Agriculture and Food Development Authority

Teagasc Technology Updates 2008–2013

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

Volume II

Animal and Grassland Research & Innovation Programme

Crops Environment & Land Use Programme

Rural Economy & Development Programme

Agriculture and Food Development Authority

teagasc
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Volume II

Compiled by Jane Kavanagh and Mary Burke

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

Foreword

Frank O'Mara
Director of Research, Teagasc

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

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

Our annual research portfolio comprises some 300 research projects, carried out by 500 scientific, technical and support staff in our research centres throughout Ireland, along with 200 Walsh Fellows. Most of these projects are carried out in collaboration with colleagues in Irish and international universities, Institutes and Technology, other research institutes and industry bodies, and we are very grateful for their contributions. Our research priorities are guided by our many stakeholders.

We are committed to transferring the latest discoveries from these research projects to end users to ensure that our research has an impact and delivers a benefit to our stakeholders and the Irish economy. We publish **Technology Updates** in respect of all completed research projects. These reports are designed to ensure transfer of new research information to the advisory and training services and to the end-user and to provide an easily accessible record of the main research findings.

This second volume of Technology Updates from agriculture, environment and rural economics and development focussed research projects completed since 2008 represents a significant body of information on state of the art technologies and up to date analysis of the sector. It will be of great interest and use to advisers, teachers, farmers, policy makers, scientists and others interested in agricultural issues.

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

Frank O'Mara

Frank O'Mara
Director of Research, Teagasc

Agriculture and Food Development Authority


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Animal and Grassland Research and Innovation Programme

This programme aims to increase the profitability, competitiveness and environmental sustainability of Irish animal production systems and enhance the quality and safety of Irish meat and milk products. This is achieved through our research and knowledge transfer activities in the following areas:

Animal and Bioscience Research

Using a combination of animal science techniques and cutting-edge molecular and computational biology tools and exploiting results from genetic and genomic research our research focuses on:

- Developing tools to more accurately identify the most profitable animal for future production systems.
- Developing optimal breeding programmes to maximise genetic gain.
- Explaining the biological causes of reproductive failure to improve reproductive performance.
- Studying mechanisms to control infectious diseases.
- Understanding the processes which lead to enhanced feed efficiency.
- Applying molecular technologies to better understand the rumen microbiome.

Grassland Science Research

Our grassland science research focuses on developing an efficient grass based ruminant production sector through high levels of grass utilisation by applying plant breeding technologies to improve sward production; developing grazing management strategies to improve growth and utilisation of grazed grass and by developing grazing nutrition, grass growth and grass intake models to improve grazing management decisions on farms.

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Livestock Systems Research

Using a farm system approach our research focuses on achieving maximum performance of the whole farm system by optimising the interaction between pasture utilisation, supplementary feeding strategy and animal performance. Our research includes the development of highly profitable sustainable production systems; farm bio-economic and biophysical modelling; development of precision farming systems encompassing increases in energy and labour efficiency; plus the production of high quality and safe meat and milk products. We use demonstration farms and decision support tools to assist in the adoption of key technologies.

Pig Development

By integrating our pig research, advice and education services we aim to improve the competitiveness of Irish pig production through:

- research focused on improving sow productivity, pig health and welfare, meat quality and food safety and reducing feed costs.
- an advisory service focused on using technology to improve profitability and which provides advice on herd performance, preparing financial plans and assisting with the preparation of development plans to comply with environmental regulations.
- the delivery of technical training courses and a structured FETAC accredited training programme for operatives on pig units.

Animal and Grassland Research and Innovation Programme

Dairy and Drystock Knowledge Transfer (KT) Activities

We provide leadership in developing technologies and decision support tools for improved efficiency and profitability on farms and to assist our stakeholders in making decisions. We interpret key messages coming from research for delivery to advisors, farmers and the wider industry and provide feedback to researchers to assist in the development of relevant research programmes.

We deliver new technologies to our stakeholders through a national network of KT Specialists and Business and Technology Advisors. Our activities include organising national events and competitions; joint programmes with industry; advisor training, support and mentoring; and developing decision support tools.

Our BETTER beef (in collaboration with the Farmers Journal) and sheep programmes, which are joint research and KT projects, aim to develop a road map for profitable beef and sheep production through improving technical efficiency within the farm gate. The Kilkenny Greenfield demonstration farm was developed to demonstrate the conversion of a greenfield farm into a profitable dairy farm using the best technologies from research.

Crops Environment and Land Use Programme

This programme aims to develop and transfer cost-effective crop production systems along with evidence based knowledge to support and underpin the development of a profitable, competitive and environmentally sustainable agri-food sector. This is achieved through our research and knowledge transfer activities in the following areas:

Crops Research

Our research focuses on developing cost-effective crop production systems, including crops for energy and bio-processing, which improve competitiveness, profitability and product quality and minimise impact on the environment. Our research activities include:

- Maximising a crop's yield potential and developing cost reduction and cost optimisation strategies compatible with high yields.
- Developing biotechnology-based tools for the genetic improvement of perennial ryegrass, white clover, potatoes and other crops.
- Breeding improved varieties of potato for a variety of markets and end uses.
- Monitoring the population structure of the most important pathogens in Irish tillage with an emphasis on their ability to overcome fungicides and varietal resistance.

Crops Knowledge Transfer Activities

Through our crops knowledge transfer activities we aim to improve farm profitability by increasing output while keeping costs under control. We deliver new technologies to our stakeholders through a national network of KT Specialists and Business and Technology Tillage Advisors. Our activities include organising conferences, seminars, farm events; training advisors, farmers and industry and publishing reports and newsletters. Our Crops BETTER farm programme aims to assist Irish tillage farmers to avail of cutting edge farm technology and business methods, to improve profitability and to develop links between research, advice and tillage farms.

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Environment, Soils and Land Use Research

Our research aims to develop technologies and management strategies that facilitate farmers to combine economic sustainability with environmental sustainability, thus allowing farmers to farm profitably while conserving or improving environmental resources. Our research covers a range of areas including soils, nutrient efficiency, gaseous emissions, water quality and agro-ecology and our research activities include:

- Understanding the role of soil biodiversity and ecology in soil functions, processes and quality.
- Developing soil specific nutrient advice for nitrogen and phosphorous.
- Developing technologies for reducing gaseous emissions on farms.
- Reducing nitrate leaching through understanding and managing the soil nitrogen cycle.
- Improving the understanding of the relationship between diversity and ecosystem function within agricultural systems.

Environment Knowledge Transfer

Working closely with our research and advisory colleagues we aim to improve the sustainability of Irish agriculture in terms of water quality, GHG emissions, biodiversity and soil fertility by integrating our activities with all the other programmes. We support our farmer clients in implementing technology aimed at increasing their competitiveness and profitability while at the same time achieving stringent environmental standards and cross compliance. We also provide support to REPS and AEOS participants.

Crops Environment and Land Use Programme

Agricultural Catchments Programme

In this programme we work in partnership with farmers to evaluate Ireland's Nitrates Action Programme and support sustainable farming. This integrated research and advisory project operates in six catchments which represent a range of farming systems and soil nutrient loss risk scenarios. The same experiment is conducted in each catchment looking at the continuum from nutrient sources to mobilisation via pathways and delivery to water, where an impact may occur. By understanding this continuum and its socio-economic background the programme aims to reveal what governs the fate of the nutrients.

Horticulture Development

Our integrated horticulture research, advice and education service is focused on exploiting the development potential of horticulture by supporting value added innovation in the mushroom, fruit and vegetable, nursery stock and cut foliage sectors. We procure and transfer knowledge to our stakeholders by collaborating with outside agencies, such as the Horticultural Development Company (HDC), through our events, courses, publications and advisory activities. Our research priorities include plant pathology, plant tissue culture, mushroom pathology, entomology and enhancing the nutrient content of brassicas and bio-control in a range of crops.

Forestry Development

By integrating our forestry research, advice and education services we aim to develop forests and forest management systems that maximise the potential of farm forestry from economic, social and environmental perspectives. Our research focuses on broadleaf tree improvement, broadleaf silviculture and thinning and harvesting management. Our knowledge transfer activities focus on providing an unbiased assessment of the suitability of a farm forest enterprise and providing forest owners with access to technologies and information to assess the status of their crops, the need for thinning and harvesting and mechanisms to effectively and profitably market their produce. This is achieved by our forestry advisors through a range of national events, training courses, group meetings, forest walks, consultations and publications.

Rural Economy and Development Programme

This programme aims to produce high quality economic and other social science research and advice to improve the competitiveness and sustainability of the Irish agri-food sector and to enhance the quality of life in rural Ireland. We also place an important focus on policy relevant research that will help policy makers to design and implement better public policy. This is achieved through our research and knowledge transfer activities in the following areas:

Agricultural Economics and Farm Surveys

We collect timely, quality financial and farm management data through the Teagasc National Farm Survey (NFS) to support decision making by our stakeholders and we undertake research to interpret trends and changes in markets and policy to enable each of our stakeholders to make better decisions. Our policy focused research, within the FAPRI-Ireland Partnership, develops economic models to quantify the effect of policy reform on agricultural markets and farm incomes in Ireland. Our core skills and technologies are agricultural production economics, economic modelling and data collection.

Agri-Food Business and Spatial Analysis Research

Our spatial analysis research, comprising Geographic Information Systems (GIS) and earth observing (EO) remote sensing (RS) technologies provides a powerful platform for the comprehensive analysis of all land–based activities at the interface between the agri-food sector, economy and environment.

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Our food market and consumer research group contributes to improving the strategic marketing performance of the Irish agri-food sector by addressing the need for more future-oriented consumer and market insights.

Our agri-innovation and learning research team supports Teagasc in making its knowledge transfer activities within the agricultural programmes more effective. By drawing on the disciplines of economics and sociology, they use quantitative and qualitative social science tools to understand how farmers make decisions, learn and innovate, and study the effectiveness of alternative knowledge transfer methodologies.

Farm Management and Rural Development Activities

By integrating our activities with the Teagasc Knowledge Transfer Directorate, our farm management and technology team provides advice, training and tools, such as the Teagasc eProfit Monitor (ePM), to support our stakeholders in making decisions that enable their business to be more effective. Through our rural development team and the Teagasc Farm Options Programme we provide specific skills to stakeholders to enable them to exploit income generating opportunities both on and off farm. Our equine team provides technical advice and training to the sport horse industry with a particular focus on improving breeding, horsemanship and equine business skills.

Animal and Grassland Research & Innovation Programme

Animal and Grassland Research & Innovation Programme Technology Updates

Animal and Bioscience Department

Grassland Science Department

Livestock Systems Department

Pig Development Department

Crops, Environment & Land Use Programme Technology Updates

Agricultural Catchments Programme

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Agri-Food Business and Spatial Analysis Department

Animal and Grassland Research & Innovation Programme

Animal and Grassland Research & Innovation Programme

Animal welfare index (AWI): an on-farm welfare evaluation of beef producing farms in Ireland and Belgium

Project number:
6153
Date:
June, 2013
Funding source:
Bord Bia
Project dates:
Jul 2011 – Jun 2013

Key external stakeholders:

Beef and dairy farmers; Bord Bia; Department of Agriculture, Food and the Marine (DAFM).

Practical implications for stakeholders:

The scientific consideration of farm animal welfare is important, due to the ethical obligation to maximise health and well-being and eliminate suffering in animals that are under human stewardship, the need to fulfil the requirements and demands of the general community and to improve the efficiency of animal agriculture by optimising animal health and productivity. There is a need to highlight the superior welfare status of Irish beef production systems when benchmarked with intensive beef production systems in Europe.

Main results:

- Beef production farms including suckler calf-to-beef (n=30), suckler calf (suckler calf/weaning/finishing (n=63), dairy calf-to-beef (n=12), and Belgian farms (n=17) were assessed during the Winter housing period using an animal welfare index. The range of farms evaluated in each country was representative of the beef production systems within the country.
- Seventy three percent (n = 96) of the farmers participating in the study were full-time (FT) while 27% (n = 26) were part-time (PT).
- The animal welfare index (AWI) that was used principally considered six aspects of the animal's environment as well as animal based measurements. Fifty-one indicators were grouped into six categories: locomotion (six indicators), social interactions (eight indicators), flooring (four indicators), environment (nine indicators), stockpersonship (thirteen indicators) and husbandry management (eleven indicators). The higher the scores, the better

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Compiled by:
Peter Lawrence
Bernadette Earley

Technology

were the conditions regarding animal welfare. The six category score were integrated and the AWI was calculated. The minimum attainable score on the AWI was -6; the maximum attainable score was 90.5 (range of 96.5 points).

- The mean AWI for the beef production systems were 70.3% (suckler calf-to-beef), 71.9% (suckler calf/weaning/finishing), 66.6 % (dairy calf-to-beef) and 56.7% (Belgian farms), respectively.
- There was no difference ($P > 0.05$) in AWI between full-time and part-time farmers.

Opportunity/Benefit:

- Demonstrated that the animal welfare index of Irish beef production systems are very high. The AWI of Irish farms were significantly higher than the Belgian farms.
- The welfare and management of farm animals are relevant concerns that need to be considered in order to increase consumer acceptance of our animal production systems in the future.

1. Project background:

Issues relating to the welfare of farm animals are becoming increasingly important within the European Union (EU). Increasing consumer concerns, reflected by the increasing amount of EU Legislation designed to improve the welfare of farm animals, show this clearly. The source of calves for Irish beef production come from the national herd of 2.18 million cows of which 49% and 51% are dairy and beef suckler cows, respectively. There are a wide range of beef production systems in use in Ireland with the two predominant systems today being the grass based suckler calf-to-beef system and dairy calf-to-beef system. In suckler beef production systems calves may be sold after weaning to a store/finisher producer or kept on the farm until slaughter. In dairy calf-to-beef production systems calves may be kept on these dairy farms until slaughter or sold as calves under the age of 6–weeks for rearing and subsequently slaughtered. Cattle destined for beef production can be categorised into three production stages: 1) Pre-weaning period, 2) Post-weaning (store period) and 3) Finishing phase. There is currently no scientific data available on the status of animal welfare on the different beef production systems in Ireland or in more intensive beef production systems in Europe, eg. Belgium. An AWI developed by Mazurek *et al.* (2010) was used to assess animal welfare at farm level in Ireland and in Belgium.

2. Questions addressed by the project:

The study was designed to address the following questions:

- What is the welfare status of Irish beef production systems using an AWI from a previously validated index (Mazurek *et al.*, 2010)?
- What is the welfare status of beef producing systems in Belgium when benchmarked with the Irish AWI?
- How do the individual category scores influence the AWI for each of the beef production systems?
- Are there differences in the AWI between full-time and part-time farmers?

The beef production farms including suckler calf-to-beef (n=30), suckler calf/weaning/finishing (n=63), dairy calf-to-beef (n=12), and Belgian farms (n=17) were assessed during the Winter housing period using the AWI (Mazurek *et al.*, 2010).

3. The experimental studies:

Farm selection

The number of farms visited, included, suckler calf-to-beef (n=30), suckler calf weaning/store (n=63), dairy calf-to-beef (n=12), and Belgian farms (n=17) were assessed during the Winter housing period using the AWI (Mazurek *et al.*, 2010). The beef Specialist Advisor of the national agriculture research and extension organisation (Teagasc) for each county, and BORD BIA, in Ireland were contacted to identify farms at random for the AWI assessment. The selected farmers were then contacted by the local Adviser to arrange access to the farm for assessment. In Belgium, 17 farms were identified and visited during the Winter housing period. The range of farms evaluated in each country was representative of the beef production systems within the country.

During the Winter housing period (2011 to 2013) 105 farms were visited in Ireland and data for each indicator of the AWI were collected for each farm.

Farm inspections

One hundred and twenty-two farms (105 in Ireland and 17 in Belgium) were visited to assess the AWI. Farms were visited once during the Winter housing period (2011–2013). Two indicators of farm size were collected: i) number of hectares, ii) number of animals in the herd (including cows, calves, heifers, bulls, steers).

AWI score

For each of the six categories, (locomotion, social, environment, flooring, stockperson and husbandry management), the indicators were evaluated and a weighting was applied. The score for each indicator within a category was summated to give a category score. The six category scores were then integrated to give an overall AWI. The minimum score possible was -6 and the maximum score was 90.5 (range of 96.5 points).

AWI assessment method

Mazurek, M., Prendiville, D., Crowe, M.A., Veissier, I., Earley, B. 2010. An on-farm investigation of beef suckler herds using an animal welfare Index (AWI). BMC Veterinary Research 2010, 6:55doi:10.1186/1746–6148–6–55.

4. Main results:

Fifty-one indicators were grouped into six categories: locomotion (six indicators), social interactions (eight indicators), flooring (four indicators), environment (nine indicators), stockpersonship (thirteen indicators) and husbandry management (eleven indicators). Two indicators relating to the size of the farm and number of animals on the farm were also collected. The mean size of the farms and mean number of animals/farm were 99 ha and 191 animals for the suckler calf-to-beef farms, 74.8 ha and 148 animals for the suckler calf to store finishing, 105.8 ha and 272 animals for the dairy calf-to-beef and 76.2 ha and 236 animals for the Belgian farms. There was no difference ($P > 0.05$) in AWI between FT and PT farmers.

The mean AWI for the farms were 70.3% (suckler calf-to-beef), 71.9% (suckler calf/weaning/finishing), 66.6% (dairy calf-to-beef) and 56.7% (Belgian farms), respectively (Table 1).

The environment, stockperson, husbandry management and social categories were significantly correlated ($P<0.001$) with the AWI for the suckler calf-to-beef systems. The social, environment, stockperson and husbandry management categories were significantly correlated ($P<0.001$) with the AWI for suckler calf/weaning finishing systems. The stockperson and environment categories were significantly correlated ($P<0.001$) with the AWI for dairy calf-to-beef systems. The environment, stockperson, social and locomotion categories were significantly correlated ($P<0.001$) with the AWI for the Belgian beef production system. *(see table 1 below)*.

The presence of tethering systems, access to grazing, duration of Winter housing, calving and the weaning methods were evaluated in the AWI. Irish beef producing systems scored better for those indicators compared with the Belgian system.

5. Opportunity/Benefit:

This study demonstrated the very high welfare standard of Irish beef production systems. There was no difference in AWI among the three Irish beef production systems, whereas the AWI of the Belgian system was lower ($P<0.001$) compared with the Irish systems.

The welfare and management systems of farm animals are relevant concerns that need to be considered in order to increase consumer acceptance of our welfare friendly beef production systems in the future.

Table 1. The mean category scores and integrated AWI scores for the Irish and Belgian beef production systems. The values are expressed as mean (± s.d.).

Beef system	Category scores						AWI – Integrated scores
	Locomotion	Social	Flooring	Environment	Stockperson	Husbandry management	
Suckler calf-to-beef (n=30)	63.1 ± 5.4	76.7 ± 5.2	59.5 ± 5.6	61.7 ± 7.1	74.3 ± 8.8	52.9 ± 7.6	70.3 ± 3.6
Suckler calf/weaning/ finishing (n=63)	64.5 ± 4.4	73.1 ± 8.6	58.6 ± 4.8	59.6 ± 9.2	72.8 ± 8.8	53.6 ± 6.7	71.9 ± 2.2
Dairy calf-to-beef (n=12)	64.6 ± 3.9	69.9 ± 4.9	57.1 ± 4.0	56.0 ± 9.0	78.3 ± 4.4	39.3 ± 17.0	66.6 ± 3.9
Belgian system (n=17)	56.3 ± 5.6	57.1 ± 3.9	38.2 ± 4.8	50.0 ± 6.8	72.7 ± 13.2	31.9 ± 8.3	56.7 ± 4.2

Animal and Grassland Research & Innovation Programme

Project number:
5741

Date:
April, 2013

Funding source:
Teagasc

Project dates:
Oct 2010 – Apr 2013

Development of a novel nanovaccine against bovine parainfluenza-3 virus for use in calves

Key external stakeholders:

Beef and dairy farmers; Department of Agriculture, Food and the Marine (DAFM).

Practical implications for stakeholders:

- Bovine respiratory disease (BRD) is one of the most economically important diseases in the cattle industry causing significant annual economic losses.
- A novel nanovaccine containing parainfluenza-3 (PI-3) virus was more effective against bovine respiratory disease in suckled beef calves when administered four weeks versus one week pre-weaning.

Main results:

- The mucosal and systemic immune responses to the candidate nanovaccine were compared with those induced by a live attenuated commercially available bovine (B) PI-3V vaccine in dairy calves with pre-existing serum antibodies and then challenged with a 'field' strain of BPI-3V.
- There was an enhanced, more sustained mucosal-based immunological response to the candidate nanoparticles (NP) vaccine in the face of pre-existing systemic BPI-3V-specific IgG in dairy calves.
- Immunising beef calves four weeks before weaning results in greater mucus IgA, serum IgG and IFN-γ responses. In contrast, beef calves immunised one week before weaning failed to show a significant serum IgG and IFN-γ response and showed a weak mucosal IgA response. Weaning affected both the humoral and cell mediated immunity for at least 7 days. Additionally, of the calves weaned one week post-immunisation treatment, only the BPI-3V-NP-treated animals exhibited increased mucus IgA concentrations by the end of the study period, but failed to show significant serum IgG titres or IFN-γ responses.

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External collaborators:
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Opportunity/Benefit:

The results of this research have:

- Demonstrated that nanoparticle (NP) stability, measured in terms of size, zeta potential and protein content was highest at 4°C compared with storage conditions at 37°C, 21°C and -20°C.
- Demonstrated that calves given the BPI-3V nanovaccine intra-nasally had significantly greater mucus IgA responses, suggesting an enhanced, more sustained mucosal-based immunological response in the face of pre-existing systemic BPI-3V-specific IgG.
- Demonstrated that immunising calves intra-nasally 4 weeks prior to weaning resulted in greater mucus IgA, serum IgG and IFN-γ responses than calves immunised 1 week before weaning.
- Mucosally delivered nanovaccines also hold out the possibility of inducing a protective immune response in the face of pre-existing maternally-derived antibodies in young calves.

1. Project background:

Bovine respiratory disease (BRD) in cattle results from an interaction between the infectious agents (i.e. bacteria and/or viruses), the environment, genetic factors and host immunity. The important viral causes of respiratory disease are bovine herpes virus type 1 (BHV-1), bovine respiratory syncytial virus (BRSV), bovine parainfluenza-3 virus (BPI-3V), and bovine viral diarrhoea virus (BVDV). Predisposing causes of BRD in pre-weaned calves are typically concurrent, and often synergistic, including stress, immunological background, and changes in nutrition.

Bovine PI-3V plays a vital role in the development of BRD and paves the way for other viral and bacterial pathogens to become involved, resulting in more severe disease. Antigen-loaded microspheres represent an exciting approach to control the release of protein antigens in vaccine formulations by reducing the number of immunisation doses required and optimising the desired immune response via selective targeting of antigen presenting cells. Poly (lactic co glycolic acid) has been commonly used for this purpose because of its proven safety record and their established use in products for controlled delivery of peptide drugs (Kavanagh *et al.*, 2013). The objective of this study was to develop a novel, slow-antigen releasing, intranasally delivered, nanoparticle vaccine (nanovaccine) against bovine parainfluenza type 3 virus (BPI-3V), an important pathogen associated with BRD.

2. Questions addressed by the project:

- What is the optimal nanocarrier storage and stability conditions, and protein load, for a novel nanovaccine encapsulating PI-3V?
- What are the immune responses to intranasal administration of the nanovaccine containing PI-3V in mice, and in dairy calves in the presence of maternally derived PI-3 antibodies?
- How does the nanovaccine compare with a commercially available vaccine against BPI-3V in dairy calves?
- What is the optimum immune response time to administer the nanovaccine to suckled beef calves pre-weaning when compared with a live attenuated commercially available BPI-3V vaccine?

3. The experimental studies:

The **first study** characterised and optimised the dose of PLGA-NPs incorporating BPI-3V proteins in terms of their size, zeta potential and entrapped protein load for intranasal delivery.

The **second study** assessed the stability of such NPs when stored at different temperatures.

The **third study** designed a pilot, 'proof of principle' study to examine the immune responses to PLGA-NPs incorporating BPI-3V antigens in a murine model before moving to assessing their equivalent effects in experimental models in calves.

The **fourth study** assessed the systemic humoral and cellular, as well as the nasal mucosal immune responses to a candidate PLGA-BPI-3V 'nanovaccine' in colostrum-fed calves with pre-existing antibodies and to compare these responses with those induced by a conventional live attenuated BPI-3V vaccine.

The **fifth study** investigated the effect of weaning stress on the systemic and nasal mucosal immune responses to this putative BPI-3V nanovaccine and a conventional live attenuated BPI-3V vaccine.

4. Main results:

Nanoparticles of a biodegradable polymer encapsulating BPI-3V antigens were prepared and optimised for intranasal delivery, initially in mice where they induced a greater serum IgG response at an earlier time point compared to solubilised BPI-3V antigen alone. The mucosal and systemic immune responses to the candidate nanovaccine were then compared with those induced by a live attenuated

commercially available BPI-3V vaccine in dairy calves with pre-existing serum antibodies and then challenged with a 'field' strain of BPI-3V. The calves given the BPI-3V nanovaccine had significantly greater mucus IgA responses, suggesting an enhanced, more sustained mucosal-based immunological response in the face of pre-existing systemic BPI-3V-specific IgG. The serum IgG responses in these BPI-3V-NP-treated calves were largely similar to those in the animals given the live attenuated vaccine.

The impact of weaning stress on the mucosal and systemic immune responses of beef calves to the BPI-3V nanovaccine, and to a live attenuated commercial vaccine was then investigated.

The findings indicated that immunising calves 4 weeks prior to weaning resulted in greater mucus IgA, serum IgG and IFN-γ responses than animals immunised 1 week before weaning for both vaccine treatments (Figure 1). Of the calves weaned one week post-immunisation, only the BPI-3V nanovaccine-treated animals exhibited increased mucus IgA concentrations by the end of the study period, but failed to show significant serum IgG titres or IFN-γ responses. This more sustained mucosal immunity induced by the BPI-3V nanovaccine may have potential if it translates into enhanced protective immunity in the face of virus challenge. Overall, the findings of this 'weaning stress' experiment suggest beef calves under such management conditions should be vaccinated at least 4 weeks prior to weaning in order to minimise the effect of this well-recognised stress on their immune responses.

5. Opportunity/Benefit:

The results of this research have:

1) Demonstrated that nanovaccine stability, measured in terms of size, zeta potential and protein content, indicate that NPs were most stable at 4°C and do not require low temperature storage; 2) Demonstrated that calves given the BPI-3V nanovaccine had significantly greater mucus IgA responses, suggesting an enhanced, more sustained mucosal-based immunological response in the face of pre-existing systemic BPI-3V-specific IgG; 3) Demonstrated that immunising calves 4 weeks prior to weaning resulted in greater mucus IgA, serum IgG and IFN-γ responses than calves immunised 1 week before weaning; 4) Demonstrated that the more sustained mucosal immunity induced by the BPI-3V nanovaccine may have potential if it translates into enhanced protective immunity in the face of virus challenge; and 5) Demonstrated that mucosally delivered nanovaccines also hold out the possibility of inducing a protective immune response in the face of pre-existing maternally-derived antibodies in young calves. This is the first project of its kind to develop, and assess the mucosal and systemic immune responses to a viral nanovaccine in calves. The use of such novel nanotechnology in the context of vaccine delivery could contribute to state-of-the-art prevention strategies against BRD and other infectious diseases of livestock and potentially make a significant contribution to improving animal health and welfare.

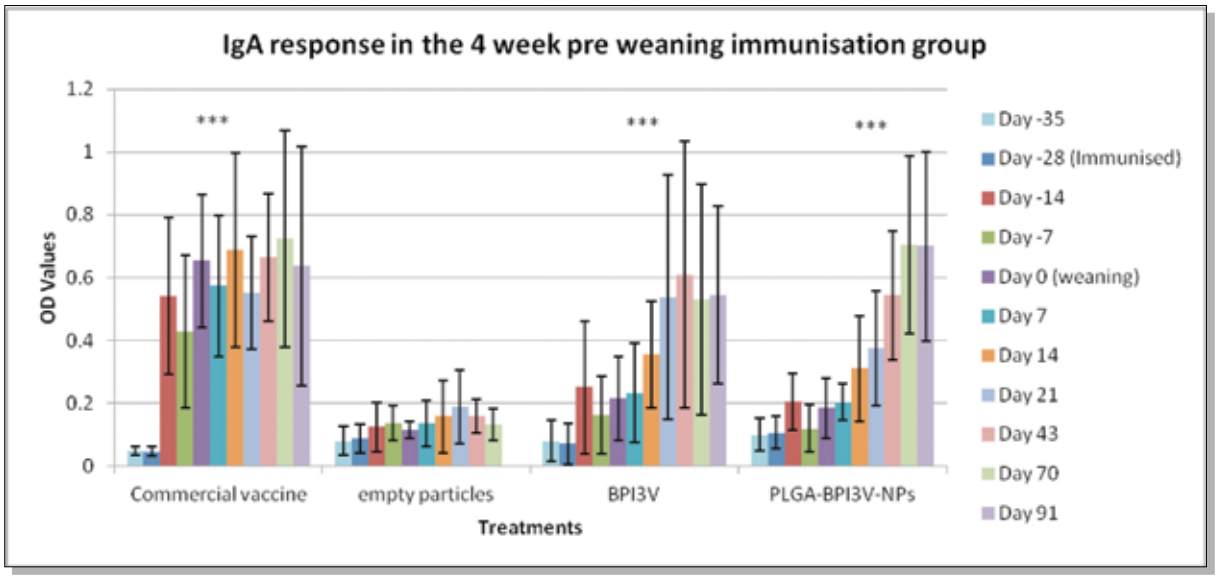

Figure 1: IgA immune response (±s.d) in four weeks pre weaning immunisation group: commercial Rispoval Intranasal vaccine; empty – negative control (empty particles); BPI-3V -positive control (purified solubilised BPI-3V proteins); and PLGA-BPI-3V-NPs vaccine under test. *** = $P < 0.001$.

