TEAGASC

Research

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A galaxy within us

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TResearch is an official science publication of Teagasc. It aims to disseminate the results of the organisation's research to a broad audience. The opinions expressed in the magazine are, however, those of the authors and cannot be construed as reflecting Teagasc's views. The Editor reserves the right to edit all copy submitted to the publication.

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EDITOR Catriona Boyle 059-918 3419 catriona.boyle@teagasc.ie
SUBSCRIPTIONS: alison.maloney@teagasc.ie

A galaxy within us - human gut microbiology

In recent years, huge strides have been made in microbiology due to the power and reduction in cost of new sequencing technologies. This has allowed whole communities of microorganisms to be examined, not just the small percentage of microorganisms in any system that can be cultured in the laboratory. Scientists can now study hitherto unknown organisms, and the complex interactions between the often hundreds or thousands of microorganisms in any ecosystem.

One field of science where this is being capitalised on to a great extent is human gut microbiology. We are now gaining a much greater understanding of the role and importance of our microbial communities, not just in digestion, but in our overall health. Of great interest to Teagasc is the fact that recent research has not only demonstrated the importance of gut microbial communities in affecting our health, especially at vulnerable stages of our life (e.g., infants and elderly), but, it also shows that diet can modify the microbial community structure and improve the health of such people.

This opens up fantastic opportunities for the food industry to develop high value products that can make a real contribution to human health. Teagasc has played a leading role in this field of research, through involvement in the highly successful SFI-funded Alimentary Pharmabiotic Centre, led by University College Cork, through significant projects funded by the Department of Agriculture, Food and the Marine, and through projects such as ELDERMET and INFANTMET. A significant feature of this research has been the multi-disciplinary approach – especially across microbiology and medicine, which demonstrates the progress that can be made with the convergence of disciplines.

In this issue of *TResearch*, the Teagasc researchers involved in these collaborations have written articles that outline recent research in this rapidly emerging area. They highlight the excellent and groundbreaking science that is being carried out, the resulting opportunities it is presenting to the food and pharma industries and, very importantly, the improvement that it could make possible in our health.

Dr Frank O'Mara
Director of Research, Teagasc
Teagasc Head Office, Oak Park, Carlow

An chruinne istigh ionainn – an mhicribhitheolaíocht i bputóg an duine

Tá dul chun cinn mór déanta le blianta beaga anuas sa mhicribhitheolaíocht cionn is go bhfuil na teicneolaíochtaí nua seichimh chomh cumhachtach sin agus go bhfuil laghdú tagtha ar na costais a bhaineann leo. Is mar gheall air seo atáthar in ann mionscrúdú a dhéanamh ar phobail iomlána miocrorgánach, agus ní hamháin ar chéatadán beag de mhiocrorgánaigh sna córais a fhástar sa tsaotharlann. Tig le heolaithe anois staidéar a dhéanamh ar orgánaigh nach raibh a fhios againn roimhe seo gurb ann dóibh ar chor ar bith agus ar an idirghníomhú casta idir na céadta agus na mílte miocrorgánaigh in éiceachórais éagsúla.

Tá réimse ar leith den eolaíocht ag teacht i dtír ar na cumais úra seo, mar atá an mhicribhitheolaíocht i bputóg an duine. Táimid ag teacht ar thuiscint níos fearr ar ról agus ar thábhacht na bpobal miocróbach ní hamháin i gcúrsaí díleáite ach maidir lenár sláinte ghinearálta. Tá suim mhór ag Teagasc i dtaighde a rinneadh le deireanas a léiríonn tábhacht na bpobal miocróbach i bputóg an duine ó thaobh na sláinte de, go háirithe ag na céimeanna is leochailí sa saol (e.g. naíonáin agus daoine aosta). Is ábhar mór spéise dúinn freisin gur féidir leis an aiste bia againn struchtúr na bpobal miocróbach a athrú agus sláinte daoine leochaileacha a fheabhsú. Tá deiseanna móra ann don tionscal bia táirgí ardluacha a fhorbairt agus cur ar dhóigh fhiúntach le sláinte daoine, agus tá ról ceannasach ag Teagasc i réimse seo an taighde. Bhí páirt ag Teagasc in Ionad rathúil Cógasbhitheach an Bhia, atá maoinithe ag Fondúireacht Eolaíocht Éireann agus a bhfuil Coláiste na hOllscoile, Corcaigh i gceannas air. Bhí Teagasc páirteach freisin i dtograí suntasacha eile maoinithe ag an Roinn Talmhaíochta, Bia agus Mara agus i dtograí mar ELDERMET agus INFANTMET. Gné shuntasach den taighde seo is ea an cur chuige ildisciplíneach, le lucht micribhitheolaíochta agus lucht míochaine go háirithe ag obair le chéile. Is léiriú é ar an oiread dul chun cinn is féidir a dhéanamh nuair a thagann disciplíní difriúla le chéile. Tá ailt san eagrán seo de *TResearch* scríofa ag taighdeoirí Theagasc atá ag glacadh páirte sa chomhoibriú. Tá cur síos acu ar an taighde atá déanta ar na mallaibh sa réimse seo atá ag teacht chun cinn go mór anois. Tá plé ann ar an eolaíocht nua ardleibhéil atá á déanamh mar aon leis na deiseanna atá ar fáil anois don tionscal bia agus don tionscal cógaisíochta. Agus níos tábhachtaí fós, tá tagairt ann don bhiseach is féidir a chur ar ár sláinte.

An Dr Frank O'Mara
Stiúrthóir Taighde
Teagasc Ceannoifig Theagasc, Páirc na Darach, Ceatharlach

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Dr Martin Danaher

Dr Martin Danaher is a Senior Research Officer with Teagasc Food Research Centre, Ashtown in Dublin and Head of the National Laboratory for Veterinary Drug Residues.
He has a BSc in Industrial Chemistry from the University of Limerick (1997) and began his career as an R&D Chemist with Gerard Laboratories in 1997.
He joined Teagasc in 2002 and completed his PhD in Analytical Chemistry at University College Cork in 2003.
He is lead scientist in the chemical contaminant programme in Teagasc and head of the NRL for veterinary drug, feed additive and pesticide analysis in food. He leads a team of approximately 12 staff.
Dr Danaher is currently head of an ISO17025 laboratory which is accredited by the Irish National Accreditation Board.
The laboratory provides a service to the Irish food industry and is also a national reference laboratory (NRL) for residue analysis.
Dr Danaher is an acknowledged expert in the area of veterinary drug residue analysis and many of his methods are used worldwide, particularly in the area of anthelmintic drug analysis. He is credited with the identification of flukicide residues as an emerging contaminant in food of animal origin, particularly milk. His work supported the setting of new EU Maximum Residue Limits for four flukicide drugs in milk, namely, triclabendazole, nitroxynil, clorsulon and closantel.
The methodology developed by his team is now used as the EU reference method for some of these drugs.
Dr Danaher has over 50 peer-reviewed publications and received 137 citations in peer-reviewed literature in 2012.
He acts as referee for more than 20 journals, including high impact journals such as *Analytical Chemistry*, *TRAC*, *Biosensors* and *Journal of Chromatography A*.
Dr Danaher's research interests have focused on four main areas:

- analytical chemistry – chromatographic separations, sample purification, mass spectrometry, biosensors and immunoassays;
- residue analysis – agrochemicals, environmental, natural toxins and adulterants;
- databases – co-ordinator of Ireland's National Food Residue Database and the Veterinary Drug and Feed Additive Database; and,
- exposure/risk assessment – exposure to, and risk assessment of, contaminants from food.

Teagasc excels in SCImago Institution Ranking

According to the 2013 SCImago Institution Ranking (SIR) report, Teagasc placed more publications in top quartile journals within its category than any other Irish research organisation. It has the second highest excellence rate in the country, coming after TCD, with 19% of Teagasc publications being among the 10% most highly cited within their field. Teagasc is the main contributor on 9% of those which, according to the SIR report, displays excellence with scientific leadership. Teagasc also has a favourable international collaboration rate of 41% and the impact of Teagasc publications are reported as 37% above the world average for similar publications. "Taken as a whole, the SIR report shows that Teagasc is up there with the very best in the world when it comes to the support we give the agriculture and food sectors through our research efforts," says Teagasc Director of Research, Dr Frank O'Mara.
Published by the Spanish-based SCImago Research Group, the SIR report analyses the research outputs of universities and research-focused institutions and compiles a range of bibliometric indicators based on publications appearing in scholarly journals indexed by the abstract and citation database, Scopus. To qualify to be included in the report a research organisation must have published at least 100 papers in the last year of the five-year period analysed in the report. The 2013 SIR report looks at the period 2007-2011 and Teagasc comfortably met the criterion having produced 1,405 scholarly documents indexed by Scopus.
The full 2013 SIR report can be found at www.scimagoir.com

Walsh fellow to present at conference down under

Teagasc Walsh Fellow student, Sarah Henneberry, competed to receive an expenses paid trip to 'Masterclass and International Conference on Food Structure, Digestion and Health 2013', in Melbourne Australia. This student competition was judged by EU FP7 on the basis of a submitted abstract. Sarah Henneberry is supervised by Dr Phil Kelly, Professor Tim Guinee and Dr Kieran Kilcawley at Moorepark, with academic supervision by Dr Martin Wilkinson, University of Limerick.

Lecturer appointment

Dr Dilip Rai, Teagasc Food Research Centre, Ashtown, has been appointed as adjunct lecturer at University College Dublin School of Chemistry and Chemical Biology.

Taste test of seaweed bread end-product on The Science Squad.

Teagasc researchers feature on The Science Squad

Teagasc researchers featured in the latest series of The Science Squad on RTÉ. Stuart Green, Spatial Analysis Unit, Ashtown, featured in an episode where he talked about his work monitoring grass growth using satellite imaging. Dr Maria Hayes and Dr Ciaran Fitzgerald, Teagasc Food Research Centre, Ashtown, spoke about the development of seaweed bread products with heart health benefits. Dr Stephen Butler, Moorepark, featured in an episode where he talked about using sexed semen in dairy production.

All episodes can be seen on RTÉ Player: http://www.rte.ie/tv/programmes/sciencesquad.html

Working with New Decade on developing Teagasc's content for the series were: Catriona Boyle, Science Writer/Editor; Eric Donald, Head of PR; and Dr Frank O'Mara, Director of Research.

Global initiatives meet on climate change and food challenges

Seven international research-related initiatives on agriculture, food security and climate change met during the summer to discuss common future research challenges, opportunities for stronger interaction, and its relevance to international climate change and food security policy discussions.

This meeting, held in Bonn, was co-chaired by the Joint Programming Initiative on Agriculture, Food Security and Climate Change and the High-Level Panel of Experts of the United Nations' Committee on World Food Security, and convened five other international initiatives from different geographical regions.

Dr Rogier Schulte, leader of Teagasc's translational research programme on sustainable food production represented Teagasc at the meeting.

Participants met for two half-days in an open and inclusive workshop, and agreed on the opportunity and need for continued and stronger interaction, including through an annual meeting, and on the value-added of shared learning on common methodological research challenges and cross-cutting questions, building on each initiative's strengths.

To build on the prevailing dynamic, the initiatives agreed to organise the workshop in June 2014, open not only to international, but also to relevant regional research-focused partners.

The gathering took place in parallel to a series of scientific and technical sessions of the United Nation Framework Convention on Climate Change.

Teagasc/IFA pig programme

The Teagasc/IFA Pig Joint Research and Advisory Programme was launched recently. Through the Joint Programme, Teagasc will support Irish pig producers by providing advice, research and education across a range of issues of importance to the sector. The funding for the programme is provided through a pig producer levy and will enable Teagasc to improve its services to the pig sector.

Ciarán Carroll, Head of Teagasc Pig Development Department welcomed the initiative saying: "The programme will enable Teagasc to provide a broader range of services to the sector. The levy will be used to fund two new advisers, two new researchers and a technician. Teagasc and IFA have been working on this programme for a few years now, so it's great to see it come to fruition".

DAFF stimulus fund

Teagasc and NUI Galway have been granted €400,000 for two joint research projects under the Department of Agriculture's €6 million Research Stimulus Fund.

The first project, 'Join-to-Farm', will explore how a broad range of joint farming ventures could enhance the sustainability of Irish agriculture. The project brings together social scientists: Dr Áine Macken-Walsh, Teagasc; Dr Kevin Heanue, Teagasc; Dr Anne Byrne, NUIG; Professor Michael Ward, UCC; and Dr Olive McCarthy, UCC.

The second project, 'Agile-Tech', examines how technology use by farmers evolves over time. The project involves social scientists: Dr Kevin Heanue, Teagasc; Dr Áine Macken-Walsh, Teagasc; Ann Lyons, NUIG; Mary O'Reilly-de Brún, Centre for Participatory Strategies; and Tomás de Brún, Centre for Participatory Strategies.

The traditional farmed landscape of the Aran Islands. Image courtesy of Patrick McGurn.

MushTV delivering new technologies to the European mushroom industry

MushTV, an EU FP7 project co-ordinated by Dr Helen Grogan of Teagasc, is half way through its three-year term and already promising results are emerging (see article on p36). The Consortium of 17 industry and research partners from across Europe (www.mushtv.eu) had their first major public dissemination event at the International Mushroom Days Trade Fair in s'Hertogenbosch, the Netherlands, earlier this year. Over 3,000 attended the event, including mushroom growers and businesses from Ireland, the UK, Poland, Australia, the US and China. The MushTV stand presented information on the project's progress, with a poster on *Trichoderma* growth in Phase 3 compost and another on Mushroom Virus X characterisation.
Thomas Martin, CEO of the Monaghan-based Commercial Mushroom Producers (CMP), attended the event with a group of Irish growers to find out about the latest market developments and technologies. He commented: "This research is ground-breaking on at least two fronts. Firstly, in examining the pathology and pathways of spread of mushroom diseases in detail and, secondly, in mapping for the first time the genomes of viruses that adversely affect crop yield and mushroom quality."

AranLIFE

The Department of Arts, Heritage and the Gaeltacht has confirmed the provision of €2.6 million funding for Aran Islands conservation under the EU's LIFE+ programme.
The AranLIFE Project will run for four years from 2014, working with local farmers to support traditional island farming practices and maintain the islands' significant natural and cultural heritage. As a project partner, Teagasc's participation involves contributing finance and funding a Walsh Fellowship for four years.
The Aran Islands are of such high value for nature that over 75% of the land area has been legally designated as Natura 2000 sites under European legislation. However, working with these designations, the small nature of island farms and the high labour input required means that farming on the islands faces many challenges. The early impacts of a reduction in farming activity are becoming evident, in the form of undergrazed pastures and overgrown fields. Traditional knowledge and practices are also being used less. These changes are affecting the islands' significant natural heritage, including their limestone pavement and orchid-rich grasslands, and will affect their social and economic fabric.
The AranLIFE project has been set up to tackle some of these challenges over the next four years, working with the farming communities, increasing awareness of the natural heritage of the islands, leading to an improvement in the condition of the Natura 2000 sites, and turning the designations from a challenge to an opportunity.
The AranLIFE Project is an integrated project between the Department of Arts, Heritage and the Gaeltacht, the Heritage Council, the European Forum for Nature Conservation and Pastoralism, Institute of Technology Sligo, Teagasc, and the farming communities of the three Aran Islands. Additional funding is provided by the Department of Agriculture, Food and the Marine, Galway County Council and Fáilte Ireland.
The Department of Arts, Heritage and the Gaeltacht is the Coordinating Beneficiary or lead applicant for the project.

CFMATTERS – €6 million EU research award

An international consortium of Cystic Fibrosis clinicians and scientists, led by Dr Barry Plant of the College of Medicine and Health, Alimentary Pharmabiotic Centre and the HRB-Clinical Research Facility, University College Cork/Cork University Hospital, has launched a major EU-funded collaboration project focused on the development and trial of personalised antibiotic treatment for patients with CF during respiratory infections. CFMATTERS, an acronym for 'Cystic Fibrosis Microbiome-determined Antibiotic Therapy Trial in Exacerbations: Results Stratified', will receive approximately €6 million in funding from the EU's Seventh Framework Programme.
The CFMATTERS consortium brings together a diverse international group of renowned CF experts from academic institutions/hospitals across Europe and the US. CFMATTERS partners include: University College Cork and Teagasc; Queen's University of Belfast; Universitätsklinikum Heidelberg (Germany); and the University of Washington in Seattle (US).
The unique project is the first randomised, controlled trial comparing the use of microbiome-directed antibiotic treatment versus standard therapy for patients with CF (PWCF) experiencing respiratory infections. Announcing the funding Dr Barry Plant, CFMATTERS coordinator and Director of the Adult CF Centre, Cork University Hospital commented: "CFMATTERS will enhance individual patient responses and decrease drug resistance by employing next-generation technologies."

Pictured at the Teagasc National Beef Conference 'Profitable Beef from the Dairy Herd' were: Dr Paul Crosson, Teagasc Animal & Grassland Research and Innovation Centre, Grange; Tom English (beef farmer, Wexford); Pearse Kelly, Head of Drystock Knowledge Transfer Department, Teagasc; Sarah Long (Dawn Meats), Dr Robert Prendiville, Bull Beef Project, Teagasc, Johnstown Castle; and Professor Gerry Boyle, Director of Teagasc.

National Beef Conference

Speaking at the National Beef Conference, Dr Paul Crosson, Teagasc, Grange examined the potential returns from the different dairy calf to beef systems: "Gross margins of almost €1500/ha and net margins of almost €900/ha are achievable from dairy calf to beef systems. The key issues are to have excellent herd health minimising losses and to attain a very high percentage of total lifetime gain from grazed grass. Systems based on early maturing crossbreds are normally more profitable; however, pure Holstein-Friesian systems are also capable of delivering good economic returns." Beef carcass specifications from the different systems and breeds were discussed at the conference with an impressive line-up of beef market experts – including beef processors, Tesco and Bord Bia – taking part in a panel discussion on what the markets now require and the bonuses that are available, particularly for the traditional breeds.
Dr Rob Prendiville of Teagasc outlined the latest research from the different calf-to-beef systems that have been running in Teagasc Johnstown Castle over the last three years.

TResearch reader survey

An online reader survey for *TResearch* magazine and subsequent qualitative interviews with key stakeholders rated the magazine very highly (four out of five across a range of criteria).
The editorial committee thanks everyone that participated in the survey and will endeavour to use the information gathered to continue to improve the publication and ensure it is meeting readers' needs.

Cow production index

A new dairy cow index is currently being developed by the research team at Teagasc, Moorepark in conjunction with the Irish Cattle Breeding Federation as part of Margaret Kelleher's PhD. The cow production index (CPI) is designed to rank cows on their expected profitability, taking cognisance of both genetic and environmental factors. The Economic Breeding Index, EBI, also developed in Moorepark with the ICBF, only includes genetic effects. The ability to identify the profit potential of cows is essential in enabling farmers to make more informed culling decisions.
The heterosis effect associated with crossbreeding is not included in the EBI; this is because heterosis is not completely transmitted from parent to offspring. This heterosis component will be included in the new cow production index and will, therefore, be of particular interest to farmers engaged in crossbreeding. Some past managerial or other environmental perturbations can affect an animal's production for the rest of its life but are not transmitted to offspring.
Examples include feeding regimes implemented during the heifer-rearing stage or an injury that influenced the animal's subsequent performance.
These are generally not under genetic control (and, therefore, not transmitted to offspring) but can influence the cow's performance for the rest of her life.
The parity of the animal and its expected next calving date also impact on the future profitability of the cow so both terms will also be included in the new index.

Teagasc authority appointments

The Minister for Agriculture, Food and the Marine, Simon Coveney, TD, has re-appointed Dr Noel Cawley as Chairperson of the Teagasc Authority for a second five-year term. The Minister has also appointed the following as ordinary members of the Teagasc Authority: Padraig Gibbons, on the nomination of ICOS (reappointment); Alan Jagoe, on the nomination of Macra na Feirme; and Professor Gerald Fitzgerald, Professor of Food Microbiology, University College Cork.

Agrofood Sector Group

Enterprise Ireland recently hosted the Agrofood Sector Group at Teagasc Ashtown Food Research Centre. The Agrofood Sector Group comes under the umbrella of The Enterprise Europe Network which helps small companies make the most of the business opportunities in the European Union. The group comprises over 50 people from 21 partner countries, which have a high number of companies working in the agrofood sector in their region that want to improve their innovation capabilities.
The objectives of the group are to raise the innovation capacity of SMEs through the promotion of technology transfer and business cooperation and to provide feedback on the EC policies in the agrofood sector on behalf of the industry. Experts from Enterprise Ireland, Bord Bia and Teagasc outlined the supports available to Irish SMEs in the agri-food sector, followed by a tour of the research centre.

