.

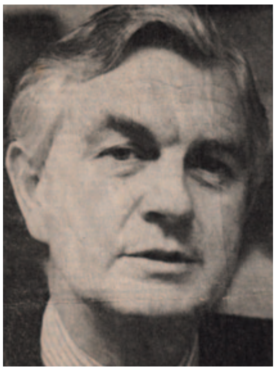
Pierce Ryan was Director of An Foras Taluntais (AFT) from 1979 to 1988, and when Teagasc was established on the amalgamation of AFT and An Chomhairle Oiliúna Talmhaíochta (ACOT) in 1988, he was appointed Director of that organisation until his retirement in 1994. He came from a strong farming and nationalist family in Taghmon, Co. Wexford. His uncle Jim would later become Minister for Agriculture and Finance, while his aunt was married to President Sean T. O'Ceallaigh. A classmate tells of how, when most of the students studying Agricultural Science with him in UCD would be making for the football field, Pierce would be heading for the Phoenix Park and the Áras, where he made good use of the extensive library there!

After Pierce finished in the local national school, he attended St Peter's College, Wexford, and thereafter headed to UCD to study Agricultural Science, qualifying in 1951. He then joined the Department of Agriculture based at Johnstown Castle in the fledgling Soils Research Centre. The man who would strongly influence his career, Tom Walsh, then a senior inspector in charge of soils and grassland research in the Department, almost immediately involved Pierce in studying the properties, characteristics and distribution of Irish soils.

During this period, he was seconded to the Food and Agriculture Organisation (FAO) of the United Nations in Rome for two years to work on problems of overseas development areas. He returned to the Department in Johnstown Castle in 1957 and obtained his MAgrSc degree from Iowa State University in 1959, concentrating on soil survey methodology.

National Soil Survey

Pierce joined the research staff of AFT in 1959, with responsibility for the establishment and operation of the National Soil Survey. Its purpose was to make an inventory of the different soils in the country, their properties, extent, drainage and suitability for various crops. The Survey was carried out on a county-by-county basis. Wexford was completed and published in 1964, followed by Limerick, Carlow, Kildare, Clare, Leitrim and Westmeath, as well as reconnaissance surveys of a number of other counties. The first soil map of the Republic was published in 1964. A later, more detailed map of the whole island, made in co-operation with experts from Northern Ireland, showed that good agricultural land occupied 50 % of the land area in the Republic, with 33 % of it deemed suitable for tillage. The seminal work of the National Soil Survey, led by Pierce, culminated in the publication of the first edition of the 'General Soil Map of Ireland' in 1969. The Soil Survey in the 1960s provided an essential framework for understanding the role of soil type in production responses and regional variability in land productivity, in addition to the identification of drainage problems and solutions for extensive areas of wetlands. Soil survey data were also used in a legal challenge to land valuation based on the Griffith's mid-19th century valuation that paved the way for the abolition of rates on agricultural land. During these times Pierce also undertook a study of certain unusual Irish soils related to the development of outwash materials from glaciation in Ireland, for



Clockwise from top left: Dr Pierce Ryan; Pierce presenting the memorial volumes of Dr Tom Walsh's scientific papers to Tom's wife Mimi while the Doc's two daughters, Rosemary and Bernadette, and his late son, Terry, look on; and, Pierce with Rena Grace, PA to Dr Tom Walsh.

which he was awarded a PhD by Trinity College in 1963. He was elected a member of the Royal Irish Academy in 1967, where he served for several years on the science committee. In the 1960s, he directed major multidisciplinary resource surveys on marginal areas in west Cork, Donegal and Leitrim. These revealed that the main barriers to progress were poor-quality land, demographics, education, access to resources and failure to apply the results of research. The studies also highlighted the incentives that would be necessary to promote the planting of private forests.

A driving force

Following a major review of AFT in the late 1960s, Pierce was appointed Deputy Director, and in that role from 1970 he became largely concerned with the implementation of the research programme and the identification of any barriers that restricted progress. He also promoted the employment of interdisciplinary teams where he thought it was the best approach to resolve issues at a commodity- or area-based level. He became heavily involved in promoting linkages with the newly established Agricultural Research Programme of the then European Economic Community (EEC), and how the research programme of AFT could benefit from Community-funded research, while at the same time complementing Community research objectives. On becoming Director in 1979, a new challenge began to emerge in the form of a dramatic change in the external environment. Whereas in the 1960s expansion of agricultural output was driven by successive programmes of economic expansion, in the 1970s accession to the EEC provided further stimulus and enhanced markets for the agricultural economy. Thus, this expansionary environment was the perfect fit for the arrival on the scene of a new agricultural production-focused research body with a well-endowed budget and its contribution became strongly associated with the marked resurgence in agricultural output, incomes and renewed vitality in the farm sector. However, from the early 1980s the Common Agricultural Policy (CAP) came under increasing pressure as agricultural surpluses began to emerge, imposing considerable strain on the EEC farm budget. Later on, severe restrictions were imposed on agricultural production, best illustrated by the introduction of the milk quota and super levy in 1984. Consequently, the AFT research programme had to recalibrate by placing more emphasis on increasing efficiency in the primary sector, enhancing capability in processing and diversification, and the establishment of a new Food Research Centre in 1985. Simultaneously, budgetary pressures necessitated the introduction of user research levies and commissioned research in order to balance the books of the organisation. It is a testament to Pierce's collegiate style of leadership that he succeeded in re-orienting the research programme towards a more broadly based focus, while at the same time coping with the financial constraints facing the organisation.

A driving force

As Director of AFT, he came with a track record of scientific achievement in the classification of soil types in Ireland, which was an essential and basic requirement in establishing the most appropriate farming systems and agronomy for Irish agriculture, while leading a relatively large research department. He adopted a collegiate and participatory actor approach in formulating and implementing the research programme, which he also demonstrated in his role as the first Director of Teagasc, as he sought liaison and co-operation with other relevant agencies. Throughout his tenure as Director, he was well regarded and respected for his leadership of the organisation in turbulent times. After Pierce retired he opted to lead a leisurely life, with his primary concern focusing on his family, and satisfied his own personal interests with an almost insatiable attraction towards libraries, and one in particular. There he would concentrate mainly on topics historical, particularly European and Irish, and he had a particular interest in the role played by his native Co. Wexford in the 1798 Rebellion. He would himself recall, when at national school under the influence of a strongly Republican teacher, marching around the schoolyard with his fellow pupils in 1948 holding replica pikes to commemorate the 150th anniversary of the Rebellion. Above all he was an avid Wexford man, proud of its GAA exploits, and he invariably left his scientific objectivity behind on matters pertaining to that county! Pierce is survived by his wife Kate, his daughters Christina and Suzy, his five grandchildren, son-in-law, sisters and brothers.

Acknowledgements

Karl Richards, Ned Culleton, Brendan Kearney, Gerry Boyle, Rosemarie Buckley, and Lance O'Brien.

Soil health physical examination

TEAGASC researchers at Johnstown Castle and Oak Park, along with collaborators from UCD, have developed soil physical health tools to use at field or national monitoring network scales.

As part of keeping healthy, we visit our doctor now and then to undergo a mixture of physical and chemical testing. The results of these tests give us an overview of our health and track a course of action where needed. Repeating such tests is prudent in terms of preventing or managing problems. This approach is also valid for soil health: without repeatedly physically examining soil structure and chemically testing soil, the health status of our soil will remain an unknown.

How do we define soil health?

Soil quality is a soil's ability to provide a range of different services through its capacity to perform specific functions under changing management and climatic conditions. Recently, this term has been replaced by 'soil health', defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans. Developing knowledge and understanding of factors affecting soil health, and monitoring the trends in soil health over time, are essential to better manage and protect our agricultural soils for future generations. The physical component of soil health is important and we need tests (indicators and tools) to map it.

Physical factor assessment

Researchers at Teagasc Johnstown Castle and Oak Park, along with colleagues at UCD, recently investigated different types of soil physical indicators as part of the Department of Agriculture, Food and the Marine (DAFM)-funded Soil Quality Assessment Research (SQUARE) project. Soil structure is a key physical factor that supports all other soil functions. The decline in soil structural quality, which leads to soil degradation, compaction and ultimately reduced plant growth, is often the consequence of more intensive management practices. This can also lead to reduced capacity for water to infiltrate and drain through the soil, to store water and to purify water in the landscape.

Physical health tools

While there are a number of tools for measuring soil structural quality, both for research and advisor use, such as soil bulk density, cone penetration resistance and soil shear strength, these are generally just measuring a single characteristic, which may not suffice for the range of complex soils on our farms.

Visual examination of soil structure (VESS) techniques are considered key for scoring the physical status of the soil (Emmett Booth *et al.*, 2016). They consist of manually breaking down a sample of soil by hand to visually assess features such as, but not limited to, aggregate size, shape and strength, pore structure and root distribution. The SQUARE project developed two VESS tools for Irish soils called GrassVESS and DoubleSpade (DS) (Emmett Booth *et al.*, 2018). GrassVESS, as the name suggests, was developed for grasslands. This method assigns a separate score to the grass root mat to account for the protection effect that this has on the lower soil layers and also adds a more user-friendly flow chart approach to aid consistent scoring. The DS method brings visual assessment techniques down to the important transition layer at 20-40 cm deep, where much of the 'damage' may be caused beneath the cultivation layer on arable cropped soils. Our research has shown the sensitivity of these techniques. DS and GrassVESS assessment were more effective than traditional quantitative tools in determining the impact of management and also had the potential to indicate

Examination of soil structure in the field using visual tools.

deterioration in soil structure quality at a point before a crop effect was measured, potentially acting as an early warning mechanism. Knowing soil structure quality allows management actions to be taken to avoid damage. This can include restricting animal and machinery traffic when soils are vulnerable or wet, working with lighter axle loads and lower ground pressures, changing headland machinery practice to reduce soil stress and, in some cases, adopting remediation measures.

The use of these tools is described in the 'Soil Structure ABC' manual, which can be accessed for free on the Teagasc website: https://bit.ly/ABC_SOILSTRUCTURE.

Tools for a national monitoring programme

Other responsive and sensitive soil physical tools for longer-term monitoring of soil physical health have been identified (Bacher *et al.*, 2019). This process involves taking intact soil cores and other soil physical measurements at key locations across the country. The data is modelled to develop soil water retention curves. The high-resolution data developed can be used to detect even slight changes to soil physical quality. Such indicators are even sensitive enough to pick up changes in soil physical quality due to earthworm movement. While these techniques are too slow to be deployed at an individual farm level, they could be used as part of a monitoring programme to map the condition of our national soils over time.

What next?

We will need long-term monitoring of soils to detect changes in soil health over time. Such a network will act as an early warning system before problems arise on farms. Simultaneously, we need practical management solutions for protecting the health and quality of our agricultural soil or for remediating soils that have been previously damaged. Our knowledge transfer service, in contact with farmers daily, will play a crucial role in implementing these tools in practice.

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Teagasc Walsh Scholars Jeremey Emmett Booth and Matthias Bacher, along with Nick Holden and Olaf Schmidt of UCD, are also involved in this research.

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The living soil

Researchers at TEAGASC are investigating the life under our feet with the aim of harnessing soil biology to provide natural-based solutions to global challenges.

Life beneath our feet

Soils are home to a staggering abundance and diversity of living organisms that are integral to the health and productivity of our farming systems. Our soils are teeming with life. Soil ranks among the most biodiverse habitats on the planet, housing greater than a quarter of all living organisms and making it a globally important reservoir of biodiversity. This diversity encompasses an enormous range of organism types, sizes, shapes and lifestyles, which operate at many different scales and occupy a variety of niches within the soil habitat. Soil organisms range from the microscopic (e.g., bacteria, fungi, protozoa and nematodes) to larger mesofauna (e.g., springtails and mites), up to the largest macro- or mega-fauna (e.g., earthworms and ants). Mainly hidden from view, these organisms are often forgotten about, but there is an increasing awareness that this life underpins the majority of processes within soil and is critical for delivering a whole range of vital ecosystem functions. Their importance to the sustainability, resilience and functioning of our farming systems cannot be overstated.

Among the most important of these functions is climate regulation, with soil microbes playing a pivotal role in both generating and mitigating greenhouse gases (GHGs), and their activity largely determining the net balance between the two. They are intrinsic to plant health and establishment: fixing, recycling, and scavenging nutrients for plant growth; providing essential plant vitamins and hormones; suppressing pests, pathogens and disease (**Figure 1**); protecting against plant stress; and, maintaining the soil structure that anchors plants. Complex and extensive below-ground microbial networks act as channels for resources and messaging, facilitating plant–microbial and plant–plant collaboration. Soil biota are known to influence the yield, quality, longevity and even flavour of crops and their products. The rich diversity of organisms within soil provides many of our antibiotics and vaccines.

Given the importance of soil biology to soil functioning, it is clear that to fully understand our soils, and how to manage them, we need to understand and work with this biology. Technological constraints, which have historically hampered investigation of microbial communities (that make up the greatest diversity of soil life), have been largely overcome with the advent of contemporary molecular approaches, offering revolutionary advances in our understanding of soil communities and how they affect agricultural systems. The abundance, diversity and functioning of these organisms are strongly impacted by agricultural practice, so managing our soils in a manner that safeguards and supports these essential members of the farming workforce is key to sustainable agricultural production.