6. Dissemination:

Main publications:

Kavanagh, O., Adair, B.M., Welsh, M.D., Earley, B. (2013). Local and systemic immune responses in mice to intranasal delivery of peptides representing bovine respiratory syncytial virus epitopes encapsulated in poly (DL-lactide-co-glycolide) microparticles. *Research in Veterinary Science*. doi:pii: S0034–5288(12)00353–0. 10.1016/j.rvsc.2012.12.001. PMID 23312498.

Mansoor, F., Earley, B., Cassidy, J.P., Markey, B., Foster, C., Doherty, S. Welsh, M.D. (2011). Immune response to the intranasal delivery of Poly Lactide-co-Glycolide (PLGA) nanoparticles containing Bovine Parainfluenza Type 3 virus (BPI-3V) proteins in mice. *Proceedings of the Agricultural Research Forum meeting*, Tullamore, Ireland, 14 – 15th March 2011.

Animal and Grassland Research & Innovation Programme

Project number:
5889

Date:
October, 2012

Funding source:
Teagasc

Project dates:
Apr 2008 – Oct 2012

National breeding objective and breeding programmes for dairy and beef cattle in Ireland

Key external stakeholders:

The Irish Cattle Breeding Federation (ICBF), (inter)national breeding industry, dairy and beef farmers.

INTERBULL and INTERBEEF, international genetic evaluation bodies, international geneticists.

Practical implications for stakeholders:

- Generated novel and more accurate measures of carcass quality measured using video image analysis and implemented into national genetic and genomic evaluations for dairy and beef cattle.
- Generated the first ever national genetic evaluations for animal price for dairy and beef cattle.
- Revised the statistical model for genetic evaluation of animal live-weight in dairy and beef cattle.
- Revised the national dairy breeding objective, the EBI.
- Revised the national dairy and beef genetic evaluations for female fertility.
- Undertook the first ever national evaluation for male fertility in Irish dairy and beef cattle.
- Undertook the first ever (inter-)national genetic and genomic evaluation for linear type traits in Irish dairy cattle using parameters estimated using only Irish dairy data.
- Undertook the first ever national genetic evaluations for management traits in Irish dairy cattle.
- Extensively revised the national genetic evaluations for animal health in Irish dairy cattle.
- Optimised further the national breeding programme for Irish dairy cattle.
- Concluded that further genetics research on including feed efficiency in Irish beef breeding objectives is currently not justified.
- Concluded that reported international genetic parameters for methane intensity are being misinterpreted.

Collaborating Institutions:
Swedish University of Agricultural Sciences
Irish Cattle Breeding Federation (ICBF)
University of Alberta

Teagasc project team:
Dr. Donagh Berry (PI)
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Dr. Noirin McHugh
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External collaborators:
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Dr. Fikse and Nasholm, Uppsala University
Dr. Crowley, University of Alberta

Compiled by:
Donagh Berry

Technology

Main results:

- Large impact of inclusion, in the national dairy and beef cattle genetic evaluations, video-image analysis of carcasses routinely available on all carcasses slaughtered in Ireland.
- Exploitable genetic variation in animal price information collected routinely in livestock marts can be used in national breeding objectives to increase genetic gain in profit.
- Use of national genetic evaluations for a wider range of suites of traits in dairy and cattle breeding can be used to augment genetic gain in a balanced overall breeding objective.

Opportunity/Benefit:

Increased genetic gain in dairy and beef cattle through more pertinent weighting factors in the national breeding objectives on a wider suite of traits accurately evaluated using Irish data.

1. Project background:

Successful breeding programmes require breeding objectives that include all traits influencing profitability optimally weighted to generate a single index value on which to rank animals. For a trait to be included in a breeding objective it must be: 1) either economically, socially or environmentally important, 2) express genetic variation, 3) be (ideally easily) routinely measureable or correlated with measureable traits that exhibit genetic variation. The economic values on traits in a breeding objective must be constantly reviewed in light of changes in economic and social policy, as well as, world markets and pricing strategies. Several new potential data sources exist which could provide new traits for possible inclusion in national breeding strategies. Genetic evaluations for linear type traits in dairy cattle for Ireland has, to-date, been undertaken in a joint Great Britain-Ireland genetic evaluation using genetic parameters derived using data from Great Britain – such a joint evaluation will no longer be possible. The large national uptake of DIY milk recording provides routine access to an objective measure of milking characteristics. Data collected as part of the national Dairy Efficiency Program offers a source of lameness and mastitis data for inclusion in national genetic evaluations.

2. Questions addressed by the project:

In this study we attempted to undertake all the necessary research to successfully implement a national breeding strategy for a wide range of traits in dairy and beef cattle. Such research included:

- Trait definition and editing criteria.
- Development of appropriate and parsimonious statistical models.
- Estimation of the necessary genetic and phenotypic parameters.
- Estimation of economic values.
- Evaluation of alternative breeding schemes.

3. The experimental studies:

- This study was desktop based and involved the analysis of datasets from the ICBF and Teagasc as well as a review of the literature.
- DIY milk recording data was used to generate novel milking characteristics traits.
- Data on mastitis, lameness and temperament from the national dairy efficiency scheme was used.
- Parameters from video image analysis of carcasses was related to carcass dissections to derive carcass cut prediction equations and subsequently genetic parameters for the predictions were estimated.
- Animal price and live-weight data from marts as well as on-farm recorded data were estimated using variance components for animal price and live-weight.
- Genetic parameters for linear type traits in Irish dairy cattle were estimated using Irish data.
- Variance components were estimated using animal linear mixed models that account for all genetic relationships among animals; covariance components were estimated using sire linear mixed models.
- Economic values were estimated using a bioeconomic model and profit functions.

4. Main results:

- Carcass primal cuts can be accurately predicted from video image analysis of carcasses and exhibit exploitable genetic variation which can increase genetic gain in profit further than selection on carcass EUROP classification.
- Exploitable genetic variation in animal price routinely collected in marts exists which can be used in national dairy and beef breeding objectives to more accurately reflect total profitability.
- Genetic parameters for linear type traits estimated using Irish data were similar (albeit slightly lower) to estimates previously used in the joint evaluations; heritability estimates varied from 0.01 to 0.45. Little re-ranking existed between sire genetic evaluations estimated in the joint analysis and estimated using the revised.

genetic evaluation. The revised genetic evaluation passed the INTERBULL test run and will therefore be used in international genetic evaluations.

- Considerable genetic variation in milking duration (from DIY milk meters) existed after adjustment for milk yield and udder health; the heritability of this trait was 0.17.
- Heritability estimates of 0.02 to 0.04 were estimated for lameness and mastitis estimated using the data generated as part of the dairy efficiency programme which, along with the genetic correlations with somatic cell count and linear type traits corroborate international estimates, thereby signifying that the data collected as part of the dairy efficiency program is sufficiently accurate to be included in national genetic evaluations.
- Heritability of female fertility was low which is consistent with international estimates but significant genetic variation existed to merit inclusion in a revised national separate genetic evaluation for dairy and beef.
- Significant differences in male fertility as well as efficiency of AI technicians existed.
- An extensive review of the literature concluded no benefit of including residual feed intake directly in a national breeding goal or selection index and in fact doing so could actually reduce genetic gain. Selection index theory analyses from a completed meta-analysis of 39 studies in growing animals clearly showed 90% of the genetic variation in feed intake could be explained by routinely recorded traits in Irish beef cattle, signifying little marginal benefit of research in attempting to capture the remaining variation (i.e., residual feed intake) while other important traits in the index require more immediate attention.
- Simulations undertaken suggest that most of the heritability reported to-date for methane intensity are primarily a function of the denominator in the derivation of methane intensity (i.e., feed intake). More appropriate phenotypes to elucidate the exploitable genetic variation in environmental footprint were derived.

5. Opportunity/Benefit:

- All research results for trait definitions, data editing criteria, genetic parameters and economic values (where available) are now implemented in national genetic evaluations for dairy and beef cattle for: 1) carcass cuts, 2) animal price, 3) live-weight, 4) female fertility, 5) male fertility, 6) linear type traits, 7) animal health, and 8) management traits.
- Gene Ireland breeding programme has been optimised further.

6. Dissemination:

International conferences: Presented at many international conferences, invited and contributed, such as the European Association of Animal Production, INTERBULL, ICAR, American Dairy Science Association Annual meeting, and the World Congress on Genetics Applied to Livestock Production.

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

Open Day: Presented at all Moorepark open days.

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

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

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

Main publications:

Berry, D.P., J. Coyne, B. Coughlan, M. Burke, J. McCarthy, B. Enright, A.R. Cromie, and S. McParland. 2012. Genetics of milking characteristics in dairy cows. J. Dairy Sci. (In Press)

Berry, D.P., and J. J. Crowley. 2012. Genetics of feed efficiency in dairy and beef cattle. J. Anim. Sci. (In Press)

McHugh, N., Evans, R.D., Amer, P.R., Fahey, A.G. and Berry, D.P. (2011). Genetic parameters for cattle price and body weight from routinely collected data at livestock auctions and commercial farms. Journal of Animal Science 89 : 29–39

Pabiou, T., Fikse, W.F., Amer, P.R., Cromie, A.R., Nasholm, A. and Berry, D.P. (2011). Genetic variation in wholesome carcass cuts predicted from digital images in cattle. Animal 5 (11) : 1720–1727

Mitigation strategies for methane emissions by dairy cows in Irish milk production systems

Project number:
5781
Date:
July, 2013
Funding source:
Teagasc, DAFM
Project dates:
Dec 2007 – Nov 2012

Key external stakeholders:

Irish dairy farmers, research institutes, grass and cattle breeding companies, DAFM.

Practical implications for stakeholders:

- Cattle consuming high quality pasture can be expected to produce less methane. Enteric methane emissions per cow, per kg milk solids and per kg dry matter intake were lower when cows were offered pasture only diets compared with those offered total mixed ration (TMR) or partial mixed ration (PMR) diets.
- There appears to be limited scope among conventional varieties of Perennial Ryegrass (PRG) to reduce methane output by grazing cattle. Methane emissions may be reduced, however, if water soluble carbohydrate concentration could be elevated.
- While white clover produced less methane compared with PRG, further research to determine its impact when included into PRG swards indicated little or no reduction in methane production.
- Dietary supplementation with specific dietary lipids will reduce methane emissions. However, when consideration is given to the cost and carbon footprint of including oils in the diet of ruminant animals, the benefit of this strategy is questionable.
- Jersey cows emitted less methane per day compared with Holstein-Friesian cows. Per unit intake or per unit output, however, no difference was found. Genetic analysis did indicate, however, that there exists the potential to mitigate enteric methane emissions through genetic selection. From a system perspective, cows originating from a balanced selection programme, such as the EBI, will reduce emissions per unit product compared with cows selected solely for milk production.

Collaborating Institutions:
University College Dublin (UCD)
Agri-Food and Biosciences Institute (AFBI) Hillsborough

Teagasc project team:
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Dr. Eva Lewis
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Dr. Padraig O'Kiely
Mr. Matthew Deighton

External collaborators:
Dr. Evelyn Doyle (UCD BES)
Dr. Tommy Boland (UCD AFS)
Dr. Tianhai Yan (AFBI Hillsborough)

Compiled by:
Frank Buckley

Technology

Main results:

- Cattle consuming high quality pasture can be expected to produce less methane. Less enteric methane emissions per cow, per kg milk solids and per kg dry matter intake resulted where cows were offered pasture only compared with TMR or PMR diets.
- Management strategies evaluated *in-vitro* using the 'Rusitec' (artificial rumen) showed limited or no potential to reduce enteric methane emissions by varying grass allowance, changing PRG varieties, including white clover or weed species in the pasture mix. Inclusion of specific dietary oils will reduce methane emissions but cost and carbon footprint implications may preclude real benefit.
- Genetic analysis provided evidence of the potential to mitigate enteric methane emissions through genetic selection. A further study demonstrated that cows with high feed conversion efficiency (FCE) had lower methane emissions per unit intake and per unit output.

Opportunity/Benefit:

GHG emissions per kg of milk solids can be reduced by 15 to 20% if several management strategies (improving animal performance, increasing N use efficiency, controlling emissions from manure storage, improving forage quality) are combined. The contribution of individual factors is, however, only small.

1. Project background:

Under the Kyoto Protocol, Ireland is required to limit total national greenhouse gas emissions. In January 2008 the EU Commission put forward a package of proposals that will deliver on the European Union's commitments to fight climate change and promote renewable energy up to 2020 and beyond. The package seeks to deliver a 20% reduction in total EU greenhouse gas emissions by 2020 (relative to 1990 levels) and at the same time increase to 20% the share of renewable energies in energy consumption. It has been estimated that enteric fermentation which naturally results in methane production accounts for 49% of the total GHG emissions associated with the average dairy unit in Ireland. The objective of this proposal is to investigate animal and dietary variables within the Irish pastoral system of milk production which could be manipulated to reduce enteric methane emissions by dairy cows.

2. Questions addressed by the project:

- Can the SF6 technique be established to evaluate methane mitigation strategies with relatively large numbers of cows across a range of component studies?
- Does grass quality influence methane emissions by grazing cattle?
- Do grazing cattle emit more or less methane compared with cattle offered TMR diets?
- Will concentrate supplementation increase or decrease methane emissions?
- Can grass be manipulated (breeding/ management) to reduce enteric methane emissions?
- Is there potential to reduce enteric methane emissions by including white clover or other species into grazing swards?
- Is supplementation with dietary oils an effective means of reducing methane emissions?
- Is it possible to breed more environmentally friendly cattle i.e. that will produce less methane?
- What level of reductions in methane emissions is possible using current technologies/ knowledge?

3. The experimental studies:

The SF6 technique was established at Teagasc Moorepark. The relationship between grass (PRG cultivars), clover and weed species and methane production was assessed by in vitro gas production and in an artificial rumen system. The effect of varying pasture quality, as well as the effects of TMR alone or as a supplement to pasture, oil supplementation and grass digestibility on methane emissions were evaluated at Teagasc Moorepark and UCD AFS. Dairy cow breed and genetic merit associations were evaluated. The SF6 technique was validated against respiration chamber measurements at AFBI Hillsborough. Data previously collected from studies using respiration chambers at AFBI were collated and statistically analysed to derive prediction coefficients for methane production by dairy cows offered different indoor type diets. The most promising findings from the above studies were incorporated into a whole farm systems/life cycle model to estimate potential effects on total greenhouse gas production from pastorally based dairy production systems.

4. Main results:

- Cows offered high quality (leafy) pasture produced 10% less methane (per day and per unit intake) compared with cows offered more mature (greater stem content) pasture.
- Cows offered TMR or PMR (partial diet as TMR) produced more methane (per cow and per unit output) compared to cows offered pasture only diets.
- There appears to be limited scope among conventional varieties of Perennial Ryegrass (PRG) to reduce methane output by grazing cattle. However, if water soluble carbohydrate concentration could be elevated this would lead to lowered methane emissions and is seen as an avenue with potential for plant breeders to research.
- In the *in vitro* studies, white clover produced less methane than grass, but as a mixture with grass resulted in higher methane emissions than from either PRG or WC individually.
- Weeds commonly found in grassland were assessed for methane output and were generally found to reduce methane output. Given that most are of poor nutritive value they are not seen to offer potential to reduce enteric methanogenesis by grazing ruminants.
- A suite of molecular tools were optimised for the analysis of microbial communities (bacteria, protozoa and fungi) in the rumen. The profile of microbial communities was found to differ between pasture and TMR diets, where diets were supplemented with dietary oils, among cow breed.
- A comparison of breeds: Holstein-Friesian, Jersey and Jersey x Holstein-Friesian, showed that while Jersey cows emit less methane per day compared with Holstein-Friesian cows, per unit intake or per unit milk solids output no difference was observed between the breed groups. A further component study evaluated cows identified as high and low FCE and found methane emissions per unit intake and per unit output were lower with the high FCE cows. Genetic analysis conducted using almost 3000 daily methane records (SF6 technique) from almost 300 individual cows indicated that there exists the potential to mitigate enteric methane emissions through genetic selection. The analysis demonstrated genetic variation, moderate heritability (0.14) and good repeatability (0.57). A modelling analysis demonstrated that cows selected through a balanced breeding programme (i.e. EBI) will reduce emissions per unit product compared with cows selected solely for milk production.
- Offering dietary oils containing high levels of polyunsaturated fatty acids will reduce the quantity of methane produced by lactating dairy cows offered concentrate supplementation at pasture. Linseed oil proved most potent. However, cost and carbon footprint implications would likely preclude meaningful benefit.
- Models developed at AFBI Hillsborough predict that methane output per unit intake can be reduced by increasing milk output, FCE, decreasing dietary fibre content and increasing feed quality.

5. Opportunity/Benefit:

In Ireland, grazing livestock are almost entirely dependant on grazed grass for 200–270 days of the year. It is incumbent upon the agricultural research community to develop strategies to reduce methane emissions from enteric fermentation under grazing. The results of this study clearly demonstrate that:

- Cattle consuming higher quality pasture will produce less enteric methane.
- Grass based systems are more favourable from an environmental foot print perspective compared with high input TMR based systems.
- There is potential to mitigate enteric methane emissions through genetic selection of animals.
- GHG emissions per unit product in dairy systems can be reduced by 15 to 20% if several management strategies (improving animal performance, increasing N use efficiency, controlling emissions from manure storage, improving forage quality) are combined.

6. Dissemination:

During the life time of this project, two open day events were held at Teagasc Moorepark. The objective of these events was to highlight research technologies that will increase farm profitability post milk quotas by instigating management practices that grow and utilise higher quantities of superior quality grass and achieve high animal performance over a long grazing season. The impact of best practice technology *vis-à-vis* its carbon footprint was highlighted at each board to impress upon stakeholders the role of technological improvement with regard to environment sustainability as well as economic prosperity. Papers from this study were also presented at the GGAA world GHG conference in Banff, Canada in October 2010. In total, 17 peer reviewed scientific articles, 44 technical (scientific) articles, as well as a smaller number of popular press articles and discussion group visits to the experiments during the active project period. The research results were also disseminated via in-service training to Teagasc Advisory staff annually.

Main publications:

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

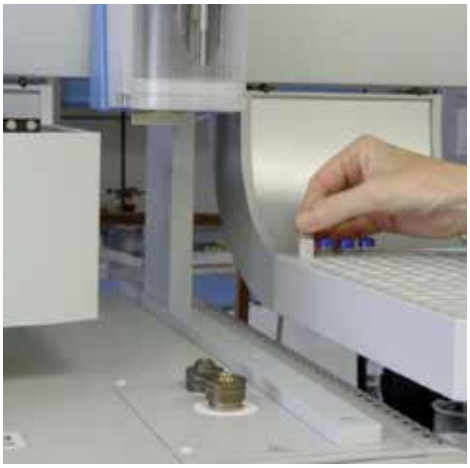
O'Brien, D., Shalloo, L., Grainger, C., Buckley, F., Horan, B. and Wallace, M. (2010) 'The influence of strain of Holstein-Friesian cow and feeding system on greenhouse gas emissions from pastoral dairy farms' *Journal of Dairy Science* 93: 3390–3402.

Yan, T., Mayne, C.S., Gordon, F.G., Porter, M.G., Agnew, R.E., Patterson, D.C. and Ferris, C.P. (2010) 'Mitigation of enteric methane emissions through improving energy utilisation efficiency and animal productivity in lactating dairy cows' *Journal of Dairy Science* 93: 2630–2638.

Popular publications:

Deighton, M.H. and O'Loughlin, B. (2011) 'Reducing dairy methane emissions' Moorepark 2011. Irish Dairying, Planning for 2015. Teagasc Moorepark Open Day, June 29, 2011.

Ether lipids as biomarkers for methanogenic Archaea in the ruminant gastro-intestinal tract



Project number:
6002
Date:
July, 2013
Funding source:
Teagasc
Project dates:
Oct 2009 – Dec 2012

Key external stakeholders:

Policymakers, dairy, beef and sheep farmers.

Practical implications for stakeholders:

Ether lipids are distinctive components of the membranes of methane-producing Archaea and can be used as markers in the following ways:

- To support molecular biology techniques used to estimate the population of methane-producing Archaea in the rumen, helping us to understand problems with some of the molecular methods.
- To provide broad estimates of methane yield (gCH_4/kg DM intake) for groups of animals. This approach does not provide good estimates for individual animals and we are exploring another possible marker technique to use with individuals.
- To provide information about the effect of the rumen environment on methanogens – in particular the ratio of diether to tetraether lipids appears to be indicative for the effect of rumen pH on methanogens and their methane production.

Main results:

- There was a poor relationship between concentrations of archaeol and most qPCR-based estimates of total methanogens in rumen fluid. However, there was a highly significant relationship between archaeol and *Methanobrevibacter ruminantium* qPCR estimates, suggesting that the primer set based on this species may have provided the best estimate of methanogen numbers.
- There was a significant positive relationship between faecal archaeol concentration and methane yield (gCH_4/ kg DM intake), when considering treatment means – but the relationship was weak within dietary treatments.
- There was no overall relationship between faecal and rumen archaeol concentrations and evidence of differences between animals in the kinetics of methanogens (i.e. in the relationship between what is present in the rumen and what flows out of the rumen). Archaeol was useful as a marker for methanogens within the rumen and suggested differences in the time course of colonisation by methanogens of grass and white clover.

Collaborating Institutions:
Organic Geochemistry Unit, School of Chemistry, University of Bristol, UK

Teagasc project team:
Dr. Richard Dewhurst (PI)
Dr. Christine McCartney

External collaborators:
Dr. Ian Bull (University of Bristol)

Compiled by:
Richard Dewhurst
Christine McCartney

Technology

- We have preliminary evidence of variation in the methanogen membrane lipid profiles in response to rumen environment (pH).

Opportunity/Benefit:

These ether lipid marker methods will be useful in allowing researchers to study the effects of dietary short- and long-term diet manipulations, as well as animal genotype, using large groups of animals. The key challenges in methane mitigation research are in understanding between-animal variation, whether due to genetics or management history, and understanding the way in which the rumen adapts to negate dietary treatments. Methanogen membrane lipids are of interest (1) to help in quantifying methanogens, and (2) in understanding how methanogens respond to adverse environments – such as the low pH conditions resulting from high levels of concentrate feeding.

1. Project background:

Methane production by ruminants is a significant contributor to greenhouse gas emissions in animal production in Ireland, and a source of inefficiency in the conversion of feed energy into milk or meat. It is a particular problem for Ireland because of our large numbers of cattle and sheep. The high-forage diets that are typical for most production systems also lead to high methane emissions. Ireland is also committed to the EU target for a 20% reduction in greenhouse gas (GHG) emissions (from 1990 levels) by 2020. Enteric methane accounts for 13.2% of Ireland's total GHG emissions and 70% of total methane emissions. Progress in reducing enteric methane is essential if we are to meet projected global growth in demand for food products of animal origin. At the same time, reductions in methane output provide a direct benefit for energy supply to animals because methane can represent up to 12% of gross energy intake. Both respiration chambers and the SF_6 technique have been used to identify dietary effects on methane production. However, there remain technical concerns about the SF_6 technique, such as uncertainty about its fate after its release from permeation tubes, and these probably contribute to greater between-animal variation in estimated methane production. The new approach investigated in this project is based on identifying distinctive markers for Archaea, the organisms responsible for methane production in the rumen. The membranes of Archaea contain distinctive ether lipids that have been used as biomarkers in a wide range of other sample types, including marine sediments, soils and peat. Recent studies at Bristol have demonstrated the occurrence of one of these biomarkers, 2, 3-diphytanyl-O-sn-glycerol (archaeol), in faeces taken from a range of ruminant and pseudo-ruminant species. This project explored variation in ether lipids in samples of intestinal digesta and faeces in order to address the questions listed below.

2. Questions addressed by the project:

- Can we use ether lipid biomarkers to study methanogenic Archaea in the rumen?
- Can we use ether lipids to investigate effects of diet and animal genetics on methanogens (and methane production)?
- What factors affect the relationship between production of ether lipids by methanogenic Archaea in the rumen and their concentration in faeces?
- Can we use ether lipids to identify the diversity and distribution of methanogens in the rumen?

3. The experimental studies:

A series of studies optimised the method for analysis of archaeol, developing more efficient methods for extraction, polar head-group cleavage and fractionation methods, as well as changes to the quantification of archaeol. Briefly, internal standard (1, 2-di-*O*-hexadecyl-*rac*-glycerol) was added to dried sample prior to a monophasic extraction procedure to obtain the total lipid extract (TLE). Removal of polar headgroups from archaeol was then achieved by acid methanolysis, and the TLE was then separated into 'apolar' and 'alcohol' fractions by column chromatography. The alcohol fraction was further trimethylsilylated and then run on the GC-MS. Archaeol was identified and then quantified against an archaeol calibration curve. The same alcohol fraction was filtered and then run on LC-MS for the detection of tetraethers.

Archaeol in rumen fluid was assessed as a total methanogen marker in comparison to the well-established quantitative real-time PCR (qPCR) technique. Genomic DNA was isolated from the ruminal fluid using the established bead beating method. Specific primer sets and probes were used to detect dominant methanogen species: *M. ruminantium, M. smithii, M. stadtmanae* and total methanogen populations, along with a prokaryote reference gene. qPCR was performed using either SYBR green chemistry or FAM dye. Methanogens were quantified relative to the prokaryote *rrs* gene using the equation: $\Delta Ct = 2^{-(Ct\ methanogen - Ct\ reference)} \times 10^6$. ΔCt values were then expressed on a sample DM basis.

Relationships between the various estimates of methanogen abundance (based on qPCR and archaeol) were made using simple linear regression (one outlier was identified on the basis of Cook's test and excluded from subsequent analysis).

Samples were obtained from three previous animal studies to allow comparison of archaeol concentrations with measured methane production. Firstly, faecal archaeol was compared to CH_4 measurements made using the sulfur hexafluoride (SF_6) tracer technique from beef cattle consuming 6 dietary treatments with varying levels of concentrate. Secondly, faecal archaeol was compared to CH_4 measurements made with dairy cows using respiration chambers from animals consuming a single dietary treatment. Finally, archaeol was assessed in faeces, total rumen contents and solid- and liquid-associated microbial fractions from dairy cows grazing either white clover or perennial ryegrass, with rumen samples taken in the morning and afternoon. Tetraethers were also analysed in some of these samples.

4. Main results:

There was only a weak relationship between archaeol concentrations and total methanogen qPCR estimates, but unexpectedly a very significant ($P < 0.001$) relationship was found between archaeol and *Methanobrevibacter ruminantium* qPCR estimates. Amplification bias with some of the qPCR primers and the dominance of *M. ruminantium* in the rumen may explain the strong relationship with this species.

There was a significant positive relationship ($P < 0.001$) between faecal archaeol and CH_4 production in the SF_6 study; however, the relationship was weak within dietary treatments. To further investigate the relationship, faecal archaeol was then compared to CH_4 measurements made using respiration chambers from animals offered just one dietary treatment. There was a significant positive relationship ($P = 0.007$) between faecal archaeol concentration and methane yield, though stage of lactation also affected the relationship ($P = 0.011$) and this may have been the result of higher dry matter intakes in mid-lactation.

There was a significant 'diet' × 'time' interaction for archaeol concentration in total rumen contents, which may be the consequence of the lower pH, lower NDF, or higher rumen passage rates when cows grazed white clover rather than perennial ryegrass. However, there was no relationship between archaeol concentrations in rumen and faecal samples, probably as a result of differences between cows in the selective retention of methanogens in the rumen.

There was a higher tetraether to diether ratio in the faecal samples from animals consuming a high concentrate diet (in comparison to those consuming a grass silage diet). An increase in the proportion of GDGT-0 may help methanogens under conditions of low pH by reducing the permeability of the cell membrane and thus conserving energy for growth. It will be important to consider both diether and tetraether membrane lipids when looking for relationships with methanogens and methanogenesis.

Overall, it seems the use of archaeol as a marker for methanogenesis is complicated by the issues of selective retention of digesta in the rumen, the wide ranging effects of diet, stage of lactation and individual differences of cattle. However, in comparison to qPCR, this method may be more robust in quantifying the total methanogen populations in the rumen.

5. Opportunity/Benefit:

The primary opportunities from the research are for companies developing anti-methanogen strategies, including dietary or other manipulations. These techniques will be of value in understanding effects on methanogen numbers, as well as the way in which the methanogens respond to nutritional or other challenges. In the longer-term, we expect that the work will contribute to selection strategies for methane production, most likely through indirect routes (i.e. identification of high- or low-emitting animals for use in detailed studies to understand the physiological basis of the phenotype).