BIG IDEAS

The Enterprise Ireland BIG IDEAS showcasing event held in the AVIVA stadium recently represented the first co-ordinated event between the Technology Transfer Offices of UCC, Cork IT and Teagasc through a common stand at the event, presenting the new consortium and available technologies seeking industry partners. This follows on from a recent successful consortium bid to the EI technology transfer strengthening initiative (TTSI) fund, led by UCC, which supports technology transfer offices of public research institutes to facilitate technology transfer from such institutes to industry. The BIG IDEAS Showcase provides a public platform for the inventors and promoters of commercial opportunities developed in Ireland's public research institutes/ organisations, including the pitching of technologies to the investor community.

Fulbright-Teagasc awards

Thirty-seven Fulbright Awardees were officially announced at an event on the ship, MS The World, which was sponsored by a US Fulbright alumnus, Dr Jack Pinkowski and his wife, Monica Pinkowski, as part of The Gathering in July. Since 1957, the Fulbright Awards have been given annually by the Irish and US governments, and provide Irish students, scholars, and professionals with the opportunity to study, lecture, and research at top universities and institutions throughout the United States. Shane Crowley is the Fulbright-Teagasc Student Awardee. Shane will be researching the isolation of individual dairy proteins in order to fortify foods and enhance their nutritional profile at the University of Wisconsin, Madison, as part of his ongoing PhD at University College Cork. Applications for the 2014-2015 academic year are due by Wednesday, November 13, 2013. See www.fulbright.ie.

42nd Annual Food Research Conference

Dr André Brodkorb (right) presenting the Teagasc Prize for the Best Oral Presentation to Ruth Keary (left) from Cork Institute of Technology for her work entitled "Use of a bacteriophage-derived enzyme for staphylococcal biofilm control" at the 42nd Annual Food Research Conference, which was hosted by Teagasc Food Research Centre, Ashtown this summer.

Dr Pierre Geber of the FAO and Dr Rogier Schulte, Teagasc, examine artist Ian McNinch's impression of the farm.

Sustainability Demonstration Farm launched

What will the farm of the future look like? How efficient are our farms in terms of nutrient use? How do we fare in fostering farmland biodiversity? How much water do our farms consume? What is the carbon footprint of Irish milk? These were the questions being debated at the launch of Teagasc's new sustainability initiative "Kildalton 2030: Leading Sustainable Growth".

Over 100 scientists, farming stakeholders and policy makers gathered on October 3 at Teagasc Kildalton College for a seminar entitled "Proof & Prospects" to discuss the green credentials of Irish agriculture and to launch a sustainability demonstration farm at the college. Teagasc is now bringing together and showcasing its expertise on sustainability in this new sustainability demonstration farm. This initiative will train the next generation of farmers in the conceptual and practical aspects of agricultural sustainability and provide a unique environment to evaluate emerging technologies in the context of an operational farm.

Irish farming claims to be among the most sustainable producers of food globally – a crucial asset in marketing Irish produce. With our grass-based livestock systems, our temperate climate and rich natural heritage, Irish farming is in an ideal position to capitalise on the demand for food that is produced sustainably.

At the launch of the "Kildalton 2030: Leading Sustainable Growth" initiative, Director of Teagasc, Professor Gerry Boyle said: "Irish agriculture has a unique opportunity to secure a future for farming, a future that is sustainable in the widest sense of the word: economically, environmentally and socially."

Principal of Teagasc Kildalton Agricultural College, Frank Murphy said: "Over the next seven years, we will transform the dairy farm at Kildalton College into a showcase of sustainable dairy production. This initiative will assist in training students in all aspects of agricultural sustainability."

Healthy heart probiotic technology

Teagasc Technology Transfer Office details a novel technology relating to a nutritional approach to lowering cholesterol through use of a lactic acid bacterial strain (LAB).

Teagasc and University College Cork (UCC) researchers, Professor Catherine Stanton and Professor Noel Caplice, have developed, and continue to develop, a probiotic-based technology relevant to the functional/medical food industry in the area of cholesterol reduction. Discussions with companies in this space are welcome, with the ultimate aim to license out the technology, when fully validated.

Background

Globally, a third of ischaemic heart disease is attributable to high cholesterol, with raised cholesterol estimated to cause 2.6 million deaths annually. The maintainance of normal blood cholesterol levels is one of the recommendations to avoid heart disease. Low consumer compliance with dietary recommendations for cardioprotective diet and the expense and side effects of drug therapy (statins), aligned with increased consumer acceptance of foods with additional health benefits has led to significant opportunity for nutritional approaches in the heart health area.

Solution

The invention broadly relates to a novel LAB strain found to express an epoxypolysaccharide (EPS) and confer cardioprotective properties when consumed. Scientific data has shown that a probiotic yoghurt containing novel EPS-producing Lactobacillus mucosae DPC6426 can lower blood cholesterol by 53% in 12 weeks, with significantly-increased cholesterol excretion found for the probiotic yoghurt-fed group. LAB strains are widely added as starter cultures in the dairy industry and have a long history of safe use. The presence of EPS in dairy products improves texture and improves the techno-functional properties of the products, while it is suggested that EPS produced by LAB interacts with cholesterol in a manner like dietary fibre.

Competitive advantage

The novel technology exhibits three key benefits:

- LAB is generally regarded as safe (GRAS) according to the FDA;
- *in situ* production of EPS throughout storage leads to high-quality yoghurt; and,
- blood cholesterol is reduced by 53% in 12 weeks.

Opportunity

Teagasc and UCC researchers are currently working on validation of this technology with the objectives of:

- establishing the efficacy of the cholesterol-lowering properties and effects on plaque stability of the probiotic in animal studies;
- determining the mechanism of action and benchmarking against plant sterol esters and oat beta-glucan; and,
- conducting a human intervention trial to compile a dossier in support of a health claim application.

Should this prove successful, the opportunity will exist for a food/ingredients company to license this technology and expressions of interest are welcome as such research progresses.

Intellectual property and funding status

A patent application was filed in 2013, protecting the novel strain, the isolated EPS and its uses for cholesterol reduction in pharmaceutical formulations and food products. Enterprise Ireland-funded Commercialisation Fund research is due to continue until 2016.

This research was supported by the Department of Agriculture, Food and the Marine and Enterprise Ireland in collaboration with UCC.

For further information:

Contact Dr Miriam Walsh, Teagasc. Tel: + 353 59 918 3477. miriam.walsh@teagasc.ie
or Kevin Dalton, UCC. Tel: +353 21 490 1798. k.dalton@ucc.ie

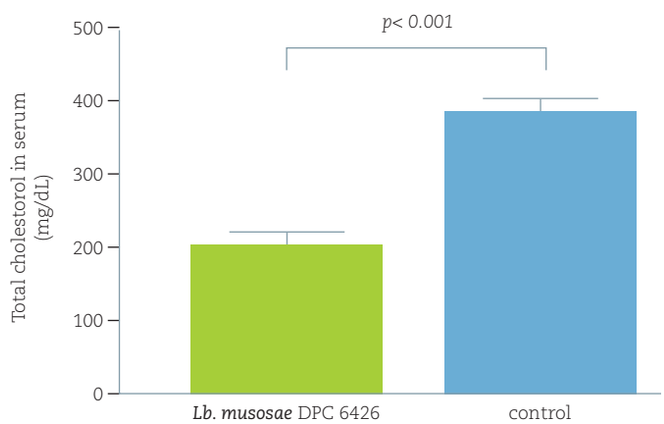

Figure 1: Total cholesterol concentrations in serum of apoE-deficient mice after 12 weeks consuming 60% (kcal) fat diet with 2% (w/w) cholesterol and administration of *Lactobacillus mucosae* DPC 6426 and control group.

Open day shares insights on Ireland's dairying potential

Dr Deirdre Hennessy gives an overview of the Teagasc Moorepark Open Day.

Dr Deirdre Hennessy, ResearchOffi cer, Teagasc, Animal & Grassland Research and Innovation Centre,Moor epark, F ermoy,CoCork . Correspondence: deirdre.hennessy@teagasc.ie.

Approximately 10,000 visitors attended the Teagasc Moorepark National Open Day, "Irish Dairying – Harvesting the Potential", sponsored by FBD Trust, on July 3. Visitors met and interacted with researchers and advisors at research stands, themed villages, demonstrations and a discussion forum. The open day took place just 21 months before the abolition of milk quota, and its focus was on:

- technologies that will help dairy farmers cope with the challenge of volatile milk prices;
- extreme weather conditions (such as those experienced in spring 2013);
- strategies to manage the risks of growing family farm businesses; and,
- the rewards that will be achievable from well-planned expansion.

The main stands dealt with positioning the dairy farm for expansion, developing sustainable dairy systems, growing more grass on farms, the role of the economic breeding index (EBI) in fuelling expansion, achieving 90% of cows calved in six weeks and achieving a healthy herd. In addition, the latest research from a range of programmes including grassland, genetics and reproduction, milk quality, new entrants and expansion, sustainability and Moorepark food research was presented. An interactive grassland demonstration proved a strong attraction, as did a financial planning workshop where real scenarios were examined and the importance of financial planning was outlined. The forum "Pathways for a Career in Dairy Farming" was very popular with visitors.

Resilient dairy farm systems for post-quota era

Irish dairy farming is moving into a period of great opportunity, but also greater uncertainty, as milk quotas are about to be removed and the challenges presented by these changes were addressed during the open day. Visitors heard that this was an opportune time for dairy farmers to review their businesses and develop resilient systems that will allow farm businesses to thrive in this new era. Resilient dairy farm systems are those that utilise their comparative advantage by having a low-cost production base, which, in Ireland, is achieved through low-cost, grass-based milk production systems. The farm system must be developed taking into consideration the land type, land production capacity and rainfall, and must provide a consistent level of production at a consistent cost of production, within the averages of climate, milk price and input price. Flexibility is also crucial to deal with unforeseen circumstances such as a very wet year (like 2012) or a very cold spring (like 2013) or low milk price (like 2009). Cash flow budgeting is crucial for all dairy farmers and particularly those considering expansion as the expansion process will put significant strain

on scarce cash resources. Developing a plan to manage cash on the farm will allow farmers to identify pitfalls and will present the opportunity to find solutions. While we cannot control the uncertainties that impact on the dairy farm business, identifying and developing strategies to deal with the risk will determine if the business can cope with external factors, and, indeed, changes within the farm gate. Developing a strategic plan for the farm business, while taking cognisance of the risks and potential risks associated with dairy farming, provides a solid foundation around which management decisions can be made.

Grassland management for milk production

Data from the National Farm Survey, reported at the open day, shows that the average dairy farm in Ireland has a stocking rate of 1.8 LU/ha on the milking platform, a grazing season length of 210 days and utilises 7.5 t DM/ha annually. Grazed grass is the cheapest source of feed for milk production in Ireland. If the forecasted dairy farm expansion takes place, dairy farms will have to grow considerably more grass.

Farmers need to know how much grass their farm is growing. The optimum stocking rate for an individual dairy farm in a low-cost, grass-based system is dependent on the ability of that farm to grow grass. Many factors influence grass growth including grazing management, poaching damage, soil fertility and perennial ryegrass content of the sward.

A recent Moorepark experiment comparing three pre-grazing herbage masses (low – 1,000 kg DM/ha, medium – 1,500 kg DM/ha and high – 2,300 kg DM/ha) showed that continuously grazing low herbage masses increased the area required for grazing by 30% compared to the medium herbage mass and doubled the area required compared to the high herbage masses. Short grazing rotations (<16 days) required to maintain the low herbage masses had negative effects on grass production. The recommendation from Moorepark is that target pre-grazing herbage mass should be 1,400 – 1,600 kg DM/ha.

PastureBaseIreland

PastureBaseIreland, a new online grassland management application, was launched at the Moorepark Open Day. PastureBaseIreland stores grassland data collected by farmers in a central data base. It has a user friendly decision support tool to aid grassland management. See video on TeagascMedia YouTube channel: www.youtube.com/teagascmedia

Animal health

Herd health is an important aspect of milk production systems. Recent Moorepark research results, which were shared with visitors to the open day, show that the main causes of calf mortality on farms include calving difficulties (dystocia), congenital defects, haemorrhage or anoxia and a combination of causes. Schmallenberg Virus can also contribute to calf mortality through abortions and deformities. Feeding sufficient quantities of high quality colostrum to calves is crucial to ensure calves are healthy and survive. Research at Moorepark shows that colostrum quality is greater in:

- cows in their third or greater lactation;
- when a short interval (<9 hours) between calving and milking occurs;
- in early calving cows (January to March); and,
- in lower yielding cows, irrespective of lactation number.

Exit poll

An exit survey (211 people) revealed that 49% found the event helpful and 50% found the open day very beneficial. 41 % of respondents came to see all exhibits. Individual exhibits that stood out for people were the first stand (Positioning the Dairy Farm for Expansion) and the third stand (Growing More Grass), the grassland demonstration, herd health and financial planning.

The importance of knowing the health status of a herd was highlighted at the open day. Good biosecurity and a good vaccination plan are key factors in helping prevent disease.

Increasing heavy soil productivity

Approximately 30% of milk production in Ireland is from soils classified as heavy. There was great interest at the open day in presentations dealing with farming on heavy soils. Following the wet year that was 2012, many visitors wanted to learn about management strategies to maximise productivity on heavy soils and land drainage. Good soil fertility, high quantities of perennial ryegrass in swards (60% +) and good farm infrastructure are crucial to increasing herbage production on farms with heavy soils. In terms of land drainage, researchers stressed the importance of undertaking a detailed site investigation using test pits before any drainage systems are installed. The two main types of land drainage systems are a ground water drainage system and a shallow drainage system. The most suitable system will depend on the particular drainage characteristics of the soil. A detailed land drainage booklet was launched at the Teagasc Moorepark Open Day (see panel below).

Other highlights

Other highlights at the Teagasc Moorepark Open Day included updates on the next generation herd; the automatic milking system; genetics, reproduction and breeding; carbon foot printing of dairy production systems; and the Moorepark Food Research Programme.

Associated publications

Berry, D., Butler, S. and Dillon, P. (Eds.) (2013) *Moorepark'13, Irish Dairying – Harvesting the Potential* Teagasc, Moorepark Animal & Grassland Research and Innovation Centre, 156 pages [online] available from www.teagasc.ie/publications

Touhy, P., Fenton, O., O'Loughlin, J. and Humphreys, J. (2013) *Land Drainage – A Farmer's Practical Guide to Draining Grassland in Ireland* Moorepark Dairy Levy Research update. Teagasc, Moorepark Animal & Grassland Research and Innovation Centre, 44 pages [online] available from www.teagasc.ie/publications

Energy demand in dairy

Energy demand analysis as a sustainability indicator in dairy production.

John Upton,
Research Officer,
Livestock Systems Research Department, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co Cork.
Correspondence :
john.upton@teagasc.ie

Why measure energy?

Energy consumption in milk production is important because it impacts directly on profitability and environmental footprint. In order to reduce energy consumption we must first understand how, and where, it is consumed. Efficient use of energy is one way to improve the cost competitiveness of the Irish dairy sector.

The aim of this study was to measure baseline data on total energy inputs, as an indicator of the sustainability of the dairy production sector. Indicators based on energy consumption, together with other indicators for land and biodiversity, water use, social effects and financial performance are valuable as tools to assess overall sustainability of agricultural activities and to ensure the continued competitiveness of our food products.

Farm description and data collection

To calculate these energy indicators, data on farm production, direct farm energy use (i.e., fuel and electricity) and indirect inputs (i.e., fertilizers, purchased feed and chemicals) were collected from 22 commercial dairy farms for 12 months. The energy use of each input was calculated using energy coefficients. The energy conversion factors for chemical fertilizers, herbicides, and ingredients of purchased concentrates were based on the international Life Cycle Assessment (LCA) database , and used to convert all inputs to the common unit of energy, the mega-joule (MJ).

Further data, in terms of scale and production, of the farms in this study are presented in Table 1. It is evident that the farms in this study had a much higher milk output than the national average farm and, therefore, were not representative for Irish dairy farms in 2011. The farms in this study represent the larger than average modern dairy farm, with a higher stocking density per ha (i.e., more intensive). However, milk output, and hence herd size, will increase in future if farmers respond to the potential for expansion in milk production identified in the *Food Harvest 2020* report. Results of this study, and hence the conclusions drawn, therefore are relevant for larger and more intensive dairy farms.

Life cycle assessment and data collection

In order to identify hot spots of energy use it was necessary to perform a single issue cradle-to-farm-gate LCA of energy use according to ISO (2006). Results were quantified in MJ per litre (L) of milk production. Data were collected for one year (2011). Over this period all inputs and outputs necessary to compile the life cycle assessment were recorded using a combination of manual recording and wireless data transfer.

Monthly questionnaires were completed by each farmer. Data collected included: quantity and type of fertilizer used; quantity of diesel consumed; area of land worked by contractors; concentrate feed used; forage/manure/slurry imported or exported from the farm; quantity and type of farm chemicals used; and a stock take of all animals. In addition to this data, milk production and composition information was obtained from the milk processors.

Electricity consumption was recorded using a wireless monitoring system. Cumulative electricity use in kilowatt hours (kWh) was recorded every 15 minutes for each electricity consuming process within the farm gate. Domestic use was excluded from the measurements.

The system boundary of the LCA was defined as being from cradle-to-farm-gate, which implies that

Parameter	Minimum	Mean	Maximum	National average
Farm area (ha)	43	76	142	57
Number of cows (herd size)	47	118	290	66
Stocking density (LU/ha)[1]	1.68	2.27	3.45	1.77
Milk production ('000 L/annum)	255	559	1329	316
Milk production (tonnes MS/annum)[2]	21	44	109	24
Nitrogen application rate (kg N/ha/annum)[3]	86	194	278	86
Kg of concentrate fed per 100kg milk produced	0.49	1.19	2.06	NA[4]

Table 1. Average production parameters for study farms compared to national average figures.
[1]LU/ha = Livestock units per hectare; [2]MS = Milk solids; [3]N = Fertilizer nitrogen; [4]NA = Not available.

energy use is quantified for all processes involved up to the moment that milk leaves the farm gate, including production and transport of concentrates, roughage, seeds, herbicides and chemical fertilizer. Such a cradle-to-farm gate LCA, therefore, resembles quantification of the direct (i.e., energy use on-farm) and indirect energy use (i.e., energy needed to produce farm inputs) of milk production (De Boer, 2003).

Besides milk, our production system also yields meat from culled cows and calves. In such a multiple-output situation, the energy use of the system has to be allocated to these various outputs. We used economic allocation implying that the energy use was allocated to the various outputs based on their relative economic value (i.e., 88.3% to milk).

Energy demand to produce a litre of milk

Total energy use averaged 2.5 MJ/L of milk produced, ranging from 1.25 to 3.90 MJ/L, of which 20% was direct and 80% was indirect energy. Figure 1 shows the relative share of total energy use by the major energy consuming farm inputs. About 57% of this energy use was accounted for by the application of chemical fertilizers (range 40-80%). Other significant energy consuming processes included production and transport of purchased concentrate feed 21% (range 8-36%), electricity 12% (range 8-21%), and liquid fuels such as diesel, petrol and kerosene 8% (range 1-15%). Other items such as seeds and herbicides represented a small portion of total energy use 2% (range 0-15%).

Of particular interest were findings in relation to energy consumption in the following categories:

- fertilizer: there were large differences in the chemical fertilizer application rates in this study. Mean energy input by chemical fertilizer was 1.14 MJ/L (range 0.87-2.44 MJ/L). The main fertilizer applied was chemical fertilizer nitrogen.
- feed: The average farm fed 542 kg of feed per milking cow per annum, which equated to 0.5 MJ/L of milk produced.
- electricity: consumption was centred around milk harvesting operations, with 80% of electricity being consumed in the milking parlour and the remaining 20% being used by water pumps and the winter housing facilities. Electricity consumption amounted to 0.31 MJ/L.
- fuel: this accounted for 66% of total fuel energy input and amounted to 0.2 MJ/L. These inputs were specifically: diesel (97.5% of on-farm fuel use), gear oil and transmission oil (1.3%) and kerosene (1.2%). Fuel used by contractors accounted for 31.7% of fuel use and transport of feed, fertilizers and forage to the farm accounted for just 2.3% of fuel use.