Harnessing soil biology to enhance agricultural sustainability

The central role played by soil biota in nutrient transformations, climate regulation and plant health has placed them at the heart of global challenges around food security and climate change. As international efforts towards carbon neutrality and environmental sustainability intensify, a key focus is on development of climate-resilient agricultural systems that are capable of maintaining food production and farm incomes, while minimising environmental impacts. Teagasc researchers, in association with national and international collaborators, have been assessing the potential to harness knowledge of soil biology towards development of natural-based solutions, underpinned by science, which support the development of sustainable agriculture systems and enhance soil health. For example, as GHGs result from microbial processes, insights into the functioning of microbial communities offer a unique opportunity to mitigate emissions while increasing nitrogen (N) use efficiency. Researchers in Johnstown Castle have shown that the abundance and activity of microbial communities that produce and mitigate GHG nitrous oxide (N_2O) in Irish and international soils are strongly influenced by the pH and phosphorus (P) content of the soils, providing an effective means of reducing N_2O by balancing soil fertility and liming where needed.

Given the importance of soil biology to soil functioning, it is clear that to fully understand our soils, and how to manage them, we need to understand and work with this biology.

Sustaining crop production against the backdrop of reduced inorganic fertiliser inputs represents a challenge for farmers that soil biology can potentially offer some solutions for. Ongoing research has identified the microbial communities involved in transforming N from organic pools to plant-available forms, and how this is impacted by agricultural management. As we better understand how and when nutrients are made available to plants by soil communities, we can better tailor fertiliser advice to maximise efficiency and reduce losses. The potential of biofertilising microbial inoculants to enhance microbial provision of nutrients within grasslands is currently being tested, and the role of mycorrhizal fungi in supplying P in limited conditions is also being characterised. Recent results indicate that the diversity of the plant community and the fertilisation strongly impacts on the diversity and function of the microbial community below ground, including how it transforms nutrients. Initial indications suggest that the diversity of the plant community also impacts the complexity of the wider food web and the potential of the soil biology to suppress pests and diseases.

FIGURE 1: Bacterial-feeding nematode from grassland soil (image: Israel Ikoyi). Nematodes are important constituents of the soil food web, providing a range of functions, including important roles in nutrient cycling and the suppression of pests and diseases.

These studies, and many more, provide data that can be incorporated into management advice to enhance soil health and functioning. We still have much to learn about the spectacular array of life that inhabits soil, and the many complex interactions happening therein, but technological advances have allowed us to look more deeply than ever before and have revolutionised our understanding of soil organisms, offering great potential to harness these communities towards providing solutions for our greatest challenges.

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Soil alchemy: the dark mystery of dirt

While many aspects of the technology we use to examine soil have advanced, much of our knowledge still comes from discoveries made in the 19th century.

Leonardo Da Vinci said: "We know more about the movement of celestial bodies than about the soil underfoot". Many centuries and much research later, we continue to research the chemical interactions in the soils that grow our food. Soil is a complex matrix, and its chemical composition often depends on the location in the landscape, the parent material underneath and the influence of the management above. Defining chemical reactions in soil is akin to the art of alchemy. In fact, the word alchemy has its roots in the Arabic word *kimia* or *khem*, which refers to the fertile black soil of the Nile Delta.

In a series of lectures between 1800 and 1812, one entitled 'Elements of Agricultural Chemistry' described soil chemistry as "changes in the arrangements of matter connected with growth and nourishment of plants" and identified 47 elements from the periodic table as influential in these processes. Since then, we've become very adept at characterising and measuring these processes with advances in instrumentation and data science.

Inside the soil matrix

Our soils are composed of sand, silt, clay, organic matter, water and air, and this matrix provides the infrastructure that allows chemical reactions to generate available nutrition for plant growth. The elements that constitute major and micro nutrients are dynamic and changeable, and can exist in different forms of availability and stability.

These transformations can happen in clay surfaces and organic matter, often called the engine room inside the soil matrix, and where many of the soil chemical and biological reactions occur. A healthy amount of soil organic matter (SOM) is essential for many of the processes that control nutrient supply and storage in soils, and if SOM is depleted or reduced, this inhibits the soil's ability to provide soluble forms of nutrients, and more importantly, its ability to store and sequester carbon. As we move towards low-emission agriculture, it is hugely important to protect and enhance our soil carbon stocks.

For essential nutrients such as nitrogen and phosphorus, these can be stored inside the soil matrix and made available when crops need them. A healthy soil will have the ability to immobilise (store) and mineralise (supply) nutrients, and this function relies on a number of soil properties to be in good working order.

For nutrient supply to function at full capacity, other soil chemical conditions must be met, for example, soil pH provides the right environment for nutrients to become soluble and for reactions on clay surfaces to happen. As many chemical reactions happen in solution, soil moisture content becomes an important characteristic for nutrient diffusion to plant roots, and this links directly to soil structure, where soil drainage class, and amount and type of clays and organic matter play an important role.

A healthy soil will have the ability to immobilise (store) and mineralise (supply) nutrients, and this function relies on a number of soil properties to be in good working order.

FIGURE 1 (from left): passive samplers deployment rig (A) and lab-on-a-disk (B) for in-situ nutrient analysis, both developed at the DCU Water Institute. (C) Bruker FTIR spectrometer used at Teagasc Johnstown Castle to scan soils.

Chemical analysis: what's changed?

In the early years of soil science, the major themes in soil chemistry were dominated by ion exchange, clay mineralogy, soil acidity, sorption processes and kinetics, all in an effort to understand how to optimise soil fertility and plant nutrition. These themes are still relevant today in productive agricultural systems, but our focus has shifted towards the role of soils in protecting water quality, biodiversity and in mitigating climate change.

The emphasis has shifted to combining disciplines in soil physics and chemistry to understand the fate and transport of nutrients, pesticides and contaminants in soils to surface and groundwater at wider landscape scales. Combining soil biology and chemistry is helping us to understand the role of SOM in soil microbiota and for sequestering carbon, which is essential if we are to protect soil health and enhance our soil carbon stocks. Measuring and monitoring these parameters has also evolved over the years, although we still use some of the methods that have stood the test of time.

For example, traditional soil tests for nutrient availability date back to methods developed in the 1950s and remain the standardised methods in use today. Properties such as texture, particle size, ion exchange, pH, and acidity lend themselves to new, predictive methods such as soil spectroscopy and chemometrics. Near-infrared (NIR) and mid-infrared (MIR) light shone on a soil sample can produce an image or spectra, unique to each soil sample, as a fingerprint is unique to each individual. This fingerprint contains peaks, or information that we convert into data points, which we can use to quantify carbon, SOM, pH, particle size fractions, clay minerals, and cation exchange capacity, to name a few.

Advances in laser and optical techniques, coupled with machine learning in statistical modelling, have given soil scientists the tools to capture multiple physical and chemical properties at once, reducing the reliance on hazardous reagents and moving toward a 'green chemistry' approach with reduced plastics and hazardous waste in routine soil labs.

Other non-chemical methods include passive samplers (**Figure 1**), which can mimic diffusion of nutrients from the soil matrix into a solution, and are a promising alternative to chemical extractions for measuring concentrations of diffuse pollutants from soil into water. Passive sampling using diffuse gradient thin films and coated FeO strips work on the fundamental soil principle that was uncovered in the 1850s, i.e., nutrients can diffuse from the soil matrix, into the soil solution and are taken up by plant roots. So as chemical methods of soil analysis incorporate advanced techniques, the principles on which they are founded can be rooted in very early discoveries from the 1800s.

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Soil research infrastructure

TEAGASC research is helping to build a new understanding of the soils beneath our feet.

The importance of soils for crop and livestock production is well understood, as 95 % of food, feed and fibre production required by humans is literally based on soils. However, in addition to food production, soils provide a range of critical ecosystem services, such as: nutrient cycling and supply; water regulation and purification; carbon sequestration and climate regulation; and, a habitat for biodiversity, to name but a few. The role of soils and the key functions they provide is increasingly recognised, and there is a new impetus from all soil users for enhanced protection of this key natural resource. Research at Teagasc Johnstown Castle has focused on many different aspects of soils for over seven decades. In this time, expertise and understanding of the soils that exist in Ireland has been developed and passed on. Maintaining our soils in good condition is as critical now as it ever has been, and farmers and decision makers need science-based, easy-to-apply and cost-effective tools and advice to assess changes in soil health and function to enable them to manage soil resources optimally to achieve sustainable production, economic and environmental goals.

Irish Soil Information System

Critical to the successful management of our soil resource is knowledge on the location of our soils, and their associated properties. The Irish Soil Information System (http://gis.teagasc.ie/soils/) brings together existing information and data from previous soil survey work in Ireland and augments it with a new field campaign (2007-2013), leading to the production of a new national soil map at a scale of 1:250,000, as well as a collection of tools to access and interact with the data. A national soil database has been developed and maintained at Teagasc Johnstown Castle, which is utilised for soils and environmental research. This national soil database is used to satisfy the information required for both soils management and effective policy implementation, and is a resource to look at changes in soil chemical health.

Long-term field experiments

Long-term field experiments, akin to living laboratories, are of critical importance for developing a new understanding of the role of soils in regulating climate change, and have been highlighted in the EU Mission on Soil Health and Food. Long-term field experiments provide an opportunity to look into the past and to help predict future implications of changing management and climate conditions over time. Teagasc has established a range of long-term field experiments, which encompass management of soil fertility, grassland swards (including clover and multispecies swards), organic amendments, tillage type, and crop rotation (including cover cropping), to name but a few. For example, the Cowlands grazed grassland phosphorus (P) experiment, established in 1968 at Johnstown Castle Research Farm, is the oldest long-term field experiment in Ireland. Recently, this experiment has been used to identify the role of P in regulating carbon and nitrogen (N) cycles, and its importance for reducing greenhouse gas (GHG) emissions in managed grasslands. The Controlled Environment Research Facility at Johnstown Castle also enables researchers to investigate the effects of environmental conditions on various soil and plant interactions, and their agronomic and environmental outcomes.

Soils and environment research laboratories

As research into soils has developed over the years, so too have the methods and equipment employed for investigation and experimentation. State-of-the-art research equipment at Teagasc soils and environment research laboratories is in place to cover the breadth of

analysis related to soil health, nutrient efficiency, water quality, gaseous emissions, soil microbiology, agro-ecology and biodiversity, and the Agricultural Catchments Programme. In recent years, laboratory infrastructure has been used to conduct analysis of stable isotope tracers in soils, plants and gases, spectroscopic measurements of soils, plants and other materials, analysis of residues and pesticides, and microbiological analysis of soils. Intensification of research efforts to understand the biological health of soils has taken place in recent years, as the technological restraints of the past have been overcome. A suite of soil biology laboratories, fully equipped with the latest molecular and next-generation sequencing approaches that facilitate a wide range of novel and exploratory analysis on soil microbiological communities, are now in place at the laboratories at Johnstown Castle. These include a range of DNA and RNA methods that enable quantification of microbial communities and their functional activity. Microscopy facilities also facilitate identification of microfauna and other components of the living soil.

National Agricultural Soil Carbon Observatory

Information on changes in soil carbon stocks across organic and mineral soils in Ireland is required to accurately reflect GHG emissions and carbon sequestration from agricultural land. The National Agricultural Soil Carbon Observatory (NASCO) is a network of flux towers, which measure gaseous emissions at high resolution across different farming systems and soil types. The network enables the targeting of mitigation measures to increase carbon sequestration to be included in the national inventory. The longest-established flux tower has been making emissions measurements on the dairy farm platform at Teagasc Johnstown Castle since 2003. The NASCO will also add value to the soil carbon sampling campaign in the new Teagasc SignPost farms and the Agricultural Catchments Programme, as they work with farmers and the wider industry to understand and mitigate GHG emissions through implementation of best management of their agricultural soils and farming systems. It also places Ireland at the forefront of EU carbon sequestration research and will enable Ireland to participate in the EU Integrated Carbon Observation System (ICOS) network. The data generated will allow Ireland to count the carbon that is sequestered from the atmosphere and stored in agricultural soils, and to benefit from the EU Effort Sharing Regulation.

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Soil memories

Researchers from TEAGASC, the University of Innsbruck and the University of Manchester are investigating how drought and drought legacies affect plant–soil interactions in grasslands.

Grasslands are relatively simple above ground, but hidden below ground is an extraordinarily complex and interconnected system, on which healthy grasslands depend. Plants and soil microbes are continuously interacting. Plants deliver carbon via their root exudates, soluble sugars that are released from their roots, and litter – parts of the plants that have died. This carbon provides fuel for soil microbes, and microbes in turn support plant growth by supplying the essential nutrients that plants need to grow. Microbes also play a critical role in helping plants cope with stress, such as drought. Therefore, considering the intimate interactions between plants and soil microbes is essential for informing management to sustain healthy grasslands in a changing climate.

Plant–soil microbe interactions and drought

In Ireland, as in many parts of the world, rainfall is predicted to become more erratic, with more of the yearly rainfall in the winter, and hotter, drier summers. These changes in weather patterns will require adjustments in grassland management to maintain their productivity, quality, and the essential ecosystem services they provide. Droughts in recent years have highlighted the vulnerability of Irish grasslands to dry spells and the resulting impacts on fodder supplies. Droughts can have long-lasting effects on grassland functioning by disrupting the interactions between plants and soil microbes. Previous research has shown that drought decreases below-ground carbon transfer from plants to the microbial community (Fuchslueger *et al.*, 2018), alters the make-up of root exudates (Williams and de Vries, 2020), and causes long-lasting shifts in plant and microbial community composition (de Vires *et al.*, 2018). These changes affect the functioning of the microbial community, with cascading effects for nutrient cycling, plant growth, and the capacity of plants to resist and recover from subsequent droughts. Drought intensity (how low the soil moisture is) plays a key role in how drought affects grassland ecosystems. More intense droughts could shift microbial communities to a point where they can no longer recover, leaving legacies that have implications for ecosystem functioning (Bardgett and Caruso, 2020).