6. Dissemination:

Results from this project formed the basis of an invited conference paper at the Greenhouse Gases and Animal Agriculture Conference in UCD, June 2013. Results have also been presented at scientific meetings, including the 8th International Symposium on Herbivore Nutrition and the British Society of Animal Science and Agricultural Research Forum annual meetings.

Main publications:

McCartney, C.A., Bull, I.D. and Dewhurst, R.J. (2013) 'Chemical markers for rumen methanogens and methanogenesis' *Animal*, 7 (s2): 409–417.

McCartney, C.A., Bull, I.D., Yan, T. and Dewhurst, R.J. (2013) 'Assessment of archaeol as a molecular proxy for methane production in cattle' *Journal of Dairy Science*, 96: 1211–1217.

Popular publications:

McCartney, C.A., Bull, I.D. and Dewhurst, R.J. (2013) 'Comparison of biomarker and molecular biological methods for estimating methanogen abundance' *Proceedings of the Greenhouse Gases and Animal Agriculture Conference, Dublin, Ireland. Advances in Animal Biosciences*, 4: 555.

McCartney, C.A., Bull, I.D., Van Rooyen, L. and Dewhurst, R.J. (2013) 'Changes in the ratio of tetraether to diether lipids in cattle faeces in response to altered dietary ratio of grass silage and concentrates' *Proceedings of the Greenhouse Gases and Animal Agriculture Conference, Dublin, Ireland. Advances in Animal Biosciences*, 4: 563.

McCartney, C.A., Bull, I.D. and Dewhurst, R.J. (2011) 'Analysis of total methanogens in rumen fluid using quantitative real-time PCR and gas chromatography/mass spectrometry' *Proceedings of the 8th International Symposium on Herbivore Nutrition, Aberystwyth, UK. Advances in Animal Biosciences*, 2: 486.

Molecular and immune mechanisms underlying bovine lameness

Project number:
6064
Date:
November, 2012
Funding source:
Teagasc
Project dates:
Oct 2010 – Oct 2012

Key external stakeholders:

Dairy farmers, dairy industry, Department of Agriculture, Food and the Marine (DAFM).

Practical implications for stakeholders:

- Lameness is considered the most serious welfare concern facing the European dairy industry. One of the most serious causes of lameness is damage to the horn of the claw.
- Dairy lameness is primarily caused by diseases or injuries to the hoof, which can be categorised as either affecting the claw horn, or the surrounding skin. Claw horn disorders (CHD; characterised by sole haemorrhages, sole ulcers and white line disease) are non-infectious in nature, and result from complex genetic and environmental interactions.

Main results:

- Cows with claw horn disorders showed a behavioural (locomotor ability) and physiological profile different to healthy cows. The stress hormone, cortisol, was associated with damage to the sole, as was the leukocyte profile (high neutrophil percentage, and low lymphocyte percentage).
- Claw horn damage was also associated with a gene expression profile associated with activation of the immune system. Several genes were identified that appear to be more highly expressed in cows with claw horn damage than in healthy cows.

Collaborating Institutions:
None

Teagasc project team:
Dr. Keelin O'Driscoll
Dr. Bernadette Earley
Dr. David Lynn
Dr. Matt McCabe

Compiled by:
Keelin O'Driscoll
Bernadette Earley

Technology

Opportunity/Benefit:

The results of this research have:

- Demonstrated that lame cows display several behavioural and physiological responses that are representative of a sickness response, indicating a lameness-associated systemic activation of the immune system.
- Demonstrated that as sole haemorrhage score increased (worsened) cows had more impaired locomotion and had higher concentrations of circulating glucose, urea, and haptoglobin.
- Demonstrated that the stress hormone, cortisol, was associated with damage to the sole, as was the leukocyte profile (high neutrophil percentage, and low lymphocyte percentage).
- Demonstrated that several genes are more highly expressed in cows with claw horn damage than in healthy cows and all of the genes that were differentially expressed are associated with general activation of the immune system.

1. Project background:

Lameness causes severe pain and distress for the cow and substantial economic losses. Dairy lameness is primarily caused by diseases or injuries to the hoof, which can be categorised as either affecting the claw horn, or the surrounding skin. Claw horn disorders (CHD) are non-infectious in nature, and result from complex genetic and environmental interactions. Weakening of connective tissue near the time of calving can also cause the pedal bone to drop and compress the corium, further disrupting claw horn formation. Early and accurate lameness detection means overall prognosis and the welfare of cows is improved. Unfortunately, early detection of lameness and CHD is extremely difficult; cows show little behavioural response to pain until injuries are advanced, and stockpersons find it difficult to detect signs of impaired locomotion. Thus it is unlikely that gait changes alone will provide accurate early detection of lameness caused by CHD, and objective measures to aid lameness diagnosis that can be clinically applied at farm level warrant investigation. Moreover, the prospect of identifying objective biomarkers of inflammatory hoof lesions could help identify animals in need of pain relief and provide appropriate targets for the development and monitoring of novel lameness therapies. Peripheral blood mononuclear cells (PBMCs) are immune cells that can be obtained relatively non-invasively, and are responsible for surveillance of the body with regard to injury and disease. They display specific expression signatures with regard to several diseases in cattle. There is little published information on the physiological and immune differences between healthy cows and cows that have claw horn disorders. This project set about addressing the knowledge gaps.

2. Questions addressed by the project:

- Is the physiological and immunological profile of cows that are clinically lame due to the presence of sole ulcers different to that of healthy cows?
- Is the leukocyte gene expression profile of cows that are clinically lame due to the presence of sole ulcers different to that of healthy cows?
- Are the physiological, immune and gene expression profiles of lame cows similar to those of cows that have mild to severe sole haemorrhages?
- Are any changes in measures of physiology and immunity associated with sole ulcers or haemorrhages evident up to three months prior to their development?

3. The experimental studies:

1. The objective of the first study was to characterise differences in leukocyte profile, cortisol and DHEA response, metabolite profile, and expression of genes associated with lameness between cows with sole ulcers and sound cows.
2. The second study compared these responses in cows with sole haemorrhages ranging from severe to mild/none.
3. The third study was a retrospective longitudinal study, comparing these responses in cows that had severe sole haemorrhaging approximately three months into the lactation with these measures at calving, and with cows that did not develop sole haemorrhages.

4. Main results:

- Using conventional blood indicators of stress (i.e physiological, haematological and immunological variables), cows with sole ulcers were shown to be in a state of physiological stress compared with healthy cows.
- Through the use of molecular techniques (i.e. real-time (RT)-qPCR and next generation sequencing technology), we identified a number of key genes regulating immune function the expression of which was different in cows that

had sole ulcers compared with healthy cows. Up- or down-regulation of this function of these genes could have a profound impact on the health of cows in terms of susceptibility to infection during a lameness episode.

- An increase in (worsening of) sole haemorrhage score was associated with impaired locomotion, increased levels of circulating metabolites and stress hormones, and a leukocyte profile associated with stress, thus indicating that horn damage not as severe as ulceration can cause systemic changes that could increase susceptibility to illness.
- An increase of sole haemorrhage scores was also associated with changes in gene expression indicative of physiological stress and changes in immune activation.
- We found no indication of any changes in metabolite or immune profile 2 – 3 months prior to sole damage that could be used as indicators of a risk of developing sole haemorrhages.

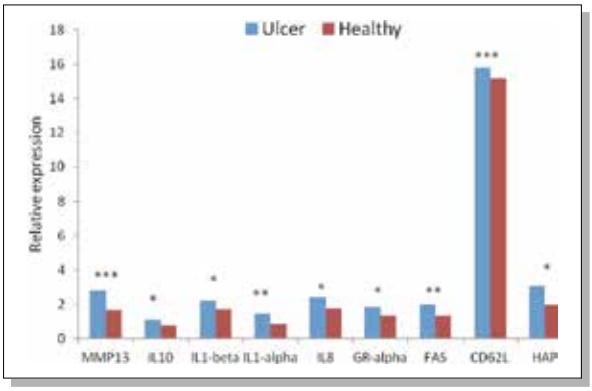


Figure 1. Differences in gene expression in white blood cells of cows that either had an ulcer or were otherwise healthy. * indicates means differ by P<0.1, ** by P < 0.05 and *** by P < 0.01.

5. Opportunity/Benefit:

The results of this research have; 1) demonstrated that cows that have sole ulcers have alterations in their immune system that could increase susceptibility to disease; and 2) demonstrated that even a more mild form of damage, i.e. sole haemorrhaging, which does not cause clinical lameness, results in alterations to the cows' gait and similar changes to the metabolic and immune profile.

6. Dissemination:

Main publications:

O'Driscoll, K. and Earley, B. (2012) 'Leukocyte profiles of cows with claw horn disorders.' *Proceedings of the ADSA/ASAS Joint Annual Meeting*, Phoenix, Arizona, USA, 15–19 July.

O'Driscoll, K. and Earley, B. (2012) 'Leukocyte profiles of cows with claw horn disorders.' *Proceedings of the Agricultural Research Forum*, Tullamore, Ireland, 12–13 March.

O'Driscoll, K., Olmos-Antillon, G., Llamas Moya, S., Mee, J.F., Earley, B., Gleeson, D., O'Brien, B. and Boyle, L. (2012) 'A reduction in milking frequency and plane of nutrition improves dairy cow immune status.' *Journal of Dairy Science* 95 (3) 1177–1187.

Animal and Grassland Research & Innovation Programme

Project number:
5517

Date:
August, 2012

Funding source:
Teagasc

Project dates:
Sep 2008 – Aug 2012

Examination of the molecular control of uterine function and fertility in cattle

Key external stakeholders:

Livestock industry, universities, veterinarians, AI industry, Department of Agriculture, Food and the Marine, Irish Cattle Breeding Federation (ICBF).

Practical implications for stakeholders:

- A panel of genes and pathways involved in metabolite transport, lipid metabolism and inflammation has been identified which may serve as potential molecular markers for fertility in cattle.
- Genetic variants in the genes *GALNT6*, *FST*, *DAP* and *ALB* exhibited significant associations with calving interval.
- Genetic variants associated with positive effects on fertility will be incorporated into the generation of a customised SNP chip for genomic assisted cattle breeding in Ireland. Data will ultimately contribute to the genomic selection programme, accelerating the rate of genetic gain in the Irish cattle population.

Main results:

- A number of genes and pathways affecting uterine function and potentially uterine-mediated conception rate variance were differentially expressed during the mid- and late-luteal phase in cattle of high and low fertility. Genes coding for metabolite transporters, specifically the solute carrier (SLC) family members were found to be differentially expressed between high and low fertility animals.

Collaborating Institutions:
University College Dublin (UCD)

Teagasc project team:
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Dr. David Kenny
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Dr. Michael Diskin
Dr. Donagh Berry
Aideen Killeen (Walsh Fellow)

External collaborators:
Professor David MacHugh (UCD)

Compiled by:
Sinead Waters
Michael Diskin
Dermot Morris
Michael Mullen
David Kenny

Technology

- The gene, *GALNT6* was decreased 7-fold in high compared with low fertility heifers. Expression of this gene is implicated in the synthesis of oncofetal fibronectin which is a protein found in plasma and cervicovaginal secretions; increased concentrations of which has been found in abnormal pregnancy states. In addition, *GALNT6* variants exhibited a significant association with calving interval.
- Variants of the genes *FST*, *DAP* and *ALB*, were also strongly associated with calving interval.

Opportunity/Benefit:

Key genes have been identified which may serve as molecular markers for cow fertility and following validation, such markers could be incorporated into future cattle breeding programmes to improve the reliability of predictions and increase the rate of genetic gain for fertility related traits.

1. Project background:

Cow reproductive efficiency is important to both the beef and dairy cattle enterprises. When there is sub-optimal reproductive performance it can be a significant cost to these multi-million euro industries. The aim of this project was to investigate a critical component of the reproductive process, with the ultimate aim of increasing our understanding of the genomic control of uterine function and overall cow fertility.

The bovine endometrium has received much attention because of its critical influence on embryo and foetal growth and survival. In particular, this outermost layer of the uterus maintains the conceptus through it's nutrient rich histotroph secretions and provides a structural point for embryonic implantation. Given the importance of this tissue in reproduction, it is important to gain a greater understanding of uterine function. The greatest increment of cow reproductive wastage occurs in the form of embryo mortality, particularly in early pregnancy prior to initiation of implantation. The extent and timing of this has been closely examined in both beef and dairy herds and it can be concluded that the majority of embryo loss occurs within 14–16 days following insemination. Specifically, it has been reported that most embryonic mortality occurs between day 8 and 16 after AI and thus it is termed "early embryo loss". Considering the nature of its timing, examination of molecular events regulating the initiation and culmination of this early embryo loss, is a priority in reproductive biology and as such days 7 and 14 of the oestrous cycle were targeted in this study. Taking these factors into account, the aim of this project was to elucidate the key genes, pathways and genetic variants potentially regulating and influencing fertility traits like early embryo survival, conception rate, calving interval and general uterine endometrial function in cattle.

2. Questions addressed by the project:

- Do endometrial gene expression profiles differ between heifers ranked as either high or low for fertility during the mid-luteal phase of the oestrous cycle (day 7)?
- Do endometrial gene expression profiles differ between heifers ranked either high or low for fertility during the late-luteal (day 14) phases of the oestrous cycle and in turn how do these compare this with the expression profiles from the mid luteal phase?
- Do variants of the genes, identified as being differentially expressed between heifers of either high or low fertility occur and are these different in bulls categorised as high and low genetic merit for calving interval, and how are these genetic variants associated with reproductive and other performance traits?

3. The experimental studies:

Reproductively normal crossbred beef heifers (n=120) were inseminated and pregnancy diagnosis was carried out 28 days later, after which animals were programmed to return to oestrus. Animals were re-inseminated followed by pregnancy diagnosis on a further four occasions. On the basis of pregnancy rate to 4 successive inseminations, animals were divided into two groups: i) those that established pregnancy on all 4 occasions (high fertility group) and ii) animals achieving pregnancy on only one occasion (low fertility group). Oestrous cycles were then synchronised following administration of a prostaglandin F2a analogue (Estrumate®). Animals from both high and low groups (n=12) were slaughtered on day 7 of their oestrous cycle and uterine endometrial tissue (ipsilateral to corpus luteum) was harvested and stored at -80°C in RNAlater solution. This was repeated with animals slaughtered and tissue collected on day 14 of the oestrous cycle. RNA was extracted, purified and DNAse treated. RNA quantity and quality was determined using spectrophometry and the 2100 Agilent. RNA samples were biotinylated and hybridised to the Affymetrix 23,000 bovine master gene chip according to manufacturers' protocol. The

microarrays were scanned and data normalised using the array analyser module of SPLUS and R. Statistical analysis and controlling for false discovery was carried out using the PUMA method in Bioconductor, R. Furthermore, Ingenuity Pathway Analysis (IPA) was used to associate changes in gene expression with key biochemical pathways involved in global biological function in the bovine uterus.

A DNAseq approach incorporating DNA pooling, target enrichment and high throughout sequencing was applied to identify polymorphisms and estimate allele frequencies in 10 candidate genes found to be differentially expressed in microarray studies. DNA samples from 150 Holstein-Friesian bulls divided into 2 groups (n=75) divergent (high and low) for genetic merit for calving interval were pooled using equimolar quantities from each animal to construct 2 Illumina® sequence libraries. A custom Agilent Technologies SureSelect™ Target Enrichment System was used to selectively capture and enrich coding, intronic and regulatory sequences of the targeted genes. These enriched libraries were then sequenced using an Illumina® Genome Analyzer II. Genetic variants with significant (≥2-fold; P<0.01) allele frequency differentials between the low and high calving interval (LCIV and HCIV, respectively) groups were genotyped in 848 dairy bulls and association studies conducted to examine the effect of these genetic variants on fertility and other performance traits in cattle.

4. Main results:

Microarray analysis detected 419 differentially expressed genes (DEG) between high and low fertility animals on day 7 of the oestrous cycle. The main gene pathways affected were, cellular growth and proliferation, angiogenesis, lipid metabolism, cellular and tissue morphology and development, inflammation and metabolic exchange. DEG included, *FST, SLC45A2, MMP19, FADS1* and *GALNT6*. 430 DEG were detected between high and low fertility animals on day 14. Pathway analysis revealed enrichment for many biological pathways including lipid metabolism, molecular transport, immune response, cell morphology and development, cell growth and proliferation and reproductive function. Important DEG included *ALB, BMPR2, CCL28, COL4A3/4, FADS1, ITGA6, LDLR, PCCB, PLCB3, PPARG, PTGS2* and *SLC27A4*. The present study highlights some of the pathways and mechanisms underpinning late-luteal bovine endometrial physiology and endometrial related conception rate variance.

DNA-Seq and subsequent association analysis of variants contained in *GALNT6* revealed several significant associations with a variety of reproductive variables. In particular, significant associations were observed between 4 SNPs in *GALNT6* and calving difficulty and gestation length, while positive associations were observed with calf difficulty and mortality. Furthermore, all of these variants resulted in non-synonymous substitutions ultimately resulting in a change in protein sequence and therefore potentially function. Another variant in *GALNT6* exhibited a significant association with increased calving interval and decreased cow survival. This specific variant also results in a non-synonymous substitution, with a 2-fold allele frequency differential between original high and low CIV animals.

Two variants in the *FST* gene, and one in each of *DAP* and *ALB* were strongly associated with shorter calving intervals. Also, DNA sequencing analysis revealed a 2.29 and 2.28 allele frequency differential for the two *FST* SNPs between HCIV and LCIV animals, respectively. The physiological role of *FST* has been extensively investigated in numerous species. *FST* is imperative in daily cellular homeostasis in early reproductive organ development and subsequent fertility. Furthermore, high vs low fertility heifers exhibited differential endometrial expression of *FST*. Furthermore, *FST* was found to be expressed in endometrium, during implantation and when treated with steroid hormones oestradiol and (or) progesterone, reinforcing the concept that this gene may play a critical role in bovine endometrial function and fertility.

5. Opportunity/Benefit:

Key genes have been identified which may serve as molecular markers for fertility. Following validation, such markers could be incorporated into future cattle breeding programmes to improve the reliability of predictions and increase the rate of genetic gain for fertility related traits.

6. Dissemination:

Killeen, A.P. (2012) 'Genomic control of uterine function and fertility in cattle.' Thesis, UCD.

Mullen, M.P., Creevey, C.J., Berry, D.P., McCabe, M.S., Magee, D.A., Howard, D.J., Killeen, A.P., Park, S.D., McGettigan, P.A., Lucy, M.C., MacHugh, D.E. and Waters S.M. (2012) 'Polymorphism discovery and allele frequency estimation using high-throughput DNA sequencing of target-enriched pooled DNA samples.' *BMC Genomics*, 13:16.

Killeen, A.P., Mullen, M.P., McCabe, M.S., Kenny, D.A., Magee, D.A., Creevey, C.J., MacHugh, D.E. and Waters, S.M. (2011) 'Allele frequency differentials of regulatory polymorphisms across 10 candidate fertility genes in dairy cattle divergent for calving interval.' *Proceedings from the 4th International Symposium on Animal Functional Genomics*, Dublin, Ireland. 10th October.

Killeen, A.P, Morris, D.G, Kenny, D.A, Diskin, M.G and Waters, S.M. (2010) 'Uterine endometrial gene expression in heifers of high or low fertility on day 14 of the oestrous cycle.' *Proceedings from the BSAS and Agricultural Research Forum,* Belfast, 12th March, p161.

Animal and Grassland Research & Innovation Programme

Project number:
5502
Date:
September, 2012
Funding source:
Teagasc, DAFM
Project dates:
Jan 2006 – Dec 2011

Evaluation of Jersey, Jersey × Holstein-Friesian and Holstein-Friesian cows under Irish grass-based spring milk production systems

Collaborating Institutions:
University College Dublin (UCD)
INRA, France

Teagasc project team:
Dr. Frank Buckley (PI)
Dr. Eva Lewis
Dr. Laurence Shalloo
Dr. David Kenny
Dr. Sinead Waters

External collaborators:
Dr. Karina Pierce, UCD
Dr. Luc Delaby, INRA

Compiled by:
Frank Buckley

Key external stakeholders:

Irish dairy farmers, ICBF, AI companies, consultancy agencies.

Practical implications for stakeholders:

- Jersey × Holstein-Friesian (F_1) cows produced less milk volume compared to Holstein-Friesians (HF). They had higher milk composition, higher milk solids yield and consequently increased milk value.
- The F_1 cows were more efficient, producing 10% more milk solids per unit area compared to HF cows. This is largely due to the innate ability of the Jersey (J) breed to consume a higher intake relative to body size, thus diluting maintenance requirements. These findings also indicate that it would not be correct to increase the stocking rate of J crossbreds relative to HF cows on a live weight basis.
- The superior performance of the F_1 equates to an increased profit potential of almost €20,000 annually for a 40 ha unit. The reduced cull cow and male calf value are more than compensated for by the overall performance of the F_1.
- Research is warranted to develop an index (independent of the EBI) that will reflect the potential extra profit per lactation that can accrue as a result of heterosis, as well as other factors in addition to additive genetic merit that affect the short term (in the current/subsequent lactation) profit potential of the dairy cow.

Technology

Main results:

- The F_1 cows produced less milk volume compared to HF. They had higher milk composition, higher milk solids yield and consequently increased milk value. They were better able to maintain better body condition, were of moderate size, and had substantially better reproductive efficiency. Milking duration and udder health was similar for the three breed groups.
- Dry matter intake was similar for the HF and F_1 but significantly lower for the J. Intake capacity was greatest for the J, intermediate with the F_1 and lowest for the HF. Yield of milk solids per unit body weight and milk solids per unit intake was more favourable for the J and F_1 compared to the HF.
- Economic analyses showed that while milk volume and cull cow revenue were highest for the HF; the value of milk output and overall farm profit was superior for the F_1 compared to either pure breed.

Opportunity/Benefit:

The improved performance associated with the J×HF cows is estimated to equate to an increased profit potential of almost +€20,000 per lactation for a 40 ha unit.

1. Project background:

The challenge for Irish dairy farmers in the years ahead is to increase the competitiveness of their business through innovation, productivity gain and increased operational scale (Shalloo et al., 2004). With revenue from milk production projected to fall, national farm statistics show that costs of milk production are increasing by 0.15c/ litre per year while the variation between the highest cost and lowest cost producers is in excess of 9.2 c/l. This data suggests that producers must focus on achieving cost efficient milk production through more efficient use of pasture. Walsh et al. (2008) suggested that crossbreeding may offer a "quick fix" to counteract some of the antagonisms of past selection policies, in particular the well documented slippage in reproductive efficiency within HF herds (Evans et al., 2002). Crossbreeding with the J is expected to offer the opportunity to maximise solids production per hectare (Penno, 1998), improve milk value due to introduction of multi component milk payment (Shalloo, 2007), and improve production efficiency (Grainger and Goddard, 2004).

2. Questions addressed by the project:

- Are J × HF cows as productive as pure HF cows?
- Do they have improved reproductive efficiency?
- Is there a difference in production (feed) efficiency between the two types of cow and are differences consistent through the production cycle?
- Do they differ in grazing behaviour?
- Are there udder health differences between the breed groups?
- How do they differ in terms of overall economic efficiency?
- Does the reduced cull cow and male calf value negate any potential economic benefits arising with the J × HF cows?

3. The experimental studies:

A five year study evaluating the comparative performance of HF, J and F_1 crossbreds, under experimental conditions representative of Irish grass-based production circumstances was established by Teagasc Moorepark at the 'Ballydague' research farm in 2006. The data incorporated 329 lactations from 65 HF, 48 J and 49 F_1 cows; 2006, 2007 and 2008 (years 1, 2 and 3, respectively). Mean calving date was February 21 (±19 d) across the three years. A total of 18, 20 and 16 sires were represented in the HF, J and F_1 groups, respectively. All sires were commonly available in Ireland. Animal performance results pertaining to milk production and milking characteristics, udder health, fertility performance, body weight, body condition score, feed intake, intake capacity, feed efficiency and grazing behaviour are presented.

4. Main results:

- Milk yield was highest for the HF and lowest for the J. Milk fat and protein content were highest for the J, intermediate for the F_1 and lowest for HF. Lactose concentration was lowest for the HF and similar for the J and F_1. Milk solids production (fat + protein yield) was highest for the F_1, intermediate for the HF and lowest for the J.
- The HF cows were heaviest, the J cows were lightest and the F_1 were intermediate. These differences were consistent throughout lactation. Body condition score tended to be highest for the F_1 and lowest for the HF throughout lactation.

- Reproductive efficiency (calving to conception interval, pregnancy rate to first service, six week in-calf rate and overall pregnancy rate) was similar for the HF and J. The F_1 exhibited substantially superior reproductive performance compared to the pure breeds.
- Dry matter intake was similar for the HF and F_1 but significantly lower for the J. Intake capacity was greatest for the J, intermediate for the F_1 and lowest for the HF.
- The highest yield of milk solids per 100 kg body weight was achieved by the J; 0.35kg and 0.27 kg for the J and HF, respectively. The F_1 produced 16% more milk solids per unit body weight compared to the HF.
- Production expressed as milk solids per unit intake was greater for the J and F_1 (0.088 and 0.087 kg/kg) compared to the HF (0.079 kg/kg). Net energy intake/unit of milk solids was also more favourable for the J and F_1 compared to the HF.
- Residual feed intake was similar across the breed groups.
- Significant estimates of hybrid vigour for milk solids/TDMI, NEI/milk solids, NEI-NEM/ milk solids and NEI-NEM-ΔNEM/ milk solids were obtained.
- Production efficiency was positively associated with milk solids yield.
- When expressed per unit body weight and per unit intake, J were more vigorous grazers compared to the HF.
- Associations were determined between grazing behaviour and intake capacity and some of the feed/production efficiency measures. A positive relationship was evident between rate of intake (grass DMI (GDMI)/minute) and intake capacity. Cows that spent more time masticating the herbage had a higher output of milk solids/100 kg BW and higher milk solids yield/GDMI. The rate of grazing mastications was positively associated with output per 100 kg BW and output per unit GDMI. Cows that had increased ruminating mastications/100 kg BW also had a higher intake capacity and produced more milk solids/100 kg BW. Similarly, cows that had more ruminating bouts had a greater output of milk solids/100 kg BW and milk solids/GDMI.
- Udder health, as indicated by somatic cell score and incidence of mastitis, were not different for the HF and J breeds. Somatic cell score and incidence of mastitis, of the F_1 were similar to the mean for pure breeds.
- Average milk flow was greater for the HF compared to the J. Peak milk flow also tended to be higher for the HF. The F_1 had higher milk flow rates compared to the mean for pure breeds. Milking duration was similar for the three breed groups.
- Economic analyses showed that while milk volume and cull cow revenue were highest for the HF; the value of milk output and overall farm profit was superior for the F_1 compared to the parent breeds. A substantial component of the superior economic performance of the F_1 was due to the superior reproduction/survival compared to the HF and J.

5. Opportunity/Benefit:

- The results clearly illustrate the potential benefits to dairy farmers achievable from crossbreeding with J in Ireland. J × HF cows are highly productive, have excellent fertility and are efficient convertors of grass to milk. This results in a substantial economic benefit.
- Teagasc and ICBF should develop an index that is independent of the EBI and which should reflect the potential extra profit that can accrue as a result of heterosis, as well as other factors in addition to additive genetic merit that affect the short term (in the current/subsequent lactation) profit potential of the dairy cow. This is essential to enable accurate sire advice and female culling decisions to be made in a crossbred population. This work has begun.

6. Dissemination:

During the life time of this project, two open day events were held at Ballydague and two others were held at Moorepark. These provided key findings from this research to Irish dairy farmers and industry representatives. The objective of these events was to highlight research technologies that will increase farm profitability post milk quotas, by instigating management practices that grow and utilise higher quantities of superior quality grass and achieve high animal performance over a long grazing season.

In addition to scientific, popular press articles and open day events, individual discussion groups frequently visited the experiment during the project. Topics covered at these events by research and advisory staff included grassland management best practice advice, animal breeding and the economic implications of research results. The research results were also disseminated via in-service training to Teagasc Advisory staff annually.

Main publications:

Prendiville, R., E. Lewis, K.M. Pierce, F. Buckley. (2010). Comparative grazing behaviour of lactating Holstein-Friesian, Jersey and Jersey × Holstein-Friesian cows and its association with intake capacity and production efficiency. *Journal of Dairy Science* 93: 764–774.

Prendiville, R., K.M. Pierce, L. Delaby, F. Buckley. (2011). Animal performance and production efficiencies of Holstein-Friesian, Jersey and Jersey × Holstein-Friesian cows throughout lactation. *Livestock Science* 138: 25–33.

Prendiville, R., L. Shalloo, K.M. Pierce and F. Buckley. (2011). Comparative performance and economic appraisal of Holstein-Friesian, Jersey and Jersey × Holstein-Friesian cows under seasonal pasture-based management. *Irish Journal of Agricultural and Food Research* 50: 123–140

Popular publications:

Kennedy J., 'The Jersey Cross Debate', 28 February, 2009. Irish Farmers Journal.