Opportunities for improvements and future work

The most significant areas for improving overall energy efficiency on Irish dairy farms are:

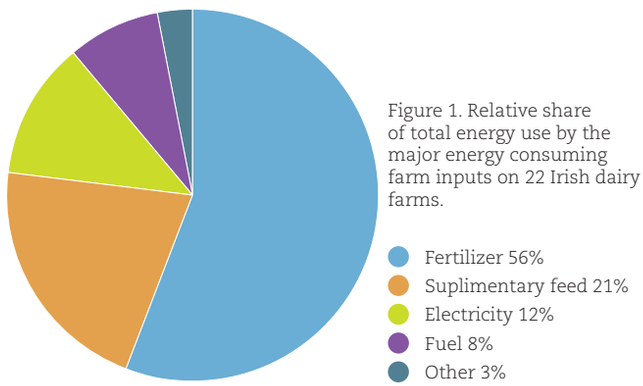

Figure 1. Relative share of total energy use by the major energy consuming farm inputs on 22 Irish dairy farms.

- sensible fertilizer management, particularly in relation to the use of chemical fertilizer nitrogen, to reduce indirect energy requirements for fertilizer manufacture;
- careful use of supplementary concentrate feed, to reduce indirect energy use embodied in the feed;
- improving the efficiency of electricity consumption through adoption of energy efficient working practices and technologies; and,
- optimising fuel use by careful selection of tractors and other farm vehicles to reduce direct use of diesel.

Monitoring of energy indicators should continue in the dairy production sector to build up a picture of trends over time. The majority of the necessary information on the direct and indirect inputs collected in this study are already collected in existing farm analysis tools, albeit in financial terms. It would be possible to convert these into energy terms, although some accuracy may be lost. Reporting energy indicators in conjunction with the usual production indicators would give useful information relating to the direction of the industry towards a sustainable path.

We acknowledge INTERREG IVB North-West Europe for financial support through the 'Dairyman' project: www.interregdairyman.eu/

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Winter feeding options for replacement dairy heifers

Emer Kennedy,
Research Technologist,
Animal & Grassland
Research and Innovation
Centre at
Teagasc Moorepark.
Correspondence:
emer.kennedy@teagasc.ie

Researchers at Teagasc Moorepark have been investigating a number of winter feeding options for dairy replacement heifers.

The replacement heifers born each year are the engine of the future dairy herd. The cost of rearing a replacement heifer (from birth to calving) is €1,486. This includes a cost for an initial value of the calf and a charge for land and labour. When these costs are excluded the cost is €805. Heifer rearing is the second largest expense in the dairy system, accounting for approximately 20% of total costs. This equates to quite a substantial investment, especially when the removal of milk quotas is considered and dairy farmers will face a more competitive environment with increased milk price volatility and, hence, less stable farm profitability.

Ensuring the best possible development of replacement heifers is critical and, although it needs to be accomplished at low cost, heifer performance should not be compromised. Optimum performance from the dairy herd during the rearing of replacement heifers is influenced by realising target weights at key points, such as at mating start date (MSD) at 15 months of age and pre-calving.

In practice, heifer rearing receives low priority on Irish dairy farms and achieving target weights is neglected by many. Reduced levels of management will result in a lesser profit, as heifers may calve later than 24 months, be underweight and produce less milk compared to better managed heifers.

Diet options during the first winter

Over the past number of years, experiments have been carried out at Teagasc Moorepark to investigate the effect of offering different over-winter diets on heifer weight gain. Results have shown that the winter diet offered to heifers significantly impacts the weight gain achieved and their realisation of target weight at MSD.

However, feed costs account for approximately 80% of the total variable costs associated with costs of production. One of the methods of reducing feed costs in particular, is by sourcing lower cost feeds

Kale grazed *in situ* ranked as the cheapest alternative to grazed grass and was considerably cheaper than grass silage in a recent Teagasc study. Kale tends to have a low neutral-detergent fibre (NDF) concentration, suggesting that feeds with a higher NDF concentration (>500 g/kg DM) – such as grass silage – may need to be offered in order to avoid acidosis. A short-term (20-day) indoor feeding experiment conducted at Teagasc Moorepark examined the effect of feeding a 100% kale diet in

comparison to varying combinations of a kale and silage diet. The results of the experiment reported that feeding a 100% kale diet did not reduce rumen pH below 6.0 nor did it induce acidosis. Thus, 100% kale feeding treatments were introduced to the experiments.

The diets investigated included:

- indoors offered *ad libitum* grass silage and 1 kg DM concentrate/day (S1);
- indoors offered *ad libitum* grass silage and 2 kg DM concentrate/day (S2);
- indoors offered *ad libitum* grass silage only (SO);
- outdoors on an out-wintering pad offered *ad libitum* grass silage and 1.5 kg DM concentrate/day (OWP);
- outdoors offered 70% kale and 30% grass silage bales (70K);
- outdoors offered 100% kale (100K)

Weight gain (kg/heifer/day)	SO	S1	S2	70K	100K
Winter weight gain	0.30	0.44	0.65	0.47	0.48
Weight gain from turnout to breeding	0.86	0.68	-	0.89	0.88

Table 1. Effect of diet on weight gain at different periods (kg/heifer/day).

The Moorepark experiments have shown that considerable variation exists in the weight gain achieved from different diets offered over the winter (Table 1). Kale has a high feeding value (1.05 UFL – similar to early spring grass); consequently heifers can achieve high levels of weight gain at a relatively low cost. Similar levels of weight gain can be achieved with grass silage and concentrate diets. Silage-only diets support weight gains of approximately 0.30 kg/heifer/day. Therefore, heifers should be well ahead of target at housing if silage only is being used during the winter as 0.30 kg/day is insufficient weight gain to achieve target weight at MSD for heifers that commence the winter period at or below target weight.

Which forage crop to use?

Another experiment was completed to establish if there were differences in weight gains achieved from three different forage crops and more conventional diets. The diets investigated were:

- indoors offered grass silage and 1 kg DM concentrate/day (S1),
- indoors offered grass silage and 2 kg DM concentrate/day (S2),
- outdoors grazing forage kale (cv. Maris Kestral) in conjunction with grass silage bales which were offered as 30% of the diet (K),
- outdoors grazing forage rape (cv. Stego) in conjunction with grass silage bales which were offered as 30% of the diet (R),
- outdoors grazing a rape x kale hybrid (cv. Red Start) forage in conjunction with grass silage bales which were offered as 30% of the diet (H).

At turnout there was no weight difference between heifers from the S2, K, R and H treatments (279 kg) but all treatments were heavier than the S1 heifers (261 kg). Thus, over-winter weight gain was least for the S1 heifers (0.38 kg/heifer/day) when compared to all other treatments which were similar (0.53 kg/heifer/day). There was no difference in the turnout body condition score (BCS) for the five winter feeding treatments.

Early turnout

Regardless of diet offered over the winter, similar weight gains are achieved when heifers are turned out to grass in spring. Weight gains achieved post-turnout are higher than those achieved during the winter. This clearly indicates that heifers should be turned out to grass as soon as possible, as they can gain up to 1 kg/heifer/day at grass compared to <0.70 kg/heifer/day while on their winter diet (Table 1). Consequently, heifers have a greater chance of attaining their target weight with early turnout.

Diet during the second winter

Many studies have shown a positive relationship between body weight at calving and first lactation milk yield. An experiment was undertaken to: investigate the effect of winter diet on pre-partum weight gain of replacement dairy heifers, and, establish the effect of pre-partum feeding treatment on post-partum milk production performance.

The treatments were:

- indoors offered a silage only diet for the duration of the experiment (SO),
- indoors offered silage and 2kg concentrate/day for 46 days followed by a silage only diet (SC),
- outdoors grazing forage kale in conjunction with grass silage bales at an inclusion rate of 30% in the diet (70K),
- outdoors grazing a 100% forage kale diet (100K).

Following the winter period daily weight gain was similar for the SC and 70K treatments (1.10 kg/heifer/day), weight gain was lower for the SO treatment (0.96 kg/heifer/day), and weight gain was further reduced on the 100K treatment (0.78 kg/heifer/day). At the end of the winter period, BCS was greatest for the SO and SC animals (3.47), significantly lower for the 70K animals (3.25) and lowest for the 100K animals (3.09).There was no difference between treatments in cumulative milk yield (3,656 kg) or milk solids yield (273 kg) for the first 29 weeks of lactation. There was no difference between treatments in average lactation fat, protein and lactose concentration (4.10, 3.38 and 4.70%, respectively).

Average body weight throughout the first 29 weeks of lactation was also similar between treatments (439 kg). Average BCS of animals from the 100K treatment was lower (2.86) than that of the SC and SO animals (3.00) but was not different to the 70K animals (2.93). There was no difference in average BCS between the SC, SO and 70K treatments (2.98).

Implications

This series of studies outlines the weight gains that can be expected from a number of winter diets offered to replacement dairy heifers. The diet offered should however ensure that heifers attain target weight at key time points, e.g., MSD and pre-calving. Thus, heifers should be regularly weighed and an appropriate diet chosen for the winter months during both the first and second winter to ensure that lifetime performance is optimised when they reach the lactating herd.

This research was funded by Teagasc core funding.

Forty years of Irish farming in the EU

When Ireland joined the EU so started Teagasc's longest running research project – the National Farm Survey. It has been an invaluable source of information on the state of farming ever since.

Dr Thia Hennessy, Head of Department, Agricultural Economics and Farm Surveys
Anne Kinsella, Research Officer, National Farm Survey, Rural Economy and Development Programme, Teagasc, Athenry
Brendan Kearney, Economic Consultant and former Assistant Director of An Foras Taluntais (now Teagasc).
Correspondence : thia.hennessy@teagasc.ie

This year marks the 40th anniversary of Ireland's accession to the European Union. Accession to the EU in 1973 brought with it an obligation to establish an annual survey of farm incomes. The Teagasc National Farm Survey (NFS), which is Teagasc's longest running research project, was established in 1972 and has published statistics on farm income annually for the last 40 years. This article uses Teagasc NFS data to review the development of the farm sector in Ireland over the last 40 years and, in particular, to examine the impact of EU policy on farm incomes.

Overview of agricultural policy developments: 1973-2013

Since the foundation of the EU, agricultural prices have been supported through the Common Agricultural Policy (CAP), which was put in place after the Second World War to ensure security of food supply in Europe. At the time of Ireland's accession, the CAP supported artificially high prices and guaranteed an unlimited intervention market for agricultural products. By the late 1970s, this generous price support system had resulted in a serious problem of overproduction. Reform was required and, in 1984, the milk quota, which would limit milk production for the next 30 years, was introduced. Limits were also imposed on the quantity of beef and cereals that could be sold at guaranteed prices.

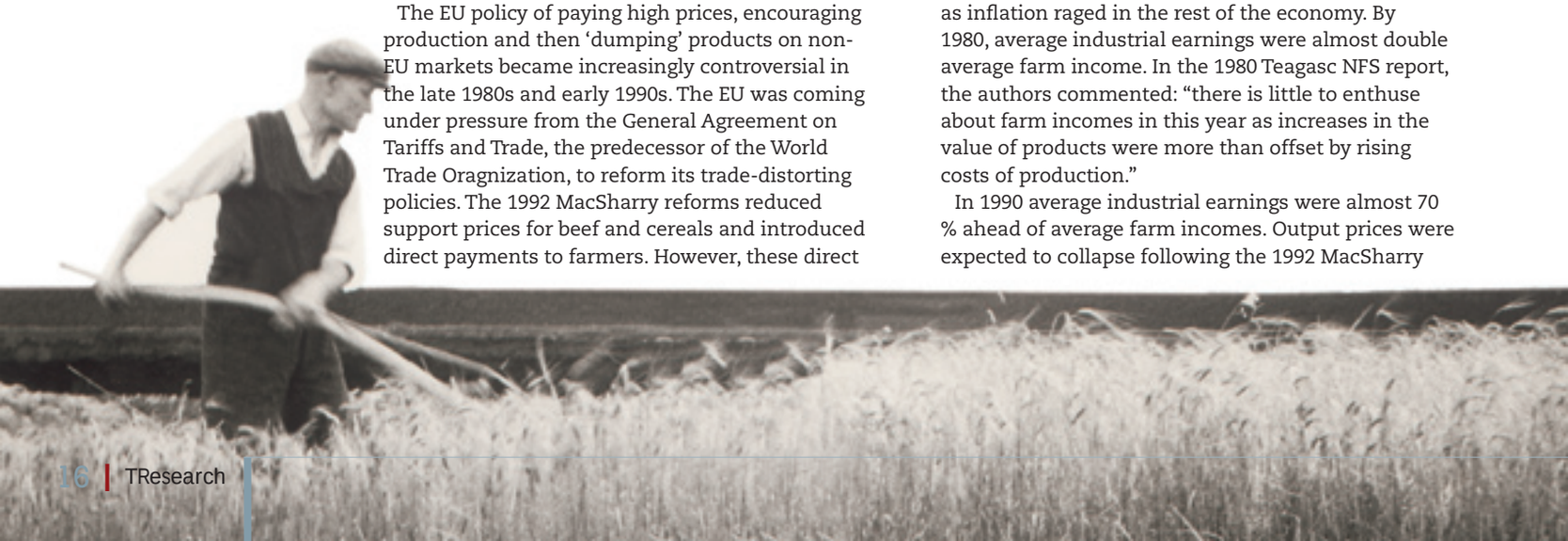
The EU policy of paying high prices, encouraging production and then 'dumping' products on non-EU markets became increasingly controversial in the late 1980s and early 1990s. The EU was coming under pressure from the General Agreement on Tariffs and Trade, the predecessor of the World Trade Oragnization, to reform its trade-distorting policies. The 1992 MacSharry reforms reduced support prices for beef and cereals and introduced direct payments to farmers. However, these direct payments were still linked to production and, hence, continued to be a source of controversy within the World Trade Organization. Further reform was required and, in 2004, the decoupling reform broke the link between direct payments and production. As payments were no longer linked to production, they could no longer be considered trade distorting. A further review of the CAP in 2008 led to the agreement to abolish the milk quota regime in 2015. The current ongoing reform of the CAP is motivated by the desire to introduce a 'more level playing field' across Europe's farming sector. In pursuit of this, the European Commission proposed a transition to flat rate payments within Member States, as well as greater equity in the distribution of the EU budget across Member States. Following considerable debate over the last two years, a more moderated version of these proposals was finally agreed earlier this year. At this stage, decisions are still required as to how the policies will be implemented in Ireland.

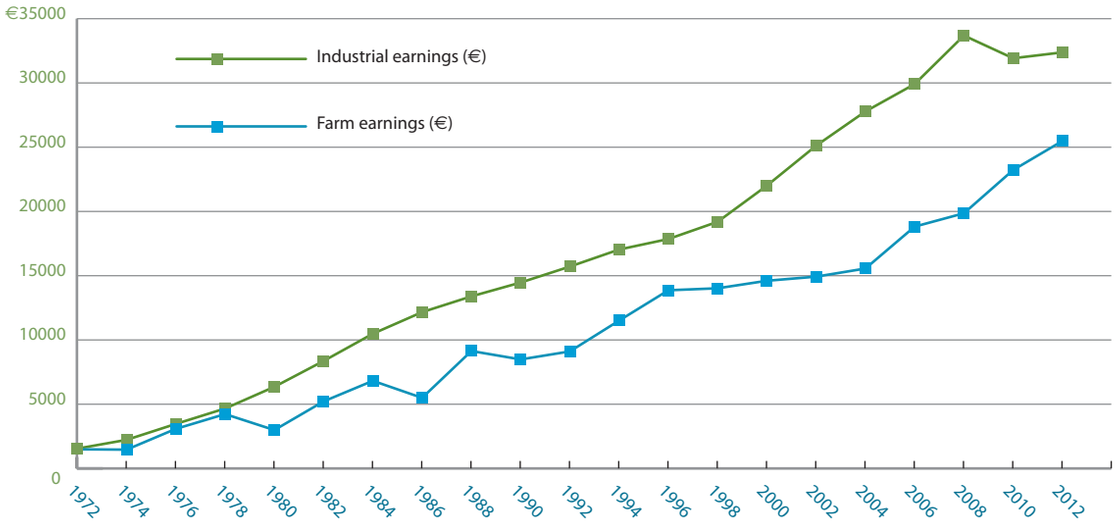
Development of the Irish Farm Sector: 1973-2013

A five-year transition period followed Ireland's initial entry to the EU in 1973; substantial increases in agricultural prices occurred during this period and farmers responded by increasing output. From 1972 to 1978, average income tripled in nominal terms and farm incomes compared quite favourably with those in the industrial sector. The 1973 Teagasc NFS report concluded: "in all, 1973 was a golden year in Irish farming when compared with its predecessors".

At the end of the transition period, prices in Ireland had converged with the higher EU internal prices. As output prices plateaued, input prices, in particular energy prices and interest rates, continued to increase as inflation raged in the rest of the economy. By 1980, average industrial earnings were almost double average farm income. In the 1980 Teagasc NFS report, the authors commented: "there is little to enthuse about farm incomes in this year as increases in the value of products were more than offset by rising costs of production."

In 1990 average industrial earnings were almost 70 % ahead of average farm incomes. Output prices were expected to collapse following the 1992 MacSharry





Comparison of annual farm income and industrial earnings during the period from 1972 to 2012.

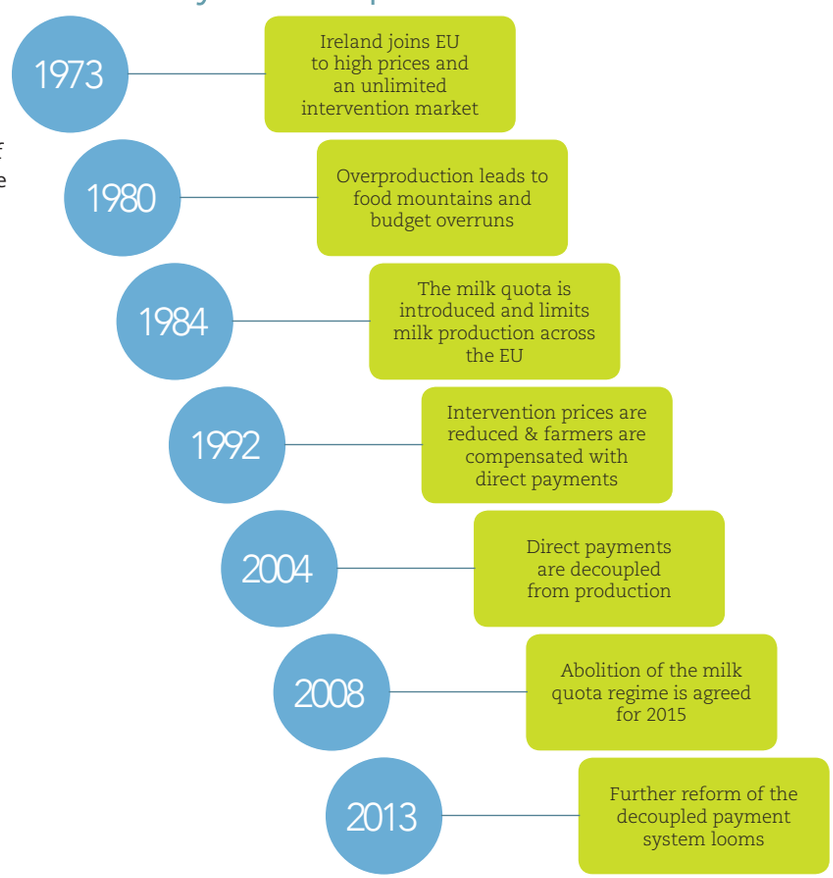
reforms, but, on the contrary, prices moved strongly upwards. Coinciding with the introduction of direct payments, farmers were essentially compensated for price reductions that did not transpire and farm incomes increased. Income from farming in 1996 was higher in real terms than at any time since the previous peak in 1979.

Driven more by the rapid expansion of other sectors of the economy rather than the contraction of agriculture, the importance of the farm sector declined in the 1990s, accounting for almost 8% of GDP at the start of the decade and less than 5%, 10 years later. As the Celtic Tiger economy roared, average industrial earnings grew by, on average, 6% per year from 2000 to 2007 and were almost 50% ahead of average farm incomes.

Farm incomes increased considerably in 2005 due to the double payment of the new decoupled Single Farm Payment (SFP) and direct payments owing from the previous year. Incomes reverted to more traditional levels in 2006. The period from 2006 to 2012 was particularly volatile. As a result of the ongoing reform to the CAP, there is now less scope for the EU to stabilise internal agricultural prices and, as such, farmers are more exposed to world price movements. The dairy and cereals sectors, in particular, have experienced a rollercoaster ride over the last five to six years, with a boom in 2007 followed by a disastrous collapse in 2009 and a good year again in 2011.