Assessing drought legacies

When and how drought legacies occur, and their implications for grassland plants and microbes, is the focus of an ongoing study. In summer 2020, grassland communities were exposed to eight different intensities of drought, from mild to intense, and their responses during and after the drought were studied. Drought reduced grassland productivity and carbon uptake. Soil microbial community functioning was compromised and carbon transfer from plants to microbes was reduced, signalling that drought disrupts the connection between plants and microbes. A week after the rains had returned, the soil microbial communities that had experienced a severe drought took up more carbon from plant root exudates than those that had experienced no drought or a mild drought (**Figure 1A**). Microbes drive nutrient cycling, and a fast microbial community recovery could affect plant nutrient uptake. Indeed, plant communities that had experienced a severe drought took up more nitrogen (N) than those that had experienced no drought or a mild drought (**Figure 1B**). Two months after the drought ended, plant communities that had previously experienced a severe drought produced more biomass than those that had not (**Figure 1C**). This could be because the plant community took advantage of an increase in N availability, as well as a shift in plant community composition: grass species became more dominant than herbs.

Future research

Much of how climate change, and associated increases in drought severity and frequency, will affect grasslands is unknown. A key outstanding question is: what are the longer-term effects of drought on grassland resilience to a subsequent drought? Do these effects change with increasing drought intensity? Future research will be focused on understanding if the legacies of drought on the soil affect grassland plant and microbial response to a subsequent drought. As droughts become more frequent and severe, these legacies will play a more prominent role in grassland ecosystem functioning, as they could hamper a grassland's ability to cope with subsequent droughts.

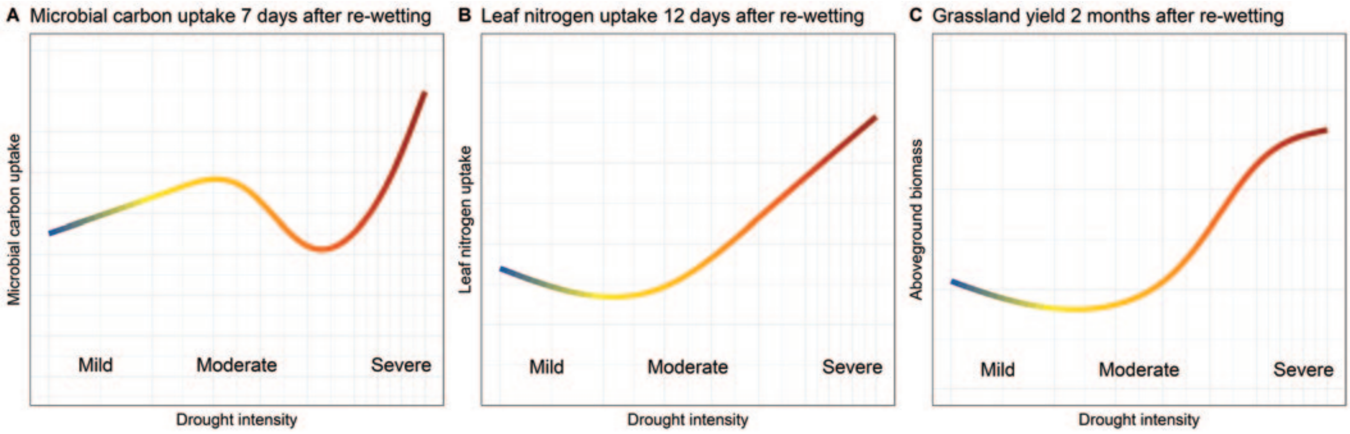
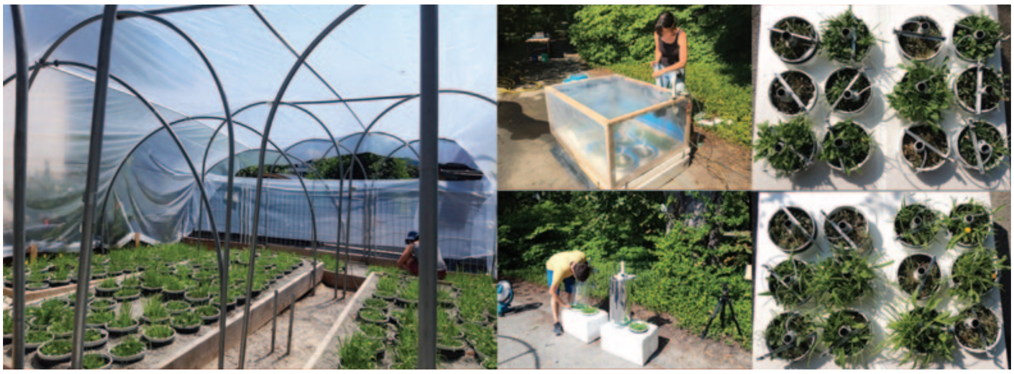


FIGURE 1: Grassland recovery dynamics after drought.



From left: Experimental set-up of mesocosm experiment used to study drought legacies; measuring grassland carbon dynamics; and, plant communities exposed to different drought intensities.

Conclusion

To understand how grasslands will respond to more intense droughts, and what the long-term consequences will be for grassland ecosystem functioning, we need to look below ground and consider plant–soil microbe interactions. The answers are blowing in the wind, but the solutions are likely under our feet.

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Nature or nurture?

Joint TEAGASC/Italian research from the National Research Council examined nutrient cycling and supply for sustainable grassland production.

Soil nutrient efficiency challenge

In Ireland the total agri-food sector is worth approximately €12.93 bn and, of this, primary production contributes €4.19 bn, which is the main support to Ireland's rural economy. Grassland management plays an important role. Grasslands are central to the cycling and sequestering of nutrients, which can ultimately lead to global environmental benefits. However, the current levels of nutrient-use efficiency (carbon (C), nitrogen (N) and phosphorus (P)) in grazed grassland systems has been shown to be relatively low (26 % for N and 65 % for P in 2015) at a national scale (Eurostat, 2015). Low nutrient-use efficiency has implications for farm profitability, as fertiliser nutrients represent one of the main input costs, at approximately €565 m in total for Irish farms. In addition, the recovery of nutrients by grassland, which are then turned into milk or meat, leads to more sustainable production in terms of protecting water quality and reducing gaseous emissions. However, intensively managed grassland-based farming systems in Ireland occur across different soil and climatic conditions and hence, nutrient efficiency varies widely from farm to farm and field to field. The need for soil-specific understanding of nutrient supply and the fate of added fertiliser nutrient resources is critical to improve the nutrient efficiency, profitability, and environmental sustainability of farms. Additionally, the importance of nutrient efficiency and low environmental footprint for the marketability of Irish food across the world is critical. This implies better management of nutrients for grassland systems in order to minimise the dependence on external fertiliser inputs.

Unlocking the biological potential of soils

Soil provides a range of ecosystem services (hereafter soil functions): (i) production of food, fibre and fuel; (ii) carbon sequestration and mitigation of climate change; (iii) water purification and regulation; (iv) nutrient storage and cycling; and, (v) habitat for biodiversity, the largest store of life on earth. It is well known that grassland soils have the capability to perform multiple functions simultaneously and that this delivery is predominantly controlled by soil biology, with variations upon different environmental and management conditions.

Researchers from Teagasc and the National Research Council in Italy are collaborating on a project, GrassGEN, which will assess the capability of grassland soils to cycle and supply nutrients and unlock the biological potential of Irish grassland soils to deliver important soil functions.

GrassGEN is investigating 20 permanent grassland soils from across the five major agro-climatic regions of Ireland. These soils represent the main mineral soil groups under grassland management identified during the Soil Quality Assessment Research (SQUARE) project (https://www.teagasc.ie/environment/soil/research/square/), and cover a range of scenarios combining different: (i) intrinsic soil characteristics; (ii) spatial/climatic conditions; and, (iii) grassland management type and intensity.

Genetic fingerprinting of grassland soils

The capacity of microbiota to mineralise nutrients stored in soils is a function of their genetic potential and their access to usable forms of substrates stored in organic matter. Furthermore, the expression of the genes responsible for the synthesis of relevant enzymes may be altered by external factors (i.e., management and climate). GrassGEN aims to develop a genetic fingerprint for grassland soils, which will be used to disentangle the microbiologically mediated transformations, cycling and fate of nutrients. Cutting-edge approaches and technologies, not routinely used in soil and environmental science, will be used:

- genetic approach;
- stable isotopes nutrients dynamics approach; and,
- functional diversity approach.

GrassGEN will elucidate the knowledge gap that exists between the expression of a biochemical function (e.g., enzyme reaction product) and the genetic potential that the soil microbiota actually has to deliver that function. Focused experiments applying genetic technologies for soil microbial diversity will identify response thresholds for nutrient cycling in soil. Stable isotopes of C and N will be used in tracing experiments to identify if a soil has the genetic potential to fully accomplish its biochemical function, or if that potential has been altered by the nutrient inputs. Using these cutting-edge approaches, we will answer some questions on whether it is the nature of the soil or its continuous nurturing that makes grasslands function to an optimal level.

Extracellular enzyme activities

The soil extracellular enzyme activities (EEA) provide a frame of reference for comparing ecosystems and a chance to relate the soil microbial community function to patterns of nutrient dynamics and soil organic matter storage within agricultural landscapes. The demand for nutrients by the soil microbiology can be linked with both the storage and supply of C, N and P in grassland soils. Investigating the C, N and P stoichiometry of the microbial biomass in relation to concentrations of specific nutrients in the soil is used to assess this demand. In addition, identifying the relationships between the enzymes present and the composition of soil organic matter will provide new insights on soil carbon storage and the potential for native soil nutrient release through mineralisation processes. During the initial phase, the GrassGEN project measured soil microbial biomass and EEA to investigate microbial nutrient demand and organic matter decomposition. The measured enzymes related to C, N and P cycles were β-glucosidase, β-N-acetylglucosaminidase and phosphatase, respectively, and varied in relation to different soil types and drainage characteristics, and potentially due to management.

Benefit to stakeholders

GrassGEN will provide the basis for future knowledge transfer and advice for farmers to better manage the rate, type, timing and placement of fertiliser applications for optimum soil fertility and sustainable production on grassland soils. The knowledge developed will underpin sustainable and environmentally friendly soil management strategies for farmers and the wider agricultural industry.

GrassGEN will provide farmers and land managers with the necessary knowledge and information to exploit agricultural soils in a sustainable manner into the future.

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Invisible lines

Virtual fencing trials are being conducted by the National Parks & Wildlife Service, TEAGASC and IT Sligo.

Various strategies to limit cattle movement either in or out of a specific land area have evolved over the years, from human supervision to wood, stone, and wire and electric fences. Now, the virtual fence is a reality. The concept involves remote mapping, GPS sensors and wireless technologies to keep animals in certain areas and out of others. The animals have a GPS collar fitted and the perimeter of the grazing area is defined by geo-co-ordinates, which can be drawn on a phone or tablet screen using the associated app. As an animal approaches the pre-virtual perimeter, the GPS collar emits an audio cue. As the animal progresses, the audio warning will increase, and if they persist, the animal will receive an electrical pulse as they cross the perimeter fence co-ordinates. This is the learning or training process for the animal, i.e., the link of the audible cue(s) to the electric pulse, such that once they experience the audible cue, the animal would be deterred from continuing to or through the perimeter. The development and uptake of this device has been slow up to recent times due to the challenging nature of the technology. However, there is now significant interest in virtual fencing (VF) systems for controlling grazing management and animal movement, including here in Ireland.

Pioneering study

Since summer 2020, the Agri-Ecology Unit of the National Parks & Wildlife Service (NPWS) and three farmers have been progressing Ireland's first VF studies on commercial farms, assisted by Teagasc, IT Sligo and Michael Martyn, Agri-Environmental Consultants. The collars were supplied by Nofence in Norway. These conservation grazing trials using innovative technologies are being undertaken on three farms participating in the NPWS Farm Plan Scheme. Rigorous, real-time animal behaviour monitoring will take place over the three years of the study, while habitat condition and farmer feedback will also be evaluated. The trials are undertaken on upland scenarios, with a view to managing important habitats and safeguarding peat soils, which in turn are important for carbon sequestration, water and biodiversity.

It is hoped that if proven successful, this could herald a new era and opportunities for the management of these important sites and other areas of environmental interest. There will likely be other wide-ranging uses for the technology elsewhere, but these initial steps are vital to inform the strengths, weaknesses, opportunities and threats in an Irish farming context. One of the primary objectives of the project is to undertake a feasibility study, to break new ground for other parties who may be interested in adopting this cutting-edge approach. There is a lot to learn and the technology should not be considered as a gadget to be used out of the box, without very careful consideration and planning.

As an animal approaches the pre-virtual perimeter, the GPS collar emits an audio cue. As the animal progresses, the audio warning will increase, and if they persist, the animal will receive an electrical pulse as they cross the perimeter fence co-ordinates.

Animal welfare

It is absolutely necessary that assurance can be given that this technology is consistent with animal welfare principles and codes of practice; therefore, stringent animal welfare regulations must be satisfied. It is crucially important that this technology is deployed and tested within a research framework with ethical approval and guidelines, together with appropriate monitoring of the technology and animal behaviour over time. By doing so, this project will provide real-life scenario testing in an Irish context to inform the approach for future roll-out. Apart from environmental management, the envisaged benefits of VF include improved lifestyle of livestock managers, due to a reduced requirement for manual labour (time and cost) and the peace of mind of knowing where animals are at any time. In summary, this virtual fence concept is now being pioneered by this research group in Ireland, with a view to evaluating:

- effectiveness in maintaining cattle in location as desired;
- applicability in delivering quality environmental goods, including biodiversity, water, and soils;
- how it works for the animals; and,
- how it works for the farmers.