Animal and Grassland Research & Innovation Programme

Project number:
5666

Date:
December, 2010

Funding source:
DAFM

Project dates:
Sep 2006 – Sep 2010

Genetics of improved health, fertility, grass intake and feed efficiency in Irish dairy cattle

Collaborating Institutions:
University College Dublin (UCD)
Irish Cattle Breeding Federation (ICBF)

Teagasc project team:
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Dr. Frank Buckley

External collaborators:
Drs. Andrew Cromie
Sean Coughlan
Francis Kearney
Ross Evans
Brian Wickham, ICBF
Bernard Eivers
National Cattle Breeding Centre (NCBC)
Dr. Ger Ryan, Dovea
Tom Baker, Eurogene
Peter Byrne
Farm Relief Services (FRS)

Compiled by:
Donagh Berry

Key external stakeholders:

The Irish Cattle Breeding Federation (ICBF), breeding industry, dairy and beef farmers, AI technicians, farm relief service.

Practical implications for stakeholders:

- Shown significant differences between Jerseys, Jersey crossbreds and Holsteins in their ability to convert feed into milk solids.
- Developed the data editing, statistical models and genetic parameters for female fertility traits in dairy and beef animals which has been disseminated at many industry meetings and has been implemented into national genetic evaluations.
- Developed the data editing and statistical models for evaluation of bull fertility and performance of AI technicians in cattle which are now routinely used by the industry to monitor performance.
- Provided genomic data for inclusion in genomic selection evaluations which are now implemented in national evaluations.
- Revised the health sub-index of the dairy EBI to include actual mastitis and lameness data with the appropriate economic weights (to be implemented into national evaluations in 2011).
- Generated scientific knowledge (in collaboration with other projects) of the associations between variation at the level of DNA and performance in Holstein-Friesian cattle.
- Shown that Johne's disease is under genetic control and significant differences exist among sires in the daughters' susceptibility to Johne's disease, which are not strongly related to current breeding goals.
- Shown that antibody immune response and cell mediated immune response in Norwegian Red and Holstein cattle were not consistent indicators of udder health.
- Shown that dry matter intake, energy balance and digestibility is under genetic control, the extent of which varies across the lactation.

Technology

Main results:

- Clear and exploitable genetic variation in male and female fertility traits in dairy and beef cattle.
- Clear and exploitable genetic variation in mastitis and lameness data collected by Irish farmers.
- Considerable exploitable genetic variation in dry matter intake, energy balance and the digestibility of feed.

Opportunity/Benefit:

Greater accuracy of genetic selection for a comprehensive suite of important traits is now possible.

1. Project background:

Although the economic breeding index (EBI) and suckler beef value (SBV) exist to improve health and fertility in dairy and beef cattle, the approaches used can be improved through the development of new phenotypes (e.g., mastitis, lameness) and redefinition of phenotypes based on now routinely available data (e.g., new fertility traits). Additionally, a key requirement of sustainability is efficient production from a pasture based system. High grass intake per unit size/production will likely result in cows more suited for grazing systems. High feed conversion efficiency (FCE) is desirable. However, data underlying the genetic variation in grass intake and FCE in grazing dairy cattle has yet to be quantified.

2. Questions addressed by the project:

The objective of this study was to quantify the genetic variation in a number of key traits that will aid the development of improved selection strategies for increased health, fertility, and efficiency, for Irish pasture-based systems. Traditional genetics and state-of-the-art genomic approaches were to be used.

3. The experimental studies:

- Most of the tasks were based on mining of the Irish Cattle Breeding database or collecting additional data (e.g., lameness) to supplement the database.
- Genomic associations in this project were based on 848 Holstein-Friesian AI sires representative of those used in Irish dairy herds in recent years.
- Research on the antibody and cell mediate immune response in the Norwegian Red and Holstein-Friesian cattle was based on 648 second-lactation cows (274 Holstein-Friesian, 207 purebred Norwegian Red, and 167 crossbreds) from 30 commercial Irish dairy herds.
- The study on the breed differences in feed efficiency was based on 110 cows (37 Holstein-Friesian, 36 Jersey and 37 crossbreds) from one research farm at Moorepark.

4. Main results:

- New fertility phenotypes, defined using routine service and pregnancy diagnosis data, are under genetic control and are better early biological genetic predictors of fertility than milk yield (which is currently used in the national genetic evaluations for dairy cattle). Greater accuracy of selection for fertility was shown to be possible using this new approach.
- Clear and exploitable genetic variation in fertility (including age at first calving) exists in beef cattle.
- Large differences exists among bulls and technicians in their ability to get cows in calf.
- Mastitis and lameness data collected by Irish farmers is suitable for inclusion in national genetic evaluations for health. The incidence rate of mastitis and lameness in the data was 11% for both. Four to 5% of the differences among animals in the incidence of mastitis and lameness were due to their genetic makeup, which can be exploited in breeding programs.
- It is possible to improve resistance to Johne's disease through breeding; the heritability (i.e., proportion of variation observed on farm due to differences in genetics of the animals) for susceptibility to Johne's disease varied from 7 to 15%. Genetic correlations between Johne's disease and milk, fat and protein yield were negative, although not always statistically significant; stronger negative genetic correlations were evident in older animals.
- Considerable exploitable genetic variation exists within the Holstein-Friesian breed in dry matter intake, energy balance and the digestibility of feed. The heritability (i.e., proportion of variation observed on farm due to differences in genetics of the animals) varied from 10 to 30% for dry matter intake, from 9 to 35% for energy balance, and from 8 to 45% for diet digestibility.

- The Jerseys had better gross feed efficiency (i.e., higher milk solids output per unit intake) compared to the crossbreds which in turn had better gross efficiency than the Holstein-Friesians.
- The Norwegian Reds had a greater primary antibody mediated immune response compared to the Holstein-Friesians and the Norwegian Red × Holstein-Friesian crossbreds. No difference was observed among the breed groups in cell-mediated immune response. While differences in mean breed group somatic cell count values were in line with group mean antibody mediate immune response values, no association was found among the traits.

5. Opportunity/Benefit:

- The results from this study have been used in the revised national genetic evaluation for female fertility in dairy cows and in beef cows and have been used for the first ever national evaluation of male fertility and AI technician performance.
- New genetic evaluation for mastitis and lameness are being developed.

6. Dissemination:

International conferences

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

National Conferences and seminars

Presented at the Agricultural Research Forums through the duration of the project and at national farmer conferences (e.g., Irish Grassland Conference).

Open Day

Presented at all Moorepark open days.

Breeding industry consultation days

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

Farmer discussion groups

Discussed at many farmer discussion groups and seminars.

Press

Results regularly presented in the Irish Farmers Journal, Farming independent, Today's Farm, TResearch, and Moorepark News.

Main publications:

Berry, D.P., J.F. Kearney, and J.R. Roche. (2011). Evidence of genetic and maternal effects on secondary sex ratio in cattle. Theriogenology. (In Press)

Berry, D.P. R.D. Evans, S. Mc Parland. (2011) Evaluation of bull fertility in dairy and beef cattle using cow field data. Theriogenology 75: 172–181.

Berry, D.P., M. Good, P. Mullowney, A.R. Cromie, and S.J. More. (2010). Genetic variation in serological response to Mycobacterium avium subspecies paratuberculosis and its association with performance in Irish Holstein-Friesian dairy cows. Livestock Science 131 : 102–107

Popular publications:

Buckley, F. and Berry, D.P. (2010). Bull Selection 2010 – Achieving improved herd fertility:- Moorepark Dairy Levy Research Update-Series No. 14 on 6th May. Teagasc IE

Buckley, F. and Berry, D.P. (2009). Genetics for grass-based systems – Irish Dairying New Thinking for Challenging Times (Moorepark Open Day 2009). Teagasc IE pp. 41–46

Buckley, F. and Berry, D.P. (2010). Breeding and Management Technologies to Increase Farm Profit: Bull selection 2010 – Moorepark Dairy Levy Research Update: Ballydague Research Farm, Series No. 13, 23rd March. Teagasc.

Animal and Grassland Research & Innovation Programme

Healthy fatty acid-enriched fresh beef: implications for shelf-life and flavour

Project number:
5409
Date:
July, 2013
Funding source:
DAFF
Project dates:
Oct 2005 – Mar 2009

Collaborating Institutions:
UCD
University of Bristol, UK
MTT Finland

Teagasc project team:
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Dr. Peter Dunne

External collaborators:
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Dr. Finbar Mulligan (UCD)
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Dr. Kevin Shingfield (MTT Agrifood, Finland)

Compiled by:
Aidan Moloney

Key external stakeholders:

Beef producers/processors, Bord Bia, health professionals.

Practical implications for stakeholders:

Strategies to manipulate the fatty acid composition of beef and the implications of the modified beef on shelf-life and flavour were examined.

- The findings will assist the beef industry in the production of beef with enhanced fatty acid composition from a human health perspective, and to prevent any associated deleterious effect on shelf-life or sensory characteristics of beef.
- The findings will also assist the marketing of Irish grass-produced beef.

Main results:

- Muscle lipids of pasture-fed cattle contained higher vaccenic acid, total and c9, t11-conjugated linoleic acid proportions than those from concentrate-fed cattle.
- Supplementation of pasture with plant/marine oils resulted in larger marginal increases in total and c9, t11- conjugated linoleic acid than supplementation of concentrate.
- The shelf-life of the modified beef was unaffected.
- The rather extreme dietary treatments had relatively small effects on shelf-life and sensory characteristics of beef.

Technology

Opportunity/Benefit:

The feasibility of producing beef with an enhanced fatty acid composition from a human health perspective, beyond that found in conventionally produced beef was demonstrated. The main challenge to industry is to develop a marketing strategy to capture this potential.

1. Project background:

Typical Irish grass-fed beef has a fatty acid composition more compatible with dietary recommendations for improved consumer health than that of competing European beef. Grass-fed beef also has higher concentrations of CLA (a range of isomers of linoleic acid that have positive health effects relating to cancer, obesity, diabetes and coronary heart disease). To fully capture the added value of Irish grass-fed beef as a healthy, functional food, the concentration of beneficial fatty acids must be optimised such that beef becomes a significant source of these fatty acids in the human diet. There is scope to increase the CLA concentration in grass-fed beef. Dietary management to enhance CLA synthesis prior to grazing together with strategic supplementation during grazing, would likely increase the final concentration in beef beyond that previously observed. The primary route of tissue CLA synthesis is via endogenous desaturation of ruminally-derived trans vaccenic acid (TVA) by delta 9-desaturase. Nutritional regulation of the delta 9-desaturase gene has been demonstrated in rodents but little is known about the regulation of this gene in beef cattle. Up-regulating the expression of the delta 9-desaturase gene, together with an adequate supply of substrate, would increase tissue synthesis of CLA. The targeted increase in CLA concentration may increase the susceptibility of beef lipids to oxidation resulting in the development of unhealthy oxidation products, decreased colour stability and altered flavour. While grass provides antioxidant protection to meat, additional antioxidants may be required when beef is further enriched with polyunsaturated fatty acids. The extent to which natural dietary antioxidants stabilise beef lipids as well as the benefit of supplementary antioxidants needs to be clarified.

2. Questions addressed by the project:

- Will supplementation of grazing cattle with plant/marine oil-based supplements increase the concentrations of CLA and omega-3 PUFA ratio in bovine muscle?
- Will increasing the duration of supplementation increase the concentrations of these fatty acids still further?
- Does supplementation decrease the shelf-life of beef?
- Does supplementation alter the flavour of beef?

3. The experimental studies:

Two beef production studies were carried out to test hypotheses concerned with dietary manipulation of the fatty acid composition of beef. In the first experiment, Charolais crossbred heifers (n = 10/treatment) were offered a basal concentrate, unsupplemented or supplemented with a high fatty acid concentrate that contained no additional antioxidant or a low, medium or high concentration of Vitamin E, unsupplemented grazed grass or grazed grass supplemented with a high fatty acid concentrate that contained no additional antioxidant or a medium concentration of Vitamin E. In the second experiment, Charolais crossbred heifers (n = 10/treatment) were offered either a standard ration or a ration designed to enhance CLA synthesis during the Winter. Within each group, animals were then offered unsupplemented grazing for 22 weeks, unsupplemented grazing for 11 weeks followed by supplementation with a blend of sunflower oil and fish oil for 11 weeks or supplementation with this oil blend for 22 weeks before slaughter. The cattle were grown at Grange Beef Research Centre and slaughtered in a commercial abattoir. The fatty acid composition of beef was measured using a combination of gas chromatography and high pressure liquid chromatography. Expression of selected genes coding for enzymes involved in lipid metabolism was measured in UCD using appropriate molecular biology techniques. Colour and lipid stability was measured in Ashtown Food Research Centre during display of meat in a modified atmosphere while descriptive flavour analysis of cooked beef was carried out using a trained panel of assessors in the University of Bristol.

4. Main results:

Cattle production

Muscle lipids of pasture-fed cattle contained higher TVA, total and c9, t11-CLA proportions; supplementation of pasture resulted in larger marginal increases in total and c9, t11-CLA than supplementation of concentrate; sunflower oil induced a higher enrichment of TVA, total and c9, t11-CLA in muscle relative to sunflower seeds; The predominant CLA isomer in the neutral lipid fraction of unsupplemented grass-fed beef was c9, t11 followed by t11, c13. Supplementation of grass with sunflower/fish oil altered this distribution such that t7,c9 became the second most prominent isomer. Supplementation of concentrates with sunflower/fish oil decreased the proportion of c9,t11 and increased the proportion of t7,c9. There was little effect of vitamin E supplementation on the isomeric distribution of CLA. At least eighteen isomers could be detected in the polar lipid fraction.

With respect to the CLA proportion in muscle lipids, there was no interaction between Winter ration composition and subsequent Summer ration; increasing the duration of consumption of a fish oil oil/sunflower oil supplement at pasture increased the proportion of CLA in muscle lipids. The highest concentration of CLA was observed in cattle that had been fed a CLA-enhancing supplement in Winter and Summer.

Gene expression

Delta-9 desaturase mRNA levels were lower in muscle and subcutaneous adipose of grass-fed animals compared to concentrate-fed animals but were unchanged in liver ($P>0.05$). Supplementation of the diet with sunflower oil/fish oil had no effect on delta-9 desaturase gene expression in any tissue examined.

Delta-9 desaturase mRNA levels were higher in muscle from animals that had received wilted grass silage during Winter. Delta-9 desaturase mRNA levels were higher after supplementation of grazing heifers with a sunflower oil-containing concentrate for 11 weeks but declined thereafter.

Shelf-life studies

While an increase in vitamin E stabilised lipids it is not required to stabilise colour of grass-fed beef; for concentrate feeding systems, the beneficial effects on redness and saturation of increasing the dietary supply of vitamin E becomes more apparent as the display period progresses; grazing is as effective as a targeted vitamin E intake of 3,000 I.U.Ÿhead^{-1}Ÿd^{-1}on a concentrate-based diet in terms of colour stability; mincing caused increased discoloration and lipid oxidation.

Long term supplementation of grazing heifers with a sunflower oil-containing concentrate increased lipid oxidation. The colour of previously-frozen muscle was less stable than fresh muscle.

Flavour

There were relatively minor differences between pre-slaughter rations and measured flavour attributes; beef from grass-fed cattle was more “greasy” than that from concentrate-fed cattle but overall liking was not affected by the dietary treatments examined.

Toughness was higher in steaks from animals that had received wilted grass silage during Winter but they had higher beef flavour intensity and lower abnormal flavour intensity. There were no significant differences in any of the descriptive flavour terms. Steaks from animals that had received oil supplementation for 22 weeks were juicier than steaks from unsupplemented animals but did not differ from those from animals that had received oil supplementation for 11 weeks. Steaks from oil-supplemented animals were more greasy and were more preferred than steaks from unsupplemented animals. In general differences, while statistically significant, were small.

5. Opportunity/Benefit:

The data generated on the impact of dietary modification on the fatty acid composition of bovine muscle will assist beef producers in the production of beef with enhanced fatty acid composition from a human health perspective. A comprehensive dataset on fresh colour, colour and lipid stability and on the sensory characteristics of bovine muscle was developed. These data demonstrate the rather small effects of rather extreme dietary treatments on muscle technological characteristics. They therefore provide encouragement to further development of such strategies.

The information obtained on the molecular basis of CLA synthesis adds to the current state of knowledge in this field and may be important in the development of future hypotheses.

Material generated in this project was used in a subsequent project coordinated by Prof. Roche (06RDTCD488) to elucidate the mechanisms underpinning the beneficial effects of beef CLA. From a beef cattle perspective, future strategies will include identification of animals/genotypes that have a greater propensity to accrete fatty acids of benefit to human health and elucidation of genotype by nutrition interactions. The variability in CLA concentration among similar cattle fed common rations merits research attention and is a potential obstacle to uptake by industry. In addition the likely necessity to produce supporting evidence for a health claim on a functional food product will require further animal models but also human intervention type studies.

6. Dissemination:

Workshops

Moloney A.P. (2008) Presentation at Teagasc event (FarmFest), Athenry.

Moloney A.P. (2008) Recent Advances in Beef Quality, Workshop, Swedish University of Agricultural Sciences (SLU).

Moloney A.P. and Roche H.M. (2009) Relay Workshop, Ashtown Food Research Centre. Moloney A.P. (2009) Industry Information Day, Ashtown Food Research Centre.

Main publications:

Moloney, A.P. (2007) 'Enrichment of omega-3 fatty acids and CLA in beef by diet modification' *Irish Veterinary Journal* 60 (3):180–185.

Moloney, A.P., Daly, C.M., Shingfield, K.J. and Monahan, F.J. (2007) 'Fatty acid composition of *longissimus* muscle from grazing or concentrate-fed cattle supplemented with sunflower seeds and fish oil' *Proceedings II International Congress on Conjugated Linoleic Acid*, Sardinia, Italy, p20–22.

Dunne, P.G., Monahan F.J. and Moloney A.P. (2009) 'Long-term supplementation with sunflower/fish oil-containing concentrates in a grass-based beef production system: effects on colour and lipid stability during retail display' *Journal of Animal Science* 87:369.

Popular publications:

Moloney, A. P. (2007) 'Producing beef that meets consumer needs' Hand-out for visit of IASTA to Grange Beef Research Centre, 4 pages.

Moloney, A.P. (2008) 'Producing quality beef for the consumer' In: *Grange Beef Research Centre Open Day Booklet*, 3 pages.

Moloney, A.P. (2009) 'Increasing the healthiness of beef' *Teagasc Beef Newsletter.*

GreenGrass – developing grass for sustainable renewable energy generation and value-added products

Key external stakeholders:

Policy makers, biorefining and anaerobic digestion industries; grass technology companies; farmers, researchers and advisors involved in grass production and utilisation.

Practical implications for stakeholders:

Although grass is normally used as an animal feedstuff it also has potential for industrial use.

- Major grassland management and grass processing technologies to support biogas production or fibre utilisation have been identified.
- Grass press-cake has limited value as a ruminant feed, moderate value for combustion (if dry) and real potential to reduce shrinkage cracking of cement mortars.
- Ireland can produce sufficient grass to meet the needs of both livestock and biogas/biorefining industries.

Main results:

- Ryegrasses were preferable for producing biogas by anaerobic digestion, but higher yielding timothy showed more potential for fibre production.
- Repeated washing (up to 2 washing steps) and mechanical pressing (3.0MPa) proved the most effective treatments for the isolation of a fibre-rich press-cake fraction.
- Press-cake derived from ensiled grass when included at 2.2kg/m^3 eliminated crack formation during restrained shrinkage in cement mortars, comparable with the performance of polypropylene fibres.

Project number:
5770
Date:
August, 2013
Funding source:
DAFM
Project dates:
Jan 2009 – Mar 2013

Collaborating Institutions:
Environmental Research Institute, University College Cork (UCC)
Questor Centre, Queens University Belfast (QUB)
University College Dublin (UCD)

Teagasc project team:
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Dr. Eoghan Finneran

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Thanasit Thamsiriroj, UCC
Dr. Elaine Groom, Questor Belfast
Dr. Angela Orozco, Questor Belfast
Dr. Mark Richardson, UCD

Compiled by:
Padraig O'Kiely
Joseph McEniry
Colman King

Technology

- Grass growth stage rather than herbage species had the largest influence on biogas produced during anaerobic digestion. The anaerobic digestion technologies and operational practices for biogas production from grass were improved.
- Recycling silage effluent to the anaerobic digester and employing digestate as a biofertiliser reduced the production cost of grass silage feedstocks.
- Anaerobic digestion and biorefining need not compete for grass with cattle and sheep production systems.

Opportunity/Benefit:

- Circumstances were identified where grass species, growth stage at harvest and conservation or fractionation methodologies could be exploited for biomass production, anaerobic digestion or the utilisation of a fibre-rich press-cake.
- The inclusion of fibre-rich press-cake can reduce surface cracking of cement mortars.
- Improved designs and operation of anaerobic digesters utilising grass as a feedstock, and the potential of hydrolytic pre-treatment, have been demonstrated. (UCC; Questor)
- Practical opportunities were identified to reduce the cost of grass as a feedstock for anaerobic digestion.
- Anaerobic digestion and biorefining would not necessarily have to compete for grass with traditional agricultural production systems. This could allow for additional farm enterprises and thus improve income.

1. Project background:

The need to develop alternatives to non-renewable fossil fuel-derived products has stimulated an interest in plant biomass as a 'natural chemical factory' to provide renewable energy, materials and chemicals. In Ireland, grassland represents the most significant biomass resource, accounting for approximately 90% of the 4.3 million hectares of agricultural land. Although grass is normally used as an animal feedstuff, it also has considerable potential for industrial use. Fresh grass can be used for such purposes, but in most cases it may be necessary to preserve it as silage to ensure year round availability and a predictable quality. This silage can be used directly (e.g. anaerobic digestion) or separated into solid and liquid fractions that can be refined into a range of marketable products. The separated solid fraction (i.e. press-cake) is rich in cellulose, hemicellulose and lignin, while the liquid fraction (i.e. press-juice) contains a mixture of protein components, organic acids, water soluble carbohydrates, minerals and other substances. These can be subjected to a series of downstream processes to recover valuable products.

Biogas (about 55% methane) produced by anaerobic digestion is generally used on-site to generate electricity that is exported directly to the national electricity grid, while the co-produced heat is ideally used on the farm or locally. Alternatively, the biogas can be upgraded to natural gas quality (>97% methane) and injected into the natural gas grid.

2. Questions addressed by the project:

- What is the potential of different grass species and red clover for use as a biomass feedstock?
- What is the potential of these species to provide fibre for industrial applications?
- What are suitable anaerobic digestion technologies for grass silage feedstocks?

3. The experimental studies:

Replicated field plots were established with Italian ryegrass, perennial ryegrass, tall fescue, timothy, cocksfoot or red clover. These were grown with either a low or a high input of inorganic nitrogen fertiliser, and harvested at five stages of the primary growth (early May to early July). In each case a representative sample was ensiled in a laboratory silo.

Silages were fractionated into press-cake and press-juice fractions, and the impact of temperature, pressure, detergent and number of washing steps on the efficiency of this hydrothermal conditioning process was determined.

Three potential applications for the fibre-rich press-cake fraction were investigated: ruminant feedstuff, biomass fuel for combustion and a fibre-reinforcement for cement mortars.

The methane production potential of these herbages and the impact of grassland management practices and ensiling were determined in small-scale (160 ml), high-throughput batch digestion tests.

Hydrolytic pre-treatment processes for grass and grass silage feedstocks were compared and optimised to maximise biogas yield and solids destruction. (Questor)

Grass silage was digested in a bespoke design two stage wet continuously stirred tank reactor (CSTR) at a scale of 300 L for a period of ca. 12 months. The organic loading rate was increased and the hydraulic retention time decreased to assess optimal operation. (UCC)

Furthermore, an innovative leach-bed reactor configuration was investigated to produce soluble organic matter-rich leachate from grass silage feedstocks. The leachate was subsequently fed to a high-rate upflow anaerobic sludge bed reactor (UASB) where the organic matter was converted to methane. This liquor from the UASB was also further re-circulated over the leach beds. This system was termed a Sequencing fed Leach Bed Reactor system coupled to an Upflow Anaerobic Sludge Bed (SLBR-UASB). The system operated at increasing loading rates for ca. 12 months. (UCC)

Mathematical modelling was used to assess the impact of a significant number of operational variables on the stability of the processes. (UCC)

The costs of providing feedstocks for anaerobic digestion were calculated, as was the average availability of grass for anaerobic digestion in Ireland.

4. Main results:

Agronomic traits that resulted in perennial ryegrass becoming the dominant grass species for ruminant production were also important for industrial use. However, timothy showed potential for fibre production. Neither red clover, tall fescue nor cocksfoot (in particular) showed an advantage for yield or compositional traits.

A fibre-rich press-cake fraction was isolated from a range of silages (mechanical pressure applied and repeated washings were particularly important) across a range of harvest dates and from contrasting grass species.

The low available energy and protein value of the separated press-cake fraction, especially at later growth stages, limits its use as a ruminant feed.

The substantial reduction in ash, N, Cl and K during fractionation improved the suitability of the press-cake fraction for combustion compared with the parent material.

The fibre-rich press-cake fraction supported tensile stresses of the order of magnitude experienced in laboratory-scale tests when cement mortars were subjected to major shrinkage under restrained conditions.

The specific methane yield of a feedstock during anaerobic digestion was determined by its digestible energy content. Hence, grass growth stage at harvest was of primary importance, while only small differences in specific methane yield were observed between common grassland species at the same growth stage.

Digestion of grass silage in a CSTR was initially problematic due to the tendency of the grass silage to float on top of the liquor surface within the first digester. This was overcome by modification of the mixing system. The CSTR system yielded 451 L methane/kg volatile solids at an organic loading rate of 2 kg volatile solids/m^3/d and a retention time of 50 days. This is equivalent to 90% destruction of volatile solids and is close to the maximum value achieved in the biochemical methane potential (BMP) assay. The SLBR-UASB achieved 350 L methane/kg volatile solids (equivalent to 70% destruction of volatiles) at a retention time of 30 days. (UCC)

Hydrolytic treatments prior to anaerobic digestion increased methane production by up to 30% at a short (21 day) hydraulic retention time. (Questor)

Directing the silage effluent stream to the digester (€4/t decrease in feedstock cost) and employing the digestate as a biofertiliser (€3/t decrease in feedstock cost) had a significant impact on feedstock cost.

It was calculated that there is a current national average annual grassland resource of *ca.* 1.7 million tonne dry matter available in excess of livestock requirements, and this could be increased by the widespread use of good grassland management technologies.

5. Opportunity/Benefit:

Circumstances were identified where grass species, growth stage at harvest, conservation methodology and fractionation methodology could (or could not) be exploited for biomass production and/or for anaerobic digestion or the utilisation of a separated fibre-rich press-cake fraction.

The inclusion of fibre-rich press-cake can reduce surface cracking of cement mortars.

Improved designs and operation of anaerobic digesters utilising grass silage as a feedstock, and the potential of hydrolytic pre-treatment, have been demonstrated. (UCC; Questor)

Practical opportunities were identified for reducing the cost of providing grass for anaerobic digestion.

Anaerobic digestion and biorefining would not necessarily have to compete for grass with traditional agricultural production systems. This could allow for additional farm enterprises and thus improve income.

6. Dissemination:

Main publications (Teagasc only):

King, C., McEniry, J, Richardson, M. and O'Kiely, P. (2012). Yield and chemical composition of five common grassland species in response to nitrogen fertiliser application and phenological growth stage. *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, 62 (7): 644–658.

King, C., McEniry, J., Richardson, M. and O'Kiely, P. (2013). Silage fermentation characteristics of grass species grown under two nitrogen fertiliser inputs and harvested at advancing maturity in the Spring growth. *Grassland Science*, 59: 30–43.

McEniry, J., O'Kiely, P., Crosson, P., Groom, E. and Murphy, J.D. (2011). The effect of feedstock cost on biofuel cost as exemplified by biomethane production from grass silage. *Biofuels, Bioproducts and Biorefining*, 5 (6; Nov./Dec.): 670–682.

Popular publications (Teagasc only):

McEniry, J., King, C. and O'Kiely, P. (2011). The grass is greener. *TResearch*, 6 (2): 26–27.

O'Kiely, P. and McEniry, J. (2010). Production of grass for biomethane. EPA funded conference hosted by Environmental Research Institute at University College Cork. Cork, Thursday 15 April, 2010.

O'Kiely, P., McEniry, J., King, C. and Lenehan, JJ. (2011). Biogas research at Teagasc Grange. International Energy Agency Task 37 Energy from Biogas. Cork 15 September, 2011.

Designing forage grass and clover with enhanced value for animal production, sustainability and profitability

Project number:
5916
Date:
September, 2013
Funding source:
Teagasc and the seed industry
Project dates:
Jan 2009 – Dec 2012

Key external stakeholders:

Grassland farmers, seed industry, advisors, agricultural consultants and researchers.

Practical implications for stakeholders:

- Breeding offers a low cost and successful means to improve the productivity and profitability of grass/clover based swards.
- Seven new perennial ryegrass varieties and one new white clover variety with greater genetic merit and improved agronomic characteristics over existing varieties were commercialised and released.
- Nineteen new perennial ryegrass varieties bred by Teagasc displayed exceptional performance in the Teagasc breeder's trials and were submitted to the official Recommended/National List trials in Ireland, UK and other countries for independent evaluation and consideration for addition to the Recommended List of Grass and Clover Varieties in the respective countries.
- Research into breeding methodology to improve genetic gain per unit time and cost determined the optimum breeding system for improving perennial ryegrass for Irish farm systems.