Despite the ups and downs in farm income over the last 40 years, productivity per farm has increased steadily over the period alongside the growing concentration of some enterprises on fewer farms. Since joining the EU, the volume of total agricultural output has increased by 50 % while farm numbers have declined by almost one-third. Productivity growth has been most pronounced in the dairy sector. Although aggregate national production is limited by the milk quota, the number of dairy farms and cows has declined rapidly over the 30 years since quota was introduced and productivity per farm and per cow has increased accordingly.

An overview of Agricultural Policy Developments 1973-2013



Research use of NFS data

Apart from providing an annual representative record of farm incomes, another key function of the Teagasc NFS is to produce objective economic data on farming for research purposes. Over the years, the data has been used to explore the impact of EU policies on farm incomes. In the early 1970s, Teagasc researcher Jim Higgins examined the impact of EU Membership on the income gap between rich and poor farmers. This question was revisited in the 1990s by Teagasc researchers Jim Frawley and Mary Keeney, when the impact of direct payments on income equality was quantified. A number of studies by Boyle, Thorne and Matthews have used NFS data to chart the productivity growth of the sector and to measure the international competitiveness of Irish agriculture. Teagasc NFS data continues to be used to the present day to inform the policy-making process and is currently being used by the FAPRI-Ireland team in analysis of the ongoing reform of the CAP.

This article summarises the recently published "Forty years of Irish farming since joining the European Union: a journey with the Teagasc National Farm Survey" by Thia Hennessy and Anne Kinsella. This book, which is available from the Teagasc publications office, provides a more thorough review of the 40-year history, as well as references to the research mentioned here.

The National Farm Survey is funded by the Teagasc core programme.

NFRD supporting the Irish food industry

Dr John Rae,
Research Officer and National Food Residue Database Administrator, Teagasc, Food Research Centre, Ashtown, Dublin 15.
Correspondence : john.rae@teagasc.ie

The National Food Residue Database (NFRD) is unique in a European context as the only public access food chemical contaminant and residue database that contains all of the nation's national monitoring programmes. It provides an enviable resource to help maintain the integrity of the Irish food chain, explains Dr John Rae.

Chemical residues in food represent one of the principal determinants for acceptability of food products to international markets. One only has to look into the recent past to see how much disruption chemical contaminant food scares can cause the Irish marketplace. Incidences such as 'bute' (phenylbutazone) in horsemeat and the pork dioxin scare in 2008 can have considerable costs – not only through product recalls, loss of markets/contracts and state compensation packages – but also by impacting on consumer confidence in food. Increasingly, in today's market, international buyers are requesting detailed background information from Irish food manufacturers, including what controls are in place for a whole range of possible chemical contaminants.

This can seem a daunting task for those new to such markets. The time needed to meet these requirements can prove demanding. This is where the National Food Residue Database (NFRD) can play a valuable role. With over 800 searchable chemical contaminants and over 500 searchable foods, the NFRD provides food manufacturers with direct access to well over a decade's worth of chemical contaminant testing of the nation's food supply.

Background

Perhaps not well known is the behind-the-scenes work carried out on a daily basis by the Irish authorities in ensuring the quality of Irish produce. Samples are taken by the Irish authorities for chemical residue testing in factories and retail every day. Testing has been carried out since the mid-1990s and a considerable body of data has been developed on contaminant residues in food produced in Ireland. This data has been generated through what is called the national monitoring programmes to comply with EU regulations, as well as ensuring high standards for food products in the domestic and export markets.

However, much of these data are in individual reports or in formats not readily available to potential users. This is where the NFRD comes in. It provides a comprehensive database for chemical residues and contaminants in food in Ireland, bringing together all of this information in one, freely-available, public access web portal http://nfrd.teagasc.ie

The NFRD data are taken from monitoring and surveillance programmes and from studies and surveys on chemical residues and contaminants in food. The scope of the data includes studies carried out on veterinary drugs, prohibited substances, pesticides, radioactive substances, heavy metals, marine biotoxins, dioxins, PCBs (Polychlorinated Biphenyls) and brominated flame retardants, mycotoxins, and other contaminants such as nitrates and PAHs (polycyclic aromatic hydrocarbons).

The NFRD was developed by the Residue Studies Group, Food Safety Department, Teagasc Food Research Centre, Ashtown, within a research project funded by the Food Institutional Research Measure (FIRM), Department of Agriculture, Food and the Marine (DAFM) and currently forms part of a research project entitled 'Safe & Healthy Foods' which is funded by FIRM, DAFM and the Health Research Board. The NFRD is unique in a European context. A similar, freely-available resource cannot be found in other EU Member States.

Food samples are tested using validated methods.

NFRD access

Access to the NFRD provides:

- food producers and stakeholders with over a decade of data;
- evidence to importers and exporters of the ongoing efforts of state agencies;
- trend analysis of chemical residues in food;
- evidence of the compliance of Irish foods with specifications and regulations;
- data for exposure and risk assessments;
- information for the food industry to assist production, manufacturing and sale of Irish food;
- information for policy agencies to support regulations and control strategies; and,
- information for the public on the safety of the food supply.

Development of the NFRD began in 1998, with a web portal created in 2002. Today the database contains over 2.5 million individual searchable data results, 500 different food types and over 800 different chemical residues. Much of the latest developments of the NFRD have involved software upgrades and have taken place behind the scenes but make for a more stable and modern platform.

Some new features that have proved very popular with users are the screen capture information videos available on Youtube with links on the website's main page. These videos provide a step-by-step guide in real-time on how to complete a search on the website. Different sectoral videos are now available on the website for the meat, dairy, seafood, and fruit and vegetable sectors.

Sampling

So how is the data generated? The first step is the collection of samples by State Agencies/Governmental bodies with the cooperation of the food industry. These samples are then transferred to designed reference laboratories for testing using validated methods. The results of this testing generates considerable data, with each individual data result consisting of a number of parameters such as:

- food sample (matrix – liver, kidney, etc.);
- residue tested;
- concentration of residue determined;
- laboratory/agency responsible for study;
- country of origin;
- sampling point;
- sampling date; and,
- analytical method used.

Indeed some test samples can have up to 25 different parameters. These data-packs are then sent to the NFRD where they are formatted and after a series of quality checks they are uploaded onto the database. The data is then published onto the website by year.

Modern analysis methods

The sensitivity of modern analytical methods such as Liquid Chromatography-Mass Spectrometry/Mass Spectrometry is truly outstanding with detection of chemical residues in food at low to very low levels. Detection is now possible at levels previously only dreamed of, ensuring that use of illegal or prohibited substances can be detected. However, the primary route of chemical residues into food is through a lack of adherence to withdrawal periods.

Each drug or pesticide has clearly labelled withdrawal periods that need to be followed to ensure that the animal, crop or nature has time to 'flush' the compound out. Inappropriate use is another route to chemical carryover into food. This can be via the use of a veterinary drug or pesticide on the wrong species of animal or crop or at the wrong time of the year or milk cycle. Another route is via contaminated feed (dioxins, pesticides, mycotoxins, etc.).

Increasing capacity

Modern analytical methods not only have enhanced sensitivity but are increasingly becoming multi-residue. This means that one test can be used for a number of different residues, greatly increasing the capacity of the testing systems and the number of chemical residues that can be tested for.

For instance, over a decade ago, 100 pesticides were tested for in cereals, fruits and vegetables by the State's Pesticide Control Services, today this has increased to over 330 pesticides. This in turn increases the data generated and available to the Irish food industry.

Importance of agrochemicals

With a growing world population, the term 'food security' has come into vogue in recent years. The need to secure an adequate supply of food to feed this growing population relies heavily on efficient agricultural production. Modern production methods are highly efficient but at their core lies the use of veterinary drugs, pesticides and specified feed additives, which greatly aid the efficiency of animal and crop production, ensuring reliable crop yields and animal weight gain. Indeed, in areas such as small ruminant animal production, this efficiency is entirely dependent on the use of medicinal compounds such as anthelmintics (worming agents). Protection of harvested and stored crops is another area where agricultural pesticides play a vital role. Grain and pulse storage relies heavily on the use of pesticides to control rodents, insects, mites and fungi. Crops can be stored safely for longer with the use of modern chemicals. Finally, for animal welfare reasons veterinary drugs are used in the treatment of animal disease and ailments.

The NFRD is a unique resource to the Irish food industry providing valuable data on chemical contaminant testing of the nation's food supply. It can help Irish food companies illustrate to third parties the testing undertaken to ensure the food safety of Irish food production.

To see NFRD instruction videos please go to Teagasc's YouTube page: www.youtube.com/user/TeagascMedia/.
Follow the NFRD on Twitter: @_NFRD

A galaxy within us

our gut microbiota and how it can be programmed by food

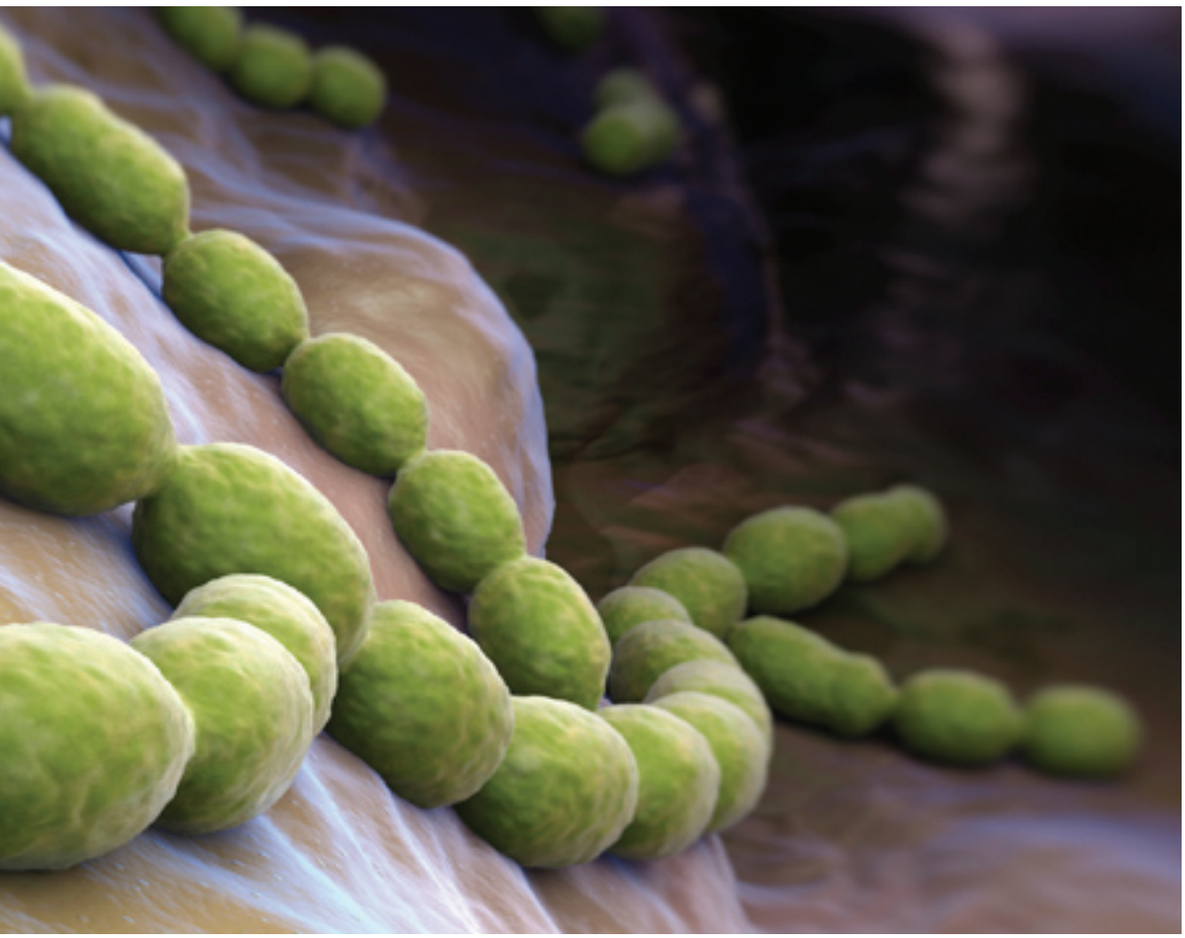
In his introduction to this issue's Gut Health Focus, Professor R. Paul Ross outlines the far-reaching implications of the study of human microbiota both for basic nutrition and the study of microbiology.

In Science, it is not very often that something comes along with the potential to change how a whole discipline thinks. To the team at Teagasc, Food Research Centre, Moorepark and partners at the Alimentary Pharmabiotic Centre (APC), the study of the human microbiota is such a topic, with the potential to change not just basic nutrition, but also much of the study of microbiology.

The discipline of microbiology, for the main part, has been limited to the study of microorganisms that could be isolated as pure cultures and cultivated in the laboratory. However, next generation sequencing has allowed us to study complex microbial communities such as the human gut microbiota (the organisms that typically inhabit the human gut) which is composed of up to a 1,000 individual species, the majority of which cannot be cultivated on an individual basis. The community exists and thrives almost like a multi-cellular organism composed of a vast myriad of bacteria that are interdependent from nutritional and competition points of view while also being dependent on their human host.

Likewise, the study of the gut microbiota is set to transform nutrition, which classically is defined as the provision of food to an organism to support life. However, each one of us contains a 'bioreactor' within us, our microbiota, which ferments and transforms much of the food we eat before it is taken up into the blood stream. As such, we believe that the microbiota has a great influence on a variety of aspects of human health – everything from nutrition-related diseases such as obesity, diabetes and liver disease to far wider conditions such as cardiovascular disease, inflammation and depression. In the last decade, the APC has pioneered the study of the human microbiota and, in particular, its relationship to health and disease status. This Science Foundation Ireland (SFI)-funded Research Centre is based at University College Cork, Teagasc, Moorepark, Cork Institute of Technology, National University of Ireland, Galway and the University of Limerick, and is led by Professor Fergus Shanahan, a gastroenterologist and a visionary in terms of the study of human gut functioning (or "the inner tube of life" as he calls it).

The composition of the human gut microbiota is shaped by a number of intrinsic and extrinsic factors. The former include host genetics, age and inflammation; while extrinsic factors include



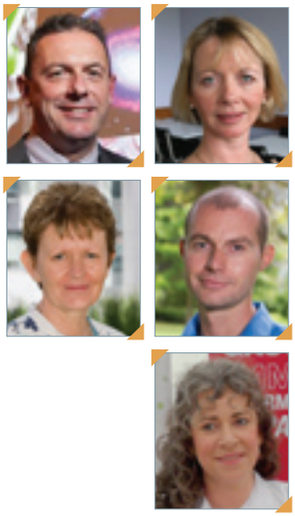
exposure to antibiotics and diet/food. Alterations in the intestinal microbiota composition are associated with several chronic conditions, including obesity and inflammatory diseases. Although the composition of the microbiota is highly stable during adulthood, there are times when it can be highly dynamic – such as at the extremes of life, e.g., following birth, during inflammatory bowel conditions, gastrointestinal infection and in the elderly. Despite this stability, the microbiota also displays a high degree of inter-individual variation reflecting differences in lifestyle, diet, host genetics, etc. In a project called ELDERMET, a team of UCC/Teagasc scientists headed by Professor Paul O'Toole has recently profiled the faecal microbiota from elderly people in different residences including community, day-hospital, rehabilitation or long-term residential care locations.

This study, published recently in the prestigious journal *Nature*, found that the microbiota correlated with the residence location. The results demonstrated that the individual microbiota of people in long-stay care was significantly less diverse than those that resided in the community. In addition, these subjects were also clustered by diet by the same residence location and microbiota groupings. Interestingly, the separation of microbiota composition correlated significantly with health parameters in these individuals including measures of frailty, co-morbidity, nutritional status, markers of inflammation and with metabolites in faecal water. Taken together, these data suggest that diet can programme the gut microbiota – the composition of which correlates with health status. Such a suggestion opens up great potential for the food industry in the design of food ingredients and supplements which may in the future shape the microbiota in a particular direction to correlate with an improved consumer health status.

In a special gut health series in this issue of *TReseach*, we have detailed a number of the key UCC/Teagasc collaborative studies surrounding the investigation of the human microbiota to demonstrate not just the breadth of the research but also its huge potential for the agri-food and pharma industries. From a national perspective, Ireland is perfectly positioned to capture and capitalise on what is one of the most exciting areas in biological research as APC and its commercial partners enter the next six-year phase of funding with SFI.

Professor R. Paul Ross
Head of the Teagasc Food Research Programme and Principal Investigator at the Alimentary Pharmabiotic Centre, Teagasc, Food Research Centre, Moorepark, Fermoy, Cork, Ireland
Correspondence: paul.ross@teagasc.ie

The Alimentary Pharmabiotic Centre



Professor R. Paul Ross, Head of Teagasc Food Research Programme
Professor Catherine Stanton, Principal Research Officer, Food Biosciences Department
Dr Mary Rea, Senior Research Officer, Food Biosciences Department
Dr Paul Cotter, Principal Research Officer, Food Biosciences Department
Dr Sheila Morgan, Senior Research Officer, Manager APC programme Food Biosciences Department, Teagasc Food Research Centre, Moorepark.
Correspondence: sheila.morgan@teagasc.ie

Teagasc has been a partner in the Alimentary Pharmabiotic Centre since its inception and, following additional investment by Science Foundation Ireland, the CSET is set to build on its many achievements.

The Alimentary Pharmabiotic Centre (APC) – a University College Cork (UCC) and Teagasc collaboration – was formed a decade ago, with the help of Science Foundation Ireland (SFI) funding, and has become a vibrant research centre of over 150 scientists and clinicians from research areas including gastroenterology, microbiology, psychiatry, food science, neuroscience, immunology, biochemistry, gerontology and paediatrics among others. The success of the APC has contributed to researchers at UCC and Teagasc being ranked second in the world in probiotic research in a Thomson Reuters Science Watch report. The APC is one of nine SFI-funded Centres of Science, Engineering and Technology (CSETs) in Ireland, and was launched in 2003. The APC is now entering its third phase of funding, and has expanded to include Cork Institute of Technology, National University of Ireland Galway and the University of Limerick. The APC is a national resource and the research activities are of tangible importance to several sectors, including food, pharma, biotechnology, infant nutrition, medical foods, diagnostics, and animal health and feed, and are pitched at the interface of the food and pharmaceutical sectors.

Role of gut microbiota in health

When originally formed, the APC was based on a very simple hypothesis: that the gut microbiota (microbes living in the human gut) play a significant role in human health and in disease. This view has been validated by the explosion of interest worldwide, and remains the guiding scientific principle of the APC. The gastrointestinal tract is a densely populated ecosystem, containing a complex community of microbes that play an important role in human health. The population structure and the beneficial effects on the host are mediated by microbial metabolites that inhibit, signal and support other microbial community members. As the APC now enters its third phase of funding for a further six years, research will focus on the close links between the microbiota, diet and human health status, and aims to provide the necessary scientific basis for the selection of health-promoting bacteria, their bioactive metabolites and bacteriophages for the generation of functional foods and pharmabiotics for improved health and treatment of inflammatory, infectious and other disorders within and beyond the gut. An important aspect of the new programme is its integration with 12 industry partners including representatives from the dairy ingredients and infant formula sectors.

The research of the APC is packaged into four principle research themes, two of which are co-led by Teagasc Principal Investigators (Microbes to Molecules – Professor Paul Ross; and Diet and Microbes at the extremes of life – Professor Catherine Stanton). In addition, two of the APC Platform Technologies are led by Teagasc staff (Culture to Product – Dr Mary Rea; and Next Generation Sequencing – Dr Paul Cotter).

Microbes to molecules

This research theme focuses on Pharmabiotics, biological entities mined from the gastrointestinal microbiota, including probiotics, bacteriocins, bacteriophages and bioactive molecules. It is believed that pharmabiotics will make significant impacts in the pharmaceutical, medical food and functional food sectors.

The APC has already discovered, patented and licensed Thuricin CD, the narrow spectrum antimicrobial active against the gut pathogen *Clostridium difficile*, while bacteriophages active against *Pseudomonas aeruginosa* have also been patented. Outputs from this research theme will focus on new anti-inflammatory and anti-infective agents,

Pictured at the recent launch of the third phase of the APC are(from left): Dr Michael Murphy, President of University College Cork; Mr Sean Sherlock TD, Minister for Research and Innovation; Professor Mark Ferguson, Director General of SFI; Professor Gerry Boyle, Director of Teagasc; and Professor Fergus Shanahan, APC director.

to support the commercial goals of existing and future industry partners and to understand the role of phage, bacteriocins, prebiotics and probiotics in human health, for the development of novel therapies and functional food ingredients for the food sector. For more see article on p26.