The group will provide a detailed report after the three years of study, but will continue to provide updates as relevant and useful, as this is an emerging and innovative approach to farming in the 21st century. Further information can be found at: https://npws.ie/research-projects/agri-ecology-research.

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Cleaning on pig farms

TEAGASC researchers evaluated different washing and disinfection methods on pig farms.

Background

Water use by livestock is of environmental concern as water resources are limited and the livestock sector, including pork production, contributes significantly to global water abstractions. Pig farms require water for both on-farm (drinking and cleaning) and off-farm (feed production) purposes. Washing of facilities and equipment on pig farms is essential due to strict biosecurity protocols to avoid disease outbreaks and optimise animal welfare, and is especially important for young pigs. However, there is a lack of data regarding both the quantity of water used and the effectiveness in reducing bacterial load of different cleaning and disinfection strategies for younger pigs. Thus, the aim of our study was to quantify the effect of three different washing treatments on water use, bacterial levels and cleaning time when washing weaner pig pens.

Washing and disinfection treatments

We evaluated three washing and disinfection treatments: 1) power washing and disinfection (WASH); 2) pre-soaking followed by power washing and disinfection (SOAK); and, 3) pre-soaking followed by detergent, power washing and disinfection (SOAK+DETER). Sprinklers were used for pre-soaking and all the pens were washed from top to bottom. After the power washing, rooms were left to dry for 24 hours before applying disinfectant, and after application of disinfectant the rooms were left to dry for 48 hours.

Data collection

A water meter was installed on the power-washing water supply line to record the volume of water used. The time taken to wash each pen was also recorded, as was the time for which sprinklers were operating for the treatments, including pre-soaking. To determine the efficacy of the different cleaning treatments, swab samples were collected from the floor, feeder and wall of each experimental pen both before washing, and after washing and drying. Microbiological analysis was conducted on the swab samples to calculate total bacterial count (TBC), and levels of *Enterobacteriaceae* and *Staphylococcus*.

Results

There was no effect of treatment on any measure of water use. There was an overall effect of treatment on the time taken to wash a pen, with SOAK and SOAK+DETER reducing the washing time per pen by 2.3 minutes (14 %) and 4.2 minutes (27 %), compared to WASH. Thus, both pre-soaking and use of detergent reduced the time taken for pen washing. None of the treatments, nor the interaction between treatment and time (before or after washing), had any effect on any of the bacterial count measurements (**Figure 1**). Overall, the time of sampling (before or after wash) had an effect on both TBC and *Staphylococcus* counts, but not on *Enterobacteriaceae* counts. After washing, there was a difference between counts at all locations, indicating that washing of the walls

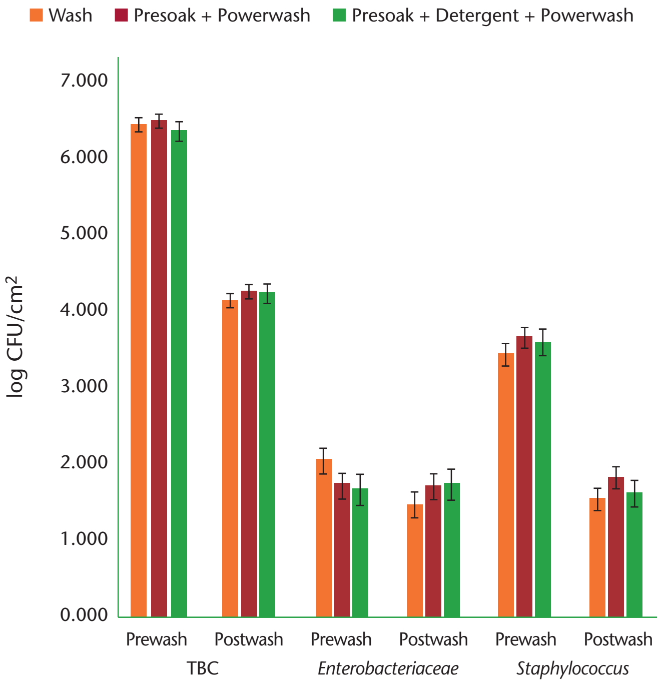

FIGURE 1: Effect of the three cleaning treatments on TBC, Enterobacteriaceae counts and Staphylococcus counts in empty weaner pens pre and post washing. Treatments: WASH – cold water power washing; SOAK – pre-soaking followed by power washing; and, SOAK+DETER – pre-soaking followed by detergent and power washing.

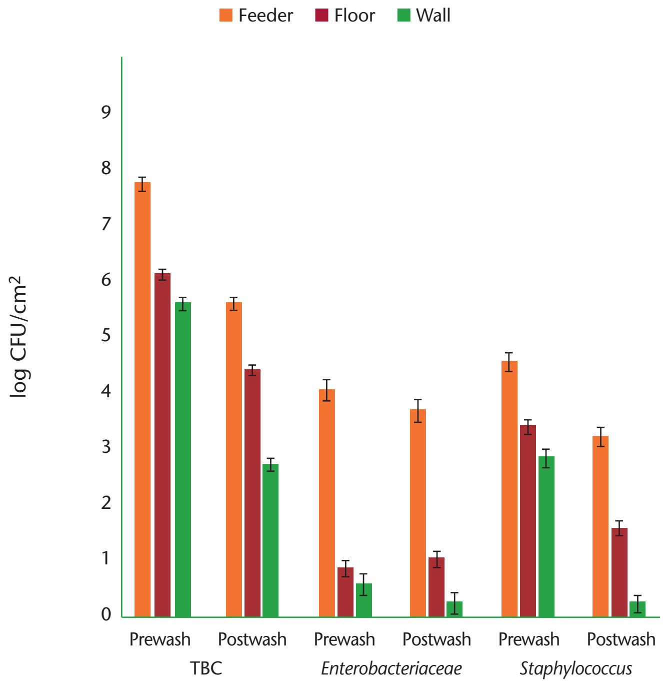

FIGURE 2: Effect of the different cleaning treatments on TBC, Enterobacteriaceae counts and Staphylococcus counts in various locations in empty weaner pens pre and post washing.

had more of an effect in reducing bacterial load than washing of floors, regardless of the washing routine used (**Figure 2**).

Benefit to the pig industry

Our results show that the three washing treatments used in this study had no significant effect on water use but there was a significant difference in washing time. All cleaning treatments reduced the levels of *Staphylococcus* and TBC from pre to post washing, even though no difference between the treatments was observed. In contrast, the levels of *Enterobacteriaceae* did not decline post washing. Since there was no difference in both water use and bacterial load, power washing without pre-soaking or detergent is the simplest method, and thus perhaps the preferred option. However, from the farmer's perspective, pre-soaking and detergent use saves time and labour costs. Moreover, water use in cleaning warrants further investigation, as the use of detergent might be of environmental concern if slurry containing detergent enters sewers or public waters.

Acknowledgements

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Managing and preventing herbicide-resistant grass weeds

To understand the extent of herbicide-resistant weeds in Ireland, TEAGASC researchers examined black-grass populations taken from tillage farms.

Conservation agriculture (CA) systems, including zero tillage and reduced tillage, may improve soil quality and reduce production costs. Irish growers are slow to adopt CA systems because of grass weed control problems in a wetter climate, which also impact on plough-established crops. Herbicide resistance and a declining armoury of herbicides are challenging our ability to control problem grass weeds like wild oats, bromes, Italian ryegrass and black-grass. The European Innovation Partnership (EIP)-funded Enable Conservation Tillage (ECT) knowledge transfer and research project focuses on co-designing cultural/non-chemical integrated weed management (IWM) strategies to mitigate grass weed problems. Mapping of herbicide-resistant grass weeds is a key research component of the ECT project.

Black-grass

Black-grass (*Alopecurus myosuroides* Huds.) is the most important herbicide-resistant weed in the UK and across Europe (Moss, 2017). It is particularly challenging in early-sown winter cereals established after reduced tillage. In Ireland, the possibility that herbicide-resistant UK black-grass has been introduced in recent years poses a significant challenge to the industry. Anecdotal evidence suggests that these populations have entered Ireland from the UK via seed, straw and machinery, and are now dispersed across tillage fields. However, it is possible that native populations were in existence, which may now carry a degree of resistance if they were regularly treated with herbicides that are active against black-grass.

Multiple herbicide-resistant black-grass

In a survey of grass weeds on tillage farms, 12 black-grass populations were collected prior to the 2020 harvest and screened for resistance with ACCase- and ALS-inhibiting herbicides. Four of these populations (R1 to R4), collected in Cork, Meath and Waterford, appeared to exhibit resistance and were subjected to detailed dose-response studies where they were compared with a known susceptible population (S2) collected in Dublin.

Plants were sprayed at the two- to three-leaf stage, with rates ranging from 0.25 to eight times the recommended label rates of ACCase-propaquizafop (Falcon) and ALS-mesosulfuron/iodosulfuron (Pacifica Plus). Herbicide effectiveness was measured by estimating the effective dose rates causing 50 % mortality of the treated plants (ED_{50}). For non-resistant weeds, the ED_{50} values should be much lower than the label rate.

For the ACCase herbicide, the ED_{50} values of populations R2 to R4 were between 1.5 and 1.8 times the label rate of 100 g active ingredient (ai)/ha (**Figure 1A**), indicating that effective control is not possible on these populations (**Figure 2A**). The R1 population was much more resistant, resulting in ED_{50} values more than eight times the label rate.

For the ALS herbicide, the ED_{50} of population R1 was well below the label rate of 500 g product/ha (**Figure 1B**), indicating that this ACCase-resistant population was highly sensitive to the ALS herbicide (**Figure 2B**). But all other ACCase-resistant populations were also ALS resistant, with ED_{50} values >2.4 times the label rate for R3 and R4, and ED_{50} values >8 times the label rate for R2, respectively. For these multiple-resistant populations, no chemical control options are available in any tillage crop and extreme IWM strategies, including grass leys/fallows for a minimum of five years, would be needed to help eliminate the seedbank. This study highlights the importance of testing different herbicide types, where resistance is found in the populations.

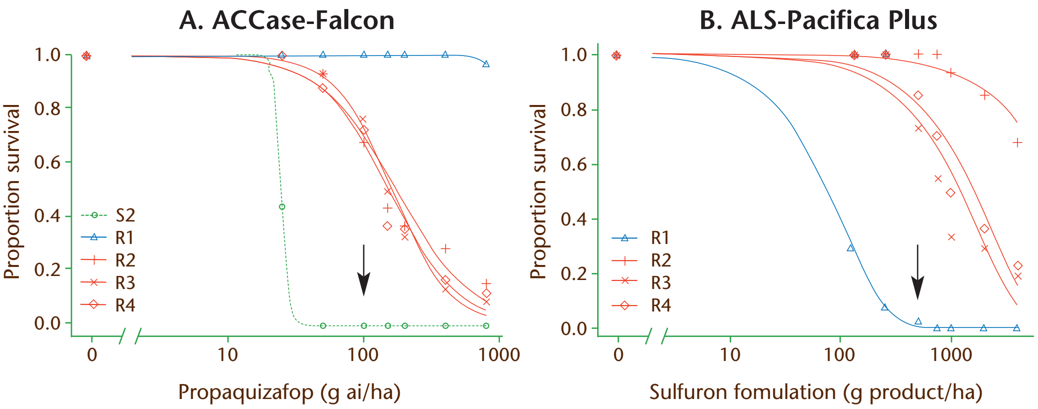

FIGURE 1: Dose-response curves for survival of susceptible (S2) and resistant (R1 to R4) populations of black-grass treated with dose rates ranging from 0.25 to eight times the recommended label rates of ACCase-Falcon (A) and ALS-Pacifica Plus (B). Arrows indicate the label rates of Falcon (100 g ai/ha) and Pacifica Plus (500 g product/ha) for black-grass control. Note: S2 was fully controlled at 0.25 times the label rate (see Figure 2B); therefore, model (B) could not be fitted with S2.

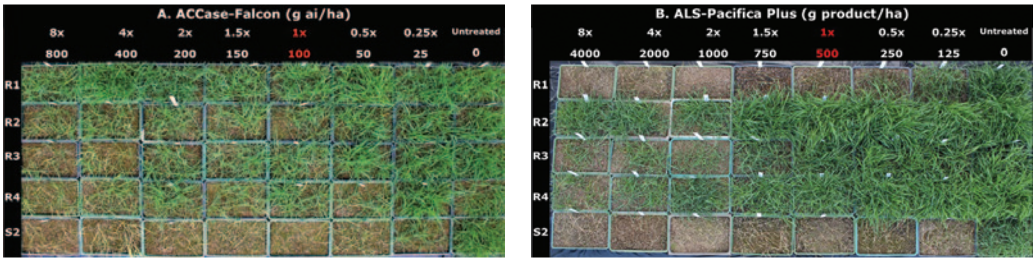

FIGURE 2: Symptoms of susceptible (S2) and resistant (R1 to R4) populations of black-grass following application of ACCase-Falcon (A) and ALS-Pacifica Plus (B) at dose rates ranging from 0.25 to eight times the recommended label rates (highlighted in red).