Collaborating Institutions:
DLF-Trifolium
Goldcrop Ltd.
University of Wisconsin-Madison
Department of Agriculture, Food and the Marine (DAFM), Ireland
Agri-Food and Biosciences Institute (AFBI) Northern Ireland

Teagasc project team:
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Dr. Klaus Nielsen (DLF-Trifolium)
Dr. Trevor Gilliland and Dr. Brian Waters (AFBI)
John Claffey and Dermot Grogan (DAFM)

Compiled by:
Patrick Conaghan

Technology

Main results:

Eight new Teagasc-bred varieties were commercialised and released. The new perennial ryegrass varieties were: Genesis (early diploid), Solomon (intermediate diploid), Giant (intermediate tetraploid), Carraig (intermediate tetraploid), Majestic (late diploid), Glenveagh (late diploid) and Kintyre (late tetraploid). The new white clover variety was Iona (medium leaf size). Research into the optimum breeding methodology for perennial ryegrass indicated that the optimum breeding system would include a mixture of genotypic recurrent selection, phenotypic recurrent selection and marker-assisted selection.

Opportunity/Benefit:

This project offers farmers new improved perennial ryegrass and white clover varieties of greater genetic merit and improved agronomic characteristics that when sown may increase the productivity, profitability and sustainability of Irish farm systems. A commercial agreement between Teagasc and the seed industry ensures the production and availability of seed for farmers.

1. Project background:

Over 90% of the agricultural area in Ireland is devoted to grassland which provides the main feed for our ruminant livestock. While sward composition, especially for old pastures, is often complex, perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens*) are predominantly the most desirable grass and legume species for grazing and the key components of the most productive pastures. Almost all forage grass and legume seed sown in Ireland is perennial ryegrass and white clover, respectively. Consequently, any improvement in these species has large potential benefit to the Irish agricultural economy.

Forage breeding is a technology that harnesses the creative power of selection. It is powerful, precise and predictable. Forage grass and clover have been subjected to very little formal breeding. Genetic variation within and among populations is still extremely high, showing no signs of decreasing. Breeding offers a low cost means of improving the profitability and productivity of perennial ryegrass.

The objective of this project was to develop and use methods that effectively select for the best phenotypes leading to the breeding of improved varieties of perennial ryegrass and white clover for Irish farm systems. The main emphasis was on improving variety performance under grazing. The primary traits for improvement were seasonal yield distribution, nutritional value, ground cover, persistency and disease resistance. World-wide propagation and marketing rights on all new varieties were offered to a commercial company ensuring the availability of new varieties to Irish farmers. This project continues, with modifications, the successful commercial forage breeding programme established at Teagasc, Oak Park, Carlow in the 1960s.

2. Questions addressed by the project:

- Can forage breeding produce improved varieties of perennial ryegrass and white clover?
- What level of genetic improvement in perennial ryegrass and white clover can be achieved through breeding?
- What is the optimum breeding system for perennial ryegrass improvement?

3. The experimental studies:

The breeding programme was based on (i) phenotypic recurrent selection involving the phenotypic evaluation of individual plants, (ii) genotypic recurrent selection involving the phenotypic evaluation of the progeny of an individual under evaluation and (iii) the production of synthetic varieties constructed by inter-crossing a number of selected genotypes. The main emphasis was on improving variety performance under grazing. The primary traits for improvement in perennial ryegrass were seasonal yield distribution, nutritional value, ground cover, persistency and disease resistance. The primary traits for improvement in white clover were annual and seasonal yield distribution of clover and grass plus clover, and clover persistency.

The best varieties were submitted to the official Recommended/National List trials in Ireland, UK and other countries for independent evaluation. World-wide propagation and marketing rights on all new varieties were offered to a commercial company ensuring the availability of new varieties to Irish farmers.

A simulation study and literature review was also conducted to investigate the optimum breeding system for the improvement of perennial ryegrass.

4. Main results:

Nineteen new perennial ryegrass varieties bred by Teagasc displayed exceptional performance in the Teagasc breeder's trials and were submitted to the official Recommended/National List trials in Ireland, UK and other countries for independent evaluation and consideration for addition to the Recommended List of Grass and Clover Varieties in the respective countries.

Seven new perennial ryegrass varieties and one new white clover variety were commercialised and released. The new perennial ryegrass varieties were: Genesis (early diploid), Solomon (intermediate diploid), Giant (intermediate tetraploid), Carraig (intermediate tetraploid), Majestic (late diploid), Glenveagh (late diploid), Kintyre (late tetraploid). The new white clover variety was Iona (medium leaf size). The varieties were shown to offer improved yield, quality and persistence characteristics for grass-based production systems. The new perennial ryegrass varieties had on average 2.0 percentage units higher annual yield and 10.5 percentage units higher spring yield at time of release than comparable varieties of similar ploidy and maturity group. Variety details are summarised in Table 1 with full variety results from the Ireland Recommended List available at www.agriculture.gov.ie and the Northern Ireland Recommended List at www.afbini.gov.uk.

Table 1: New Teagasc-bred varieties.

Variety	Key characteristics	Recommended List
Genesis	- Early diploid perennial ryegrass - Exceptionally high spring growth - Very high silage yields	Ireland, Northern Ireland, England, Wales, Scotland and Germany
Solomon	- Intermediate diploid perennial ryegrass - Remarkably high spring grazing yields - Outstanding silage production	Ireland, Northern Ireland, England, Wales and Scotland
Giant	- Intermediate tetraploid perennial ryegrass - Excellent spring growth - Outstanding sward density	Ireland and Germany
Carraig	- Intermediate tetraploid perennial ryegrass - Outstanding spring yields - Very high Autumn growth	Ireland
Majestic	- Late diploid perennial ryegrass - Excellent Autumn yields - High sward density	Ireland
Glenveagh	- Late diploid perennial ryegrass - Excellent Autumn growth - Remarkably high ground cover	Ireland, Northern Ireland and Scotland
Kintyre	- Late tetraploid perennial ryegrass - Outstanding annual yields - Excellent digestibility	Ireland, Northern Ireland and Scotland
Iona	- Medium leaf white clover - Excellent clover yields - Good grazing persistency	Ireland, Northern Ireland, England, Wales and Scotland

Research into the optimum breeding methodology for perennial ryegrass indicated that the optimum breeding system depends on the traits to be improved, and the resources and skills available. Careful consideration should be given to the expression of the trait under the management regime imposed in the breeding programme and under real-world sward conditions in the target region. Three distinct breeding systems may be applied: (i) phenotypic recurrent selection based on the phenotypic value of individuals, (ii) genotypic recurrent selection based on the phenotypic value of the progeny of an individual under evaluation and (iii) marker-assisted selection based on molecular (DNA) marker scores. Genotypic recurrent selection will be a necessary part of the breeding system if forage yield is a trait for improvement and may be practiced using full-sib or half-sib families, each with their own advantages/disadvantages. Phenotypic recurrent selection in tandem (i.e., within-family selection) or in succession with genotypic recurrent selection should be used to improve traits that have a high correlation between measurements on spaced plants and those on sward plots. Genome-wide selection represents the most interesting and exciting potential application of marker assisted selection.

In conclusion, the Teagasc forage breeding programme continues to (i) improve the methodology for breeding and evaluating perennial ryegrass, and (ii) develop new improved varieties of perennial ryegrass and white clover with greater genetic merit and improved agronomic characteristics than existing commercial varieties.

5. Opportunity/Benefit:

This project highlights the benefit of perennial ryegrass and white clover breeding to grassland agriculture and the large improvements in forage productivity that may be achieved through breeding. This project offers farmers new improved perennial ryegrass and white clover varieties of greater genetic merit that when sown may increase the productivity, profitability and sustainability of Irish farm systems. A commercial agreement between Teagasc and the seed industry ensures the production and availability of seed for farmers. Research conducted offers improved breeding methodology and insight for perennial ryegrass improvement that may increase the rate and reduce the cost of the genetic gain in perennial ryegrass breeding programmes.

6. Dissemination:

This information has been widely disseminated to grassland farmers via discussion groups, open days, farm walks, popular press and Teagasc publications. It will continue to be disseminated through Teagasc advisors at discussion groups. Full variety results have also been published in the Recommended List of Grass and Clover Varieties for Ireland, Northern Ireland, Scotland, England and Wales.

Main publications:

Conaghan, P. and Casler, M.D. 2010. Opportunities using new technologies: Marker-assisted selection. In: Grasses for the Future. Perennial Ryegrasses: Current and Future Genetic Potential (ed. M. O'Donovan and D. Hennessy), Teagasc, Cork, Ireland, pages 69–97.

Conaghan, P. and Casler, M.D. 2011. A theoretical and practical analysis of the optimum breeding system for perennial ryegrass. Irish Journal of Agricultural and Food Research 50: 47–63.

Recommended List of Grass and Clover Varieties for Ireland (DAFM; www.agriculture.gov.ie) Northern Ireland (AFBI; www.afbini.gov.uk) and England and Wales (NIAB; www.bspb.co.uk)

Popular publications:

Irish Farmers Journal, Farming Independent and Today's Farm.

An investigation into the agronomic and environmental benefits of applying the nitrification inhibitor dicyandiamide (DCD) on Irish grasslands

Project number:
5903
Date:
September, 2013
Funding source:
Teagasc
Project dates:
Jan 2009 – Dec 2012

Collaborating Institutions:
University College Dublin (UCD)
NUI Maynooth

Teagasc project team:
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Compiled by:
Deirdre Hennessy

Key external stakeholders:

Scientists, fertiliser industry, farmers.

Practical implications for stakeholders:

- The application of DCD to urine patches did on occasions increase herbage production and influence other parameters such as N uptake, soil mineral N content and herbage CP but the results were inconsistent between sites and years.
- Dosing DCD into the rumen of dry dairy cows did not affect the digestibility of the ingested grass, did not affect rumen pH or rumen function.
- During the 6-day treatment and measurement stage, the average recovery of the dosed DCD in urine was 82.3%, with a further 2.1% recovered in the faeces.

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Main results:

- The results of the plot experiments show that the application of DCD to urine patches did on occasions increase herbage production and influence other parameters such as N uptake, soil mineral N content and herbage CP but the results were inconsistent between sites and years.
- The pulse-dosing of DCD into the rumen of cows can be achieved without deleterious effect on rumen function, and 84.4% of the DCD was recovered in six days.
- There were no deleterious effects of pulse dosing DCD into the rumen of cows on the blood plasma parameters, rumen function and diet digestibility measured in the experiment.
- The use of urine from cows pulse-dosed with DCD reduced nitrous oxide emissions and nitrate leaching by 57–84% and 86–91%, respectively, depending on soil type.

Opportunity/Benefit:

Dicyandiamide application to urine patches can reduce nitrate leaching and nitrous oxide emissions but there are small and inconsistent benefits in terms of herbage production. Passage of DCD through the rumen did not negatively impact on herbage digestibility. Further research is required to examine the amount of time required for the DCD concentrations in urine and faeces to reach zero and to examine whether DCD fed to dairy cows would be excreted in the milk of lactating animals.

1. Project background:

Urine excreted by dairy cows is a source of nitrogen (N) to the sward in grazed grassland. The N content of urine is high, up to 1000 kg N ha^{-1}. Nitrogen supplied by urine is usually in excess of sward requirements and so the excess N is potentially lost through means such as nitrate leaching and nitrous oxide emissions. Dicyandiamide (DCD) is a nitrification inhibitor used in the agricultural industry in parts of New Zealand to reduce nitrate leaching and nitrous oxide emissions. In New Zealand DCD has also been shown to increase N availability for herbage production by slowing the conversion of ammonium to nitrate.

2. Questions addressed by the project:

- Will applying DCD to urine patches in Autumn increase grass growth on these areas over Winter?
- If DCD is dosed into the rumen of dairy cows, will it affect rumen function and what will the recovery of DCD in the urine be?
- Will applying urine from dry cows dosed with DCD into the rumen reduce nitrate leaching and nitrous oxide emissions?

3. The experimental studies:

Four experiments were undertaken:

Experiment 1 examined the effect of applying DCD to urine and non-urine patches on grass plots with and without fertiliser on two soil types (free draining and heavy soil) over a two year period. The treatments (+/- urine +/- DCD) were applied in September, October or November each year. Half of the plots received a second application 90 days after the first. Herbage production, herbage N content and herbage N uptake were measured from February to October in year 1 and February to April in year 2. Soil N content was measured from November to April.

Experiment 2 examined the effect of applying DCD to urine and non-urine patches on grass plots receiving fertiliser N on two soil types (free draining and heavy soil) over a two year period. The treatments (+/- urine +/- DCD were applied in July, August or September each year. Half of the plots received a second application 90 days after the first. Herbage production, herbage N content and herbage N uptake were measured from February to October each year. Soil N content was measured from November to April.

Experiment 3 investigated the effect of pulse-dosing DCD into the rumen of non-lactating dairy cows on rumen function and the recovery of DCD. Rumen fistulated dairy cows were placed in stalls and fed fresh grass harvested daily. Cows were dosed into the rumen with DCD dissolved in water, or with distilled water only. Rumen samples were collected on three days and faeces and urine were collected, weighed and sampled for 6 days. The quantity of DCD in the rumen fluid, faeces and urine was then measured.

Experiment 4 quantified nitrate leaching and nitrous oxide emissions from lysimeters treated with urine from cows dosed with DCD or not dosed with DCD in *Experiment* 3. The lysimeters contained a free draining soil or a heavy soil. *Experiment* 4 also examined the effect of urine from cows dosed with DCD or not dosed with DCD on herbage production on the free draining soil only.

4. Main results:

Experiment 1: Applying DCD did not increase spring herbage production. Over the two years, the application of 5 or 10 kg DCD/ha increased annual herbage production when applied to October and November deposited urine patches on the free draining soil when no fertiliser N was applied to the plots. Urine application increased herbage production in spring and annually on both soil types when no fertiliser N was applied, and increased herbage crude protein content and herbage N uptake in treatments receiving urine. The application of urine increased soil ammonium and total oxidised N content in the 0–100 mm horizon on both soil types.

Experiment 2: Applying DCD in August at a rate of 10 kg/ha significantly increased spring and annual herbage production by 14% and 15%, respectively, on the free draining soil type when applied following urine application in year 1. There was no effect of DCD applied in year 1 on herbage production on the heavy soil type. The application of DCD in August resulted in lower soil total oxidised N content up to sampling day 56 post urine application, on the free draining soil type in year 1, retaining higher N content in the soil. There was no effect of DCD on any of the parameters measured in year 2 at either site. Urine application did not increase spring herbage production. Urine significantly increased annual herbage production on the free draining soil type only in year 1. Urine application increased annual herbage N uptake, herbage crude protein content and soil mineral N at both sites in both years.

Experiment 3: The administration of DCD into the rumen of dry cows resulted in no deleterious effect on blood metabolites, rumen function and diet digestibility, as all were not significantly different from the control treatment and were within the normal biological range. During the 6-day treatment and measurement stage, the average recovery of the dosed DCD in urine was 82.3%, with a further 2.1% recovered in the faeces. No DCD was recovered in the urine and faeces 10 days following the cessation of dosing.

Experiment 4: Total nitrate leaching losses from the free draining and heavy soil types were reduced from 100 and 81 kg nitrate/ha on the urine only treatment, respectively, to 9 and 11.6 kg nitrate/ha on the urine with DCD treatment, respectively. This equated to a 91% and 86% reduction, respectively. Total nitrous oxide emissions during the study were significantly reduced by applying urine with DCD on both the free draining and heavy soil types; from 13.6 and 12.1 kg nitrous oxide/ha on the urine only treatment, respectively, to 2.23 (-84%) and 5.24 (-57%) kg nitrous oxide/ha on the urine with DCD treatment, respectively. The addition of urine to grass plots increased soil N concentration. Urine with DCD inhibited the nitrification process of ammonium to total oxidiseable N for up to 56 days after treatment applications. There was no significant effect on herbage production when urine with DCD was applied to grass plots.

5. Opportunity/Benefit:

Overall this project shows that the effects of applying DCD to urine patches on herbage production, herbage CP content, herbage N uptake and soil mineral content in the rooting zone were not consistent, and so DCD cannot be recommended as a tool to increase herbage production and N uptake. The pulse-dosing of DCD into the rumen of cows can be achieved without deleterious effects on rumen function, and 84.4% of the DCD was recovered in six days. Dicyandiamide can provide a successful mitigation strategy to reduce the environmental emissions of urine deposited by cows in the Irish dairy industry but the method of using animals to excrete DCD with urine to pastures requires further research for adaptation by the agricultural industry. It will be important to investigate if DCD could be fed to lactating cows, and the likelihood of residual DCD being present in meat or milk following feeding to livestock.

6. Dissemination:

An overview of the project was given at the Moorepark Open Day in 2009 and 2011. Visitors to Moorepark, both national and international, received presentations on the project and many interesting discussions took place. Poster and oral presentations were made at the Agricultural Research Forum, British Grassland Society Research Conference, and EGF Conference. Three papers have been published from this project, and one more is in preparation.

Main publications:

P.J. O'Connor, D. Hennessy, M.B. Lynch, H. Slattery, E. Lewis. The effect of pulse-dosing non-lactating dairy cows with the nitrification inhibitor dicyandiamide (DCD): the recovery of DCD and DCD effects on blood metabolites, rumen function and diet digestibility. *Livestock Science*. 155: 30–37.

O'Connor, P.J., Hennessy, D., Brophy, C., O'Donovan, M. and Lynch, M.B. (2012) The effect of the nitrification inhibitor dicyandiamide (DCD) on herbage production when applied at different times and rates in the Autumn and Winter. *Agriculture, Ecosystems and Environment*, 152: 79– 89

P.J. O'Connor, M.B. Lynch, E. Cahalan, M. O'Donovan and D. Hennessy. The effect of the nitrification inhibitor dicyandiamide (DCD) on spring and annual herbage production in urine patches when applied in late Summer or early Autumn. *Grass and Forage Science (published on line* – DOI: 10.1111/gfs.12011)

Popular publications:

O'Connor, P.J., Hennessy, D., Cahalan, E., O'Donovan, M. and Lynch, M.B. (2012). The effects of nitrification inhibitor dicyandiamide (DCD) on herbage nitrogen uptake when applied in late Summer or early Autumn. In: Proceedings of the 24th General Meeting of the European Grassland Federation, Lubin, Poland, 3–7 June 2012, 17: 628–630.

O'Connor, P.J., Hennessy, D., O'Donovan, M. and Lynch, M.B. (2011) The effect of the nitrification inhibitor dicyandiamide (DCD) applied in late Summer, Autumn and Winter on soil ammonium and total oxidisable nitrogen. British Grassland Society 10th Research Conference, Le Mon Hotel and Country Club, Belfast and Agri-Food and Biosciences Institute, Hillsborough, Belfast, Northern Ireland, 20th – 21st September 2011. pp. 123–125.

O'Connor, P.J., Hennessy, D., O'Donovan, M. and Lynch, B. (2010) The effects of the nitrification inhibitor dicyandiamide on herbage production when applied at varying time points and rates in Autumn. In: 'Advances in Animal Biosciences – Food, Feed, Energy and Fibre from Land – A vision for 2020' – Proceedings of the British Society of Animal Science and the Agricultural Research Forum 2010. p. 318.

Grass digestibility

Project number:
5893
Date:
September, 2013
Funding source:
Teagasc
Project dates:
Jan 2009 – Dec 2012

Key external stakeholders:

Dairy farmers, dairy industry, grass breeders and evaluators, animal nutrition companies and consultants.

Practical implications for stakeholders:

Grass is the cheapest feed available to Irish dairy farmers. Much information is available on the physical and chemical composition of grass and on dairy cow production performance. Information is lacking, however, on the degradability of grass in the rumen of the cow and the digestibility of grass in the total digestive tract of the cow. This project resulted in the generation of information on the rumen pH of grazing dairy cows, and on the digestibility of grass varying in quality and structure in different dairy cow genotypes.

Main results:

- Grazing dairy cows have a lower rumen pH than cows offered silage-based diets indoors.
- Rumen pH is lower in spring/early lactation than later in the grazing season/ lactation.
- Despite the low rumen pH, grazing dairy cows do not generally exhibit signs of milk fat depression or lameness, as a result of low rumen pH.
- Grazed grass is highly digestible, indicating that it has a high energy content.
- High pre-grazing herbage mass results in lower grass digestibility than low pre-grazing herbage mass.

Collaborating Institutions:
University College Dublin (UCD)
INRA, France
Lincoln University, New Zealand

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Mr. Jim Gibbs, Lincoln University, New Zealand

Compiled by:
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- The leaf and pseudostem are the most digestible parts of the grass plant, while the stem and dead material are the least digestible parts of the grass plant.
- Differences exist between dairy cow genotypes in the extent to which they digest perennial ryegrass, with Jersey cows able to digest more of the grass than Holstein-Friesian cows. Jersey x Holstein-Friesian cows had intermediate digestibility.

Opportunity/Benefit:

These results provide data on the digestibility of grass and on the effects of grazed grass on rumen pH to dairy farmers, the dairy industry and animal nutrition companies and consultants enabling them to safely offer grazed grass as a high quality feed to dairy cows.

1. Project background:

The optimal use of grazed grass is identified as a key component of profitability in Irish dairy production systems. Grassland is cited as an area of strategic national importance by Teagasc. In order to make the most efficient use of grass, it is important to maximise utilisation of the grass ingested by the animal, as well as to increase the proportion of grazed grass in the diet via management techniques. Hence, the objective of this project was to measure the rumen pH and total tract digestibility of grazed grass through the grazing season. The outcome of this project was a unique suite of results demonstrating the degradative and digestive profiles of grass through the grazing season. These data provide an important fundamental understanding of how dairy cows perform when offered a grazed grass diet.

2. Questions addressed by the project:

- What is the rumen pH of grazing dairy cows?
  - being offered different grass-based diets.
  - at different stages of the lactation/grass growing season.
- What is the digestibility of grass?
  - at different pre-grazing herbage mass.
  - at different stages of the grass growing season.
  - by different dairy cow genotypes.

3. The experimental studies:

Rumen pH is an important factor related to milk fat %, fibre degradation, nutrient absorption and overall cow health and welfare. Most of the information on rumen pH derives from work done with feeding high grain diets however, with little information available on the rumen pH of grazing dairy cows. A system was developed to monitor rumen pH on a continuous basis throughout the day in order to measure the average rumen pH across 24 hours and the time spent below certain rumen pH thresholds. The rumen pH of dairy cows offered different grass-based diets at different stages of lactation/ grass growing season was measured. Organic Matter Digestibility (OMD) is a common measurement of grass quality. High sward digestibility, or excellent quality, is key to the delivery of good nutrition to Irish dairy cows. With the abolition of the EU milk quota in 2015, milk production in Ireland is anticipated to increase by 50% by 2020. High grass OMD is essential to achieve this. Grass is composed of four morphological fractions: leaf, pseudostem, true stem and dead. These proportions change over the course of the grass growing season, and differ between grass cultivars. The digestibility of the four fractions, through the grazing season, in four different grass cultivars was measured. Pre-grazing herbage mass is used as a tool to aid grassland management. The digestibility of grass of different pre-grazing herbage mass was measured. Production efficiency differences exist between dairy cow genotypes but the digestibility of grass in these genotypes is not known. The digestibility of grass offered to three different dairy cow genotypes, namely Holstein-Friesian, Jersey and Jersey x Holstein-Friesian was measured.

4. Main results:

- Grazing dairy cows have a lower rumen pH than animals offered silage-based diets indoors.
- Rumen pH is lower in spring/early lactation than later in the grass growing season/lactation.
- Despite the low rumen pH, grazing dairy cows do not generally exhibit signs of milk fat depression or lameness, as a result of the low rumen pH. This is attributed in part to low lactic acid concentrations in the rumen of grazing dairy cows.
- Grazed grass is highly digestible, indicating that it has a high energy content, and that it is a high quality feed.
- High pre-grazing herbage mass results in lower digestibility than low pre-grazing herbage mass.
- Accordingly, detailed measurements of the grass plant revealed that the leaf and pseudostem are the most digestible parts of the grass plant, while the stem and dead material are the least digestible parts of the grass plant.
- Every attempt should therefore be made to offer medium to low pre-grazing herbage mass grass which is leafy and highly digestible to grazing dairy cows and to minimise the proportions of dead and stemmy material (seen in high pre-grazing herbage mass swards).
- Differences exist between dairy cow genotypes in the extent to which they digest perennial ryegrass, with Jersey cows able to digest more of the grass than Holstein-Friesian cows. Jersey x Holstein-Friesian cows had intermediate digestibility.

5. Opportunity/Benefit:

These results provide data on the digestibility of grass and on the effects of grazed grass on rumen pH to dairy farmers, the dairy industry and animal nutrition companies and consultants, enabling them to safely offer grazed grass as a high quality feed to dairy cows.

6. Dissemination:

The primary stakeholders for this research are Irish dairy farmers, animal nutrition companies and consultants and grass breeders and evaluators. The results of this project have been disseminated through the popular press and at the Teagasc Moorepark Open Days, as well as at scientific conferences and in scientific peer-reviewed publications.

Main publications:

Beecher, M., Hennessy, D., Boland, T.M., McEvoy, M., O'Donovan, M., Lewis, E. 2013. The variation in morphology of perennial ryegrass cultivars throughout the grazing season and effects on organic matter digestibility. Grass and Forage Science doi: 10.1111/gfs.12081

Lewis, E., Coughlan, F., Murphy, J.P., Galvin, N., O'Donovan, M., O'Neill, B.F. 2011. The effect of supplementing grazed grass with mixed ration on rumen pH and rumen ammonia, volatile fatty acid and lactic acid concentrations. In: Proceedings of the 8th international symposium on the nutrition of herbivores, Aberystwyth, Wales, 6–9th September, pg. 284

O'Donovan, M., Lewis, E., O'Kiely, P. 2011. Requirements of future grass-based ruminant production systems in Ireland. Irish Journal of Agricultural and Food Research, 50: 1–21

Popular publications:

Lewis, E. and Buckley, F. 2011. Variation in dairy cow feed efficiency amongst breeds. Irish Dairying Planning for 2015 (Moorepark Open Day 2011). Teagasc IE pp. 50–52

Lewis, E., Hennessy, D., McEvoy, M., Enriques Hidalgo, D., Wims, C., Coughlan, F. 2012. Rumen function in grazing dairy cows. TResearch 7(3): 38–39

Lewis, E., O'Donovan, M., Kennedy, E., O'Neill, B., Shalloo, L. 2011. Feeding the dairy cow: supplementation requirements and responses. In: Proceedings of the National Dairy Conference, Cork and Athlone, 15–16th November, pg. 71–81

Grass cultivar evaluation

Project number:
5793
Date:
October, 2013
Funding source:
Teagasc
Project dates:
Jan 2007 – Dec 2012

Key external stakeholders:

Dairy farmers, dairy industry, grass breeders and evaluators, animal nutrition companies and consultants.

Practical implications for stakeholders:

- Grass cultivars re-rank depending on the evaluation protocol to which they are subjected.
- Differentiation of cultivars for grazing or silage use should take place within recommended lists.
- Grass cultivars which had the highest DMD values were also those that were grazed tightest by dairy cows, i.e. had the best 'grazing out score'.

Main results:

- This study clearly showed that there is a re-ranking of individual grass cultivar performance depending on the management protocol that the cultivar is exposed to.
- Grass cultivars which performed well under simulated grazing (SG; 10 cuts per year) did not perform as well under the 2CUT system (two silage cuts plus four other cuts) or AG (animal grazing, 10 rotations) system.
- Differentiation of cultivars for grazing or silage use should take place within recommended lists.
- Highest DM production was achieved on the 2CUT>SG>AG protocol.
- There was a 2,083 kg DM/ha difference between AG (10,055 kg DM/ha) and SG grazing, and a 5,876kg DM/ha between AG and the DAFM protocol.
- Within the animal grazing protocol it was found that some cultivars have a better 'grazing out score' which is linked to the grass digestibility of the cultivar.
- Further research is required to quantify long term grass cultivar persistency.

Collaborating Institutions:
DAFM (Department of Agriculture, Food and the Marine), Ireland
AFBI, Northern Ireland
INRA, France

Teagasc project team:
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Dr. Tommy Boland, UCD

Compiled by:
Michael O'Donovan

Technology

Opportunity/Benefit:

These results provide data illustrating a clear re-ranking of grass cultivar performance depending on evaluation system. This provides the grassland industry with knowledge that grass cultivars perform differently depending on the management system they are exposed to. The opportunity and benefit of this work has been that Irish grass cultivar evaluation systems have now been redesigned to incorporate both simulated grazing and intensive silage harvest protocols, to establish the most appropriate grass cultivars for Irish ruminant grazing systems. This change in grass cultivar evaluation will increase our knowledge of new cultivars and will assist in the development of the grass economic index which is dependant on having a simulated grazing protocol. This work showed that further work and analysis is required to quantify cultivar persistency under different grazing management systems.