Diet and microbes at the extremes of life

This research theme focuses on the interplay between diet, the microbiota and health at the extremes of life; infants and older subjects, with a unifying emphasis on nutrition, cognition and inflammatory disease. In infants and older people, the gut microbiota is in a state of flux, so these are particularly relevant life-stages in which to modulate the microbiota in a health-promoting direction. Outputs will include the development of biomarkers of microbiota alteration and metabolite depletion and new food ingredients for infant formula and for the elderly. See articles on p32 and p24.

Brain-gut-microbiota axis

This theme addresses the communication between the brain and the gut and how it can be influenced by the gastrointestinal microbiota. This is an area of significance in infancy, where important links between diet, microbes and cognition are established. The influence of the microbiota on obesity and metabolic syndrome are also increasingly recognised. This area represents a real opportunity for foods designed for cognition, infant brain development, functional gastrointestinal disorders and for healthy ageing. These are significant growth areas for healthcare and food companies, and microorganisms, or microbial components, have a role in either causing or preventing these conditions.

Host-microbe dialogue

This research explores the network of signalling interactions among the microbiota, host immune-inflammatory responses and metabolism and the impact of diet on each component of this triad. The gut microbiota influences human health and susceptibility to most common diseases, including immune-allergic, colon cancer and various metabolic diseases. Each of these chronic disorders has an immune or inflammatory component. This low-grade inflammation, and associated diseases are a significant healthcare burden in developed countries, and represents a multi-billion euro opportunity for companies in the food, pharmaceutical and diagnostic sectors.

APC platform technologies

The APC has a range of 'platform technologies' designed to support the overall research activities of the APC and benefit industry clients interested in furthering their R&D agendas. The APC studies the most complex ecosystem in nature – the human microbiota and deals with thousands of bacterial strains, stored in a well-catalogued collection (Culture to Product Platform), which is an invaluable resource based on over a decade of 'mining microbes for mankind'. For bacteria that cannot be grown in a laboratory, sequencing technologies (Next Generation Sequencing Platform) are used to identify and characterise complex bacterial communities (see article on p34). Hardware within the next generation sequencing platform includes Ion Proton, Ion PGM, Illumina MiSeq, Roche-454 GS-FLX sequencing instruments at Teagasc, funded through SFI, Department of Agriculture, Food and the Marine and Teagasc. Analysis of resulting complex datasets requires sophisticated bioinformatics expertise (BioIT Platform). To establish how pharmabiotics influence health is a central goal of the APC, and in the pre-clinical unit (Pre-Clinical Models Platform) significant expertise in *in vitro*, *ex vivo* and *in vivo* models of many acute and chronic diseases have been established. One of the most sophisticated models is the use of gnotobiotic or germ-free animal models (Germ Free Platform). The objective of the APC is to work from bench to bedside, which requires access to patient groups and healthy populations, provided by APC clinician scientists (Human Studies Platform). Another significant resource in this context is the ability to select and identify a minimal microbiota and to perform complete microbiota transplants, (Microbiota Transplantation Platform).

The gut microbiota remains a vast repository of bioactive novel functional food ingredients and pharmabiotics. The APC is actively mining, so watch this space: http://apc.ucc.ie

ELDERMET and ELDERFOOD

Two research projects are defining the dietary needs of the elderly based on their microbiota.

Mairéad Coakley,
Food Biosciences Department, Teagasc Food Research Centre, Moorepark, Fermoy, Co Cork.
Correspondence:
mairead.coakley@teagasc.ie

The proportion of the elderly (>65 years of age) in our population is increasing due to improved medical care and lifestyle. Information on the composition and stability of the gut microbiota of these people is required to develop strategies to promote healthy ageing. Ongoing collaborative research between University College Cork (UCC) and Teagasc Food Research Centre, Moorepark has successfully demonstrated the link between diet, health and gut microbiota composition for a large group of elderly Irish people. The findings are being used to develop foods and food ingredients that may be used to modulate the gut bacteria composition to assist healthy ageing. This article outlines two collaborative projects focusing on the elderly: ELDERMET, which is near completion and ELDERFOOD, which has recently commenced.

Gut microbiota of the elderly

The human gastrointestinal tract is comprised of a complex mix of bacteria that contribute to various aspects of human health, including immunity, nutrition, pathogenesis and digestion. While the gut microbiota remains relatively stable throughout adult life, as we approach old age (>65 years of age) the composition and stability changes. This is due to a number of factors including diet, health, changes to the digestive tract and lifestyle. Some alterations to the microbiota that occur with age include decreased numbers of *Bifidobacterium spp*. and *Bacteroides spp*., increased numbers of facultative anaerobes and shifts in the dominant species in some bacterial groups. Such disruption of the intestinal microbiota has been linked to a number of human disease states including obesity and inflammatory bowel disease.

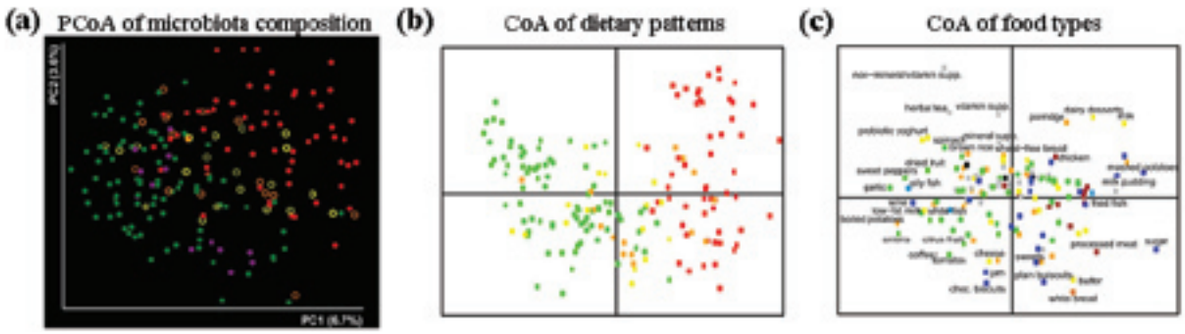
ELDERMET

The ELDERMET project (http://eldermet.ucc.ie) based at UCC and Teagasc Food Research Centre, Moorepark is led by Professor Paul O'Toole, Microbiology Department, UCC, and commenced in 2008 with the aim of understanding the links between diet, health and life-style of older Irish people by examining the composition of the bacteria in their gut. A large team of multi-disciplinary scientists and medical professionals (from bioinformaticians and microbiologists to research nurses and geriatricians) are involved in the project.

ELDERMET aims to recruit 500 elderly Irish people (male and female, ≥65 years of age) at clinics at local hospitals (Cork University Hospital, St Finbarr's Hospital, Cork and Mercy University Hospital, Cork). The recruits are either community-based, in long-term residential care, in short-term rehabilitation hospital care or attending out-patient hospitals. Subjects are further separated based on antibiotic therapy, *Clostridium difficile* infection and colorectal cancer. To date, 487 people have been recruited, with a follow-up complete for 252 people at month three and 236 at month six. The ELDERMET team sampled blood, saliva, urine and faeces, and compiled information on diet, health and lifestyle. Next generation sequencing technologies and culture-dependent techniques were used to elucidate the composition of the gut microbiota and to isolate bacterial strains with potential probiotic properties, respectively.

ELDERMET findings

Culture-dependent methods were implemented to isolate selected beneficial gut bacteria (lactobacilli and bifidobacteria) from hundreds of elderly subjects. As a result, the ELDERMET Culture Collection is now comprised of over 6,500 bacterial isolates. Intestinal strains with antimicrobial activity were



Colour codes for residence locations in (a) & (b): community (●), long-stay (●), rehabilitation (●) and day hospital (●). Colour Codes for (c): ■ fruit and vegetables ■ grains such as potatoes cereals and bread; ■ meat; ■ fish; ■ dairy products ■ sweets, cake and alcohol; ■ vitamins, minerals and tea.

Figure 1. The microbiota composition and dietary patterns of the elderly living in the community are very different to elderly subjects residing in long-term care. (a) Principal coordinate analysis of the microbiota composition illustrates that the subjects are separated based upon where they live (each dot represents data from an individual elderly subject). (b) Correspondence analysis of food frequency questionnaires representing dietary patterns of the elderly subjects again separated the subjects based on residence location. (c) Food types that define the dietary patterns of the elderly subjects. Reproduced from Claesson *et al.* (2012) *Nature* 488 (7410): 178-184.

also isolated and include *Lactococcus lactis, Lactobacillus gasseri, Lactobacillus salivarius, Lactobacillus acidophilus* and *Streptococcus mutans* (Lakshminarayanan *et al.*, 2013). These isolates will be used for the development of targeted probiotic products for the elderly. The impact of antibiotic therapy on the intestinal microbiota of the elderly was also investigated (see article on p30).

The advent of next generation sequencing technology has driven research efforts relating to the human gut microbiota. Faecal samples collected from the elderly subjects were used to profile the gut microbiota. The faecal microbiota of the elderly subjects included high levels of *Bacteroidetes* and *Firmicutes* and there was a large variability between individuals (Claesson *et al.*, 2010a). However, the faecal microbiota composition remained stable over time (to three months). Additionally, the core elderly microbiota had a distinct pattern when compared to the microbiota of younger adults (Claesson *et al.*, 2009; 2010b).

Information on diet, cognitive function, health and lifestyle was correlated with microbiota composition of the elderly volunteers. There was a significant difference in microbiota composition between the community and long-stay groups (Figure 1a), with the microbiota of long-stay subjects being less diverse than community subjects, which was also associated with poorer health status in the long-stay group. Dietary data available from food frequency questionnaires again separated these two residence locations (Figure 1b); with higher intake of vegetables and fruit being documented by the community group (Figure 1c). Four dietary groups were established based on fat and fibre content, with the community subjects mostly consuming a low fat/high fibre diet and the long-stay subjects mostly consuming a high fat/low fibre diet (Claesson *et al.*, 2012).

Overall, a healthy diverse diet was linked to healthy people living in the community and correlated with a more diverse gut microbiota. These results suggest that an individual's diet programmes the gut microbiota, which is associated with health status in the elderly. Thus, while we cannot control some changes associated with ageing that affect our gut microbiota, our diet can be influenced as we age.

ELDERFOOD

As a follow-on project, ELDERFOOD recently commenced with the aim of developing foods and food ingredients to positively influence gut health. Initial focus is on the impact of refined dairy ingredients on the gut microbiota of elderly consumers. ELDERFOOD builds on ELDERMET, which has outlined that altering our diet may promote healthy ageing following changes to the gut microbiota. ELDERFOOD will strengthen scientific and technological expertise in the area with the aim of expanding the range of targeted health-promoting products available to our expanding ageing population.

Acknowledgements

ELDERMET is funded by the Department of Agriculture, Food and the Marine and the Health Research Board under the Food for Health Research Initiative (FHRI), as well as by a Science Foundation Ireland award to the Alimentary Pharmabiotic Centre. ELDERFOOD is funded by the Department of Agriculture, Food and the Marine.
For references mentioned in this article and a full listing of peer reviewed scientific papers relating to this research see: http://eldermet.ucc.ie/scientific-articles/

ELDERMET consortium

For full details of the work of the ELDERMET consortium see http://eldermet.ucc.ie at University College Cork and Teagasc, Moorepark. Consortium members include: Professor Paul O'Toole, Dr Marcus Claesson, Dr Ian Jeffrey, Dr Eileen O'Herlihy, Dr Siobhan Cusack, Dr Eibhlis O'Connor, Dr Susana Conde, Susan Power, Hugh Harris, Jennifer Deane, Dr Guillaume Borrel, Professor Colin Hill, Professor Ted Dinan, Professor Gerald Fitzgerald, Dr Tony Fitzgerald, Professor Fergus Shanahan, Dr Douwe van Sinderen, Dr Julian Marchesi, Dr Denis O'Mahony, Dr Michael O'Connor, Dr Norma Harnedy, Dr Kieran O'Connor, Mr Michael O'Riordan, Professor Paul Ross, Professor Catherine Stanton, Mairéad Coakley, Dr Órla O'Sullivan, Dr Mary Rea and Bhuvaneswari Lakshminarayanan. Fodhla Ní Chonchúir and Alexandra Ntemiri have recently joined ELDERFOOD.

Pharmabiotics
health benefits beyond the gut

Dr Mary Rea, Senior Research Officer
Dr Debebe Alemayheu, Research Officer
Dr Eileen O'Shea, ResearchOffi cer
Microbiologists, Department of Food Biosciences, Teagasc Food Research Centre Moorepark and Alimentary Pharmabiotic Centre, UCC.
Correspondence: mary.rea@teagasc.ie

Teagasc researchers and their UCC colleagues are investigating the potential of microbiota-based health promoting substances and organisms.

The human adult gut is colonised by approximately 10^{14} (about 2kg) microbial cells – 10 times more than all the tissue cells in the body. It is now recognised that the gut microbiota play a vital role in maintaining the health of the human host; not only aiding the host in digestion and the manufacture of essential nutrients, but also affecting the immune system and protecting us against gastrointestinal functional disorders, inflammation, infections or cancer. Fluctuations in the composition of the gut microbiota have been associated with various disease states including inflammatory immune disorders, obesity and cancer. As a result, the gut microbiota is increasingly becoming a target for drug and dietary therapy to treat such disorders, as well as a source of novel drugs and bioactive compounds.

The term 'Pharmabiotics' was coined by the Alimentary Pharmabiotics Centre (APC – see article on p22) to describe any biological entity 'mined' from the gastrointestinal microbiota, such as probiotics, bacteriocins and bacteriophage (Shanahan *et al.*, 2009).

Probiotics

Probiotics are live microorganisms which, when administered in adequate amounts, confer a health benefit on the host. They work by positively influencing the composition and activity of the microorganisms in the gut, which in turn helps to maintain a beneficial balance of intestinal bacteria. Currently, probiotic strains are normally lactic acid bacteria such as *Lactobacillus* and *Bifidobacterium* species, which are GRAS (generally regarded as safe) organisms with a long history of safe use. However, now health claims for probiotics will not get approval from the European Food Safety Authority without the underpinning high-quality scientific evidence to support those claims. Much of the work currently underway jointly within the APC is aimed at producing such evidence to support health claims using both animal models and human intervention trials. We have shown in a recent study that, feeding a *Bifidobacterium* strain can influence the fatty acid composition of tissues including the colon, liver and brain and that this activity has been found to be strain-dependent among different *Bifidobacterium breve* strains. More recently, eicosapentaenoic acid (EPA) has been identified as the key ω–3 fatty acid in depression, and we have been able to show that feeding a particular *B. breve* can increase EPA in murine tissue. Other ongoing studies are looking at the anti-obesity, cholesterol-lowering and anti-infective properties of a range of *Lactobacillus* and *Bifidobacterium* species (Barrett *et al.*, 2013).

Dairy foods such as cheese and yogurt are particularly good vehicles for administration of probiotics. For example, a probiotic strain from the human gut – *Lactobacillus paracasei 338* sustained high viability in cheese during ripening and survived well during gastric transit demonstrating that Cheddar cheese can be an effective vehicle for delivery of some probiotic organisms to the consumer.

Bacteriocins

Many gut bacteria produce bacteriocins, which are small peptides (series of amino acids) produced by bacteria, which have antimicrobial activity against a range of pathogenic or spoilage organisms. They can have a narrow spectrum of antimicrobial activity, killing only closely-related bacteria; or have broad

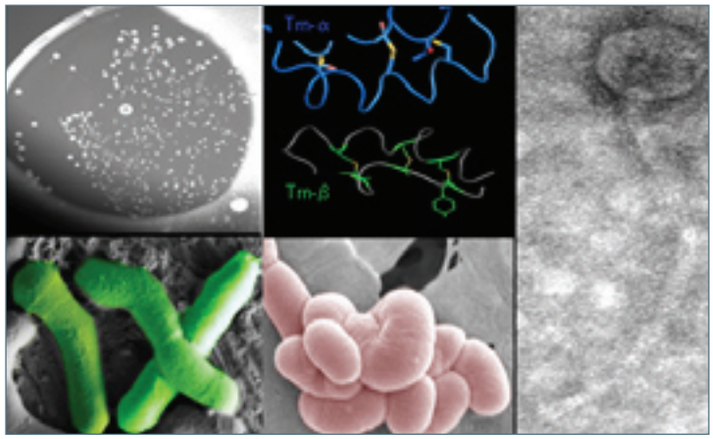


Figure 1. Pharmabiotics (clockwise from left): Bacteriocin-producing culture showing inhibition of *C. difficile* in a seeded agar overlay; the 3D structure of Trn-α and Trn-β the two peptides that make up thuricin CD; anti-*C. difficile* bacteriophage; probiotic *Lactobacillus* and *Bifidobacterium*.

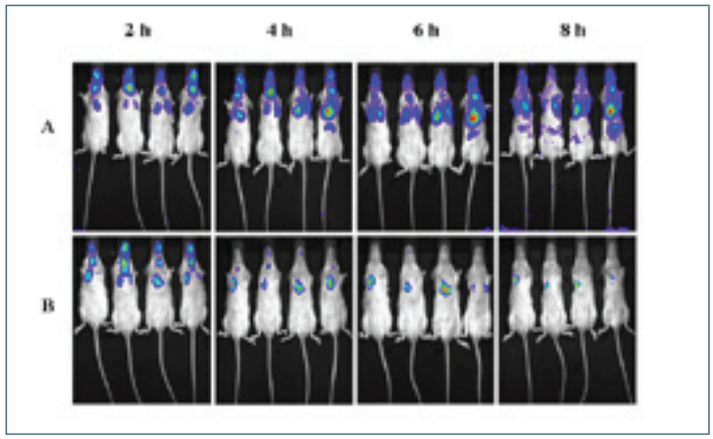


Figure 2. Clearing of *Pseudomonas* infection from lungs of infected mice by bacteriophage. Mice (n = 8) lungs were infected with light producing *Pseudomonas aeruginosa*, a pathogen causing lung infection in cystic fibrosis patients. Top row (A) shows control mice, no phage given and bottom row (B) shows phage-treated mice. *Pseudomonas* was cleared from lungs of phage treated mice. Source: Alemayehu *et al.*, 2012.

spectrum of activity, killing a wide variety of bacteria. Indeed, the production of bacteriocins can also be considered a probiotic trait because they have been shown to protect against infection with *Listeria monocytogenes* in an animal model. The increase in the use of broad spectrum antibiotics has led to the emergence of pathogenic bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA), which are resistant to many commonly used antibiotics. Bacteriocins may play a role in the future as therapeutics to overcome the problem of antibiotic resistance.

Broad-spectrum antibiotics can also disrupt the microbial balance in the gastrointestinal tract, allowing pathogens, which would not normally compete well there, to flourish. Therefore, we in the APC embarked on a programme to mine the gut microbiota for antimicrobial producing organisms that have a narrow spectrum of activity against gut pathogens such as *Clostridium difficile*. From this work we now have a bank of antimicrobial-producing cultures that have activity against both food spoilage and pathogenic bacteria. Two bacteriocin producing bacteria have been patented, namely *Bacillus thuringiensis* DPC 6431 and *L. salivarius* DPC 6502. The *Bacillus* strain produces thuricin CD, a narrow spectrum antimicrobial that can specifically target *C. difficile* in the gut without disrupting the surrounding bacteria as most antibiotics do. In contrast, the *Lactobacillus* strain has potent antibacterial activity against *L. monocytogenes* and *S. aureus*.

Bacteriophages

Bacteriophages (phages) are viruses that attack and kill bacteria. Phages are generally very specific to the bacteria they infect and so, like thuricin above, do not cause collateral damage to surrounding beneficial bacteria. The interest in the use of bacteriophage as bio-control agents against food spoilage, food pathogens and pathogenic bacteria has increased in recent years. A significant level of reduction of *Salmonella* through the use of bacteriophages has been demonstrated for a number of foods such as cheese, meat, fruit and vegetables. A commercial product containing anti-*Listeria* bacteriophages is on the market for the control of *Listeria monocytogenes* in cheese.

Bacteriophages have also been used successfully to control infections in humans, (particularly in Eastern Europe), animals and animal models of infection. Efficacy of bacteriophage to control *Pseudomonas* infections in dogs, humans and mice is well documented. Very recently, we demonstrated the effective use of bacteriophage to control *Pseudomonas* lung infections (a major cause of lung infection in cystic fibrosis patients) in a validated mouse model and on biofilms formed on human airway cells by using a cocktail of two phages, ϕMR299-2 and ϕNH-4 (see Figure 2), which are now patented.