Benefits to industry

This is the first study to confirm herbicide-resistant black-grass in Ireland. Knowledge of resistance levels and cross-resistance among the main herbicide types, coupled with weed pressure and previous herbicide use on an individual field, will inform the actions needed to eliminate or control the resistant populations. More importantly, this knowledge should help to prevent resistance evolution. This information is being disseminated among growers and industry, but to build more robust IWM, there is a need for more comprehensive knowledge on the evolution of herbicide resistance and the genetic mechanisms that are involved. If we allow resistance to develop and fail to control challenging grass weeds, the sustainability of the tillage industry will be threatened.

> Black-grass is the most important herbicide-resistant weed in the UK and across Europe. It is particularly challenging in early-sown winter cereals established after reduced tillage.

Acknowledgements

The ECT project (grant no. LLOC1079) is EIP funded by the Department of Agriculture, Food, and the Marine (DAFM) under the Rural Development Programme 2014-2020. We acknowledge the inputs of Jimmy Staples, ECT Project Manager/Advisor, and David Schilder, ECT Project Technician, and the contribution of growers and industry to the project. A special thanks to Sarah Cook (ADAS, UK) for advice on glasshouse experiments.

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Circular protein

TEAGASC researchers are looking at how wastewater from dairy processing can be used in the cultivation of duckweed, a plant with great potential as a food source.

What is a circular economy?

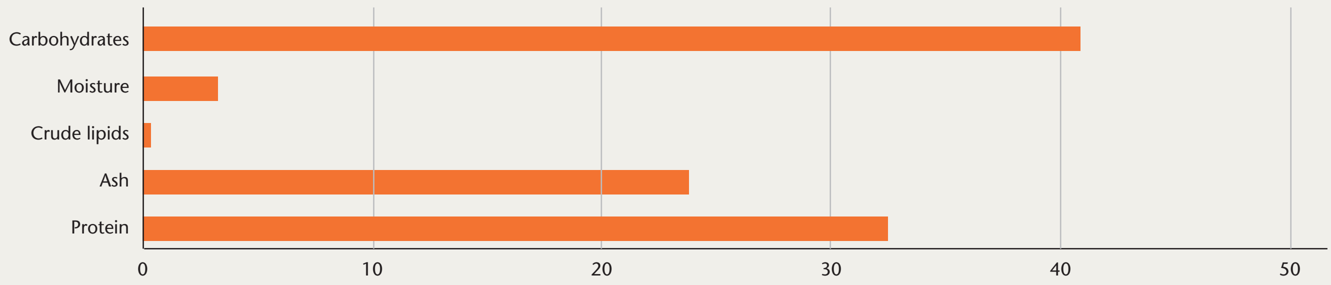
A circular economy is a comprehensive approach to economic growth with a vision to mutually benefit businesses, society and the environment by eliminating unnecessary waste while also enabling the continual use of resources. Considering the circular economy perspective, the food industry is now seeking alternative methods for food processing and new sources of ingredients. This is more crucial now than ever as there is an increasing population and a consequent increase in demand for food. One key area that has shown great promise is the redirection of materials that may have been previously labelled as food waste or wastewater for the production of valuable materials. For example, in certain areas in the food industry such as dairy processing, significant amounts of wastewater can be generated. Previously, this wastewater would be treated in a wastewater treatment plant, at considerable expense. However, this waste stream could actually be highly valuable, containing important nutrients including ammonia, nitrate and phosphate, with lower concentrations of other important elements such as iron, magnesium and calcium. Duckweed requires nitrogen and phosphorous for growth, and the high concentrations of nitrate, ammonia and phosphate present in dairy processing wastewater makes it a medium suitable for plant growth. Growing duckweed will rapidly take up nutrients, and break down other environmentally damaging products such as lipids and sugars. Duckweed, which is a source of high-quality aquatic-based protein, can then be used as a feed supplement for animals and/or as fish feed.

Duckweed: circular protein

Duckweeds are aquatic floating plants belonging to the family of *Lemnaceae* consisting of five genera (*Landoltia*, *Lemna*, *Spirodela*, *Wolffia*, and *Wolffiella*) with 38 species, which thrive in freshwater or brackish water bodies. Several species of *Lemnaceae* are native to Ireland. Duckweed displays some highly interesting advantages over terrestrial plants such as: high growth rates (under ideal conditions biomass could double in one day); high biomass yields (20-30 t/ha on a dry basis, displaying a more than 10-fold higher protein yield compared to soya crops); and, a high amount of proteins (up to 45 %) and micronutrients. Duckweed is a very promising source for animal/fish/human nutrition. Its growth in aquatic environments negates the need for fertile and arable land; thus, there is no competition for land and water compared to conventional food production systems. Cultivation in constructed ponds increases the water and nutrient application efficiency by reducing losses to the environment. Simple harvest by sieving or other methods is possible due to duckweed's relatively large size (2-20 mm), and it grows on still or slow running water, and therefore does not require the use of powerful agitation, which results in less energy consumption. The nutritional value of duckweed is shown in **Figure 1**.

Researchers from Teagasc and University College Cork are trialling duckweed growth in conjunction with Bord Iascaigh Mhara. Furthermore, Teagasc researchers, with Irish and European partners, are currently developing novel, sustainable aquatic plant-based protein processing systems as part of the BlueBio-funded AquaTech4Feed project. AquaTech4Feed is involved with best use of food waste in boosting a zero-waste circular economy at local level. The biomass, including duckweed, is processed into feed ingredients, contributing to reduced resource depletion, and fostering long-term economic growth. Development of innovative protein ingredients for foods and feeds, compared to the current benchmarks, will result in a sustainable economic impact and business opportunity for European aquaculture producers, especially when residues and wastes are used. In fact, in this case they will benefit from reduced costs for their disposal.

Research at Teagasc is involved in developing a technology suite to process and develop protein-rich ingredients from duckweed by employing state-of-the-art cell disruption technologies (**Figure 2**). Various technologies are involved in the processing of duckweed, including drying, high-pressure processing, microwave and ultrasound-assisted extraction.



	Protein	Ash	Crude lipids	Moisture	Carbohydrates
gm/100 g DM	32.06	23.51	0.88	3.11	40.44

FIGURE 1: Nutritional composition of dried duckweed. DM = dry matter.

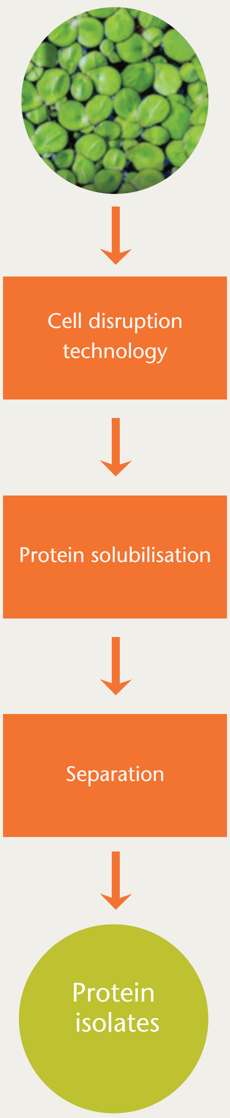


FIGURE 2: Duckweed protein production process.

Conclusions

Duckweed is one of the most promising novel sources of proteins for food and feed application. Novel extraction technologies will allow the development of a new value chain for commercial exploitation.

Acknowledgements

The authors would like to acknowledge the Marine Institute and Science Foundation Ireland under the BlueBio ERA-NET COFUND project.

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Raman spectroscopy to assess nutritional quality in dairy

TEAGASC researchers are developing methods to predict the composition of dairy products using faster alternatives to conventional labour-intensive techniques. One of them is Raman spectroscopy.

What is Raman spectroscopy?

Spectroscopy techniques study the interaction between matter and light. In particular, Raman spectroscopy is based on the phenomenon of inelastic light scattering. When a sample is illuminated, part of the incident light is scattered in different directions. Most of it is elastically scattered; that is, there is no change in the energy of the scattered photons. However, a tiny fraction of that light (typically 0.0000001 %) exchanges energy with the sample by causing changes in the vibrational levels of its molecules. This is known as inelastic scattering of light, and it results in photons with a different wavelength (colour) than the incident light. Raman spectrophotometers detect this tiny amount of inelastically scattered photons, generating Raman spectra that feature a number of peaks or bands. Some examples are shown in **Figure 1**. These spectra are like 'chemical fingerprints' for compounds, as they are specific for each particular substance.

Applications of Raman spectroscopy

Since the Raman scattering of a molecule depends on the type of bonds within its chemical structure, Raman spectroscopy can be used as an extremely sensitive method to detect specific compounds within a product. This technique not only provides detailed information about the chemical structure of molecules, but also about their phase, polymorphy, and even intermolecular interactions within a complex product.

Additionally, by combining Raman spectroscopy with microscopy tools, it is possible to obtain not only compositional information, but also information about the spatial distribution of components in complex matrices with micrometric spatial resolution. Plus, it is a non-destructive, label-free analysis technique. Its capability to detect and identify analytes even at trace concentrations has already been exploited in a number of fields, including forensic sciences, biomedicine and materials engineering, where it has led to important technological breakthroughs. In recent years, new applications of Raman spectroscopy have also emerged to assess food quality and safety.

To further exploit and validate the potential of this technique, Moorepark researchers are currently working on expanding its application to raw milk and other dairy products, in collaboration with University College Cork and funded under VistaMilk.

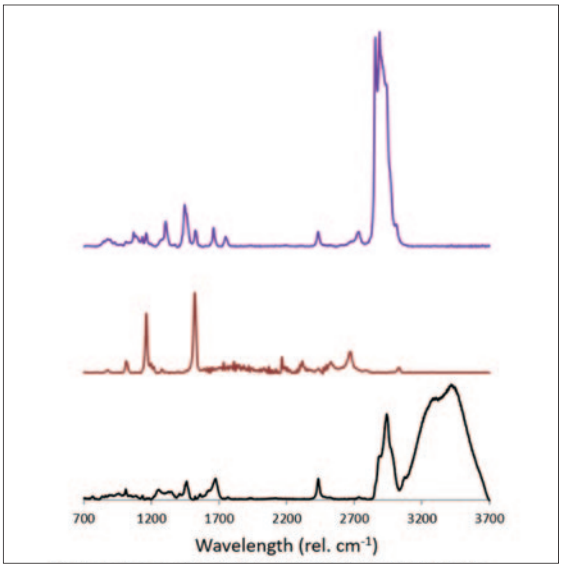

FIGURE 1 (Top to bottom): Raman spectra of butter, β-carotene and whey protein gel.

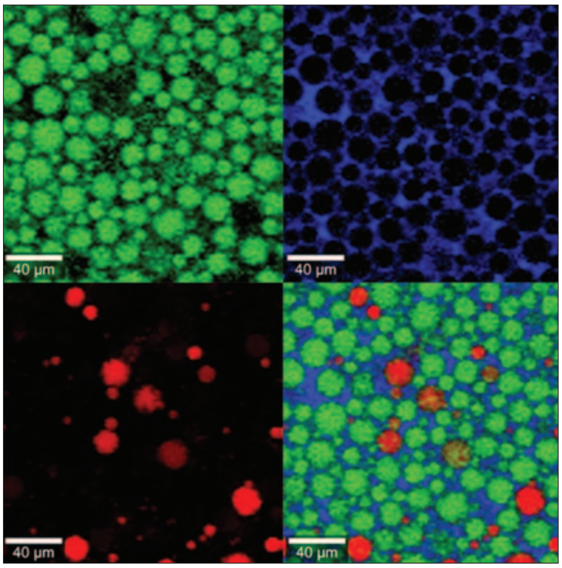

FIGURE 2. Raman micrograph of an emulsion containing β-carotene only in some of its fat droplets. Green, blue and red colours depict fat, water and β-carotene, respectively.

Raman spectroscopy in dairy

Pioneering work carried out on butter samples at Teagasc has demonstrated the ability of Raman spectroscopy to distinguish pasture-derived butter from that produced from indoor feeding systems (Gómez-Mascaraque *et al.*, 2020).

The information obtained from the Raman spectra of butter correlated well with the fatty acid profile of the butter samples, with the advantage that the testing time was greatly reduced using Raman spectroscopy. In addition, strong correlations were found between the Raman spectra of butter and indicators of its nutritional quality, such as the thrombogenic index, which could be used for predictive purposes.

Raman microscopy has also allowed Teagasc researchers to map the distribution of micronutrients such as carotenoids within dairy emulsions (**Figure 2**). To further exploit and validate the potential of this technique, Moorepark researchers are currently working on expanding its application to raw milk and other dairy products, in collaboration with University College Cork and funded under VistaMilk.

This will allow the collection of larger spectral datasets to build more accurate and robust prediction models that are expected to broaden the application of Raman spectroscopy as a rapid tool to evaluate the nutritional quality of milk and dairy products.

Industry impact

Milk composition, functionality and processability vary considerably due to a number of factors (e.g., animal feed, cow genetics, seasonality). This poses considerable challenges for milk processors and manufacturers, so there is a need for prediction of these variations. However, most of the methods used for quantitative compositional analysis and assessment of milk quality are time consuming and expensive. The implementation of robust and rapid verification techniques to predict the quality of milk and dairy products is therefore essential to support the growth and development of the Irish dairy industry. As 'grass-fed' labelling becomes more prominent on the market, rapid and label-free methods for verification of feeding systems are also required.

Acknowledgments

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Perceptions of protein

A TEAGASC survey of older adults revealed that protein is an underappreciated nutrient among this cohort in Ireland.

Older adults should eat a more protein-dense diet than younger adults, according to a new report issued by the Food Safety Authority of Ireland (FSAI, 2021). Eating enough protein, found in foods such as meat, dairy, eggs and beans, is essential to help preserve muscle mass and physical function to ensure healthy ageing. However, a recent survey of Irish consumers conducted by Teagasc showed that those who need protein most – middle-aged and older consumers – are not aware of the increasing importance of protein in the diet as we age.