1. Project background:

Ireland's low cost seasonal grass-based ruminant livestock production system has traditionally given producers an advantage over international counterparts. With the selection of modern dairy cow genetics, increased emphasis on product quality and issues associated with nitrogen leaching, greenhouse-gas emissions and animal welfare, pasture based systems will in the future require higher per-animal productivity. This will necessitate the development of grazing systems that will be underpinned by the selection of grass cultivars that are highly productive yet do not compromise grass quality and ultimately will maximise daily dry matter (DM) intake. Given the importance of Recommended Lists in the selection and use of grass cultivars on farms, it is imperative that they identify the most suitable cultivars for the intended end user – the grassland farmer. Different grass cultivar evaluation protocols are employed throughout Europe, and testing is generally conducted under cutting management practices. The protocols employed can generally be segregated into simulated grazing or conservation based cutting regimes, with some integrating both conservation and simulated grazing. Simulated grazing protocols entails more frequent harvesting and mirrors or 'simulates' typical animal grazing rotations with eight to ten harvests per year. Grass evaluation protocols based on conservation cutting regimes have less frequent harvesting with two to three conservation harvests and five to six harvests in total. The objective of this study was to compare three methods to evaluate perennial ryegrass cultivars, in terms of DM production, herbage digestibility and persistency and to identify which management identified cultivars are most suitable for an intensive grazing scenario. The study aimed to identify if the relative performance of cultivars remained the same under actual animal grazing or simulated grazing. Both the animal grazing and simulated grazing managements were compared to a two cut silage management, which acted as a control as it is the management currently used to evaluate perennial ryegrass cultivars in the Republic of Ireland.

2. Questions addressed by the project:

- Do grass cultivars perform differently depending on the grazing management they are exposed to?
- Does Ireland need to change the way grass cultivar evaluation is undertaken?
- Are grass cultivars grazed preferentially by grazing ruminants?

3. The experimental studies:

An experiment was set up to investigate the effect of cultivar evaluation method on 10 perennial ryegrass cultivars. The study was executed as a randomised block design with each cultivar having three replicates. Three evaluation protocols were put in place as follows: i) Animal Grazing (AG); 10 animal grazing rotations from February to November receiving 355 kg N/ha/year; ii) Simulated Grazing (SG); 10 mechanical defoliations from February to November receiving 355 kg N/ha/year; iii) Two cut silage management (2CUT); 6 mechanical defoliations from March to October with cuts of silage harvested in mid May and late June, receiving 350 kg N/ha/year. Ten cultivars were evaluated under each of the three managements; the cultivars were Abermagic, Aberstar, Astonenergy, Dunluce, Magican, Millennium, Navan, Spelga, Twystar and Tryella. Measurements included seasonal and annual herbage production, DM digestibility (DMD), ground score, tiller density and grazing out score. As part of the study, under the AG treatments, a new measurement 'grazing out score' was established. The grazing out score relates to the preference the animals have for grazing out a cultivar to the lowest post grazing height across the plots in this study.

4. Main results:

- Year had a significant effect on total and seasonal DM production. Total DM yield was 2,090 kg DM/ha greater (P<0.001) in Year 1 compared with Year 2.
- Management influenced total DM yield (P<0.001), the highest total DM yield was recorded under the 2CUT management (15,931 kg DM/ha) which yielded 3,793 and 5,876 kg DM/ha greater than the SG and AG managements, respectively.
- Cultivar had a significant impact (P<0.001) on total DM yield, with a range of 1,862 kg DM/ha recorded between the highest and lowest yielding cultivars.
- There was an interaction (P<0.001) between cultivar and management for DM yield as the relative performance of cultivars changed between managements. Astonenergy ranked 3rd under SG; whereas it ranked bottom when under the AG management. Navan ranked 2nd under the 2CUT management, while ranking 8th under the SG management.
- Grass quality varied across the three protocols, DMD was 803 g/kg DM for AG, 796 g/kg DM for SG and 805 g/kg DM for the 2CUT protocol. The largest difference in DMD took place in spring – 813 g/kg DM for AG, 771 g/kg DM for SG and 841 g/kg DM for 2CUT. There were management (P<0.001), year and cultivar effects on DMD.
- Sward tiller density and ground scores were different between cultivars and managements. Tiller density was 5762 tillers/m^2 for AG, 4425 tillers/m^2 for SG and 7058 tillers/m^2 for 2CUT protocols.
- Astonenergy and Magician achieved the highest grazing out scores (lowest post grazing sward height) while Abermagic and Aberstar were consistently the lowest (highest post grazing sward height). While the magnitude of the difference in post grazing height was 0.13 cm, which is low, the consistency of results across years illustrates that some cultivars are difficult to utilise in an intensive grazing situation.
- Grass cultivars with the best grazing out score also had the highest DMD.
- Further work is required to examine persistency over time.

5. Opportunity/Benefit:

These results provide data illustrating a clear re-ranking of grass cultivar performance depending on evaluation system. This provides the grassland industry with knowledge that grass cultivars perform differently depending on what management system they're exposed to. The opportunity and benefit of this work has been that Irish grass cultivar evaluation systems have now been redesigned to incorporate both simulated grazing and intensive silage harvest protocols to establish the most appropriate grass cultivars for Irish ruminant grazing systems.

6. Dissemination:

The primary stakeholders for this research are Irish dairy farmers, grassland companies, grass evaluators and grass breeders. The results of this project have been disseminated through the popular press and at the Teagasc Moorepark Open Days, a major international grassland conference in 2010 ('Grasses for the Future') hosted by Teagasc, a PhD thesis, presentations at scientific conferences and in scientific peer-reviewed publications.

Main publications:

O'Donovan, M., Lewis, E., O'Kiely, P. 2011. Requirements of future grass-based ruminant production systems in Ireland. Irish Journal of Agricultural and Food Research, 50: 1–21

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

McEvoy, M., O'Donovan M. and Shalloo, L. Capturing the economic benefit of Lolium Perenne performance. Irish journal of Agricultural and Food Research, 50; 83–98, 2011.

Popular publications:

McEvoy, M and O'Donovan M. Evaluation of perennial ryegrass cultivars. (2011). Moorepark open day proceedings, p68–69.

Wims, C., McEvoy, M., T. Boland and O'Donovan M. A comparison between cut and intensively grazed swards on DM yield of perennial ryegrass. Proceedings of the British Society of Animal Science and the Agricultural Research Forum (2010). P326.

McEvoy, M., O'Donovan M., Wims, C. and Kennedy E. The effect of evaluation protocol on the dry matter yield performance of Lolium Perenne varieties. Proceedings of Grassland Science in Europe, Vol 15 (2010). P314.

Wims, C., McEvoy, M., T. Boland and O'Donovan M. A comparison between cut and intensively grazed swards on DM yield of perennial ryegrass. Proceedings of Grassland Science in Europe, Vol. 15 (2010). P578.

Effects of shearing strategy on the performance of ewes and finishing lambs

Project number:
5674
Date:
September, 2012
Funding source:
Teagasc
Project dates:
Oct 2006 – Dec 2011

Collaborating Institutions:
None

Teagasc project team:
Dr. Tim Keady (PI)
Dr. Seamus Hanrahan
Noel McNamara

External collaborators:
None

Compiled by:
Tim Keady

Key external stakeholders:

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

Practical implications for stakeholders:

- Shearing ewes at housing increases lamb birth and weaning weights by up to 0.6 and 2.0kg/head respectively.
- Relative to shearing at housing, shearing prior to mating has no effect on ewe fertility or litter size but produces lighter lambs.
- Relative to shearing in June or prior to mating shearing ewes at housing increases fleece weight by 0.3 and 0.5 kg respectively.
- Results obtained from research studies at Athenry are repeatable on a commercial farm.
- Shearing finishing lambs, which are housed, increases food intake by 8%, has no impact on carcass gain therefore reduces efficiency of carcass gain from 5.23 to 4.71 g of carcass per meja joule of metabolisable energy intake.

Technology

Main results:

- Shearing ewes at housing increases lamb birth weight and subsequent performance, thus enabling lambs to be drafted up to 2 weeks earlier.
- Increased lamb birth weight from shorn ewes is probably due to reduced heat stress which subsequently results in increased food intake until lambing.
- Shearing prior to mating has no beneficial effect on pregnancy rate or litter size.
- Results achieved at Athenry were replicated on a commercial farm.
- Shearing lambs at finishing had no beneficial effects on lamb performance.
- Diet type, and consequently metabolisable energy intake, did not effect the response to shearing of finishing lambs.

Opportunity/Benefit:

The results of this project demonstrate the benefits of shearing ewes at housing on ewe and subsequent lamb performance. The benefits include heavier lambs at birth and increased daily gains to weaning thus increasing weaning weight and reducing the age at drafting. Whilst shearing prior to mating provides an alternative opportunity to shear ewes, there is no benefit in terms of ewe fertility or litter size. Furthermore, the results of this project show that, regardless of diet type there is no benefit to shearing lambs which are finished during the Winter indoor feeding period.

1. Project background:

Ewes are normally shorn once yearly, normally in early Summer, to maintain sheep welfare by reducing potential ectoparasite problems. Winter conditions in Ireland are characterised as being relatively mild. Consequently, ewes which are housed unshorn may have difficulty dissipating body heat due to the unique insulating properties of the fleece, leading to ineffective heat regulation. Results from a previous study undertaken at Athenry (Project 4925) demonstrated that ewes which are shorn at housing produce lambs of similar birth weight to ewes which are extended grazed during pregnancy.

Shearing ewes at other times of the year may impact on ewe and lamb performance. In Ireland, currently there is a paucity of data on the effect of pre-mating shearing on ewe fertility and performance. Many lamb Winter finishers shear at housing with the expectation of achieving higher daily live weight and carcass gains. However, there is a paucity of data on the effect of shearing finishing lambs on animal performance during the finishing period.

As the commercial producer is the end user of new technology developed at Research Centres it is essential to demonstrate that benefits to technology are replicated on commercial farms.

2. Questions addressed by the project:

- What is the impact of shearing at housing on the performance of pregnant ewes and their lambs?
- What is the effect of season of shearing on ewe fertility and litter size of March lambing ewes and on subsequent lamb performance?
- Are benefits to technology achieved in Research Centres replicated on commercial farms?
- What is the effect of shearing on the performance of finishing lambs?
- Does the response to shearing of finishing lambs depend on diet type and energy intake?

3. The experimental studies:

Experiment 1. Effects of Winter shearing and grass silage feed value on ewe and lamb performance.
Eighty crossbred ewes (40 first and 40 second crop: initial liveweight 67.6kg) were allocated to 4 treatments in a randomised design study from mid-December to lambing in mid-March. The 4 treatments were 2 shearing treatments (shorn at housing, unshorn) x 2 silage feed values. All ewes were offered a total of 23.4kg concentrate during the last 6 weeks of pregnancy. All ewes and their lambs were turned out to pasture within 3 days of lambing. Ewes rearing singles or twins and their lambs received no concentrate supplementation post lambing. Ewes rearing triplets were grazed as a separate flock and received a daily allowance of 1kg concentrate until 5 weeks post lambing and their lambs had access to a maximum of 300g of concentrate per lamb daily until weaning. All lambs were weaned at 14 weeks of age.

Experiment 2. An evaluation of the effect of season of shearing on ewe and progeny performance. One hundred and thirty ewes (66 first crop, 64 second crop) were allocated to four shearing treatments as follows: conventional (C), prior to mating (M), housing (H) and twice yearly (MH) and were shown on 29th May, 9th September, 30th November and 29th May and 9th September respectively. The ewes on the M and H treatments had been shown the previous December whilst the ewes on the C and MH treatments had been shown the previous May. The ewes were managed as one flock from the partition prior to the study. Post lambing the ewes were turned out to pasture within 3 days of lambing and managed as described for Experiment 1.

Experiment 3. An on-farm evaluation of the effects of season of shearing on ewe and subsequent lamb performance. The study was undertaken on a commercial farm. A total of 353 ewes were allocated at random in September 2006 to one of the three shearing treatments as follows: shorn prior to mating (September 2006), at housing (December 2006) and conventional shorn (June 2007). Subsequently, the ewes on the prior to mating, at housing and conventional shorn treatments were shorn on 7th September 2007, December 2007 and 13th June 2008, consequently all ewes had been shorn 12 months previously. All ewes were mated at natural oestrous in Autumn 2007, as one flock to rams which were joined with the ewes on 21st October. The ewes were housed in mid-December and offered hay until mid-January. Subsequently, the ewes were grouped according to litter size (based on ultra-sonic scanning) and received a straw-based diet supplemented with concentrates. Post lambing ewes and their lambs were turned out to pasture.

Experiment 4. The effects of shearing on the performances of finishing lambs offered a range of diets. A total of 264 store lambs (Suffolk X, initial liveweight 39.0kg) were allocated to dietary treatments designed to vary metabolisable energy intake by 60%, and thus daily performance. The lambs were housed in groups of 6 in slatted pens for 54 days prior to slaughter. Half of the lambs on each dietary treatment were shorn at the beginning of the study. The lambs were slaughtered at an EU approved abattoir under continuous veterinary inspection by the Department of Agriculture, Food & Marine.

4. Main results:

Experiment 1.

- Shearing at housing increased silage intake by 15%.
- Ewe weight and condition post lambing was not influenced by shearing prior to housing.
- Shearing ewes at housing increased lamb birth and weaning weights by 0.58 and 2.0kg respectively.
- Shearing ewes at housing improved lamb growth rate from birth to weaning by 15g / lamb daily.

Experiment 2.

- Shearing ewes twice yearly had no beneficial effect on lamb performance.
- Shearing ewes at housing increased lamb birth and weaning weights by 0.54kg and 1.3kg respectively.
- Shearing ewes prior to mating tended to improve lamb birth weight by 0.31kg and increased weaning weight by 2kg.
- Season of shearing had no effect on litter size or number of lambs reared per ewe joined.

Experiment 3.

- Shearing ewes prior to mating and at housing changed fleece weight by -0.2kg and +0.3kg respectively.
- Season of shearing had no effect on litter size or number of lambs reared per ewe lambing.
- Shearing prior to mating had no effect on lamb birth or weaning weights.
- Shearing at housing tended to increase lamb birth and weaning weights by 0.24kg and 1.0kg respectively.

Experiment 4.

- Shearing lambs increased food intake by 8% and final liveweight by 1kg (due to presence of the fleece).
- Lambs which were shorn had a higher kill out percentage (47.4% vs 46.7%) due to the absence of the fleece.
- Shearing had no effect on daily liveweight or carcass gains or on final carcass weight.
- Shearing at housing reduced the efficiency of conversion of metabolisable energy (ME) to carcass gain. For the unshorn and shorn lambs the efficiency of carcass gain was 5.23 and 4.71 grams of carcass per mega joule of metabolisable energy intake, respectively.

5. Opportunity/Benefit:

- Shearing pregnant ewes at the appropriate time (i.e., at housing) increased subsequent lamb performance thus enabling lambs to be drafted up to 2 weeks earlier.
- From an animal's performance point of view, there is no benefit to shearing finishing lambs.
- The information for this project has been disseminated to the industry and to the knowledge transfer personnel through presentations and articles to the scientific, technical and producer communities.

6. Dissemination:

Main publications:

Keady, T.W.J. and Hanrahan, J.P. (2007). 'Effects of extended grazing, grass silage feed value and Winter shearing on ewe and lamb performance'. *Proceedings of the Agricultural Research Forum,* p 49.

Keady, T.W.J. and Hanrahan, J.P. (2008) 'Effect of season of shearing on ewe and progeny performance'. *Proceedings of the British Society of Animal Science,* p 124.

Keady, T.W.J. and Hanrahan, J.P. (2009) 'Effects of shearing at housing, grass silage feed value and extended grazing allowance on ewe and subsequent lamb performance'. *Animal* 3: pp143–153.

Keady, T.W.J. and Hanrahan, J.P. (2009). 'An on-farm evaluation of the effects of season of shearing on ewe and subsequent lamb performance'. *Proceedings of the British Society of Animal Science,* p165.

Keady, T.W.J. and Hanrahan, J.P. (2012). 'The effects of forage type and feed value, concentrate feed level and protein concentration and shearing on lamb performance'. *Proceedings of the XVI International Silage Conference, Hameenlinna, Finland,* pp 168–196.

Popular publications:

Keady, T.W.J. (2007). 'Season of shearing impacts on subsequent lamb performance'. *Irish Farmers Journal Vol. 60, No. 37,* p 22.

Keady, T.W.J. (2008). 'Making the most from shearing'. *Irish Farmers Journal, Vol. 61, No. 22, Part 3,* p7.

Keady, T.W.J. (2010). 'Shearing ewes at housing increases flock profitability'. *Irish Farmers Journal, Vol. 63, No. 51,* p 28.

Keady, T.W.J. (2012). 'Season of shearing impacts on flock profitability in Technical Updates on Sheep Production'. *Teagasc,* pp 85–89.

Precision pasture management

Project number:
5795
Date:
July, 2012
Funding source:
DAFM
Project dates:
Oct 2007 – Sep 2011

Key external stakeholders:

Grassland industry, grassland farmers, business and technology advisors, seed merchants and dairy co-ops.

Practical implications for stakeholders:

- Increased efficiency through increased stocking rates, longer grazing season length and higher levels of sward renewal can increase grass utilisation on farms.
- Grassland farmers need to increase their usage of grassland management tools and technologies.
- Reseeding levels are too low on dairy farms and need to increase.
- Higher grass dry matter (DM) can be achieved at farm level by increasing the level of perennial ryegrass within grass swards.

Main results:

- Greater utilisation of pasture through increased stocking rates and improved grazing management can be achieved on Irish dairy farms.
- Uptake of grassland management technologies is low, despite the fact that many of the limitations reported by survey participants could be improved through greater adoption of such technologies.
- The level of sward renewal on dairy farms must increase if more intensive grass-based systems of production are to be adopted.
- The DM production capacity of a grass sward is significantly increased by increasing perennial ryegrass content.
- Perennial ryegrass ground score can be used as a method of estimating perennial ryegrass content and DM production capacity of pastures.

Collaborating Institutions:
University College Dublin (UCD)
Trinity College Dublin (TCD)
Agri-Food and Biosciences Institute (AFBI)
INRA, France

Teagasc project team:
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Dr. Emer Kennedy

External collaborators:
Dr. Tommy Boland, UCD
Dr. Trevor Gilliland, AFBI

Compiled by:
Michael O'Donovan

Technology

Opportunity/Benefit:

Dairy farmers have large financial gains to make if adoption of new improved grassland management techniques takes place. Stocking rate, milk solids per cow and per hectare, grazing season length and the level of concentrates offered all show that there is under-utilisation of grassland taking place nationally. Large opportunities are available if these deficiencies are addressed, higher levels of grass utilisation can be achieved which will increase profitability on dairy farms. Perennial ryegrass content has a significant effect on grass DM production within swards. Increasing sward perennial ryegrass content will increase the DM production capacity of farms.

1. Project background:

Irish dairy farms have the potential to produce up to 15 t of grass dry matter (DM) ha over a long growing season providing the lowest cost feed source available, with the ability to supply a large proportion (>0.75) of the diet of the Irish dairy cow as grazed grass. It is estimated that, nationally, there is approximately 7.1 t of DM ha being utilised on the average specialist dairy farm, indicating that far higher levels of production can be achieved with greater grass utilisation on Irish dairy farms. Approximately 0.44 of the difference in net profit per hectare between farms can be explained by grass utilised per hectare. There is virtually no knowledge indicating the level of uptake of herbage mass measurement techniques at the farm level, even though it is promoted extensively. The renewal of swards is an expensive practice so sward persistence and lifetime DM production performance are important issues to address at farm level. Forage grasses and varieties of the same species vary in the rate of tiller survival. Over time, most swards will lose grass tillers, creating open spaces, which can become invaded by weed species. Grass persistency can be measured by evaluating the decline in percentage of ground covered by sown species, or by documenting the DM yield stability of the sown species over time. The development of a reliable method of assessing sward perennial ryegrass density, coupled with DM yield measurement, could significantly aid sward renewal management programs on commercial farms, by more accurately predicting the optimum timing of sward renewal.

2. Questions addressed by the project:

Two main studies were undertaken in this project, the objective of study 1 was to quantify and understand: i) grassland management practices employed on Irish dairy farms including grazing season length, turnout and housing dates, and concentrate feed input; ii) the uptake of new grassland research and technology to increase grassland utilisation and reduce costs; and iii) the frequency and methods of sward renewal, which are issues that are central to increasing and realising the competitive advantage of Irish dairy farming. The objective of study 2 was to quantify the effect of sward perennial ryegrass (PRG) density and defoliation method on seasonal and total DM yield, as well as the effectiveness of ground score (GS) estimates in predicting PRG density and dry matter (DM) yield, under simulated and animal grazing managements.

3. The experimental studies:

Study 1 – Survey analysis of Irish grassland dairy farms.

A sample survey population was chosen from a proportionate representation of all milk suppliers taken from three of the largest dairy processors in Ireland. These three processors between them have a supplier base in the Southern, Eastern and Western geographical regions of Ireland, representing approximately 9,690 of the 19,400 national milk producers, and together supplying just under half of the national milk output of 5,440 million litres (DAFF, 2009). The sample was subdivided into three quota categories and three stocking rate categories post-data collection. A total sample size of 1041 suppliers was selected. A telephone survey was the chosen method of data collection. In total, the survey contained 46 questions which were designed to create a profile of each individual farm by extracting data on the physical background, grassland management and reseeding. The survey focused on three primary sections:

1. **Background:** data on land area, stock numbers and milk output.
2. **Grassland:** the key grassland management indicators including herbage mass measurement (kg herbage DM ha available for grazing, grazing-season length, quantity of concentrates offered per cow, and perceived grazing limitations.
3. **Reseeding:** reseeding program on the farm, timing of reseeding, area reseeded and cultivation method.

Study 2 – Effect of perennial ryegrass density on grass DM production.

Intermediate perennial ryegrass (*Lolium perenne* L.; PRG, *cv. AberElan (D), Delphin (T)* and *Greengold (T)*), was sown at five different seeding rates 5, 7.5, 12, 20 & 30 kg/ha, based on viable seed numbers, to establish swards with relative PRG densities of 0.17(A), 0.25(B), 0.40 (C), 0.67(D) and 1.00(E), swards. The aim was to simulate a range of sward types from an old permanent pasture (sward A) to a recently reseeded sward (sward E). Two defoliation managements were imposed, a simulated mechanical grazing (SG) and animal grazing by dairy cows (AG). Both managements were defoliated concurrently, nine times from February to October to a residual sward height of 4 cm.

4. Main results:

In *Study 1*, both stocking rate and quota category had significant effects on the proportion of participants adopting grass-based technologies and on the amount of supplementary feed offered. Grazing season length increased from 228 days in quota category 1 (167,251 litres) to 249 days in quota category 3 (521,597 litres). Limitations to extending the length of the grazing season were similar for both the Spring and Autumn, with soil conditions and low grass availability the main limiting factors identified. Stocking rate had a significant effect on the total amount of concentrate offered per cow annually. Participants in SR1 (1.2 LU/ha) offered, on average, 645 kg concentrate/cow per year. This increased to 697 kg/cow per year for SR2 (1.8 LU/ha) and to 828 kg/cow per year for SR3 (2.7 LU/ha).

The proportion of the grazing area reseeded annually was significantly affected by stocking rate increasing from 0.04 to 0.10 of the grassland area as stocking rate increased from SR1 to SR3 with no effect of quota category. The results of this survey show that, on average, just 18% of Irish dairy farmers currently use grazing management technologies.

Study 2

Annual dry matter yield under simulated grazing was 10.7 (A), 11.0 (B), 11.3 (C), 11.8 (D), 12.0 (E). Under simulated grazing the higher density swards (C, D and E) had significantly greater DM yield in Autumn and total DM yield than the low density swards (A and B). Annual dry matter yields under animal grazing were 10.3 (A), 10.7 (B), 11.0 (C), 12.1 (D), and 12.2 (E). Sward PRG density significantly affected DM yield in Summer, Autumn, and total DM yield under animal grazing. The production from all PRG sward densities was stable within specific grazing managements, i.e. the variance of high PRG swards was not significantly different to that in low PRG swards under either management. There was a significant effect of defoliation method on sward DM yield stability with simulated grazing yields more stable than animal grazing yields.

The relationship between sward DM yield and ground score was significant for both grazing managements with correlations based on raw data ranging from 0.84 to 0.92 for GS-June and GS-December, respectively, under simulated grazing and 0.80 to 0.94 for GS-June and GS-December, respectively, under animal grazing. The relationship between DM yield and ground score was investigated. Each one unit increase ground score in June (GS-June) related to a 350 kg DM ha increase in annual DM yield under simulated grazing and a 721 kg DM ha increase with animal grazing. For ground score densities recorded in December (GS-December), every unit increase gave an annual increase in yield equal to 460 kg DM ha or 1194 kg DM ha in simulated and animal grazing, respectively.

5. Opportunity/Benefit:

The information generated from this project has been disseminated by knowledge transfer personnel and is currently being integrated into reseeding management practices to assist the extension of the grazing season, thereby reducing feed costs and helping to improve overall farm profitability.

6. Dissemination:

Main publications:

A survey analysis of grassland dairy farming in Ireland, investigating grassland management, technology adoption and sward renewal. Authors – P. Creighton, E. Kennedy, L Shalloo, T. Boland, M. O'Donovan. Grass and Forage Science 66, 251–264 (2011).

Creighton, P., Kennedy, E., Gilliland, T., Boland, T. and O'Donovan, M. Effect of sward Lolium Perenne density on productivity under simulated and actual cattle grazing, Grass and forage Science (accepted with changes November 2011).

Shalloo, L, Creighton, P. and O'Donovan, M. The economics of reseeding a dairy farm. Irish Journal of Agricultural and Food Research, 50; 113–122 (2011).

Creighton, P, Kennedy, E., Gilliland, T., Boland T. and O'Donovan M. The effect of sward perennial ryegrass content and defoliation method on seasonal and total dry matter production. Proceedings of the British Society of Animal Science and the Agricultural Research Forum (2010). P149.

Creighton, P, Kennedy, E., Gilliland, T., Boland T. and O'Donovan M. The effect of sward perennial ryegrass content and defoliation method on seasonal and total dry matter production. Proceedings of Grassland Science in Europe, Vol 15 (2010). P904.

Popular publications:

Irish Farmers Journal – 8 individual technical articles on reseeding from March – May 2010, edited by Jack Kennedy.

Development of a Grass Dry Matter Intake Prediction Model

Project number:
5797
Date:
May, 2012
Funding source:
Teagasc
Project dates:
Jan 2008 – Dec 2010

Key external stakeholders:

Dairy farmers, dairy industry, policymakers.

Practical implications for stakeholders:

In order to improve the efficiency by which novel grassland management strategies are evaluated, a mechanism is required to accurately estimate the effects of changes in nutritional factors on animal productivity, by accurately estimating grass dry matter intake (GDMI). Dry matter intake is possibly the single most important factor influencing ruminant production. The prediction of GDMI is also essential in diet evaluation, and the management, of grazing dairy cows at farm level. However, GDMI is difficult for farmers to estimate. Hence the development of a GDMI model is important at both farm and research level.

- Accurate estimation of GDMI enables a greater degree of accuracy in dairy cow nutrition.
- Analysis of the relationships between sward variables and animal performance conducted during model development characterises the pasture characteristics affecting productivity.
- The development of a GDMI prediction model will provide a means for the efficient evaluation of milk production performance potential of different grass cultivars, grassland management techniques, supplementary feeding strategies, etc.
- The model will be capable of assessing the implications for dairy grazing systems of future component research findings.
- Dry matter intake is a key driver of methane emissions by ruminants:
  - an accurate assessment of dairy cow intake will enable more accurate prediction of methane emissions.
  - a model to predict GDMI will enable prediction of methane emissions from different feeding and management scenarios.

Collaborating Institutions:
INRA, France
Massey University, New Zealand

Teagasc project team:
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Dr. Michael O'Donovan
Dr. Laurence Shalloo
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External collaborators:
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Mr. Luc Delaby, INRA, France
Dr. Nicolas Lopez Villalobos, Massey University, New Zealand

Compiled by:
Eva Lewis
Joe Patton

Technology

Main results:

- The GrazeIn model of GDMI prediction was chosen as a suitable GDMI prediction model for Ireland.
- Input variables including cow bodyweight and BCS, grass quality, supplementary feed quality and grazing management are readily available and/or estimable.
- Statistical analysis demonstrated that the model, in its current form, is very accurate with a mean prediction error of 0.12 at herd level and 0.16 at individual cow level for GDMI.

Opportunity/Benefit:

These results have implications for dairy farmers, the dairy industry, policy makers and the research community enabling grazing dairy cow GDMI to be accurately estimated.

1. Project background:

Dry matter intake is possibly the single most important factor influencing production in ruminants. In the Irish grass-based system this equates to GDMI. Efficient utilisation of grazed pasture for milk production is a key element in the competitiveness of the Irish dairy industry. The productivity of grazing systems may be enhanced by improving pasture quality via management, perennial ryegrass cultivar selection, modification of concentrate supplementation, etc. The productivity of a dairy production system is governed by a range of associative and interacting environmental and animal variables. In order to improve the efficiency with which strategies to improve performance are evaluated, a mechanism is required to accurately estimate the effects of changes in nutritional factors on animal productivity, by accurately estimating GDMI. The prediction of GDMI is also essential in the evaluation of the diet and the management of grazing dairy cows at farm level. However, GDMI is difficult to estimate on-farm. Dry matter intake is a key driver of methane production by ruminants. An ability to accurately predict dairy cow GDMI would enable the impact on methane of future nutritional and management strategies to be evaluated. Hence the development of a model to predict GDMI is important at both farm and research level.