A bacteriophage that efficiently lyses the Shiga toxin-producing *E. coli* O104:H4 strain (a pathogen responsible for the large food poisoning outbreak in Germany in 2011) has been suggested as a potential therapeutic against such antibiotic resistant pathogens. In another study, we have shown how bacteriophages and their lysin (phage-encoded enzyme that degrades the bacterial cell wall) could be effectively used in the treatment of MRSA and *C. difficile*, the two most prevalent pathogens associated with hospital-acquired infections today.

Potential of pharmabiotics

In conclusion, we believe that the gut microbiota itself contains a large variety of solutions that can be mined and exploited to the benefit of human health. These pharmabiotics range from bacteriocins that could be used as food bio-preservatives to probiotic cultures and phage with the ability to protect against some of the most dangerous and persistent of human pathogenic bacteria.

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Gut microbes and obesity

Dr Paul Cotter,
Principal Research Officer,
Teagasc Food Research Centre,Moor epark.
Correspondence:
paul.cotter@teagasc.ie

Research at Teagasc Food Research Centre, Moorepark and University College Cork (UCC) is focussed on how best to take advantage of the links between gut microorganisms and obesity in order to control weight gain.

The emerging obesity pandemic

Ireland is facing into an impending obesity pandemic. In 2008, the World Health Organisation (WHO) estimated that there were over 1.5 billion overweight adults in the world and, of these, approximately 500 million are clinically obese. Indeed, more deaths are caused worldwide by excessive weight than those caused by being underweight. This problem is becoming more significant and it is estimated that by 2015 these figures will come to 2.3 billion and 700 million, respectively. A report by the National Task Force on Obesity found that 39% of Irish adults are overweight and that 18% are obese. It also attributed approximately 2,000 premature deaths to obesity annually and estimated the economic cost of obesity to the State to be €4bn. Similarly, a Health Service Executive report in 2009 stated that 'the future health of the Irish population is threatened by the twin epidemics of obesity and diabetes. Obesity is a multifactorial condition but can be most simply described as being the result of a long-term imbalance between energy intake and energy expenditure. While modern eating habits and ever increasingly sedentary lifestyles are the major contributory factors, researchers are gaining an ever greater appreciation of other important risk factors. One such issue that has emerged in recent years is the link between obesity and the composition and functionality of the microorganisms in our gut (Clarke *et al.*, 2012).

Gut microorganisms contribute to weight gain

One of the many pieces of evidence highlighting the role of gut microorganisms (the gut microbiota) in obesity was provided a few years back by researchers in Professor Jeff Gordon's laboratory in Washington University, St Louis, USA. These researchers highlighted the fact that 'germ-free' mice (i.e., mice that are born by Caesarean section and raised in sterile, isolation chambers so that there are no microorganisms in their gut) do not become obese even when they are fed a high-fat diet. However, when the gut microbiota from normally reared obese and lean mice is transferred to germ-free animals, those that acquire an 'obese microbiota' gain weight

more rapidly than those that receive microorganisms from lean animals (Turnbaugh *et al.*, 2006). While it is not practical for people to exist in a germ-free state, nor would we want to, given that many gut microorganisms contribute considerably to our health and wellbeing, it may be possible to identify and control the specific undesirable microorganisms that contribute to excessive weight gain. The ability of researchers to identify such microorganisms has been considerably improved in recent years as a consequence of the developments that have been made with respect to Next Generation DNA Sequencing technologies (see article on p34). These technologies have allowed us to compensate for the fact that many of the microorganisms present in the gut do not grow well, or at all, in the laboratory. While such microorganisms would previously have been overlooked by classical microbiological techniques, it is now possible to detect their presence using DNA-based technologies that do not require their growth in the laboratory. Using these approaches, a number of types of microorganisms have been identified that are thought to contribute to excessive weight gain and thus, by extension, the development of diet-based strategies to control these microorganisms may ultimately be used together with exercise and diet as part of a multi-faceted approach to controlling weight.

Probiotic and bacteriocin-mediated modulation

One such diet-based strategy involves the identification and use of probiotics (i.e., health-promoting gut bacteria) that produce antimicrobials that control the growth of undesirable, obesity-associated microorganisms. Notably, it is already known that the production of antimicrobials, known as bacteriocins, is a common trait among probiotics and, crucially, bacteriocins and bacteriocin-producing cultures can be, and frequently are, used in food. Importantly, researchers in Teagasc Food Research Centre, Moorepark (led by Professor Paul Ross and Dr Paul Cotter and including Dr Mary Rea and Dr Sheila Morgan), and University College Cork (led by Professor Colin Hill and including Dr Des Field) have a long history in the field of bacteriocin research that has been funded by Science Foundation Ireland (SFI; via the Alimentary Pharmabiotic Centre); the Department of Agriculture, Food and the Marine; and Enterprise Ireland. However, of particular relevance to the obesity issue discussed above is the fact that a research team in Teagasc, led by Dr Cotter and including Dr Caitriona Guinane, Dr Clare Piper, James Hegarty and Calum Walsh with contributions from Siobhan Clarke and Dr Orla O'Sullivan, are also specifically funded by the SFI-funded project, 'Obesibiotics', to identify new bacteriocin-producing probiotics that can control obesity-associated microorganisms. These bacteriocins will be selected such that they will modulate specific undesirable components of the gut microbiota without causing major collateral damage to the remainder of the gut population. Initial investigations performed with Professor Paul Ross (Teagasc); Professor Fergus Shanahan and Professor Paul O'Toole (UCC) and Dr Eileen Murphy (Alimentary Health Ltd.) have highlighted the potential of this strategy. In one instance, a bacteriocin-producing probiotic, *Lactobacillus salivarius* UCC118, was administered for an eight-week period to mice fed a high-fat diet and weight gain was compared to those fed a version of the probiotic that did not produce the bacteriocin and to a third group that were instead fed a placebo. The results showed that the bacteriocin-producing probiotic modulated the composition of the gut microbiota and successfully reduced weight gain (Murphy *et al.*, 2013). While this reduction in weight gain became less noticeable towards the end of the study, it does represent an important development and suggests that further studies with other bacteriocin-producing probiotics, as well as a variety of food bioactives currently under investigation, may have even more dramatic effects.

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Antibiotic therapy and gut microbes

Dr Orla O'Sullivan,
Research Officer;
Bioinformatics, Department of Food Biosciences, Teagasc Food Research Centre, Moorepark.
Correspondence:
orla.osullivan@teagasc.ie

Researchers are investigating the effect of antibiotic therapy on the intestinal microbiota.

The human intestine is colonised by microorganisms at birth and evolves throughout early childhood until reaching a stable adult composition. These microbial colonisers confer numerous health benefits on the host, including roles in nutrition, metabolism and conditioning of the immune system. Recently, the intestinal microbiota has been associated with brain biochemistry and function in animal trials. Indeed, disruption of the intestinal microbiota has been correlated with conditions such as obesity, type II diabetes and inflammatory bowel disease. In addition to natural changes that occur during the ageing process, many things can alter the composition of the intestinal microbiota, including diet, lifestyle, BMI and antibiotic therapy.

Effect of antibiotics

Antibiotics are substances that inhibit the growth of or kill microorganisms. Since the discovery of the first antibiotic, penicillin, by Alexander Fleming in the early 20th century, antibiotics have transformed medicine; allowing treatment of numerous bacterial diseases that had previously proved fatal, thereby greatly improving life expectancy. There are numerous types of antibiotics, which can be categorised as narrow- or broad-spectrum antibiotics; the former target a limited range, while the latter target a wide range of bacteria. Development of broad-spectrum antibiotics is more attractive for most pharmaceutical companies as these compounds can be used to treat multiple types of infections and negate the need to establish the causative agent of infection. While antibiotics remain our most efficient defence against infection, the negative consequences of antibiotic therapy cannot be overlooked. The recent advent of next-generation sequencing technologies has revealed the extent to which antibiotics affect the intestinal microbiota. In particular, broad spectrum antibiotics not only eradicate the target pathogenic bacterium but also cause extensive collateral damage across the intestinal microbiota and can result in increased antibiotic resistance among the surviving microbes, antibiotic associated diarrhoea and an altered inflammatory response. The reduction in microbial diversity brought about by broad spectrum antibiotics is also undesirable. Reduced microbial diversity has been observed in children susceptible to allergies and in sufferers of diseases such as inflammatory bowel disease, irritable bowel syndrome and *Clostridium difficile* infection. More specifically, antibiotic therapy reduces the numbers of beneficial bacteria in the intestine including *Bacteroides* spp., *Bifidobacterium* spp., *Lactobacillus* spp. and *Faecalibacterium* spp. Understanding the effect of antibiotic therapy on the composition of the intestinal microbiota is fundamental to the development of targeted treatments for improved health. Within the Alimentary Pharmabiotic Centre (see article on p22), we have focused on the effects of antibiotics on the intestinal microbiota at two extremes of life – infancy and elderly.

Antibiotic use in infants

During the first two years of life, the infant intestinal microbiota is in a state of flux moving from the commensal *Lactobacillus* and *Bifidobacterium* rich composition to a complex adult composition. Antibiotics are used in infants, particularly in pre-term infants, to treat and prevent infection. Any perturbations to the intestinal microbiota, especially to commensal populations could potentially

have long-term health consequences. While these long-term consequences are not known, broad-spectrum antibiotic use in early life has been linked to the subsequent development of asthma, allergies, colitis and increased risk of obesity. In one study we elucidated the intestinal microbiota of 10 pre-term infants and discovered that *Bifidobacterium* spp. were only detectable in the single infant not receiving antibiotic therapy. This reduction in beneficial bifidobacteria was further demonstrated in a study with 18 full-term infants, half of which received antibiotic therapy. Notably, infants receiving antibiotic therapy also had reduced microbial diversity, reductions in beneficial *Lactobacillus* spp. and increased populations of the potentially disease-causing *Enterobacteriaceae* family.

Antibiotic use in elderly

ELDERMET, an Irish study funded to study the intestinal microbiota of 500 elderly people, also investigated the consequences of antibiotic therapy. Microbiota profiling was performed on 185 subjects, 42 of which had received an antibiotic within the previous four weeks. Numerous differences between the antibiotic-treated and antibiotic-untreated groups were observed. On the whole, the impact of antibiotic therapy on the intestinal microbiota appears to be individual and antibiotic-type specific. There was a reduction in the overall diversity of bacteria identified in the antibiotic-treated subjects (n=58), compared to untreated subjects (n=79) and significant perturbations across nine genera following antibiotic therapy. Antibiotics were sub-classified based on their mode of action, namely nucleic acid synthesis inhibitors and cell envelope antibiotics. While there was an overall seven-fold reduction in *Bifidobacterium* spp. numbers post antibiotic therapy, this increased to a 23-fold reduction when only nucleic acid synthesis inhibitors were administered. More alterations in the intestinal microbiota were observed post nucleic acid synthesis inhibitor therapy; most notably a decrease in *Faecalibacterium spp*. numbers. *Faecalibacterium* have been linked to positive health benefits including a protective effect against Crohn's disease and colorectal cancer; reductions in *Faecalibacterium* post-antibiotic therapy may negate such positive associations.

Alternatives to antibiotics

To circumvent the collateral damage sustained post-antibiotic therapy, alternatives are being investigated. Vaccinations, prebiotics, probiotics and, in particular, phage therapy and bacteriocins, have all been mooted as potential alternatives to antibiotics (see article on p26). Phage therapy uses bacteriophage, a virus which infects and kills bacteria, to treat bacterial infections and is a more targeted approach than antibiotic therapy, with each bacteriophage having a limited range, thereby reducing the risk of killing beneficial microbes. Bacteriocins are peptides that are produced by a bacterium and kill other bacteria; similarly to antibiotics they can be broad or narrow spectrum. Within APC, we are investigating a narrow spectrum bacteriocin, thuricin CD, which is a potent killer of *C. difficile* (see article on p26). Using a model of the human distal colon, we demonstrated that while thuricin CD works as effectively as conventional antibiotics, it has very limited impact on other members of the intestinal microbiota (Figure 1). Ingesting probiotics and/or prebiotics during and post antibiotic therapy may aid in repopulating the intestinal microbiota with beneficial bacteria.

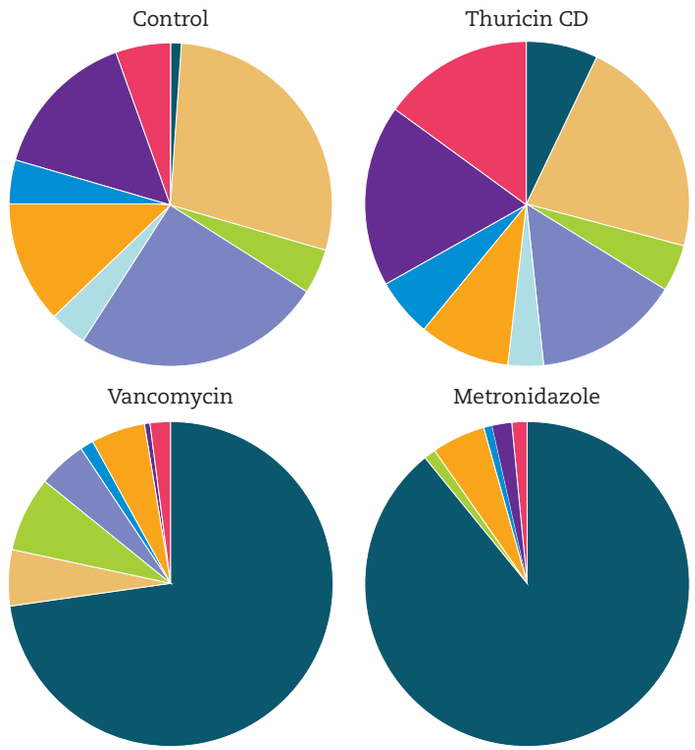

Figure 1. Illustration of the reduction in the diversity of intestinal microbiota post treatment with the broad spectrum antibiotics, vancomycin and metronidazole and the narrow spectrum bacteriocin thuricin CD. Each segment of the pie chart represents a different bacterial family.

Recently, the concept of faecal transplantation (transplanting intestinal microbiota from a healthy donor to a compromised recipient) has been suggested as a means of reversing the collateral damage incurred after prolonged infection and antibiotic therapy. Indeed, successful outcomes have been reported using this approach to counteract *C. difficile* infection.

Future prospects

While antibiotics remain an essential medical tool, the further development and application of more targeted anti-microbial therapies should be explored to prevent intestinal dysbiosis. Probiotic and/or prebiotic use and, in particular, strategies designed to increase levels of *Bifidobacterium* spp. and other desirable bacteria, may be one approach to compensate for situations where broad-spectrum antibiotic therapy is unavoidable.

Acknowledgements

This work was funded by the ELDERMET and Infantmet research projects (see p24 and p32), which are funded by the Department of Agriculture, Food and the Marine, and the Health Research Board under the Food for Health Research Initiative and by the Alimentary Pharmabiotic Centre. Dr Orla O'Sullivan presents an overview of work carried out in TFRC, Moorepark in collaboration with Professor Paul O'Toole, Dr Marcus Claesson, Dr Susana Conde, Professor Colin Hill, Professor Gerald Fitzgerald, and Professor Fergus Shanahan, (all University College Cork); and Professor Paul Ross, Professor Catherine Stanton, Mairéad Coakley, Dr Mary Rea, Fiona Fouhy, Dr Eoin Barrett and Dr Paul Cotter, (all Teagasc, Moorepark) and Professor Anthony Ryan, Dr Eugene Dempsey, Colm Kerr, Dr Seamus Hussey and Dr Brendan Murphy (all Cork University Hospital).

Programming the infant microbiota through nutrition

INFANTMET is an ongoing, four-year study funded by the Food Institutional Research Measure (FIRM) of the Department of Agriculture, Food and the Marine, led by Teagasc, Moorepark, and involving a partnership with Cork University Maternity Hospital (CUMH) and University College Cork (UCC).

Professor Catherine Stanton, Teagasc Food Research Centre, Moorepark, Fermoy, Co Cork.
Correspondence: catherine.stanton@teagasc.ie

Breast milk is the gold-standard feeding regime for newborn infants and represents a baseline for the functional performance of infant formulae. In terms of infant health, it is imperative to understand how early infant nutrition influences the development of a healthy gut microbiota, which plays an important role in host health, influencing the maturation of the immune system and regulating energy metabolism. Establishment of the intestinal microbiota commences at birth, and colonisation with a healthy gut microbiota is thought to be an essential aspect of infant health, particularly with respect to protection against infection. The gastrointestinal tract of the newborn infant becomes rapidly colonised by a diverse range of up to 10^{14} microorganisms from over 1,000 different species during the first year of life. Knowledge of the precise impact of the first diet on the evolution of the infant gut microbiota has been limited by the technologies available and issues with gathering a sufficiently large cohort of infants for specific investigations. These issues are now being addressed through collaborative links between Teagasc, Cork University Maternity Hospital (CUMH) for access to specific cohorts of infants (healthy term and preterm babies) and via the use of high throughput sequencing technologies for analysis of the infant gut microbiome (UCC/Teagasc).

The objective of the INFANTMET study is to define the composition and functional performance of the baseline microbiota in developing breast-fed infants over time, using state-of-the-art pryo-sequencing technology. In the INFANTMET study, we are studying gut microbiota composition correlated with infant health in three groups of infants during the first two years of life: the first group involves infants delivered naturally and fed exclusively on breast milk for minimum of first four weeks of life; the second group involve infants delivered via Caesarean-section delivery, and fed exclusively on breast milk for minimum of the first four weeks of life; and, the third group involves preterm infants.

Gut microbiota of infants

The human intestinal microbiota evolves from an immature and unstable ecosystem during infancy into a more complex and stable ecosystem in adulthood. The colonisation of the microbial population in the gut begins during birth, and, initially, has an unstable composition, which undergoes marked changes as it develops into a relatively stable community in the adult. The adult gut microbiota is a complex ecological

Ireland contributes approximately 12% of the entire global exports of infant formula and, in 2008, had a combined turnover of €667 million. "Through investment and innovation, Ireland's traditional leading export sectors have been strengthened and safeguarded, augmented by world-leading expertise in ingredients, infant formula and other functional and prepared consumer foods." (*Food Harvest 2020*, an industry-led strategy, supported by Government that sets out the ambition, vision and targets for growth of the Irish agri-food sector towards 2020). This project will form a baseline for the development of new 'intelligent formulas' for our infant formula industry and the dairy companies which supply them.

system harbouring trillions of bacteria that vary according to location in the gastrointestinal tract. This ecological niche provides an excellent site for complex interactions between the host and its microbial inhabitants. Molecular methods currently indicate that there are approximately 1,000 prevalent bacterial species in the intestine, with as many as 10^{12}-10^{14} microorganisms present, of which 70-80% remain uncultured. In its entirety, the human intestinal microbiota is estimated to contain 150-fold more genes than its host's genome. Initial bacterial population of the infant gut depends on a number of factors including mode of delivery, feeding type, antibiotic usage and the surrounding environment. For example, the microbiota of infants delivered by Caesarean section reportedly consists of relatively lower numbers of bifidobacteria and higher numbers of *Clostridium difficile* and *Escherichia coli* than infants delivered vaginally. Colonisation is also delayed in infants delivered by Caesarean section compared to vaginally-delivered infants. Not surprisingly, bacteria involved in the initial colonisation of the gut of vaginally-delivered infants (predominated by *Prevotella* species and lactobacilli) have been shown to reflect their own mother's faecal and vaginal bacteria. Another important factor is antibiotic treatment of newborns, which has been shown to negatively influence the intestinal colonisation in infants, whereby antibiotic-treated infants have lower microbial numbers and diversity in the gut, compared with healthy age-matched controls. Diet is another important factor contributing to the composition and diversity of the human intestinal microbiota. The feeding regime of newborn infants is one of the major factors affecting intestinal colonisation. Breast milk, which contains a complex mixture of oligosaccharides is believed to stimulate the growth of beneficial bacteria such as *Bifidobacterium* in the infant gut, and to inhibit the binding of pathogenic bacteria and toxins, offers the best nutritional regime for maturation of the infant gut.