Protein important for keeping muscles strong

Beginning in our forties, we start to lose ~1 % of our muscle mass and 2-3 % of our strength per year. Over time, this can lead to a disease called sarcopenia, which is characterised by low muscle mass and strength. Sarcopenia can impair mobility, making it more difficult to independently perform daily physical tasks. Furthermore, it increases the risk of falls, fractures, poor quality of life, and the need for long-term care. The most effective way to prevent sarcopenia is the combination of regular physical activity, especially ability-appropriate resistance exercise (such as lifting weights), accompanied by a nutritious diet that provides adequate protein.

Compared to younger adults, older adults are less efficient at using the protein they eat to build new muscle, so they may need to eat more protein to help preserve their muscle mass as they age. In order to stimulate muscle building, older adults are encouraged to eat a moderate serving of high-quality protein-rich foods at each meal. High-quality protein foods include meat, poultry, fish, milk, yoghurt, and eggs, and to a lesser extent, beans, peas, lentils and nuts. In addition, consuming protein after exercise enhances the muscle-building effects of the exercise.

Lack of awareness

A survey recently conducted by Teagasc explored attitudes to food and health among 513 men and women aged 45 to 81 years living in Ireland. As part of this survey, people were asked about protein in the diet. A total of 63 % of the respondents believed that older people do not need more protein than younger people. In addition, a substantial proportion of the individuals (36 %) did not perceive protein as being an important part of their diet. Those who did not recognise the importance of protein experienced slightly lower physical ability, perceived their diets as less healthy, used convenience more when preparing meals, were less influenced by advertising, and had lower income and education compared to individuals who did identify protein as being an important part of their diet (**Figure 1**).

Overall, the respondents rated taste as the most important motivating factor when choosing food, followed by health, cost, convenience and, lastly, sustainability. However, among those who did not identify protein as being important in their diet, cost and convenience were slightly more important, while health and sustainability were more important in those who recognised protein as important.

How much protein do we need?

The amount of protein we need each day depends on our age, body weight, activity levels, and health status. The FSAI recommends that healthy older adults should consume 0.75 g of protein per kg body weight each day.

This would correspond to 53 g of protein for a person weighing 70 kg, which, in food terms, would be equivalent to a glass of milk at breakfast, two eggs and a yoghurt at lunch, and a small salmon fillet at dinner. This

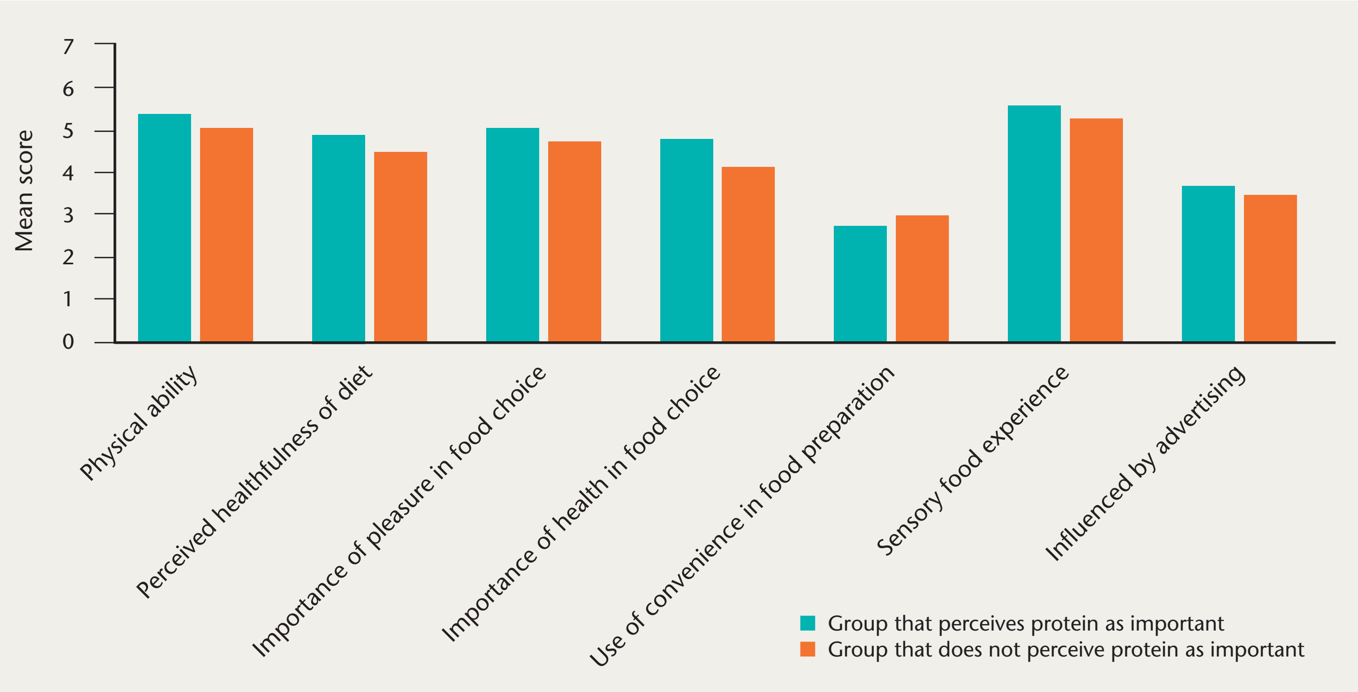

FIGURE 1: Comparison of characteristics between middle-aged and older adults who perceive protein as important in their diet and those who do not perceive it as important.

is taken a step further for older adults at risk of sarcopenia, for whom the FSAI recommends protein intakes that are 25-50 % higher than the recommendation for healthy older adults. Importantly, previous research conducted at UCD, within the Department of Agriculture, Food and the Marine-funded Nutrimal Programme led by Helen Roche and Clare Corish, has shown that more than half of independent-living older Irish adults have some impairment in strength, muscle mass and/or physical performance. Therefore, this higher protein intake recommendation is applicable to a relatively large proportion of older adults in Ireland. Thus, clear and targeted public health messaging is needed to communicate these protein guidelines effectively for healthy ageing.

Conclusion

Consuming sufficient dietary protein is required to optimise healthy ageing. A substantial proportion of middle-aged and older consumers in Ireland do not identify protein as being an important aspect of their diets. Clear public health campaigns are required to communicate the importance of protein to support healthy ageing. Campaigns should also highlight tasty, convenient and cost-effective ways to include sufficient protein in the diet in order to influence food choice among consumers who are less motivated by health. In addition, opportunities exist for the food industry to produce tasty, protein-dense products targeted at the older adult market to both promote and facilitate healthy ageing.

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Eating for ageing

TEAGASC research looked at functional foods for healthy ageing and asked: do older adults want them?

Are anti-ageing foods the future?

As we get older, we may swap our usual skincare products for ones marketed as having "anti-ageing" properties, but should we do the same for our food? Staying healthy as we age is fundamental to making the most of the extra 30 years of life expectancy we have gained in the past century. Good nutrition is a key ingredient for healthy ageing, and as we get older our nutritional needs change. For example, our skin becomes less efficient at making vitamin D from sunlight, so older people are advised to consume more vitamin D through food and supplements. We become less effective at building new muscle, so eating enough protein becomes increasingly important. In addition, as we age our risk of diseases like heart disease and osteoporosis rises. Therefore, foods that help older adults to achieve their nutritional needs and reduce their risk of disease could help to support healthy ageing.

What are functional foods?

Functional foods are those that have been reformulated to deliver additional or enhanced health benefits over and above their basic nutritional value. This can be achieved through: 1) adding a beneficial ingredient that would not normally be present (e.g., spreads with added cholesterol-lowering plant sterols and stanols); 2) adding more of an existing beneficial ingredient (e.g., milk with an increased calcium content); or, 3) removing a potentially harmful ingredient (e.g., reduced salt in soup). Unlike dietary supplements provided as pills and powders, these functional foods deliver health-enhancing ingredients in a convenient and tasty form. Functional foods for healthy ageing represent an exciting opportunity for food innovation due to the rapidly expanding older adult market and growing consumer interest in health.

Do older adults want functional foods?

In order to create useful and successful functional food products, new product development must match real-world consumer needs and demands. To gain insight into middle-aged and older consumers' attitudes to diet and functional foods, researchers at Teagasc recently conducted a survey in over 500 men and women living in Ireland aged between 45 and 81 years. In the survey, participants were presented with a range of different functional foods and asked to indicate on a scale of one (strongly disagree) to seven (strongly agree) their willingness purchase these products. In general, participants were most interested in foods to improve heart and bone health, followed by foods developed to increase energy, manage health conditions (e.g., high cholesterol) and improve mental performance. There was slightly less interest in foods nutritionally developed for their age group and least interest in healthy and convenient ready meals.

Profiling participants based on their responses regarding functional foods revealed three distinct groups of consumers: those with a high interest in buying functional foods (33 % of participants); those with a medium interest (42 %); and, those with a low interest (25 %). Further analysis found a number of key differences between the groups with low, medium and high interest in using functional foods. At one end of the spectrum, the high interest group were the most highly motivated by health when making food choices; they paid the most attention to food labels and advertising, and made the most conscious effort to eat healthily.

Despite this, they still believed that their diet was not healthy enough and could be improved. At the other end of the spectrum, the low interest group were more motivated by taste when making food choices compared to the high interest group.

They were also the most involved in cooking, used the least convenience foods, and were more inclined to believe that their diets were healthy enough and did not need to change.

Although this survey did not directly determine the reasons why the low interest group were less interested in functional foods, it is possible that those individuals believe that functional foods are a less tasty or perhaps less natural option, and/or that they are not motivated to increase the healthiness of their diets.

Acceptance of functional foods did not differ by sociodemographic characteristics but rather by health attitudes. This emphasises the importance of promoting the health attributes when marketing new functional food products to consumers.

Trusted sources for nutrition information?

In order to market health-promoting functional foods to ageing consumers, another critical consideration is who they trust for their nutrition information. In this survey, participants ranked doctors, closely followed by friends and family, as the most trusted sources of nutrition information. The next most trustworthy sources were health promotion and food safety authorities, followed by food manufacturers, while newspapers and magazines were seen as the least trustworthy.

Conclusion

This study provides important information for food companies with an interest in developing functional foods targeting healthy ageing. The most attractive functional foods were those developed to improve bone and heart health, suggesting that these could be good targets for functional food innovation. Acceptance of functional foods did not differ by sociodemographic characteristics but rather by health attitudes. This emphasises the importance of promoting the health attributes when marketing new functional food products to consumers. Finally, our study shows that ageing consumers place a lot of trust in the nutrition information provided by their doctors, friends and family. Therefore, communicating the benefits of functional foods designed for healthy ageing should be directed at these trusted groups, as well as at the older consumers themselves.

Acknowledgements

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RED

Highs and lows of collaboration

Researchers from TEAGASC and UCD detail an initiative by Irish farmers who set about working together for sustainable agriculture by applying to the EIP-AGRI initiative.

Farming in Ireland, like the rest of the EU, is diverse in terms of the food and livestock different farms produce and raise, the methods they employ, and the social and environmental contexts in which they operate. Diversity is a challenge for policymakers as 'one size' will not suit all farm households or enterprises. In response, the EU, through the Common Agricultural Policy (CAP), is placing greater emphasis on 'locally-led' initiatives that engage farmers and other stakeholders in the creation and implementation of projects that match their needs, the local context, and EU/national policy objectives. Locally led approaches may receive funding through the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) mechanism, which seeks to enhance the productivity and sustainability of the agricultural sector (European Parliament and the Council of the European Union, 2013).

Locally led approaches are an opportunity for policy stakeholders such as farmers, advisors, researchers, community development professionals, and other parties to collaborate in the development of solutions to the challenges of social, economic, and environmental sustainability. The international literature highlights the benefits, but also the challenges, of multi-actor collaboration in agricultural sustainability (Prager, 2015; Toderi *et al.*, 2017). Few studies have assessed the processes through which collaboration arises, the roles of different stakeholders, and the leadership skills required to establish and practise collaborative decision-making (Westerink *et al.*, 2017).

In recently completed research, we evaluated the process by which one multi-actor group formed to develop an application to EIP-AGRI. In this case, a group of farmers initiated the creation of an Operational Group that produced a proposal linked to the management of commonage grazing in an upland area in the west of Ireland. The area is dominated by low-intensity sheep production, with many farmers grazing their animals on unfenced mountain for much of the year. We conducted 47 interviews with people who were involved in, or supported, the Operational Group. The goal of these interviews was to elicit narrative accounts that would allow us to trace the processes of collaboration from a variety of different perspectives. We conducted coding-based data analysis and triangulated the results through workshops in two other upland areas.

Results and discussion

As part of their Expression of Interest (EOI) application, the group developed a proposal centred on establishing a co-operative shepherding scheme, managing invasive species, and protecting water quality in the local catchment. Although the farmland of 200 farmers was included in the proposal, our analysis reveals that a small group of key people drove the process. This group included three to five lead farmers and a number of institutions based in, or with links to, the case study area. This core group established decision-making processes that were largely facilitated by personnel from a Local Development Company, serving to build support among local farmers and developing a proposal with input from a range of different individuals (**Figure 1**). By tracing this process in detail we identified three key findings with particular policy relevance.