2. Questions addressed by the project:

This project had one very clear over-arching goal, which was to develop a model to predict GDMI of grazing dairy cows, utilising easily available input variables.

An accurate GDMI prediction model will enable the following to be achieved:

- a greater degree of accuracy in the nutrition of the dairy cow within the context of the grazing system.
- improved characterisation of the relationships between pasture characteristics and dairy cow performance.
- the efficient evaluation of milk production performance potential of:
  - different grass cultivars in grass breeding programmes.
  - different grazing management techniques.
  - different supplementation strategies.
- assessment of the implications for dairy grazing systems of future component research findings.

3. The experimental studies:

Grass dry matter intake has been estimated using the n-alkane technique at Teagasc Moorepark for the last 24 years. A database was created containing information from grazing studies conducted over the period 1988 to 2009 on the research farms of Teagasc Moorepark. All of these studies measured GDMI. Thus the database contains the GDMI of each cow in each grazing experiment along with other pertinent animal, grass, supplementary feed and environmental variables. This resulted in a database containing 8,787 individual GDMI (and associated) measurements from 1,526 cows in 522 grazing herds from 19 published studies.

A number of existing models which predict DMI were then chosen and evaluated using the data from the database. Such models included the animal biology model for feed intake, production and reproduction from the Australian GrazPlan, the New Zealand model Moosim and the French model GrazeIn. Of these, the French GrazeIn model was chosen as the most suitable. GrazeIn was originally developed as part of the European Grazemore decision support system project. The GrazeIn model combines the main interactions between GDMI regulation, milk synthesis in the udder and the

regulation of body reserves. It is based on the INRA Fill Unit system which is utilised in Ireland. The model input variables are categorised into those related to the cow, to the grass, to the grazing management and to the supplement, and all are readily available/estimable by the farmer and researcher alike.

4. Main results:

- The GrazeIn model of GDMI prediction was chosen as a suitable GDMI prediction model for Ireland.
- Input variables including cow bodyweight and BCS, grass quality, supplementary feed quality and grazing management are readily available and/or estimable.
- Statistical analysis demonstrated that the model, in its current form, is very accurate with a mean prediction error of 0.12 at herd level and 0.16 at individual cow level for GDMI.
- Further development of this model may include:
  - Incorporation of even more readily available input variables, e.g. pre- and post-grazing sward height.
  - Incorporation of other scenarios important at farm level, e.g. on-off grazing.
  - Development of a user-interface which would facilitate use of the model as a decision-support tool for research/extension purposes.

5. Opportunity/Benefit:

Dry matter intake is possibly the single most important factor influencing ruminant production. This means that an understanding of dairy cow DMI, and in the context of Ireland GDMI, is important right across the dairy industry from the research community to policy makers to dairy advisors and dairy farmers alike. The French GrazeIn model was identified as a suitable model for use in Ireland, and its validation as accurate in the context of Irish grazing systems is an important step. The model can be used by dairy advisors and dairy farmers to evaluate the effects of grazing management and nutritional supplementation strategies on dairy cow GDMI and milk production. The model can be used by policy makers and the research community to evaluate the effects of novel grassland management techniques, altered grass chemical composition and supplementation strategies on dairy cow GDMI and milk production. Future work will further improve the accuracy of the model for Ireland.

6. Dissemination:

The primary stakeholders for this research are Irish dairy farmers, research scientists and policy makers. One benefit of this project will be conferred via the use of the GDMI prediction model for directly estimating GDMI. However, the benefits of using this tool extend far greater in terms of its use in aiding to interpret research findings impacts on dairy cow performance.

Main publications:

O'Neill, B.F., Lewis, E., O'Donovan, M., Shalloo, L., Mulligan, F.J. and Delagarde, R. (2011) 'Evaluation of the GrazeIn model of grass dry matter intake and milk production for Irish grass-based production systems.' In: Proceedings of the Agricultural Research Forum, Tullamore, Co. Offaly, 14–15 March 2011, pg.137.

O'Neill, B.F., Lewis, E., O'Donovan, M., Shalloo, L., Boland, T.M., Mulligan, F.J. and Delagarde, R. (2011) 'Investigation of the relationship between bodyweight and grass dry matter intake in Irish dairy cows.' In: Proceedings of the Agricultural Research Forum, Tullamore, Co. Offaly, 14–15 March 2011, pg. 78.

O'Neill, B.F., Lewis, E., O'Donovan, M., Shalloo, L. Galvin, N., Mulligan, F.J., Boland, T.M. and Delagarde, R. (2011) 'The prediction of grass dry matter intake for grazing Irish dairy cows.' In: Proceedings of the Walsh Fellowship Forum, Dublin, 8 November 2011, pg. 56

Animal and Grassland Research & Innovation Programme

Project number:
5518
Date:
August, 2010
Funding source
Teagasc
Project dates:
Jan 2006 – Dec 2009

Grass based milk production systems for regions of high rainfall and heavy clay soil types

Collaborating Institutions:
Dr. Luc Delaby, INRA
Mr. John O'Callaghan, Kerry Co-op

Teagasc project team:
Dr. Michael O'Donovan
Mr. James O'Loughlin
Mr. Frank Kelly
Dr. Laurence Shalloo

External collaborators:
Mr. John O'Callaghan, Kerry Co-op

Compiled by:
Michael O'Donovan

Key external stakeholders:

Dairy farmers on heavy soils.

Local milk processors – Kerry, Dairygold, Arrabawn, Lakeland dairies and Connacht Gold Consultancy agencies.

Practical implications for stakeholders:

In all livestock systems the ability to achieve high levels of grass utilisation is influenced by climatic and soil conditions. In wetland regions grass utilisation is difficult in periods of high rainfall and is a major constraint. The findings of this research project based at Kilmaley research farm indicate tha:

- Dairying on heavy clay soils is challenging but potential exists to increase animal productivity from grass (with the use of on/off grazing) in periods of marginal grazing conditions.
- Stocking rates used in wetland regions must be appropriate to minimise the importation of bought in feed. The economically optimum system of milk production in this study did not vary depending on milk price, lower stocking rate systems are less exposed to the cost of imported feed, higher stocking rate systems are exposed irrespective of milk price to high feed costs.

Technology

1. Project background:

There is a large variation in the cost of milk production in specialised dairy farms in Ireland. Some of the variation in cost may be associated with variation in soil type and climatic conditions. Previous work at the Kilmaley Research Farm indicates that the most profitable spring milk production system is based on a feed budget of 2.1 tonnes of grass silage, 2.8 tonnes of grazed grass and 0.5 tonnes of concentrates per cow at a stocking rate of 2.0 cows per hectare with a nitrogen input of 210 kg per hectare. An alternative system of milk production for high rainfall heavy clay soils is a higher concentrate feeding system allowing for higher animal performance per unit area. This system will be less dependent on achieving high animal performance from grass silage, while at the same time lowering fixed costs per unit of output. If concentrate supplementation could be used efficiently, allowing a higher stocking rate to be carried, this may potentially result in profits similar to pasture-based systems in free draining soils with low rainfall.

2. Questions addressed by the project:

Survey information compiled by Creighton et al (2010 in press) shows that dairying farms in wetland regions have low stocking rate (1.83 LU/ha), low output per cow (310kg milk solids/cow) with 674kg concentrate input per cow and grazing season length of on average 238 days. The question addressed in this project was to determine the biological efficiency of two different production systems on a high rainfall heavy clay soil based on differences in concentrate supplementation level and stocking rate. A main aspect of the study was to examine whether stocking rate could be increased on heavy soils and what impact this would have on the dynamics of the system relative to a low stocking rate system.

3. The experimental studies:

The objective of this study is to compare the biological and financial efficiency of two pasture-based production systems, the blueprint system adapted from Kilmaley previous research programme, the second based on increasing stocking rate. Sixty two spring calving dairy cows were randomised and assigned to a two treatment (n = 29) feeding system study, 24% of the herd were primiparious. Mean lactation number was 2.8 (s.d. 1.6), mean calving date 23 February (s.d. 25 days), respectively. The two treatments were, Blueprint (Blu), low stocking rate (2.18 cows/ha), 220 kg N/ha, target 500 kg concentrate, two main silage cuts. A high concentrate system (HC) had a stocking rate of 2.87 cows/ha, target concentrate input (1.3t/cow), 240 kg N/ha, one main silage cut. Separate farmlets, each of 19 individual paddocks were in operation for both systems. In both systems from turnout the objective was to minimize grass silage feeding. Once grass supply was sufficient both herds were managed on a grass only diet, the HC herd was supplemented to a higher level in both early and late lactation.

4. Main results:

- Grazing season length was on average 180 days (2006–2009).
- On/off grazing can successfully be used to increase grazing days.
  - Milk solids production was 378kg/cow (832kg/ha) for the blueprint system and 402kg/cow (1166kg/ha) for the HC system.
  - Milk fat and protein content were unaffected by production system.
- There was no significant influence of production system on cow reproductive performance.
- Concentrate input was 681kg (blueprint) and 1356kg (HC) on average over the four years.
- The optimum system of production did not vary with milk price. Higher profit was realised with the blueprint system at low, med and high milk prices.
- The HC system was too reliant on imported feed, decreasing the competitiveness of the system.
- This study shows that dairy milk production systems with low stocking rates can be viable in regions with high rainfall and heavy clay soils. Key aspects to profitable milk production are compact calving with a high EBI herd, targeting high grass utilisation with the use of on/off grazing, strategic concentrate supplementation and minimizing the purchase of imported feed.

5. Dissemination:

An open day took place in Kilmaley in 2006. In addition to open day events, individual discussion groups frequently visited the experiment during the project. Topics covered at these events by research and advisory staff included grassland management best practice advice, animal breeding and health recommendations and economic implications of research results.

Main publications:

O'Donovan M., O'Loughlin, J., and Kelly, F. (2007) Milk production systems to increase competitiveness in regions of high rainfall and heavy clay soil types. Grassland Science in Europe, Vol 13, Biodiversity and Animal Feed, pp 840–842.

O'Loughlin, J. O'Donovan M and Kelly, F. Grass based milk production systems for regions of high rainfall and heavy clay soil types. Agricultural Research Forum, Tullamore (2007). P108.

O'Loughlin J and O'Donovan M (2006) Increasing the competitiveness of milk production in areas with high rainfall and heavy clay soils. Moorepark Dairy Levy Research Update pp 37.

Breeding improved varieties of white clover

Key external stakeholders:

Grassland farmers, seed industry, advisors, agricultural consultants and researchers.

Practical implications for stakeholders:

The research programme focussed on breeding improved varieties of white clover for Irish farm systems. The primary traits for improvement were annual clover yield, seasonal yield distribution and persistency. Key results were:

- Three new white clover varieties, Chieftain (medium leaf size), Galway (small leaf size) and Pirouette (micro leaf size), offering improvements in clover productivity and persistency over existing varieties, were commercialised and released.
- A new market for the white clover variety Susi (medium leaf size) was established in France with the addition of the variety to the French National List.
- Teagasc bred white clover varieties, Chieftain and Avoca, were the highest yielding medium leaf size clover varieties on the 2012 Recommended List of Grass and Clover Varieties for Ireland.
- Four other white clover varieties bred by Teagasc displayed exceptional performance in the Teagasc trials and were submitted to the Department of Agriculture, Food and Marine for consideration for addition to the Recommended List of Grass and Clover Varieties for Ireland.
- Breeding offers a low cost and successful means to improve the productivity and profitability of white clover based swards.

Project number:
4755

Date:
October, 2012

Funding source:
Teagasc and the seed industry

Project dates:
Jan 2001 – Dec 2008

Collaborating Institutions:
DLF-Trifolium
University of Wisconsin-Madison
DAFM
Agri-Food and Biosciences Institute in Northern Ireland

Teagasc project team:
Dr. Patrick Conaghan

External collaborators:
Prof. Michael Casler (University of Wisconsin-Madison)
Dr. Klaus Nielsen (DLF-Trifolium)
Dr. Trevor Gilliland and Dr. Brian Waters (AFBI)
John Claffey and Dermot Grogan (DAFM)

Compiled by:
Patrick Conaghan

Technology

Main results:

The Teagasc bred white clover variety Chieftain (medium leaf size) was added to the Recommended Lists of Grass and Clover Varieties for Ireland, Northern Ireland, Scotland, England and Wales. Chieftain is a large-medium leaf size variety suitable for cattle and sheep grazing, and intensive silage production. Chieftain offers excellent clover yield, total grass and clover yield, and persistency. Chieftain is the highest yielding variety in the medium leaf size group on the Recommended Lists for Ireland and Northern Ireland. The Teagasc bred white clover variety Galway (small leaf size) was added to the Recommended List of Grass and Clover Varieties for England and Wales. Galway is primarily suited for sheep grazing offering significant improvements in spring yield and persistency, and excellent total yields under hard defoliation. The Teagasc bred white clover variety Pirouette (micro leaf size) is a very small leaf size variety used for amenity purposes throughout Europe with the addition of the variety to the German National List. The microclover variety persists well and grows densely under frequent lawn mowing. Pirouette keeps the lawn much greener and healthy without the application of fertiliser nitrogen. Commercial seed of Teagasc bred varieties are produced and distributed worldwide by DLF-Trifolium, Germinal Holdings Ltd and Semental Ltd.

Opportunity/Benefit:

This project offers farmers new improved white clover varieties of greater genetic merit and improved agronomic characteristics that when sown may increase the productivity, profitability and sustainability of Irish farm systems. A commercial agreement between Teagasc and the seed industry ensures the production and availability of seed for farmers.

1. Project background:

White clover (*Trifolium repens*) is one of the most nutritious species available in grassland/ruminant production systems. In association with grass, this species increases protein, mineral content, intake and nutritional value of the total forage. Because of its nitrogen fixing capacity, white clover has the potential to reduce, or in the case of organic systems, eliminate the need for inorganic nitrogen fertiliser on grassland. Grassland-based animal production is a major part of the Irish agricultural economy and consequently any improvement in this legume has large potential benefit in this sector.

Forage breeding is a technology that harnesses the creative power of selection. It is powerful, precise and predictable. White clover has been subjected to very little formal breeding. Genetic variation within and among populations is still extremely high, showing no signs of decreasing. Breeding offers a low cost means of improving the profitability and productivity of white clover.

The objective of this project was to breed improved varieties of white clover for Irish farm systems. The primary traits for improvement were annual clover yield, seasonal yield distribution and persistency. World-wide propagation and marketing rights on all new varieties were offered to a commercial company ensuring the availability of new varieties to Irish farmers. This project continues, with modifications, the successful commercial white clover breeding programme established at Teagasc, Oak Park, Carlow in the 1960s.

2. Questions addressed by the project:

- Can forage breeding produce improved varieties of white clover?
- What level of genetic improvement in white clover can be achieved with forage breeding?

3. The experimental studies:

The breeding programme was based on (i) recurrent phenotypic selection involving the evaluation of individual plants, (ii) recurrent genotypic selection involving the evaluation of the progeny of different crosses and (iii) the production of synthetic varieties constructed by intercrossing a number of selected genotypes. The main emphasis was on improving variety performance under grazing. Selection was based mainly on clover performance in mixed grass-clover swards. The main traits for improvement were annual and seasonal yield distribution of clover and grass plus clover, and clover persistency. The best varieties were submitted to the official Recommended/National List trials in Ireland, UK and other countries for independent evaluation. World-wide propagation and marketing rights on all new varieties were offered to a commercial company ensuring the availability of new varieties to Irish farmers.

4. Main results:

Fifteen new varieties of white clover were constructed. The best seven varieties were submitted to the official Recommended/National List trials in Ireland, UK and other countries for independent evaluation. Three new varieties, Chieftain, Galway and Pirouette, were found to have greater genetic merit and improved agronomic characteristics over existing commercial varieties and were added to the Recommended/National Lists of Grass and Clover Varieties in Ireland, UK and other countries.

Chieftain (medium leaf size) was awarded Recommended Listing in Ireland, Northern Ireland, Scotland, England and Wales. Chieftain is a large-medium leaf size variety suitable for cattle and sheep grazing, and intensive silage production. Chieftain offers excellent clover yield, total grass and clover yield, and persistency. Chieftain is the highest yielding variety in the medium leaf size group on the 2012 Recommended Lists of Grass and Clover Varieties for Ireland and Northern Ireland. Chieftain had 3% higher total yield of grass and clover than the mean of the medium leaf size group on the 2012 Recommended Lists for Ireland and Northern Ireland.

Galway (small leaf size) was awarded Recommended Listing in England and Wales. Galway is primarily suited for sheep grazing offering significant improvements in spring yield and persistency, and excellent total yields under hard defoliation. Galway had 21% higher spring yield and 13% higher ground cover than the mean of the small leaf size group on the 2011 NIAB (England and Wales) Recommended List of Grass and Clover Varieties.

Pirouette (micro leaf size) is a very small leaf size variety used for amenity purposes throughout Europe following addition to the German National List. The micro clover variety persists well and grows densely under frequent lawn mowing.

Full variety results from the Ireland Recommended List are available at www.agriculture.gov.ie and the Northern Ireland Recommended List at www.afbini.gov.uk.

In conclusion, the Teagasc white clover breeding programme continues to produce new improved varieties of white clover with greater genetic merit and improved agronomic characteristics than existing commercial varieties.

5. Opportunity/Benefit:

This project highlights the benefit of white clover breeding to grassland agriculture and the large improvements in white clover productivity that may be achieved through breeding. This project offers farmers new improved white clover varieties of greater genetic merit and improved agronomic characteristics that when sown may increase the productivity, profitability and sustainability of Irish farm systems. A commercial agreement between Teagasc and the seed industry ensures the production and availability of seed for farmers.

6. Dissemination:

This information has been widely disseminated to grassland farmers via discussion groups, open days, farm walks, popular press and Teagasc publications. It will continue to be disseminated through Teagasc advisors at discussion groups. Full variety results have been published in the Recommended List of Grass and Clover Varieties for Ireland, Northern Ireland, Scotland, England and Wales.

Main publications:

Recommended List of Grass and Clover Varieties for Ireland (DAFM) at www.agriculture.gov.ie

Recommended List of Grass and Clover Varieties for Northern Ireland (AFBI) at www.afbini.gov.uk

Recommended List of Grass and Clover Varieties for England and Wales (NIAB) at www.bspb.co.uk

Popular publications:

Irish Farmers Journal, Farming Independent and Today's Farm.

Breeding improved varieties of perennial ryegrass

Project number:
4758

Date:
October, 2012

Funding source:
Teagasc and the seed industry

Project dates:
Jan 2001 – Dec 2008

Key external stakeholders:

Grassland farmers, seed industry, advisors, agricultural consultants and researchers.

Practical implications for stakeholders:

The programme focussed on breeding improved varieties of perennial ryegrass for Irish farm systems. The main emphasis was on improving variety performance under grazing. The primary traits for improvement were seasonal yield distribution, nutritional value, ground cover, persistency and disease resistance. Key results were:

- Five new perennial ryegrass varieties with greater genetic merit and improved agronomic characteristics over existing varieties were commercialised and released.
- The new varieties were: January (early diploid), Shandon (intermediate diploid), Glenstal (intermediate tetraploid), Tyrconnell (late diploid) and Glencar (late tetraploid).
- Eleven other perennial ryegrass varieties, newly bred by Teagasc, displayed exceptional performance in the Teagasc trials and were submitted to the Department of Agriculture, Food and Marine for consideration for addition to the Recommended List of Grass and Clover Varieties for Ireland.
- Research conducted indicated that variety performance varied substantially from year to year and that the level of variation from year to year was unpredictable. Only varieties included on the Recommended List of Grass and Clover Varieties for Ireland, that have a strong history of high performance in Ireland, should be used by Irish farmers.
- Research into breeding methodology to improve the genetic gain per unit time and cost determined the optimum allocation of field resources for breeding for increased forage yield in perennial ryegrass.
- Breeding offers a low cost and successful means to improve the productivity and profitability of perennial ryegrass based swards.

Collaborating Institutions:
DLF-Trifolium
University of Wisconsin-Madison
Department of Agriculture, Food and the Marine, Ireland
Agri-Food and Biosciences Institute in Northern Ireland

Teagasc project team:
Patrick Conaghan

External collaborators:
Prof. Michael Casler (University of Wisconsin-Madison)
Dr. Klaus Nielsen (DLF-Trifolium)
Dr. Trevor Gilliland and Dr. Brian Waters (AFBI)
John Claffey and Dermot Grogan (DAFM)

Compiled by:
Patrick Conaghan

Technology

Main results:

Five new perennial ryegrass varieties were awarded Recommended Listing in Ireland and/or UK, and commercialised and released. Summary characteristics of the new varieties are presented below in Table 1. Full variety results from the Ireland Recommended List are available at www.agriculture.gov.ie and the Northern Ireland Recommended List at www.afbini.gov.uk.

Commercial seed of Teagasc bred cultivars are produced and distributed worldwide by DLF-Trifolium.

Research into the optimum testing methodology for perennial ryegrass yield trials indicated that fresh weight yield could be successfully used as a proxy for dry matter yield in breeding yields. This would facilitate the evaluation of a greater number of plots for the same level of resources thereby increasing genetic gain by on average 11%.

The optimum allocation of resources for a perennial ryegrass variety testing programme was estimated at four replicates per location, and either two locations and three sowing years or three locations and two sowing years with two harvest years for each sowing year.

Research conducted on variety trials across Ireland indicated that variety performance varied substantially from year to year and that the level of variation from year to year was unpredictable. Only perennial ryegrass varieties included on the Recommended List of Grass and Clover Varieties for Ireland, that have a strong history of high performance in Ireland, should be used by Irish farmers.

Table 1: New Teagasc bred varieties.

Variety	Key characteristics	Recommended List
January	- Early maturing - Diploid - Exceptionally high spring growth - Very high silage yields	Ireland, Northern Ireland, England, Wales and Scotland
Shandon	- Intermediate maturity - Diploid - High total yield - Excellent spring growth	Ireland
Glenstal	- Intermediate maturity - Tetraploid - Excellent total yield - Outstanding spring yield - Very good sward density	Northern Ireland, England, Wales and Scotland
Tyrconnell	- Late maturity - Diploid - Exceptionally late season growth - Outstanding ground cover	England, Wales and Scotland
Glencar	- Late maturity - Tetraploid - Excellent total yield - Very good spring growth - Exceptionally high 1st cut silage yield	Ireland, Northern Ireland, England, Wales and Scotland

Opportunity/Benefit:

This project offers farmers new improved perennial ryegrass varieties of greater genetic merit and improved agronomic characteristics that when sown may increase the productivity, profitability and sustainability of Irish farm systems. A commercial agreement between Teagasc and the seed industry ensures the production and availability of seed for farmers. The research findings on the optimum methodology for the evaluation of perennial ryegrass yield will increase the efficiency and reduce the cost of the breeding and cultivar trials in Teagasc and the Department of Agriculture, Food and the Marine.

1. Project background:

Over 90% of the agricultural area in Ireland is devoted to grassland which provides the main feed for our ruminant livestock. While sward composition, especially for old pastures, is often complex, perennial ryegrass (*Lolium perenne*) is the most desirable species and the key component of the most productive pastures. Almost all forage grass seed sown in Ireland is perennial ryegrass. Consequently any improvement in this species has large potential benefit to the Irish agricultural economy.

Forage breeding is a technology that harnesses the creative power of selection. It is powerful, precise and predictable. Forage grass has been subjected to very little formal breeding. Genetic variation within and among populations is still extremely high, showing no signs of decreasing. Breeding offers a low cost means of improving the profitability and productivity of perennial ryegrass.

The objective of this project was to develop and use methods that effectively select for the best phenotypes leading to the breeding of improved varieties of perennial ryegrass for Irish farm systems. The main emphasis was on improving variety performance under grazing. The primary traits for improvement were seasonal yield distribution, nutritional value, ground cover, persistency and disease resistance. World-wide propagation and marketing rights on all new cultivars will be offered to a commercial company ensuring the availability of new cultivars to Irish farmers. This project continues, with modifications, the successful commercial white clover breeding programme established at Teagasc, Oak Park, Carlow in the 1960s.

2. Questions addressed by the project:

- Can forage breeding produce improved cultivars of perennial ryegrass?
- What level of genetic improvement in perennial ryegrass can be achieved with forage breeding?
- What is the optimum allocation of replicates, locations and years for a perennial ryegrass variety evaluation programme in Ireland?
- Can fresh matter yield be used as a proxy for dry matter yield in breeding for increased dry matter yield in perennial ryegrass?

3. The experimental studies:

The breeding programme was based on (i) recurrent phenotypic selection involving the evaluation of individual plants, (ii) recurrent genotypic selection involving the evaluation of the progeny of different crosses and (iii) the production of synthetic varieties constructed by intercrossing a number of selected genotypes. The main emphasis was on improving variety performance under grazing. The primary traits for improvement were seasonal yield distribution, nutritional value, ground cover, persistency and disease resistance. The best varieties were submitted to the official Recommended/National List trials in Ireland, UK and other countries for independent evaluation. World-wide propagation and marketing rights on all new cultivars were offered to a commercial company ensuring the availability of new cultivars to Irish farmers.

An extensive data set of historical perennial ryegrass yield trials in Ireland from the Teagasc Oak Park breeding and Department of Agriculture, Fisheries and the Marine variety evaluation programmes was mined and re-analysed. The information provided by these past experiments was used to make recommendations on the optimal allocation of resources and methodology for future perennial ryegrass trials.

4. Main results:

Twenty four new perennial ryegrass varieties bred by Teagasc displayed exceptional performance in the Teagasc breeder's trials and were submitted to the official Recommended/National List trials in Ireland, UK and other countries for independent evaluation and consideration for addition to the Recommended List of Grass and Clover Varieties in the respective countries.

Five new perennial ryegrass varieties were awarded Recommended Listing in Ireland and/or UK, and commercialised and released. The new perennial ryegrass varieties are: January (early diploid), Shandon (intermediate diploid), Glenstal (intermediate tetraploid), Tyrconnell (late diploid) and Glencar (late tetraploid). The varieties were shown to offer improved yield, quality and persistence characteristics for grass-based production systems with on average 2.2 percentage units higher annual yield at time of release than comparable existing varieties of similar ploidy and maturity group.

Research into the optimum testing methodology for perennial ryegrass yield trials indicated that fresh weight yield could be successfully used as a proxy for dry matter yield in breeding yields. This would facilitate the evaluation of a greater number of plots for the same level of resources thereby increasing genetic gain by on average 11%.

The optimum allocation of resources for a perennial ryegrass variety testing programme was estimated at four replicates per location, and either two locations and 3 sowing years or three locations and 2 sowing years with 2 harvest years for each sowing year.

Research conducted on variety trials across Ireland indicated that variety performance varied substantially from year to year and that the level of variation from year to year was unpredictable. Only perennial ryegrass varieties included on the Recommended List of Grass and Clover Varieties for Ireland, that have a strong history of high performance in Ireland, should be used by Irish farmers.

In conclusion, the Teagasc grass breeding programme continues to improve the methodology for breeding and evaluating perennial ryegrass, and develop new improved varieties of perennial ryegrass with greater genetic merit and improved agronomic characteristics than existing commercial varieties.

5. Opportunity/Benefit:

This project highlights the benefit of perennial ryegrass breeding to grassland agriculture and the large improvements in white clover productivity that may be achieved through breeding. This project offers farmers new improved perennial ryegrass varieties of greater genetic merit that when sown may increase the productivity, profitability and sustainability of Irish farm systems.

Research conducted offers improved testing methodology for grass breeding and evaluation that may increase the rate and reduce the cost of the genetic gain in perennial ryegrass breeding and variety evaluation programmes by improving the precision and accuracy of the yield estimates, and optimising the use of the available resources.

6. Dissemination:

This information has been widely disseminated to grassland farmers via discussion groups, open days, farm walks, popular press and Teagasc publications.

Main publications:

Conaghan, P., O'Kiely, P., Howard, H., O'Mara, F.P. and Halling, M.A. 2008. Evaluation of *Lolium perenne* L. cv. AberDart and AberDove for silage production. *Irish Journal of Agricultural and Food Research* 47:119–134.

Conaghan, P., Casler, M.D., McGilloway, D.A., O'Kiely, P. and Dowley, L.J. 2008. Genotype × environment interactions for forage yield of perennial ryegrass sward plots in Ireland. *Grass and Forage Science* 63:107–120.

Conaghan, P., Casler, M.D., O'Kiely, P. and Dowley, L.J. 2008. Efficiency of indirect selection for dry matter yield based on fresh matter yield in perennial ryegrass sward plots. *Crop Science* 48:127–133.

Animal and Grassland Research & Innovation Programme

Project number:
6260
Date:
July, 2013
Funding source:
DAFM
Project dates:
Nov 2011 – May 2013

Review of factors impacting on the processing quality of raw milk produced in Ireland

Collaborating Institutions:
University College Cork (UCC)
University College Dublin (UCD)

Teagasc project team:
Dr. Bernadette O'Brien (PI)
Dr. Kieran Jordan (co-PI)
Dr. Sinead McParland
Dr. Donagh Berry
Dr. David Gleeson
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External collaborators:
Prof. Alan Kelly, UCC
Dr. Karina Pearce, UCD

Compiled by:
Bernadette O'Brien
Kieran Jordan

Key external stakeholders:

Policymakers, food researchers, food manufacturers, dairy industry, dairy farmers.