Expected benefits

Ireland is a major manufacturer of infant milk formula, contributing approximately 12% of entire global exports. Little is known about how gut microbiota composition may be manipulated in a positive sense through infant formula for the developing infant. This project will, therefore, generate a thorough understanding of the evolving composition and metabolic capabilities of the gut microbiota in early life, thereby providing nutrient-based opportunities for its manipulation in a positive sense. The project will deliver information on the evolving gut microbiota of infants born at CUMH over the first two years of life. Thus, the project will provide new opportunities for optimisation of infant milk formula composition, with appropriate new bioactive ingredients such as milk fractions, probiotics and prebiotics to effectively programme the early infant gut microbiota in a manner closer to mother's milk. This project will provide manufacturers with a baseline blueprint of the composition of the gut microbiota in response to optimal breast feeding. Consequently, next generation formulations and ingredients can be designed using this information as an essential microbial biomarker. The information generated in this project will provide the infant formula manufacturers, their dairy suppliers and the health professionals for the paediatric community with essential knowledge relating to the bacterial composition and functionality of the infant gut microbiota, how it may be positively modulated by infant formula and the impact of early antibiotic administration. Traditionally, infant milk formula has been developed based on compositionally mimicking human breast milk where possible. However, there is now an increasing appreciation that the functional attributes in terms of health maintenance and promotion are just as vital. In this respect, this platform project will provide the sophisticated biological readouts by which any formula/ingredient can be assessed and, hence, will lead to a new generation of ingredients that actively influence the composition of the infant gut microbiota in a healthy (breast-fed) direction. As such, this outcome should give a major competitive advantage to our infant formula manufacturers and the dairy companies that supply them.

The INFANTMET management team includes Professors Catherine Stanton and Paul Ross, Teagasc Moorepark, neonatologist Professor Tony Ryan, CUMH, and microbiologist Professor Paul O'Toole, UCC.

Gut health and DNA sequencing

Dr Paul Cotter, Principal Research Officer, manager DNA Sequencing Centre
Dr Fiona Crispie, APC-funded sequencing technician
Teagasc Food Research Centre, Moorepark
Correspondence: paul.cotter@teagasc.ie

The Alimentary Pharmabiotic Centre and Teagasc have expanded their DNA sequencing centre which will greatly benefit research across a wide variety of fields, including investigations relating to gut health.

Expansion of Teagasc DNA Sequencing Centre

Advanced DNA sequencing technologies have led to a revolution in almost all fields of biological research. In particular, the sequencing of some or all of the genome of specific humans, farm animals, fish, crops, cells and microorganisms has had a major influence on research relating to human and veterinary health and disease and on food and agriculture. These investigations relate to several National Priority Areas (Research Prioritisation Steering Group, 2012), including diagnostics, therapeutics, food for health, sustainable food production and processing and medical devices, and are thus also relevant to a large proportion of research projects across the country.

Despite the advances made since the release of the first 'high throughput' DNA sequencer in 2006, the importance of being able to access advanced DNA sequencing technologies is expected to become even more critical in the coming years. Crucially, Teagasc has further expanded its DNA Sequencing Centre at Moorepark such that, in addition to the existing Roche GS-FLX instrument, it now also contains state-of-the-art Illumina MiSeq (funded by Teagasc infrastructure funding), Ion PGM and Ion Proton (both funded by a Science Foundation Ireland infrastructure grant) sequencers, with further support coming from the Alimentary Pharmabiotic Centre. Importantly, the availability of these platforms will lead to significant reductions in the cost and turn-around-time of advanced DNA sequencing projects and the Centre's flexibility will ensure that projects with considerable (Ion Proton), moderate (GS-FLX, MiSeq and PGM) and low (MiSeq and PGM) sequencing needs can all be accommodated.

DNA sequencing and gut health research

Given the importance of the gut microbiota to human health and of specific gut microbes to many Teagasc projects, it is of great benefit to have

immediate access to DNA sequencing technologies. The vast majority of the gut microbiota cannot be grown in the laboratory and it is not possible to accurately investigate these populations, assess their impact on health and disease, or establish the consequences of interventions (dietary, probiotic, prebiotic, antibiotic and/or chemotherapeutic) on these populations in the absence of access to DNA sequencing technology. DNA sequencing technology can provide information as to what microorganisms are present in the gut and what their function might be. Gut microbial populations that have been investigated to date include the elderly (Eldermet, led by Professor Paul O'Toole of UCC – see article on p24), infants (Infantmet, led by Professor Catherine Stanton of Teagasc – see article on p32) and athletes; with the corresponding data providing an insight into how microorganisms contribute to the health of these individuals and how diet can be changed in order to alter the composition of these microorganisms in a beneficial way. A variety of other smaller scale animal studies have also taken place in which the impact of other dietary bioactives, probiotics, antibiotics, and even GMO crops, on the gut microbiota of animals have been investigated.

Similarly, genomic sequencing of specific health-promoting bacterial strains (probiotics) has been, and will be, of key importance with respect to functional genomics, i.e., deciphering the associated health-promoting mechanisms of action, ensuring the absence of virulence factors and assessing the suitability of strains for large-scale industrial production. Sequencing of disease-associated microorganisms also allows us to determine how to best control populations and, in turn, prevent infection. The sequencing service is available to all Irish research institutes and industry. Researchers, including many from Teagasc, University College Cork, University College Dublin, University of Limerick, NUI Galway, Cork Institute of Technology and Waterford Institute of Technology, as well as a number of companies, have used this service in the past.

Other applications

Finally, it should be emphasised that while this article specifically highlights how the Teagasc DNA Sequencing Centre has been and will be used by Teagasc researchers and their academic and industrial partners and clients with respect to the gut microbiota, there are a myriad of other ways in which this technology can be utilised. These include various other areas of particular interest to Teagasc, including:

- agrigenomics (crops and other plants – improved disease resistance, enhanced pest resistance, breeding for enhanced production efficiency);
- livestock (healthier herds, more accurate prediction of genetic merit, advanced breeding programmes);
- aquaculture (faster growth rates, greater disease resistance, improved stress tolerance); and,
- microbial genomics (starter bacteria, soil bacteria, disease and spoilage-associated microbes as well as viruses in food).

This technology will also be available to other institutes on a commercial basis for other applications, e.g., those relating to forensic genomics, cancer genomics and genetic disease.

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Healthy mushrooms.

MushTV

An EU research project led by Teagasc researcher, Dr Helen Grogan, is delivering new technologies to the European mushroom industry.

Dr Helen Grogan,
Mushroom Research Group,
Teagasc Food
Research Centre,
Ashtown, Dublin 15.
Correspondence :
helen.grogan@teagasc.ie
Research Partners:
Dr Caoimhe Fleming-Archibald,
Teagasc, Ireland
Dr Johan Baars, Plant Research
International, the Netherlands
Dr Nancy Pyck, Inagro, Belgium
Dr Kerry Burton, East Malling
Research, UK
Mairead Kilpatrick,
Agri-Food and
Biosciences Institute,
Northern Ireland

MushTV is a three-year EU FP7 project generating scientific information and technologies for the European mushroom industry. The MushTV Consortium is made up of 17 partners across all sectors of the industry and includes six grower associations, five compost companies and five research organisations in Ireland, Britain, Belgium, the Netherlands and Poland. The project is focussed on generating scientific information and technologies in the areas of disinfectants, disease diagnostics and biopesticides to deal with two important diseases affecting mushroom production. *Trichoderma aggressivum* is a fungus that causes compost green mould, which dramatically reduces mushroom yield, while Mushroom Virus X (MVX) disease is associated with a complex of viruses that cause mushroom browning and poor quality crops. Both diseases can have quite severe effects if they infect modern, technologically advanced "bulk phase 3" compost facilities.

Bulk phase 3 mushroom compost is produced in large tunnels of up to 200-400 tonnes. When it is ready to produce mushrooms, this very vulnerable, living, product is 'bulk-handled', using automated winches and conveyors, and then transported in bulk to mushroom growers. Infections in bulk compost can go unnoticed, partly due to the high level of automation involved, and the sheer volume of compost being handled. This means that the pathogens can be widely dispersed around compost facilities and mushroom farms before either green mould or virus problems develop.

Halfway through the project term, good progress has been made by the research partners and the main achievements of the seven research areas are summarised below.

Alternative disinfectant products and methods

Identification of alternative disinfectant products that are effective against *T. aggressivum* and MVX (which is carried by the mushroom itself - *Agaricus bisporus*) is a priority for the industry. A shortlist of products for evaluation was drawn up in consultation with the consortium and, under laboratory test conditions, spores of *A. bisporus* and *T. aggressivum* were killed by most disinfectants. However, when the organisms were within compost particles it was difficult to kill either *A. bisporus* or *T. aggressivum*. During the final year of the project, a technical factsheet will be prepared on the efficacy of disinfectants in killing *Trichoderma* and virus-infected

Agaricus propagules on farms and compost facilities. It will give clear guidance on the best ways to achieve good disinfection of machinery and facilities. Information will also be given to industry through workshops, seminars and conference presentations.

MVX – characterisation and improved diagnostic tests

Characterising the MVX viruses present in MVX-infected mushrooms is key to understanding this complex disease. Sequencing and bioinformatic analysis has tentatively identified 17 viruses that fit into all of the 11 classes of virus described for fungi. This suggests that *A. bisporus* has received viral infection on multiple occasions. It is unknown whether these have occurred historically or in recent times. Only one of these viruses, Mushroom Bacilliform Virus (MBV), has previously been fully sequenced. The remaining 16 viruses are new to science. This new genetic information will facilitate the development of sensitive QPCR diagnostic tests that will be made available to mushroom industry service-providers. Progress has also been made in simplifying virus extraction from compost samples, which should enable diagnostic tests to be more reliable.

Volatile-based diagnostic method for *T. aggressivum*

Being able to detect volatile organic compounds (VOCs) of *T. aggressivum* in infected compost would greatly improve control of compost green mould. Preliminary results indicate that VOC profiles from *T. aggressivum*-infected compost can be discriminated from healthy compost after 14 days of growth in bulk tunnels. Data analysis is progressing. Ultimately, this research will lead to the development of a volatile-based diagnostic method to detect *T. aggressivum* in phase 3 compost. Such a piece of equipment will alert composters when there is a *T. aggressivum* infection in phase 3 tunnels. Composters can then take action to minimise the impact of a potential disease outbreak and focus their attention on more rigorous hygiene measures.

Reservoirs of T. aggressivum and MVX on mushroom facilities

Identifying where reservoirs of *T. aggressivum* and MVX inoculum occur on compost and grower facilities highlights weaknesses in their hygiene measures. Pilot studies have been completed and critical locations were identified for sampling. Four composters and four growers have been surveyed, and samples were tested for *T. aggressivum* and MVX. Results were reported back to industry on a confidential basis. Further testing of farms and compost facilities are planned or underway. This information will help individual SMEs to be more informed of disease risks on their facilities.

Work on tracking the incidence and spread of MVX inoculum on mushroom facilities, before, during and after an outbreak, is just starting.

Biocontrol of mushroom pathogens using *Bacillus subtilis*

Identifying new products to control mushroom diseases is a high priority as there is only one approved product available in most EU countries. *Bacillus subtilis*, a biocontrol agent, is therefore being evaluated. Results show that it has little effect on mushroom production but it was ineffective against both *Mycogone* (wet bubble) and *T. aggressivum*. Further work is ongoing to test it against pathogens causing dry bubble and cobweb disease. A second product, Natamycin, is also being evaluated. Should a successful disease control product be identified, the consortium will co-operate with any company that will support the registration of the product for use in Europe. A new, effective disease control agent would greatly reduce anxiety within the mushroom industry. A technical factsheet on disease-control will be produced for any successful product identified.

Mushroom growers talk to Teagasc's Dr Helen Grogan at the MushTV stand during Mushroom Days 2013 in the Netherlands.

Growth of *T. aggressivum* in bulk phase 3 tunnels

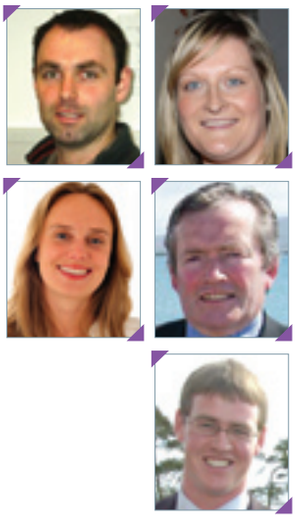
In order to characterise the growth of *T. aggressivum* in bulk-incubation tunnels, trials were conducted in experimental tunnels (1.8 tonnes), subdivided into vertical and horizontal sections. A *T. aggressivum* infection was introduced into the bottom left hand corner at the rear of the tunnel. During tunnel emptying (end of spawn-run), *T. aggressivum* was not generally visible in the tunnel. However, yield from compost at the back of the tunnel (near infected area) was reduced by 100%, while compost from the front cropped normally. Further trials will involve mixing the compost to replicate the bulk-handling and transportation processes that occur at commercial bulk phase 3 facilities. This research is increasing our understanding of how *T. aggressivum* grows and is dispersed within the phase 3 compost system. Information from all the *Trichoderma*-related research areas above will be used to compile a technical factsheet for mushroom growers and composters. Information will also be given to industry through workshops, seminars and conference presentations.

Dissemination and training

To date, a number of articles have appeared in the mushroom press in the various partner countries (Ireland, Britain, Netherlands, Belgium and Poland) and a public website for the project is available at http://www.mushtv.eu. The first major dissemination event was held in May at "Mushroom Days 2013", the International Trade Show for the Mushroom industry in the Netherlands. A summary of results to date has also been given to the Polish Mushroom Industry at one of their Mushroom Conferences and it will also be given to the Irish and UK mushroom industries at the forthcoming Ireland and UK Mushroom Conference in Monaghan on October 17, 2013.

Acknowledgements

This research was funded by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 286836 - MushTV.



Nutrient management plan development

Dr Cathal Buckley,
Research Officer, Agricultural Catchments Programme, Athenry, Galway
Sarah Mechan,
Data Manager, Agricultural Catchments Programme, Johnstown Castle, Wexford
Dr Aine Macken-Walsh,
Research Officer, Rural Economy and Development Programme, Athenry, Galway
Dr Kevin Heanue,
Research Officer, Rural Economy and Development Programme, Athenry, Galway
Stan Lalor,
Research Officer, Environment and Land Use Programme, Johnstown Castle, Wexford
Correspondence : cathal.buckley@teagasc.ie

The Agricultural Catchments Programme has facilitated an open innovation approach to developing nutrient management plans.

Nitrogen and phosphorus are key elements in agricultural production and inefficient use has consequences for both economic returns to agricultural production and the risk of nutrient transfer to water. Nutrient management optimisation involves matching nutrient supply to crop demand at the field level. Ideally, this involves the development and implementation of a nutrient management plan (NMP). A NMP is a management strategy for chemical and organic manures based on an inventory of land, cropping, stocking rate and soil fertility data.

At present, a NMP is produced by applying a series of calculations to farm data to estimate fertilizer requirements and ensure compliance with EU Nitrates Directive-based regulations. Preparing a NMP requires the calculation of nutrient recommendations for each field. Developing a NMP is often perceived as a cumbersome task; requiring the collection of data from a number of disparate sources, and resulting in complicated and lengthy spreadsheet outputs. This format poses difficulties for easy and routine consultation, reducing its potential to be used as a farmer decision-making aid on a day-to-day basis.

Against this background, an open innovation research project was initiated to examine:

- how existing Teagasc nutrient management planning software tools and associated outputs are currently being used;
- if the end users (advisors and farmers) would like to see them changed to make them more user friendly and practically useful; and,
- if so, how should they be changed?

Open innovation

Open innovation is a knowledge management strategy that uses the input of end users to improve internal innovation processes. It incorporates user-led (farmer and advisor) innovation and the co-development (by technologists and users) of a technology. This strategy seeks to ensure that the use of the outputs is optimised by incorporating user insights into the development of outputs at the design stage. This research process comprised three elements; two surveys and an open innovation process.

Initially, two surveys were administered to Teagasc advisors and farmers asking questions about the desirable features of a NMP. The advisor survey was web based and was completed by 150 respondents. The farmer survey, which targeted over 50 Teagasc offices, was completed by 400 farmers.

Farmers ranked the provision of whole farm nutrient management summary information, detailed information at field level and colour-coded maps as the top three desirable features of a NMP. Advisors ranked software functionality issues as priorities, including rolling plans over from year to year and being able to link electronic data sources. In addition, the ability to print the plan to one page and the provision of colour-coded maps were important requirements.

Following the surveys, a more intensive consultation process was initiated with farmers and advisors familiar with Teagasc's NMP software and its outputs. Utilising a stakeholder participatory co-design framework, focus groups were held with farmers and advisors. The aim of the focus groups was to elicit opinions on how to make the software and its outputs more user-friendly and usable. A total of eight farmers and eight Teagasc advisors from different farm enterprise backgrounds and geographic locations across Ireland were brought together over two days to participate in the focus group sessions. After introducing the topic and the objectives of the research, separate farmer and advisor focus group

sessions were convened. Some of the primary issues to emerge from these focus groups are outlined below.

Advisor focus group

Advisors are the main generators of a NMP, hence this focus-group session focused on issues around the NMP development process and related software issues. Some of the issues to emerge from the advisor focus group were:

- The NMP development process is heavily focused on compliance.
- The software needs to be easy to use with the ability to generate a NMP swiftly, using all relevant electronic data sources.
- The software should have the ability to 'tailor' each plan to individual farm circumstances and transition data from year to year.
- The software should have built-in functionality to ensure compliance with regulations.
- The software should allow agronomic trends to be analysed temporally.
- The software should have integrity checks to assist advisors in recognising when a farmer is deviating from a plan at the review stage.
- Advisors made recommendations across a range of technical areas about how the current software might be improved.

Farmer focus group

Some of the issues to emerge from the farmer focus group were:

- Farmers tend not to be heavily involved in the NMP development process. This is a role generally undertaken by an advisor due to the perceived complexity. There was a consensus that farmers should develop and use NMPs as fertilizers are expensive and it's important from an agronomic and environmental perspective to use efficiently.
- Farmers would welcome more exposure to information about managing soils. For example, it emerged that farmers may not understand the soil nutrient index system. A NMP needs to be useful to the farmer and not just deal with compliance.

A NMP has to be simple and flexible

Farmer focus-group participants were asked to make recommendations and were given a blank template to design the ideal form of output from a NMP. The farmers made the following recommendations:

- The NMP should contain nitrogen, phosphorus, potassium, lime and potentially trace element recommendations.
- Maps are a very useful visual aid and would be a good way to present recommendations.

An ideal output would be a one page A4 laminated sheet where recommendations for the year are outlined via a map on one side and in tabular form on the reverse. This could be readily stored on farm machinery, making it more accessible for day-to-day implementation when applying fertilizers.

Figure 1. Farm level nutrient management map.

Consultation on software design and outputs

Having established and recorded the suggestions and recommendations of both advisors and farmers through individual focus groups, the potential software features and output templates were demonstrated to a joint grouping in another part of the open innovation process.

The map in Figure 1 was presented to farmers as an example of the potential map output they suggested. The recommendations from this open innovation co-design process are informing a Teagasc nutrient management software re-design process. It is envisaged these changes will improve the quality and efficiency of the NMP planning process for advisors and provide more user friendly outputs for farmers to interpret and implement nutrient management planning on their farms. Continuing the participatory co-design ethos of the open innovation process, farmers and advisors will be invited back to comment on the new software product and outputs at the prototype phase of their development.

Since its inception, the Agricultural Catchments Programme has been developing a novel geo-computational information management system to collate and manipulate multiple farm nutrient and geospatial data sets to assist in the coordination of nutrient management planning on farms. When combined with the existing Teagasc nutrient management programmes widely used within the organisation, this new system has the potential to broadly address the demands of both the advisors and farmers as identified in focus groups and general surveys.

END-O-SLUDG

Wastewater transformed for good

Teagasc researchers collaborate on EU FP7 project to determine risk of pathogen transmission associated with use of sewage sludge in agriculture

Sewage sludge is defined as the mass of settleable solids accumulated during the sedimentation phase of the wastewater treatment process. It is rich in nutrients and organic matter, and can be utilised as a sustainable substitute for mineral fertilisers in agricultural systems. However, sludge can also contain contaminants including pathogenic microorganisms, which pose a potential risk to public health. Currently, the EU produces approximately 10Mt of sewage sludge annually, and this figure is expected to increase. Traditional methods of disposal include incineration, landfill and application to agricultural land, the latter is the most economic and environmentally sustainable option. It is important to ensure that the agricultural route is maintained by optimising sludge safety and changing public perceptions. END-O-SLUDG is a European-funded project that consists of 14 partners from academia and industry. Its overall aim is to improve the marketability of sewage sludge and its derivatives. The consortium is tasked with devising novel and efficient treatment strategies to reduce the volume of sludge produced, and to quantify and minimise the risk associated with pathogens and micro-pollutants in an effort to instil greater public confidence.