1. Decision-making was locally adapted

The EIP-AGRI Initiative was non prescriptive in terms of how the Operational Groups should form. Accordingly, the group in the case

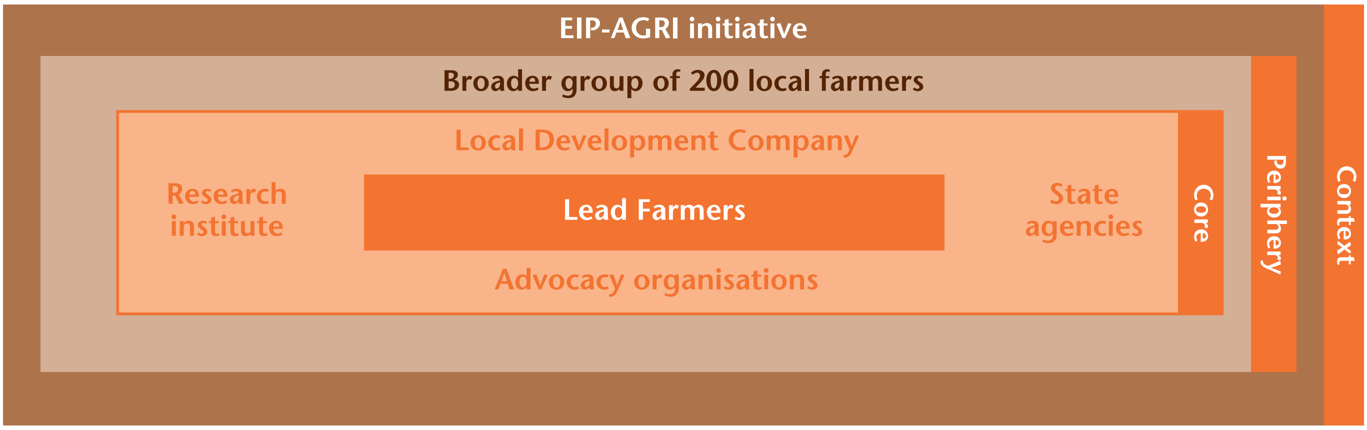

FIGURE 1: People and agencies involved in the local EIP-AGRI application.

study area was able to develop decision-making structures in ways that it deemed appropriate. Importantly, these structures drew on the capacity and support of the Local Development Company, with whom many local farmers had pre-existing working relationships. This points to the importance of existing local institutions and working relationships in the development of collaborative initiatives.

2. Organisation, collaboration, and knowledge sharing require significant time, labour, and skill

The process of linking with institutional actors to build the Operational Group began roughly two years before the application was submitted. The lead farmers began gathering information through visits to the Burren Programme as early as 2010, in anticipation of an EIP-type initiative. This highlights the importance of local leadership and vision combined with access to flagship initiatives and experience-based learning. The group held between 15 and 20 meetings over the two years, which could each last three to four hours. These meetings were conducted in evenings on a voluntary basis. Finally, leadership, administrative, facilitative, and scientific skills were all available in the case study area and contributed to the development of the EOI proposal. From a policy perspective then, there is a need to reflect on the extent to which these types of resources are available in different areas, and the extent to which this kind of approach to governance relies on voluntary labour and skills.

3. Dealing with rejection

Our case study Operational Group's application was successful in an initial assessment phase and the group received some funding to develop a more extensive application. However, the group was ultimately unsuccessful and did not receive funding to implement the proposed project. This points to an issue identified by Jones *et al.* (2019) pertaining to groups that expend labour, enlist expertise, and develop strong working relationships but are not funded. This was a major disappointment for our case study group and, so far, that group has not engaged in new initiatives. This final aspect also needs consideration in refining the EIP-AGRI approach.

Many of these topics were discussed in depth at a Teagasc-run seminar held on March 3. Presentations and video can be found here: https://www.teagasc.ie/publications/2021/working-together-for-sustainable-farming-agri-environmental-policy-practice-and-experience.php.

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Quotas and emissions

Joint TEAGASC, NUIG and University of California research examined milk quota abolition, dairy expansion and greenhouse gas emissions.

Agricultural greenhouse gas (GHG) emissions are currently at the forefront of climate change policy in Ireland. The agricultural sector in Ireland generates a much larger proportion of the State's GHG emissions (35 %) compared to the EU average (9 %). The 2021 Climate Action Bill proposes a 51 % cut in GHG emissions by 2030, and agriculture will be subject to a sectoral target under this framework. While details are to be set during 2021, GHG reduction targets will dictate the direction of the sector to 2030.

A complicating factor in achieving agricultural emission reduction targets in Ireland is the major dairy herd expansion that has taken place around the abolition of the EU milk quota regime in 2015. Irish dairy farmers are in a particularly challenging situation as livestock numbers and chemical nitrogen (N) fertiliser are key drivers of agricultural GHG emissions. Both have increased since EU milk quota abolition, and more dairy cows and increased fertiliser application rates have led to higher absolute GHG emissions.

Irish dairy farmers have altered their production methods over time. For example, dairy farms are producing considerably more milk per farm now than before the milk quota abolition. These production increases are mainly due to larger dairy herd sizes and increased yields per cow. These production adjustments have led to changes in emission intensities per kg of milk produced. This research explores how changes in production methods have influenced GHG emission intensity of production during a time of significant policy change for the dairy sector.

Data and methodology

This analysis uses data from the Teagasc National Farm Survey (NFS) between 2000 and 2017 (inclusive) for dairy farms, and is based on 5,639 observations (Dillon *et al.*, 2018). The data include detailed information on farm and farmer characteristics, as well as farm-level GHG emissions. This includes both absolute GHG emissions and GHG emission intensity of production. GHG emissions are calculated following the Intergovernmental Panel on Climate Change (IPCC) methodology. For this, activity data derived from the NFS data are multiplied by emission factors (Buckley *et al.*, 2019). We used statistical methods to estimate total factor productivity and then measured the relationship between productivity, farm size and GHG emission intensity of milk production over an 18-year period that included milk quota abolition.

Declining GHG emission intensities

Our results indicate that average GHG emission intensity per kg of milk produced decreased by 13 % between 2000 and 2017 (from 0.84 to 0.73 CO_2eq/kg of milk; **Table 1**). This means that dairy farmers are now producing each kg of milk with considerably fewer emissions than 20 years ago.

We also find that, on average, absolute GHG emissions have increased by 86 % per farm over the same period. While this increase in absolute GHG emissions per farm is significant, average milk output per farm has increased by much more (123 %). This suggests that without improvement in environmental efficiency of production, farm-level emissions would have increased to a greater extent.

These figures have to be interpreted in the context of the general development of the national dairy sector.

For example, the number of dairy farms in Ireland has been reducing steadily since milk quota introduction in 1984. Between 2005 and 2016, the number of dairy farms in Ireland reduced by 17 %. The numbers remained relatively stable at 18,000 between 2010 and 2016; some of this was driven by new entrants to the industry (Kelly *et al.*, 2020). Conversely, dairy cow numbers have increased by over one-third and milk deliveries by over 50 % since 2008 based on Central Statistics Office data.

Productivity and milk quota abolition

Our results indicate an inverse relationship between productivity improvements and GHG emission intensities per kg of milk produced. Hence, as productivity increased, emission intensities of milk production declined. We also find that this important effect gets stronger with increasing farm size, indicating economies of scale.

Table 1: GHG emission and farm characteristics – specialist dairy farms in Teagasc National Farm Survey.

	2000	2006	2012	2015	2017	% change
Emission intensity (kg CO_2eq/kg milk)	0.84	0.80	0.77	0.74	0.73	-13.1
Total farm emissions (tonnes CO_2eq)	271.2	323.7	423.2	466.1	503.9	85.8
Total farm emissions/ha (tonnes CO_2eq)	7.39	7.33	7.69	8.26	8.60	16.49
Milk output (litres per farm)	194,281	255,115	326,021	397,144	433,856	123.31
Milk yield/cow (litres)	4,677	5,000	4,975	5,428	5,390	15.25
Number of dairy cows (per farm)	39.98	49.17	63.52	70.88	77.25	93.21
Utilisable agricultural area (hectare)	37.1	44.5	55.5	57.6	58.9	58.92

Data are weighted to represent the Irish dairy population; weighted averages are reported.
Source: own calculations from NFS data.

When we explored the implications of milk quota removal, our results revealed that increasing productivity had a stronger effect on GHG emission intensities in the quota removal soft landing phase (i.e., between 2008 and 2014), when compared to the quota phase (i.e., from 2000 to 2008, based on our data).
This suggests that milk quota expansion did play a role in reducing GHG emission intensity of production due to increases in productivity. However, the considerable growth in milk production in Ireland after quota abolition led to higher absolute GHG emissions, despite achievements in reducing GHG emission intensities.
It is important to be aware of the difference between reducing emission intensities and reducing absolute emissions. While lower emission intensity will result in lower total GHG emissions when milk production is constant, this link gets more complicated when milk production increases, as has been the case in Ireland over the last decade.

Research implications

Results from this study indicate that further reductions in GHG emission intensities can be achieved by increasing farm productivity. However, pushing productivity growth as a mitigation option for GHG emissions from the dairy sector is not a panacea. For instance, if dairy farms expand output through greater use of chemical fertiliser or imported purchased feeds, this could lead to productivity gains, but at the same time increased emission intensity, and consequently higher total GHG emissions. The same could be said for farmers entering dairying from a different sector (livestock or tillage), as these tend to have lower farm-level emissions.
Hence, in order to reduce emission intensity, productivity gains need to be achieved through pathways that reduce GHG emissions, such as those identified in the Teagasc GHG MACC Report (Lanigan *et al.*, 2018). This means that productivity growth needs to be complemented with further mitigation measures to directly reduce absolute GHG emissions. The Teagasc Signpost Programme, a new initiative to lead climate action in agriculture, directly aims to address this issue.

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Competitive without quotas

Research from TEAGASC is looking at the international competitiveness of the Irish dairy sector post quotas.

The dairy industry in the European Union (EU) has undergone significant structural adjustments over recent years due to various factors such as prices, weather, environment, and policies. Of particular importance to this study is the removal of the EU milk quota regime in 2015. The milk quota system was introduced in 1984 to constrain the growth of milk production and to ensure that the EU would be able to continue to fund the growing cost of the price support framework. While the policy was beneficial in the beginning, it later became a constraint on the development of the industry because the demand for dairy exports was growing much faster than supply, especially for a net export-oriented country like Ireland.

The objectives of this research are to examine how the competitiveness of the Irish dairy sector at farm and trade level, relative to selected EU member states, has evolved in the post-quota period. The countries selected for comparison in the analysis are among the largest milk producers within the EU, accounting for approximately 75 % of raw cow's milk delivered to dairies in the EU in 2015. The methods employed in the research examined data for a pre-quota abolition period (2012-2014) and a post-quota period (2015-2017), and include:

- partial productivity measures and accountancy-based indicators constructed at the farm level using data from the European Commission's Farm Accountancy Data Network (FADN); and,
- trade-based indicators to assess export competitiveness, namely net export market share and normalised revealed comparative advantage (NRCA), which were constructed using international trade data.

Farm-level indicators of competitiveness

Partial productivity indicators examined included milk yield and solids per cow, stocking rate per hectare, milk production per hectare, milk solids per hectare, and milk production per labour unit. All of the indicators showed that Ireland had the fastest partial productivity growth compared to a list of competitor countries in the EU in the post-quota period.

In addition to partial productivity indicators, both cash costs and total economic costs per kg of milk solids and as a percentage of total output value were also examined. Cash costs of production include all specific costs directly incurred in the production of milk and overhead costs, less depreciation.

Total economic costs include all cash costs of production, plus depreciation and an imputed opportunity cost for family-owned labour, equity and land. While cash costs of production are considered an appropriate indicator of competitive performance in the short term, total economic costs are considered more appropriate indicators of medium- to long-run competitive performance.

Despite the high opportunity costs for owned land and labour in Ireland, Ireland still ranked first in terms of lowest total and cash costs per kg of milk solids post quota (**Figure 1**). This demonstrates an improvement in the competitive ranking for Irish dairy farms from the pre-quota period.

The objectives of this research are to examine how the competitiveness of the Irish dairy sector at farm and trade level, has evolved in the post-quota period, relative to selected EU member states.

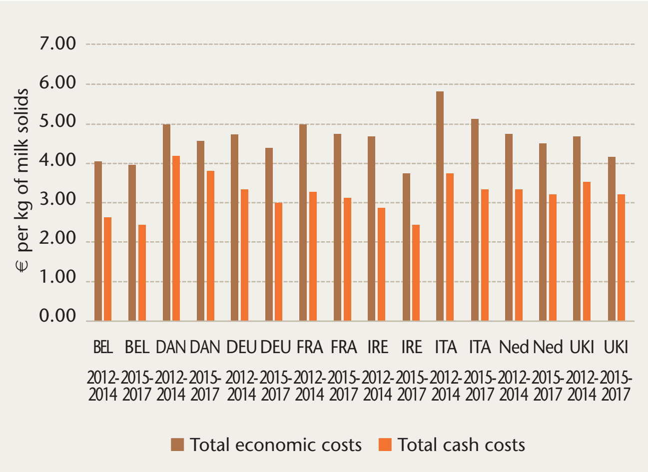

FIGURE 1: Costs per kg milk solids pre and post quota. Source: authors' estimates based on FADN data.

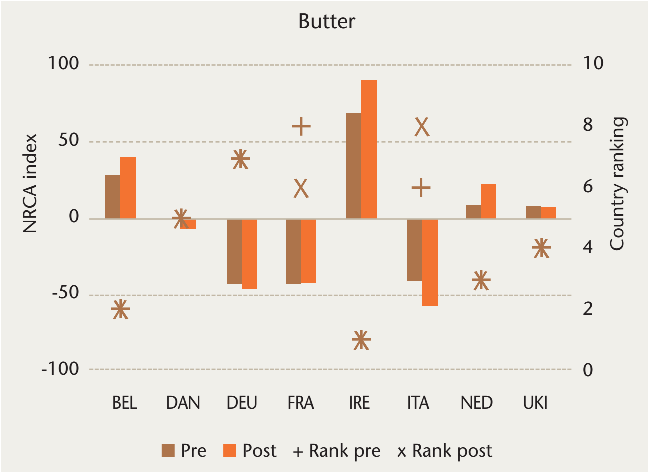

FIGURE 2: NRCA competitiveness ranking across countries for butter. Source: authors' estimates based on FAOstat dataset.

Trade-based indicators of competitiveness

The NRCA was the key indicator of trade-based competitiveness for milk products used in the analysis. The NRCA considers both the country's market share of all commodities in the world export market and the specific commodity market share in the world market.

The higher (or lower) the NRCA score is from zero, the greater the comparative advantage (or disadvantage) for a country. The country with the highest NRCA score is the most competitive across countries within a particular commodity.

The results from the NRCA analysis indicate that Irish dairy products (butter and whey) have demonstrated growth in competitiveness post quota. Irish butter and whey were ranked in the top three across countries, while cheese and liquid milk declined in competitiveness post quota. The results for the NRCA for butter are illustrated in **Figure 2**.

Implications

The study is the first of its kind to use both farm- and trade-based competitiveness measures to analyse the Irish dairy industry relative to other countries.

The results indicate that among the EU countries examined, Ireland was ranked as the most competitive at farm level in the post-quota period and the competitive position in Ireland has improved in the post-quota period.

Unlike previous studies on dairy export competitiveness, this study has disaggregated processed dairy products, which facilitates the ranking of countries at the product level. Similar to the results at farm level, the competitiveness position of Ireland in the butter and powders market has improved in the post-quota period and Ireland is one of the most competitive exporters in the EU.

However, Ireland's competitiveness position in the international cheese market has declined in the post-quota period, an interesting finding that warrants further investigation.

Acknowledgements

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Structured for success?

Researchers from TEAGASC and UCC examined the impact of land structure on the economic performance of dairy farms.

Efficient and effective land management is a key element of a more productive and environmentally sustainable pasture-based livestock sector. The efficiency of dairy farming has implications for the environment, in terms of the efficient use of natural resources and farm inputs, and the rural economy, in improving productivity of the sector.

Ireland's agricultural land market

The Irish agricultural land market is particularly interesting given the notably low levels of sales each year, reflecting high sentiment for family-owned land. Agricultural land sold in 2018 was just 0.3 % of available agricultural land in Ireland (CSO.ie, 2019). In addition, 19 % of agricultural land is rented in Ireland compared to an EU average of 54 % (European Commission, 2018). Furthermore, agricultural land in Ireland is fragmented, with many farms containing a number of scattered land parcels. This results in increased labour and machinery costs for farmers. There has been rapid expansion of the dairy sector following the abolition of EU milk quotas in 2015. Dairy farming is largely pasture based and, therefore, sensitive to land availability.

> Irish agricultural land is fragmented, with many farms containing a number of scattered land parcels.

The transferring of agricultural land through sale and rental agreements helps to reduce land fragmentation. In recognition of the importance of land management to the overall productivity of the dairy sector, tax relief has been introduced for land consolidation and long-term land leasing. Capital Gains Tax relief is available for land consolidated by sale, purchase or exchange (Revenue, 2020a). Stamp duty of 1 %, reduced from 6 %, is applied to the excess value of land acquired over the value of the land disposed of. The exchange must occur within a 24-month period (Revenue, 2019). From 2015, up to €40,000 of income tax relief can be obtained on a 15-year land lease (Revenue.ie, 2019). Evidence suggests that the tax relief is encouraging long-term land leasing as the number of long-term land leases in Ireland has increased from 5,130 in 2014 to 10,820 in 2018 (Revenue, 2020b).

Research on land fragmentation in Ireland

Research carried out by economists at Teagasc and University College Cork, recently published in the *Journal of Agricultural Economics*, examines the impact of land structure on dairy farm efficiency.

A farm is deemed to be efficient if it is maximising its milk production from a given set of inputs (e.g., land, labour, capital and herd size). Data from the Teagasc National Farm Survey and the Spatial Land Identification Database for Éire (SLIDE) are analysed to assess the effect of the following aspects on dairy farm efficiency: the number of land parcels; parcel size; the distance between parcels and the dairy platform; and, the portion of land on the main farm.

The Land Parcel Identification System (LPIS) dataset was merged with a spatial data storage model known as 'Ordnance Survey Prime 2' to create the SLIDE database.

The data shows that the average number of land parcels on dairy farms in Ireland is six. The distribution of land parcels across dairy farms is provided in **Figure 1**.

Our findings show that as dairy farms increase in size, they become more efficient. However, the opposite is true when farm size is increased through additional land parcels. Our analysis also finds that farming land parcels of less than three hectares can reduce efficiency. Having a greater portion of land on the main farm and shorter travel distances to land parcels were found to improve efficiency. Notably, farms with a high percentage of rented land are increasingly efficient. Farmers can, therefore, benefit from expanding their land through renting land that is adjoining or close to their existing farmland. Two additional means to increase efficiency are the employment of hired labour when family labour resources are not sufficient and the use of advisory services.

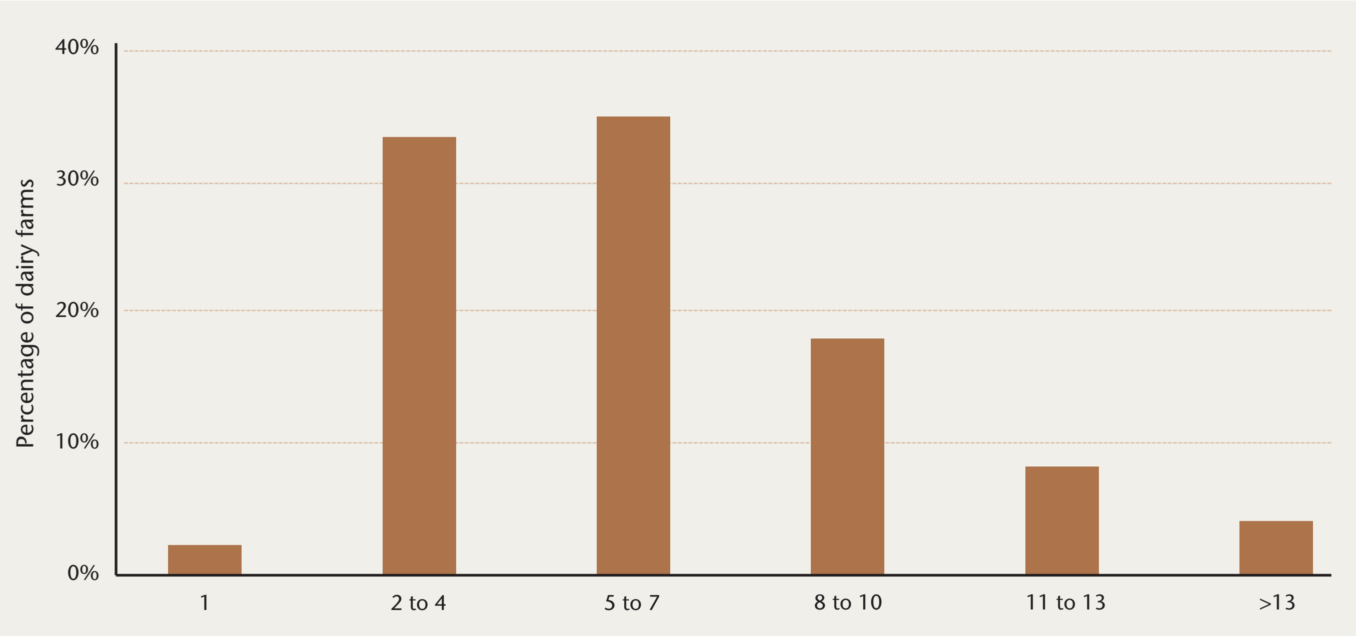

FIGURE 1: Land parcels on Irish dairy farms. Data source: SLIDE (2014).

Policy recommendations

Our results confirm that incentives to encourage land leasing and consolidation are justified to improve the efficiency of dairy farming, especially given the extremely low level of land sales in Ireland each year. With tax relief in place for leasing out or transferring land, landowners can financially benefit from leasing or transferring underutilised land. These policies benefit farmers, the aggregate Irish economy and, more generally, food security through increased milk production. Additional policy implications lie in the advantages hired labour offers to individual farms and the overall economy.
Therefore, the promotion of job creation in the dairy sector, along with secure employment contracts, will improve farm performance and boost the economy through the multiplier effect.
This is important for the retention of employment in agriculture and rural areas. The use of advisory services should also be encouraged due to the benefits they provide in improving dairy farms' efficiency.

Acknowledgement

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Further information

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August

August 16 to 19

WAFL 2021 CONFERENCE

The 8th International Conference on the Assessment of Animal Welfare at Farm and Group Level takes place virtually this year. The science of animal welfare has a large part to play in helping to attain a sustainable way of living in the future. There is also growing awareness and concern among many people around the world regarding the treatment and welfare of animals, and our responsibilities towards them. This has led to a growing shift in focus away from simply ensuring that managed animals do not have poor welfare, and towards providing them with a good quality of life. Attendees will share and learn about advances in this field of study, and help to strengthen connections between animal welfare scientists around the world.

Contact: wafl2021@abbey.ie
https://www.wafl2021.com/

August 4 (9.30am-10.30am)

TEAGASC RESEARCH INSIGHTS WEBINAR: INCREASING ENERGY USE EFFICIENCY ON IRISH FARMS

This webinar will focus on technologies to increase energy use efficiency on Irish farms, looking at dairy and pig farms specifically. There will also be an update on opportunities for agri-renewables.

Contact: Padraig.French@teagasc.ie
https://www.teagasc.ie/about/research--innovation/teagasc-research-insights-webinars/

September

September 1

INFOGEST WEBINAR SERIES ON FOOD DIGESTION

These webinars begin on September 1 and continue on the first Wednesday of each month until December. Understanding the effect of food on human health is a current research priority in Europe. INFOGEST is an international network of scientists from academia and industry, with the aim of sharing information on food digestion. The INFOGEST webinar series is hosted by André Brodkorb of Teagasc. Each webinar focuses on a different theme related to the INFOGEST working groups and features speakers from the INFOGEST network and beyond.

Contact: andre.brodkorb@teagasc.ie or muireann.egan@teagasc.ie
https://www.teagasc.ie/food/research-and-innovation/webinars/infogest-webinar-series/

September 14 — *Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork*

MOOREPARK'21 OPEN DAY

The Moorepark'21 Open Day will take place on September 14, subject to Covid-19 restrictions. The theme of Moorepark'21 is 'Irish Dairying: Delivering Sustainability'. The Irish dairy industry has expanded significantly in recent years. Morepark'21 will highlight the various technologies and practices available to underpin future farm and sector profitability and sustainability.

Contact: Margie.egan@teagasc.ie
https://www.teagasc.ie/news--events/national-events/events/moorepark21-open-day.php

September 17

SEASOLUTIONS WEBINAR:

Seaweeds & seaweed-ingredients to reduce enteric methane emissions from pasture-based sheep, cattle and dairy cows

Reducing methane emissions from cows, cattle and sheep is one of the biggest challenges to face the agricultural sector in the last decade. The SEASOLUTIONS project is committed to making a positive impact on methane emissions in agriculture by positively affecting the rumen and rumen microbiota using seaweeds and seaweed-derived ingredients to reduce methane emissions and improve ruminant health. This multi-actor webinar will present current findings from the project and planned future activities.

Contact: Maria.Hayes@teagasc.ie
Visit: https://seasolutions.ie/

October

October 26

FOOD INNOVATION GATEWAYS – INNOVATIVE AND SUSTAINABLE DRYING TECHNOLOGIES

Food Innovation Gateways is part of the Teagasc Food Technology and Knowledge Transfer Strategy to support Irish food companies. The Gateways initiative promotes opportunities for the Irish food industry to engage with Teagasc. The subject of the next Gateways event is 'Innovative and Sustainable Drying Technologies', and it will be held as a virtual event. Researchers from Teagasc will present the latest concepts and technologies in dairy processing capabilities, spray drying, powder analysis and next-generation dehydration technologies. Registration details will be announced closer to the event.

Contact: eoin.murphy@teagasc.ie
https://www.teagasc.ie/food/research-and-innovation/research-areas/food-industry-development/food-gateways/

November

November 7-14

FESTIVAL OF FARMING AND FOOD – SFI SCIENCE WEEK AT TEAGASC

Join Teagasc for a series of exciting virtual events this Science Week. This festival is a celebration of the science underpinning sustainable agriculture and food production aimed at a broad audience ranging from primary school students to open events for the general public. This is the International Year of Fruit and Vegetables (United Nations, Food and Agriculture Organization) and the festival will incorporate this theme into many of its activities. This includes an event on sustainable eating from a nutrition and planet perspective, and an event on nutrition and healthy ageing. Other events include A Day in the Life of a Cow where attendees will join us on a virtual tour of the farm and find out what's happening from start to end of the day for the cow.

Contact: science.week@teagasc.ie
https://www.teagasc.ie/scienceweek

For more details on Teagasc's full range of webinars, see https://www.teagasc.ie/news--events/daily/webinars/

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