Maximising fertiliser value of sewage sludge

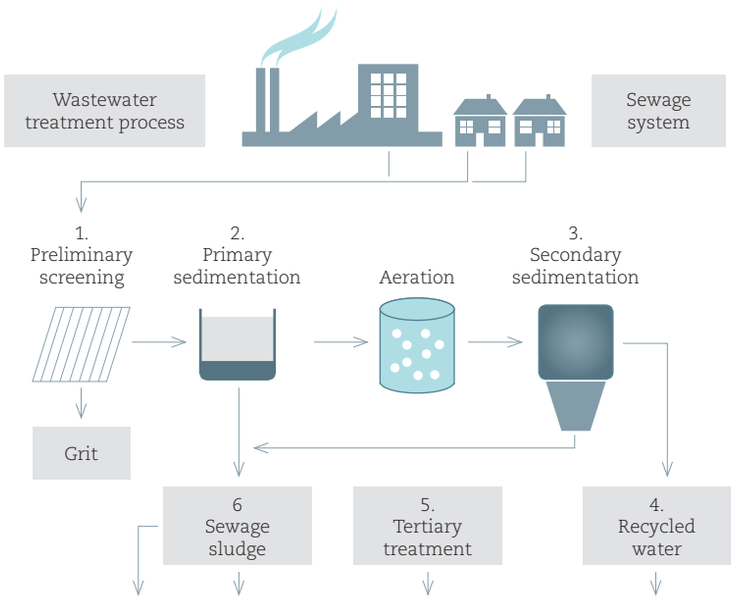
A range of primary, secondary and tertiary sludge treatment options are available and efforts within the END-O-SLUDG project are focusing on optimising these treatment processes. Collaborators are working on chemical oxygen demand (COD) and phosphorus removal from wastewater, enhanced volatile solids destruction, suppression of *Escherichia coli* in sludge cake, nutrient recovery and the development of new fertilizer products. Teagasc's main role in this project is to determine the pathogen risk associated with the application of sewage sludge to agricultural land. Pathogens, including bacteria, protozoa, viruses and helminths, are shed in human waste. Various forms of heat treatment are primarily used to destroy them, including digestion, pasteurisation and composting. Effective treatment is a function of both retention time and temperature, and the final product is classed as either conventional- or enhanced-treated sludge, depending on the level of pathogen removal. Other factors that affect pathogen survival during the treatment process include sludge physico-chemical composition, pH, design and operation of the wastewater treatment plant and microbial antagonism. Although treatment is employed to control pathogen concentration in the final sludge product, it is unlikely to achieve total destruction. Therefore, pathogens are potentially released to the wider environment when sludge is applied to soil.

Pathogen transmission in agricultural environment

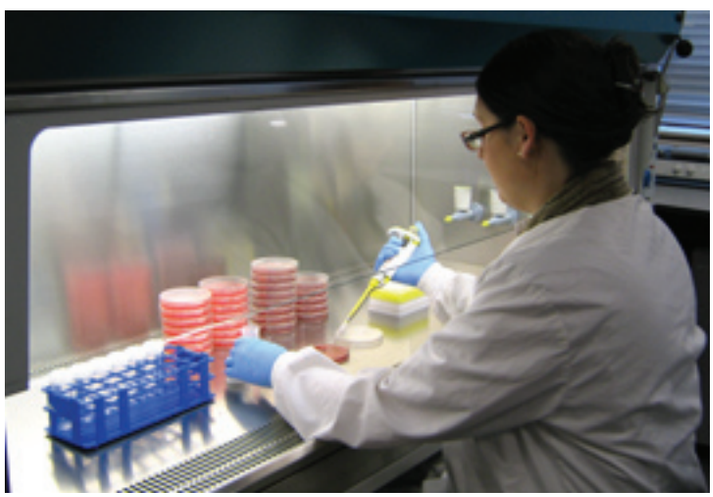
Soil plays a major role in attenuating pathogens, which are inactivated through a combination of physical, chemical and biological processes. The major physico-chemical factors that influence the survival of introduced microorganisms in soil are soil texture and structure, pH, moisture, temperature, UV radiation, nutrient and oxygen availability, and land management regimes. Biotic interactions include antagonism from indigenous microorganisms, competition for resources, predation and occupation of niche space. However, if encased within a protective organic matrix such as sludge, pathogens may not be exposed to environmental extremes associated with decay. In this instance, viable pathogens can be lost to water supplies, via overland or subsurface flow, or may contaminate crops intended for human consumption, resulting in a threat to public health.

Dr Emma Moynihan, Research Technician, Teagasc, Crops, Environment and Land Use Research Programme, Johnstown Castle
Dr Fiona Brennan, Environmental Microbiologist, James Hutton Institute, Aberdeen AB15 8QH, UK
Stephanie Ellis, Teagasc Walsh Fellow PhD student, Johnstown Castle
Professor Karl Ritz, Chair in Soil Biology, Cranfield University, United Kingdom
Dr Sean Tyrrel, Senior Lecturer, Cranfield University, United Kingdom
Professor Bryan Griffiths, Soil Scientist, SRUC, Edinburgh EH9 3JG, UK
Dr Karl Richards, Head of Agri-Environment Department, Teagasc, Crops, Environment and Land Use Research Programme, Johnstown Castle
Correspondence: emma.moynihan@teagasc.ie

Land application of sewage sludge can result in environmental release.



Simplified schematic of the wastewater treatment process of viable pathogenic microorganisms.



Assessing pathogen survival in soil and sewage sludge.

Filtration apparatus used for extraction of *E. coli* from soil and sewage sludge.

Clay minerals influence survival of sludge-derived pathogens

Researchers at Teagasc, Crops, Environment and Land Use Research Programme, Johnstown Castle, have devised a number of experiments to investigate the effect of various soil and sludge parameters on pathogen survival and microbial community dynamics. For instance, soil clay content is an important factor that can influence pathogen survival. Although studies have shown that clay is generally associated with increased persistence in soil, little is known regarding the effect of specific clay minerals on survival. In this experiment, soil was amended with clay minerals montmorillonite, kaolinite or illite, and spiked with known concentrations of *Listeria monocytogenes*, *Salmonella Dublin* or non-toxigenic *E. coli* O157. Pathogen survival data showed that death rate was highest in unamended soil, with clay minerals enhancing persistence. Generally, montmorillonite supported the greatest survival, followed by illite and kaolinite; however, this varied according to pathogen type and sampling time. This study indicates that the effect of sewage sludge on pathogen survival may vary depending on the mineralogical composition of the soil, and the pathogen type in question. This should be taken into account when assessing the survival capacity of pathogens introduced to the soil environment via sludge application.

Effect of sludge loading on pathogen survival

A key focus of this work is to determine the importance of sewage sludge loading (i.e., proportion of sludge to soil) on pathogen dynamics. However, microcosm studies conducted with both laboratory strains of *E. coli* and *Salmonella*, and indigenous sludge-derived *E. coli* indicated that there was no significant association between sludge loading and survival. Based on these results, it was hypothesised that nutrient levels in sludge were not sufficient in this case to activate the soil microbial community, thus limiting the potential for interaction to occur. Currently, an experiment is underway to assess the survival of sludge-derived *E. coli* in soil and sludge microcosms amended with energy-rich substrate, to stimulate microbial activity and maximise the probability of microbial interactions between soil and sludge communities.

Preventing pathogen regrowth

Another important aspect of pathogen dynamics in sludge is the bacterial regrowth phenomenon frequently observed during the sludge treatment process. This resurgence in indicator organisms may be due to contamination within the centrifuge during the dewatering process, reactivation of viable but non-culturable (VBNC) organisms, or increased niche space and nutrient availability in the sludge post-treatment. Therefore, research is being carried out to investigate *E. coli* and total microbial community shifts as a function of the sludge treatment process, in an effort to determine *E. coli* genetic grouping and growth characteristics in soil and sludge, and to link the presence/absence of specific species to the emergence of particular *E. coli* strains.

Acknowledgements

This work is supported by the European Commission within the END-O-SLUDG project (FP7-265269).

Perennial grasses for marginal soils

Teagasc is leading an EU-funded project GrassMargins, which aims to evaluate the suitability of marginal land for biomass production.

Dr Susanne Barth, Research Officer
Dr Manfred Klaas, Research Officer
Brendan Burke, Research Technician
Deirdre Doyle, Research Technician
Dr John Finnan, Research Officer
Teagasc, Crops, Environment and Land Use Programme, Oak Park Research Centre,Ca rlow.
Correspondence : susanne.barth@teagasc.ie

Perennial grasses, which, once established, can be harvested and re-grown annually, have a number of other beneficial characteristics that suit them as biomass crops. These include high resource-use efficiency, high productivity, good environmental qualities and a wide range of end uses. Environmental benefits include high rates of soil carbon sequestration, enhanced biodiversity and soil stabilisation.

Furthermore, perennial grasses naturally colonise marginal areas of land, which often impose severe restrictions on the growth of vegetation. Marginal land is defined as land of poor quality for agriculture which yields poor returns for the farmer. Marginal conditions comprise, for example, poorly drained soils (see Figure 1 for Irish poorly drained soils), soils with high salt concentrations, sites prone to severe cold and frost stress and drought prone sites.

The aim of the GrassMargins project is to identify, characterise and develop novel varieties of C_3 cool season grasses (*Dactylis glomerata, Festuca arundinacea* and *Phalaris arundinacea*) and the C_4 warm season genus *Miscanthus* that show high and stable productivity and require the minimum of additional inputs when grown on different forms of marginal land. These species were selected since they are known from previous work to adapt well to temperate and colder climate conditions. The major elements of the project are as follows:

- use of computer modelling to identify the optimal characteristics and geographical distribution of perennial grasses for biomass production;
- pre-breeding of novel varieties;
- investigation of stress tolerance; and,
- investigation of post-harvest drying characteristics.

The GrassMargins project is funded under the cooperation scheme of the 7th EU framework programme and has partners from a range of disciplines (modelling, agronomy, ecophysiology, genetics, geography and dissemination specialists) from eight countries (Ireland, UK, Denmark, Sweden, China, Russia, Poland and Germany).

Modelling and mapping biomass production

Computer modelling is being used to predict biomass production from perennial C3 and C4 grasses under different growth conditions. Current work focuses on the production of a new process-based perennial grass crop production model. A "Review of optimal morphological and physiological traits and management practices to gain higher biomass production in perennial rhizomatous grasses" has been produced and submitted for peer review.
The occurrence of the grasses *Dactylis glomerata, Festuca arundinacea* and *Phalaris arundinacea* is being mapped across Europe and will be incorporated into a high resolution Geographical Information System within http://grassportal.org/

Climate envelope modelling, which is based on the determination species' tolerance, is being used to predict the full geographical range of C_3 and C_4 perennial grasses.

Pre-breeding

Within the project, new genotypes of the project grass species are collected from a range of habitats and novel *Miscanthus* hybrids are generated by crossing existing genotypes. Genotypes for crosses were selected from existing *Miscanthus* spp. genotype collections from GrassMargins partners. To date forty-two crosses have been made between *Miscanthus sinensis* and four crosses between *Miscanthus sinensis* and a *Miscanthus sacchariflorus* accession from Russia.

From these crosses, 14,588 propagated plants were planted at partner locations in trials in early summer 2012. Collections of *Phalaris arundinacea* and

Figure 1. Map of poorly drained soils in the Republic of Ireland (map kindly compiled by Dr Stuart Green, Teagasc Spatial Analysis Unit). Poorly drained soils are shaded in green.

Dactylis were made in the UK and Ireland in 2012 and in Poland, Germany, Denmark and Sweden in 2013. The development of novel molecular markers and next generation sequencing genotyping of the project species is underway.

Stress screening

Stress screening of the abiotic stress factors affecting biomass production in the partner countries of the project are being investigated. A salt screening test of around 140 entries showed that *Festuca* had the best tolerance to elevated levels of sodium in the soil, while *Phalaris* was most affected by sodium and showed significant growth reduction under low salt stress.

Extensive measurements on *Miscanthus* cold tolerance were done using several hundred genotypes. Measurements of leaf growth, photo synthesis, visible frost damage and content of pigments and photosynthetic enzymes were used to differentiate between genotypes. A large genotypic variation in cold and frost tolerance was observed, and the most tolerant genotypes have been selected for detailed investigation in climate chambers during 2013. For the environmental stresses, RNA sequencing work has commenced to identify transcripts involved in the regulation of those stress conditions for the four species investigated in this project.

Biomass production

The next step was to quantify the biomass production of perennial grass species on marginal land, in order to see if economical yields of biomass can be obtained. The biomass of perennial grass species on marginal land is being quantified in order to see which genotypes/species are best suited for marginal land. These trials are managed according to an annual multi-cut harvest system, which would supply biomass to an anaerobic digestor or bio-refinery.

Four *Miscanthus* genotype trials have been established on different types of marginal land in Ireland in order to identify which grow well. These trials will be harvested annually in spring, as *Miscanthus* is typically cultivated as a feedstock for combustion.

Impact of the GrassMargins project

The research will provide information vital to the realisation of a previously untapped bioenergy resource, that of grass production on marginal lands. This information includes a range of genetic resources on grass species (*Miscanthus, Phalaris, Festuca* and *Dactylis*) which are potentially suitable as biomass feedstock. It will identify the genes responsible for traits that are desirable in biomass species, and develop models of the physiological and micrometeorological processes affecting their performance in different habitats. Furthermore, it will assess the extent to which selective breeding may generate desired improvements in the traits that determine their suitability as biomass species.

Partners have been chosen for their expertise and knowledge of grasses in a wide range of marginal habitats worldwide. The consortium will also assess the suitability of collected species for cultivation in different types of marginal lands challenged by extremes of salt, flooding, drought and cold. Finally, GrassMargins will study some of the factors that are believed to affect biomass production on marginal lands, including the relative merits of grass mixtures versus mono-species, and the factors affecting plant moisture levels.

Dissemination

The project will produce a significant database of geographically referenced information on the grass species of relevance to the project for biomass production. This data will be available for both the scientific community and the general public to help build an understanding of the propensity of grass species for improved biomass production on currently underutilised marginal land. The ultimate goal of this data is to make a significant agricultural impact in the EU by informing companies and institutions interested in growing, breeding and propagating grass species that are strongly resilient in the presence of abiotic stresses. Secondly, the results will inform the general public on the challenges relevant to the development of a sustainable biomass crop production strategy.

No conflict with land for food

Bioenergy produced from marginal lands can be exploited without undue conflict with food production. The identification of additional bioenergy resources will become increasingly important as fossil fuel prices continue to rise but also as the 2020 targets for renewable energy production are approached.

Meeting these targets, established in the renewable energy directive (2008/28/ec) for each EU Member State, will require the identification of additional renewable energy resources as the 2020 target date approaches. As such, this proposed research is timely as it will facilitate the exploitation of this important renewable energy resource and the availability of results will coincide with demand for additional resources.

The GrassMargins project will contribute scientific proceedings to the 2014 Dublin Federation of European Societies of Plant Biology meeting in its plant biology for bioenergy session (June 22-26, 2014, Dublin Convention Centre, see: www.fespb.org).

Dr Susanne Barth is the coordinator of the GrassMargins EU 7th framework project (KBBE-2011-5-289461; www.grassmargins.com) and Dr John Finnan is leading the Biomass Production and Land Suitability work.

Events

OCTOBER

22 October — Teagasc Food Research Centre, Ashtown, Dublin

Food Innovation Gateways – Big ideas for SMEs

This exciting event provides an opportunity for all food companies and in particular SMEs and food entrepreneurs to experience at first hand: technology opportunities from the Teagasc Food Research Programme and a diverse range of research and development activities.
Contact Mary Reilly, Tel: 01 805 9500;
E-mail: FoodInnovationGateways2013@teagasc.ie

24-25 October — Teagasc Research Centre, Ashtown, Dublin 15

7th Irish Earth Observation Symposium 'Big Data for Earth Observation'

This symposium provides an opportunity for those working in the Irish Earth Observation sector to meet and present their work. The theme of the 2013 symposium is 'Big Data for Earth Observation' and the integration of remote sensing data streams with other information to provide direct services to end users. E-mail: stuart.green@teagasc.ie or irisheos13@gmail.com

30 October — Ardboyne Hotel, Navan, Co Meath

Teagasc National Liquid Milk Event 2013

This conference and farm tour will cover topics such as: high quality grass silage - getting the basics right, facts on feeding fibre, benchmarking herd performance and improving calving pattern. This event is kindly sponsored by AIB.
Contact 087 130 9827 for more information. www.teagasc.ie/events

31 October — Teagasc Food Research Centre, Ashtown, Dublin 15.

The World Is Your Oyster: How You Eat It Is Up to You - Insights into Careers in Marine and Food Research

This NutraMara event aims to create a forum for discussion on career experiences and options available to researchers in the fields of marine and food research. The invited speakers will share their experiences of forging career paths within this sector and offer advice for emerging scientists.
Contact: Dr Fiona Manning, E-mail: fiona.manning@teagasc.
Tel: 01 805 9785 www.nutramara.ie/

NOVEMBER

5 & 6 November — Bridge House Hotel Tullamore, Co Offaly

National Organic Training Skillnet

This conference includes parallel sessions on beef and sheep, horticulture and dairy. There will also be talks on CAP reform and insights from key players in the Irish food industry and a networking and trade event.
Book online: www.nots.ie; Tel. 071 964 0688; E-mail: info@nots.ie

7 November — Teagasc Conference & Training Centre, Ashtown, Dublin 15

Agricultural Economics Society of Ireland (AESI) Annual Conference

Proceedings will include a keynote address from Professor Alan Renwick (UCD School of Agriculture and Food Science), presentations by invited speakers and contributed papers relating to agricultural economics and other relevant disciplines.
Further details from society secretary, Emma Dillon
E-mail: secretary@aesi.ie. http://www.aesi.ie/

7 November — Tullamore Court Hotel, Offaly

National Agri-Environment Conference 2013

The conference will focus on the future of agrienvironmental schemes in Ireland and will examine new approaches to delivering agrienvironment measures on farms. Please contact Mark Gibson, Environment Specialist; Tel: 091 845 222; E-mail: mark.gibson@teagasc.ie

8 November — Louis Fitzgerald Hotel, Newlands Cross, Dublin

National Bioenergy Conference

The Government has published a Strategy for Renewable Energy '2012 – 2020'. One of the strategic goals in the Renewable Energy Strategy is to develop a sustainable bioenergy sector supporting renewable heat, transport and electricity generation. This conference will feature sessions on: policy, energy crops and biomethane and forestry.
Contact: Jessica Cullen
E-mail:Jessica.cullen@teagasc.ie; Tel: 059 918 3483 www.teagasc.ie/energy

10-17 November — Teagasc locations nationwide

Science Week 2013

In addition to open days at Teagasc locations, Dr Sinead Waters and Dr Rita Hickey will form part of Forfás' Science Week Smart Futures STEM careers roadshow and will be speaking at events in Sligo Institute of Technology and University of Limerick.
Contact: Catriona Boyle, e-mail: catriona.boyle@teagasc.ie www.scienceweek.ie

12 & 13 November — Limerick and Cavan

National Dairy Conference

The theme for the conference is 'Strategies for Sustainable Success'. The Conference will outline the key strategic decisions required by farmers in the areas of grassland, breeding and business planning in order to successfully grow their dairy business and to harvest its potential.
Pre-booking is essential for the conference.
dairy.conference@teagasc.ie or Tel: 025 42664. www.teagasc.ie/events

20 November — Conference & Training Centre, Teagasc Food Research Centre, Ashtown, Dublin 15

Food Labelling & Allergen Update

A timely opportunity for all sectors of the food industry to get the latest updates on the food information for consumers' legislation as well as permitted nutrition and health claims. This is a joint Teagasc, FSAI and safefood event.
For further information: Tel: 01 817 1310. E-mail: labellingupdate@fsai.ie
Or check out events on the Teagasc or FSAI websites:
http://www.teagasc.ie/events/EventsBy.aspx

28 November — RDS, Dublin

Annual Walsh Fellowship seminar

Teagasc Walsh fellows (PhD and MSc) near the end of their training get the opportunity to present their results.
Contact: Hilary King, e-mail: hilary.king@teagasc.ie; Tel: 059 918 3478.

28 November (6.30pm) — RDS Dublin

Teagasc & RDS Public Lecture Series 2012-2014

Professor Charles Godfray delivers the fourth lecture in this series entitled 'Sustainable Intensification and the Role of Science and Technology in Meeting the Food Security Challenge'. Professor Godfray is Hope Professor of Zoology at Jesus College, Oxford and Director of the Oxford Martin Programme on the Future of Food.
www.teagasc.ie/events