Practical implications for stakeholders:

The outcome/technology or information/recommendation is that any future research programme on milk quality should address the following issues:

- The optimal product mix to maximise export markets for dairy products.
- The milk quality requirements to achieve premium quality products.
- How to achieve these milk quality parameters within the most profitable production system.
- How to manage these milk quality parameters at both milk production and milk processing stages.

Main points

This will allow the dairy industry to develop an efficient and valuable milk processing and dairy product marketing sector.

In turn, a stronger dairy industry from farm production stage to product export stage will result in greater national income and employment.

Technology

Main results:

The gaps in knowledge identified:

- Chemical residues – occurrence of residues (Quaternary Ammonium Compounds, growth promoting agents, antibiotics [cephalosporins, aminoglycosides], thiouracil and semicarbazide, in food PBDEs and DEHP) and the impact of these residues on dairy product manufacture.
- Microbiological perspective – continuous monitoring for pathogens is necessary, development of methods for quantification of *B. cereus* in milk and study of biodiversity and the factors that affect it are also necessary.
- Quality parameters such as somatic cell count (SCC) – the relationship between milk volume produced and SCC needs further elucidation.
- The milk processor decides on payment on quality parameters based on their product portfolio – more discussion with milk quality personnel and milk producers may assist in improving milk quality.

Opportunity/Benefit:

The identification of gaps in knowledge as a potential impediment to manufacture of premium dairy products from Irish milk will allow all of the stakeholders to focus on these issues in the very near future through research, advice and payment incentives.

1. Project background:

Expansion in milk production towards 2020 will require the Irish dairy industry to process this additional milk while at the same time develop markets for the increased supply of dairy products. This will require milk of the highest standard in terms of milk composition and processability, bacteriological status and residue levels. Much research work on milk quality has been completed in recent years and both the generic definition of milk quality and the factors that affect it are known. However, new research is required to deal with 'harder to attain' current and future quality standards as well as impediments to achieving optimum milk quality from modern, expanded farm systems that need to be profitable and sustainable. Specifically, the concept of individual markets (e.g. infant milk formula [IMF] and cheese manufacturers) requesting specific dairy product quality standards (which is largely determined by raw milk quality) is a particular challenge facing the dairy processor. Criteria for raw milk supply in EU legislation is outlined in EU (2004, 2005), e.g. plate count of ≤ 100,000 cfu/ml at 30°C and SCC ≤ 400,000 cells/ml. However, some specific sectors within the industry require specific quality criteria, e.g. trichloromethane (TCM) levels of < 0.03mg/kg in butter and < 250 µg/kg of iodine in milk intended for use as a raw material for infant feed formula. There is also a preference by the Russian market for milk of <200,000 cells/ml.

2. Questions addressed by the project:

The essential question is 'What are the knowledge gaps that need to be addressed in order to: (i) meet raw milk quality standards necessary for international markets, (ii) diversify the current product range and (iii) expand the duration of the year for which these products can be manufactured.

To identify these knowledge gaps, the questions asked are:

- What milk quality parameters are used in competitor EU, and other countries, e.g. New Zealand?
- Describe the demography of the Irish dairy cow population and their management with respect to factors that affect raw milk quality, e.g. genetics, age, location, feeding management and stage of lactation.
- Determine national trends and cow lactation profile for milk quality parameters including SCC and TBC from grass based systems of production.
- Review the state of knowledge of the microbiological quality of Irish milk.
- Identify existing and emerging residue contamination concerns for milk and potential impact for the dairy industry.

3. The experimental studies:

- Information on the milk quality payment systems in different countries was requested. A questionnaire was designed and sent to colleagues in other countries, and colleagues in the International Dairy Federation. Seventeen questionnaires were distributed and 9 returned.
- Milk recording data on 58,659,604 test day records from 2,789,000 individual cows across 8,669,464 lactations were obtained from the Irish Cattle Breeding Federation national database. Corresponding information on fixed effects of animals including ancestry, breed fractions, date of birth, parity, herd identifier as

well as herd information including region of location were also obtained from the national database. On average animals had 21.0 test day records across their lifetime, or 6.8 test day records per lactation. Data were then analysed.

- Bulk tank milk quality data was supplied by ten individual milk processors representing 11,824 individual milk suppliers from across the Republic of Ireland. Data were supplied from 2006 to 2011, inclusive. Trends in SCC and TBC across year, across month and across herd size were quantified using mixed models in ASReml.
- Recent microbiological data on Irish milk was collated, and state-of-the-art methodologies for studying biodiversity were investigated. Experimental studies were conducted to test the effectiveness of a number of milking machine wash routines on the hygienic quality of milk.
- A comprehensive review was carried out on the residues that may be of concern for the dairy industry.

4. Main results:

- Information on the milk quality payment systems in different countries was obtained. Only one country has a national payment system. The payment systems are confidential to the different processors and not publically available. This gives flexibility to the processors to pay for quality parameters they require for their product portfolio.
- All animal and herd factors tested had a significant effect on somatic cell count. Older animals, animals which were younger at calving than contemporaries and Holstein animals have higher somatic cell count than younger alternative breed animals who calve at the median age at calving. In addition, mixed calving production systems and herds in Connaught had higher somatic cell count than Spring calving herds in the other regions of Ireland.
- There was no consistent trend in either SCC or TBC across years to demonstrate that milk quality is either improving or disimproving. Lowest SCC and TBC were observed in the Summer months and in the largest herds. Poor weather appears to have an adverse effect on SCC, however further research is required to quantify the association between rainfall and increased SCC.
- Recent microbiological data on Irish milk was collated, and state-of-the-art methodologies for studying biodiversity were investigated. Effectiveness of a number of milking machine wash routines on the hygienic quality of milk was established. Clear guidelines have now been published in the form of four defined milking machine wash routines.
- A comprehensive review was carried out of the residues that may be of concern for the dairy industry. Priority residues were identified that may be of concern at present and in the future including, banned substances (i.e. recombinant bovine somatotropin), cephalosporin antibiotics, anti-parasitic agents, biocides (quaternary ammonium compounds, chlorinated disinfectants), aflatoxin M1, plant toxins, plasticisers and persistent organic pollutants (PCBs and brominated flame retardants).

5. Opportunity/Benefit:

- As the information on payment for quality is confidential, the results of this task are of limited value, except to know that other countries don't have a national payment system.
- Recent recommendations have promoted calving animals at a younger age however this study has shown that animals that are younger than the average age of their contemporaries at calving have higher somatic cell count. The regional differences observed in somatic cell count indicate that further effort is required in Connaught to reduce somatic cell count and may require greater education, or a revision of recommended practices to deal with somatic cell count in production systems in Connaught.
- This study provided the first quantification of the somatic cell count and total bacterial count across the majority (66%) of the national herd. The results from this study indicate that SCC and TBC are not improving in the national herd. However, in order to quantify improvements, baseline figures are required such as were provided by this study.
- The microbiological data will be used to inform future research. The wash routines are freely available and should be widely used by milk producers.
- This succinct report identified key residues that are of concern to the dairy industry. This included residues that should be monitored on an ongoing basis and new emerging residues that warrant further research. The latter may become an issue for the industry in the future due to improvements in analytical detection.

6. Dissemination:

Through the 'Milk and Product Quality Forum' that meets bi-annually, the information generated by the study has been shared with Researchers within the scientific community, Irish Dairy Board and Department of Agriculture personnel, Irish regulatory bodies, most Irish milk processors and milk purchasers, Teagasc Advisory service, AHI (Animal Health Ireland), ICBF (Irish Cattle Breeding Federation), ICOS (Irish Co-operative Organisation Society) and IMQCS (Irish Milk Quality Cooperative Society) personnel.

Two milk quality workshops have been held at which different aspects of this work has been disseminated, and a Milk Quality Conference is planned for December 2013. The results have also been disseminated to Teagasc Advisory personnel through in-service training sessions.

Main publications:

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Gleeson D – milking equipment wash routines. Available at: http://www.agresearch.teagasc.ie/moorepark/Articles/milking%20machine%20cleaning%20routines.pdf

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Jordan, K.N., Beresford, T., O'Brien, B. and Gleeson, D. (2012) 'Milk quality maintaining standards' Tresearch 7 (1) : 34–35.

Teagasc web page: http://www.agresearch.teagasc.ie/moorepark/milkquality

Animal and Grassland Research & Innovation Programme

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

Key external stakeholders:

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

Practical implications for stakeholders:

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

Main results:

- Producing milk by grazing cows over the Winter at low stocking density (1.2 cows/ha) had no effect on milk output per cow, milk composition and the processing characteristics of the milk but substantially lowered the cost offering Irish dairy producers a viable option to produce organic milk during the Winter months when a premium price is paid for the milk.
- Trampling in Winter resulted in less of a reduction in pre-grazing herbage yield than trampling in Spring due to lower soil surface deformation and longer recovery periods. Grazing during the Winter resulted in significant increases in clover content, herbage production and N-fixation estimates. The results show that grazing during the Winter can increase clover content, BNF and herbage production and is therefore a useful management tool for maintaining or increasing clover contents of swards.

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Technology

- A 42-day rotation with a low defoliation height (2.7 to 3.5 cm) during the Autumn and early Winter gave the most desirable results in terms of herbage yield and white clover stolon mass in the following Spring/Summer.
- Grazing over the Winter period on this site had no effect on N losses to groundwater due to high natural buffering capacity of the soils associated with heavy texture, high SOC, high soil pH, anaerobic conditions and presence of shallow groundwater. Mean concentrations of DON, NH4-N, NO2-N and NO3-N were 2.16, 0.35, 0.01 and 0.37 mg L^{-1} respectively.

Opportunity/Benefit:

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

1. Project background:

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

2. Questions addressed by the project:

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

3. The experimental studies:

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

4. Main results:

- Producing milk by grazing cows over the Winter at low stocking density (1.2 cows/ha) had no effect on milk output per cow, milk composition and the processing characteristics of the milk but substantially lowered the cost, offering Irish dairy producers a viable option to produce organic milk during the Winter months when a premium price is paid for the milk.
- Trampling in Winter resulted in less of a reduction in pre-grazing herbage yield than trampling in Spring due to lower soil surface deformation and longer recovery periods. Grazing during the Winter resulted in significant increases in clover content, herbage production and N-fixation estimates. The results show that grazing during the Winter can increase clover content, BNF and herbage production and is therefore a useful management tool for maintaining or increasing clover contents of swards.
- A 42-day rotation with a low defoliation height (2.7 to 3.5 cm) during the Autumn and early Winter gave the most desirable results in terms of herbage yield and white clover stolon mass in the following Spring/Summer.
- Grazing over the Winter period on this site had no effect on N losses to groundwater due to high natural buffering capacity of the soils associated with heavy texture, high SOC, high soil pH, anaerobic conditions and presence of shallow groundwater. Mean concentrations of DON, NH4-N, NO2-N and NO3-N were 2.16, 0.35, 0.01 and 0.37 mg L^{-1} respectively.

5. Opportunity/Benefit:

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

6. Dissemination:

Main publications:

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

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

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Phelan, P., Keogh, B., Fitzgerald, E., Casey I.A. and Humphreys, J. (2011). The effect of trampling by dairy cows on a rotationally grazed grass-clover sward. *Proceedings of the 10 th research conference of the British Grassland Society*, 20th–21st September 2011. Belfast. p7.

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

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Animal and Grassland Research & Innovation Programme

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Studies on the management and utilisation of soiled water and dilute slurry on Irish farms

Collaborating Institutions:
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Compiled by:
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Key external stakeholders:

Dairy farmers, dairy industry, policymakers.

Practical implications for stakeholders:

- Dairy Soiled Water (DSW) is water from concreted areas, hard stand areas and holding areas for livestock that has become contaminated by livestock faeces or urine, chemical fertilisers and parlour washings.
- This project examined Dairy Soiled Water produced on Irish dairy farms, to assess soiled water quantity and composition, and the best management options available to farmers.
- On average, 9784 l of DSW are produced per cow per year, containing 6.9, 0.9 and 6.3 kg of N, P and K, respectively and has potential as an organic fertiliser on-farm.
- Dairy Soiled Water has a high fertiliser replacement value for grass growth. Greater effectiveness as a fertiliser than slurry due to better infiltration and decreased ammonia losses.
- Current management of slurries and soiled water in Ireland is regulated primarily by the Nitrate Regulations (SI No. 101 of 2009) giving effect to Council Directive 91/676/EEC.
- The Nitrate Regulations define soiled water as having a Biological Oxygen Demand (BOD) of less than 2,500 mg/l or a dry matter (DM) content of less than 1 %. Anything more concentrated is considered a slurry.
- The highest economic savings can be attained using low cost storage and application methods combined with strategic application during the growing season for optimum NFRV and DM response.

Technology

Main results:

- Dairy Soiled Water contains significant quantities of nutrients (N, P, K) and has potential as an organic fertiliser on-farm. High fertiliser replacement value for grass growth.
- On average, 9784 l of DSW are produced per cow per year, containing 6.9, 0.9 and 6.3 kg of N, P and K, respectively.
- For a typical Irish dairy farm stocked at 2.5 cows ha^{-1}, this DSW could supply approximately 17.2, 2.3 and 15.8 kg ha^{-1} of N, P and K, respectively, across the farm, annually.
- Woodchip can be used as a filter medium as an effective method of reducing the concentration of organic matter, suspended sediment, and nutrients, which proved to be an effective alternative treatment process for DSW.
- The results illustrate that, integration of Dairy Soiled Water (DSW) into nutrient management planning, while applying during conventional agronomic practices, reduced total N emissions and leaching losses compared to inorganic fertiliser.

Opportunity/Benefit:

These results have implications for dairy farmers, the dairy industry, policy makers and the research community. The findings provide valuable data on Dairy Soiled Water focusing on its nutrient and biological content, agronomic response, environment losses, treatment options and the economic implications of different management practices. These findings allow DSW to be integrated into farm nutrient management planning, enabling farmers to use DSW as a replacement for inorganic fertiliser N in temperate grassland systems.

1. Project background:

Irish agriculture must conform to EU requirements under the EU Nitrates Directive and the Water Framework Directive to reduce the nitrate loss from farming systems to improve the quality of water. Currently producers are under increased economic pressure due to volatile product prices and increasing costs of production while minimising any negative effects on the environment. Producers are increasingly looking towards adopting efficient low cost production systems, while utilising all available resources of the enterprise.

This project characterised soiled water produced on Irish dairy farms and examined the effects on its management and utilisation.

Dairy Soiled Water (DSW) is a farm effluent produced through the washing-down of milking parlours and holding areas to maintain hygiene levels in the production of high quality milk. Dairy Soiled Water consists of a relatively dilute mixture of cow faeces, urine, spilt milk and detergents. This effluent typically contains nutrients that are potentially plant-available but may also pose a risk of environmental pollution if not managed correctly. The best management option for organic residues, both in Ireland and internationally, is land application and appropriate applications are widely recognised as an opportunity to enhance plant nutrient supply and soil structure. However, while they can be beneficial, a number of studies have also confirmed the environmental problems associated with organic residue application. Current management of these effluents in Ireland is regulated primarily by the Nitrate Regulations giving effect to the EU Nitrates Directive. The regulations are focused on decreasing N loss to ground and surface waters through improved on-farm nutrient management. The Nitrates Directive states that there should be a balance between nitrogen supply from animal manures and chemical fertilisers and the nitrogen demand of the crop, thus avoiding nitrogen surpluses and associated losses to water. However, little is known about its nutrient content, and the effect of management practices on DSW production. Knowledge of nutrient sources on-farm is a prerequisite to effective nutrient management planning to increase farm efficiency and profitability while protecting water quality.

2. Questions addressed by the project:

- The project was established, to identify soiled water/dilute slurry management practices which maximise nutrient uptake by grass and minimise risk of nutrient loss to the environment.
- To devise and disseminate best-practice guidelines for the management of soiled water/dilute slurry.
- Promote sustainability, reducing risk to the environment by providing better management solutions for soiled water/dilute slurry. Increasing nitrogen efficiency; decreasing the impact of reduced organic nitrogen limits. Increasing nutrient recovery from soiled water/dilute slurry while reducing fertiliser requirements and costs.

3. The experimental studies:

This study quantified DSW production on Irish dairy farms and assessed the agronomic benefit and environmental risks associated with application to grassland. Sixty dairy farms across 18 counties were surveyed to characterise the volumes and chemical composition (nutrients and other biochemical parameters) of DSW produced on Irish dairy farms and to relate them to management practices. The number of farms selected in each county was reflective of it's share of the national dairy herd so that each farm represents between 10,000 and 20,000 dairy cows. Dairy Soiled Water was evaluated to assess the risks of loss of nitrogen to the environment through leaching and gaseous emissions using Lysimeters with two contrasting soil types. Laboratory scale and farm scale wood chip filters were constructed to test the potential of woodchips as a filter for treating and polishing soiled water. A plot experiment was undertaken to evaluate herbage yield response from DSW applied to grassland on two sites with contrasting soil and drainage conditions. The effect of application timing (season) and dilution on yield was also investigated. Inorganic NFRV of DSW for herbage production was calculated to assess the potential of DSW as a replacement for inorganic fertiliser N in temperate grassland systems. An economic evaluation was undertaken to assess a range of solutions for the management of soiled water/dilute slurry on Irish farms. The different management solutions investigated the economic effect of contrasting storage and application methods, combined with a range of storage periods.

4. Main results:

- On average, 9784 l of DSW are produced per cow per year, containing 6.9, 0.9 and 6.3 kg of N, P and K, respectively.
- A typical Irish dairy farm stocked at 2.5 cows ha^{-1} this DSW could supply approximately 17.2, 2.3 and 15.8 kg ha^{-1} of N, P and K, respectively, across the farm, annually.
- Mean nitrogen fertiliser replacement values of 72 to 90% indicate that DSW has the potential to substitute for inorganic fertiliser N.
- Dairy Soiled Water has the potential to be used as a fertiliser to increase grass herbage production during the growing season. Yield response to soiled water application were similar to that of inorganic fertiliser.
- The optimal application timing, agronomically and environmentally, is during the growth period, from March to September. The integration of Dairy Soiled Water (DSW) into nutrient management planning, while applying during conventional agronomic practices, reduced total N losses from nitrate leaching and nitrous oxide emissions.
- The total N losses observed for integrated DSW treatments were significantly lower than that of FN.
- Total N losses (leaching) for the DSW integration treatments were reduced by 45–38%, when compared to chemical fertiliser.
- The integration of DSW into nutrient management planning, while applying during the grazing season, significantly reduced the production of N_2O (3.97 kg N $ha^{-1}yr^{-1}$) when compared to inorganic fertiliser (6.36 kg N ha^{-1} yr^{-1}).
- Application of DSW during the Winter period significantly increased nitrate leaching and nitrous oxide losses.
- For the laboratory-scale filters, average COD, SS and TN decreases of 95, 99 and 88%.
- The dominant treatment mechanism was physical filtration, but sorption and biological uptake also played a role. As the filters were aerobic, mineralisation and nitrification occurred.
- The farm-scale filters had average COD, SS, NH_4-N, PO_4-P and TN reductions of 66, 86, 72, 31 and 57%, respectively, giving effluent concentrations of 1,961 mg L^{-1}, 84 mg L^{-1}, 37 mg L^{-1}, 24.7 mg L^{-1} and 153 mg L^{-1}. Effluent nutrient concentrations remained relatively stable over the study period, indicating the robustness of the filter.
- The effluents exiting the woodchip filters were put through a further filtration process using a Sand filter to further polish the effluent. The COD SS, TN exiting the sand filter was reduced by a mean of 55%, 62%, 57% respectively, Sand filters appear to offer an effective method of achieving good decreases in the concentration of organic matter, suspended sediment, nutrients and coliforms, highlighting sand filters are an effective component in the treatment process of DSW.
- The economic analysis highlighted, storage and application were the main costs associated with DSW.

- Storing DSW together with slurry proved to be up to 45% more cost effective per m^3 stored than storing DSW separately.
- Higher savings can be attained using low cost storage and application methods combined with strategic application during the growing season for optimum NFRV and DM response.

5. Opportunity/Benefit:

- Dairy Soiled Water has the potential to be used as a fertiliser to increase grass herbage production during the growing season. Yield response to soiled water application were similar to that of inorganic fertiliser and can substitute inorganic fertiliser N, offering cost savings to farmers and decreasing farm N surpluses and their associated environmental impacts.
- Strategic application of DSW during the growing season reduces emissions and leaching loss from N and increases herbage DM production.
- The N_2O emissions and NO_3 leaching losses from DSW were dependant on timing (season) of application. Winter application of DSW resulted in the highest N_2O emissions NO_3 leaching. The integration of DSW into nutrient management planning, with applications during the grazing season, significantly reduced the production of N_2O emissions NO_3 leaching, when compared to inorganic fertiliser. Soil type was not found to affect N_2O emission significantly, despite a strong contrast in soil type and drainage conditions.
- The use of woodchip as filter medium for treating DSW highlighted that, woodchip is a low cost, minimal maintenance treatment system using a renewable resource that can be easily integrated into existing farm infrastructure, as a treatment and management option for the DSW.
- The best economic and agronomic savings were generated from reduced purchase of fertiliser N and additional DM grown during the Spring and Summer months from strategic applications of DSW.
- The different DSW management strategies investigated highlight the highest economic savings can be attained using low cost storage and application methods combined with strategic application during the growing season for optimum NFRV and DM response.

6. Dissemination:

The primary stakeholders for this research are Irish dairy farmers, research scientists and policy makers.

Findings have been presented at national and international conferences. Publication in peer-reviewed journals is on-going- one paper accepted, 5 more submitted and 3 in preparation. Dissemination using the popular press (The Farmer's Journal, Today's Farm, TResearch, Irish Examiner) and the internet (articles on Moorepark website) has been undertaken.

Main publications:

Ruane, E., Murphy, P., Clifford, E., O'Reilly, E., French, P., Rodgers, M. 2012. Performance of a woodchip filter to treat soiled water. Journal of Environmental Management 98 49–55.

Ruane, E., Murphy, P., Clifford, E., Healy, G., French, P., Rodgers, M. 2011. On-farm treatment of Dairy Soiled Water using aerobic woodchip filters. Water research 45 6668–6676.

Minogue, D., French, P., Bolger, T. & Murphy, P. 2011. The fertiliser potential of Dairy Soiled Water in temperate grasslands. Agricultural Research Forum 2011, Tullamore, Ireland.

Popular publications:

Murphy PNC., Minogue, D., Ruane, E., French, P., Bolger, T. & Rodgers, M., 2011. Soiled water – a valuable resource. TResearch 6 (3), 26–27.

Murphy PNC., Minogue, D., Boland, A., and French P. 2011. Fertiliser value of Dairy Soiled Water. Irish National Dairy Conference 2011, The Irish dairy industry to 2015 and beyond, 84–88.

Animal and Grassland Research & Innovation Programme

Project number:
5794

Date:
December, 2012

Funding source:
DAFM

Project dates:
Dec 2007 –Jun 2012

Development of an integrated farm and processing sector model for the Irish dairy industry

Key external stakeholders:

Dairy farmers, dairy processors, cattle breeding organisations, DAFM.

Practical implications for stakeholders:

- Optimum configuration of the Irish dairy industry.
- Optimum milk supply profile for the Irish dairy industry.
- Development and the introduction of multiple component pricing systems.
- Development of seasonal milk pricing systems for Ireland.
- Quantification of the potential expansion post milk quota removal.
- Evaluation of the economic affect of increasing grazing season length in Ireland.

Main results:

- A milk processing and a milk transport model was developed for the Irish dairy industry.
- A seasonal milk supply profile was shown to be more profitable to the Irish dairy industry than moving towards a less seasonal (split calving 50% Spring, 50% Autumn) milk supply profile.
- A seasonal supply profile with a mean calving date of mid-February relative to mid-March is optimal for the farm and processing sector.
- The optimal structure of the Irish dairy industry is to have six milk processing sites located in: North West, Mid West, Munster West, Munster South West, Munster East, South Leinster.

Collaborating Institutions:
University College Dublin (UCD)
University College Cork (UCC)
Cork Institute of Technology (CIT)

Teagasc project team:
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Una Geary
Dr. Pat Dillon
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Dr. Doris Laepple

External collaborators:
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Dr. Declan O'Connor, CIT
Dr. Michael Wallace, UCD
Dr. Michael Keane, UCC
Dr. Carrie Quinlan, UCC
Karin Heinschink, UCD

Compiled by:
Una Geary
Laurence Shalloo

Technology

- Models have simulated that there will be a 45% increase in milk output by 2020 post milk quota removal.

Opportunity/Benefit:

The project has developed milk pricing strategies around both seasonal milk payment and the multiple component pricing systems, demonstrating how rapidly such systems can act as a signal to farmers. This project is responsible for methodologies for most processors in Ireland around the A+B-C systems of milk payment. Using these methodologies seasonal milk payment systems for various milk processors have been developed. The identification of locations where expansion will occur nationally has helped the decision making process around building additional processing capacity. The modelling of expansion by 2020 has reinforced the view that the Food Harvest 2020 targets can be achieved.

The Moorepark Processing Sector Model (MPSM) has been developed and can be used in further analysis (e.g. EBI development, quantifying animal health issues on product yield and quality).

1. Project background:

Milk quota removal have presented real opportunities for the dairy industry to generate increased milk production and higher returns and ultimately higher industry profitability (farmer and processor alike). However for the Irish dairy industry to truly reap the rewards of this policy change a number of questions needed to be answered: will milk production in Ireland increase when quotas are abolished, if so where will it be produced, is the current structure of the processing sector adequate to process it, should the processing sector continue to process at a peak to trough ratio of 6.0 to 1, should the milk supply profiles be flattened or should there be more plant capacity constructed with expansion, if additional plant capacity is required where should it be constructed? Therefore to help inform the optimal strategy for the industry, that is profitable for both the farmer and processor alike while maintaining international competitiveness, clarity on each of these issues was essential.

2. Questions addressed by the project:

- To develop a milk processing sector and milk transport model for the Irish dairy Industry.
- What is the most profitable milk supply profile for the Irish dairy industry as a whole (farmer and processor)?
- What milk price, value per kg of fat and protein should be paid to farmers?
- Where is the expansion in milk production likely to occur?
- What effect will (i) increased milk output, (ii) different tanker sizes and (iii) different supply patterns have on milk transport costs and on carbon emissions from milk transport?
- What effect will the projected expansion in milk supply have on the processing capacity of the Irish dairy industry?
- In terms of capacity investment what is the optimal site location and scale of the required investment to support the future milk supply?

3. The experimental studies:

The Moorepark Processing Sector Model (MPSM) was developed which simulates the production of dairy products. The MPSM estimated the quantities of products and by-products that can be produced from the available milk pool. Processing costs are simulated, and the return from raw milk and its individual component values are calculated. The MPSM was linked with Moorepark Dairy Systems Model (MDSM) to examine the effect of a change within the Irish dairy industry (change to the milk supply profile, increased milk production etc) throughout the dairy system. In addition a simulation/optimisation milk transport model was developed for the Irish dairy industry. This model allowed the examination of a wide range of efficiency factors in milk transport, it was also used to examine processing capacity, investment requirements and to help determine the optimal expansion strategies in terms of site location and scale. Data from the National Farm Survey was used to model expansion post milk quota removal.

4. Main results:

1. A mean calving date of mid-February relative to a mean calving date of mid-March is more profitable for the Irish dairy industry, generating an additional net profit of €17.7 million per annum.
2. Moving from a seasonal milk supply profile with a mean calving date of mid-February to a less seasonal milk supply profile with 50% of the herd calved in Spring and 50% calved in Autumn results in a reduction in industry profit of €83 million per annum. Therefore, the seasonal milk supply profile is more profitable than the less seasonal milk supply profile.
3. Milk output expected to increase by 2020:

   @26 cents/L. Projected increase in milk supply: 25% South, 22% SouthWest, 15% East, 9% Rest.

   @28 cents/L. Projected increase in milk supply: 43% South, 38% SouthWest, 27% East, 34% Rest.

   @30 cents/L. Projected increase in milk supply: 52% South, 42% SouthWest, 44% East, 37% Rest.
4. Increase in volume resulted in an increase in milk transport costs but at a decreasing rate (volume effect).
5. Tankers with capacity of 27,360 litres are more economical and environmentally friendly compared with tankers with capacity of 22,800 litres.
6. The optimum structure of the Irish dairy industry is 6 sites: North West, Mid West, Munster West, Munster South West, Munster East, South Leinster. An increase in capital costs of 50% did not effect the optimum configuration.

5. Opportunity/Benefit:

The project has developed milk pricing strategies around both seasonal milk payment and the multiple component pricing. This project has quantified the benefits associated with staying with the current seasonal milk supply profile and it demonstrated that the optimum strategy for the dairy industry centres around remaining with the seasonal milk supply profile and expanding milk output through building additional processing capacity at a number of optimum sites. The identification of locations where expansion will occur nationally has helped the decision making process around building additional processing capacity. The MPSM and MDSM are available to support any analysis for the Irish dairy industry. The research carried out in this project clearly demonstrated the power of component milk pricing systems and how rapidly such systems can act as a signal to farmers. Over the duration of this project numerous one to one meetings with processors and their boards have been completed resulting in the implementation of the A+B-C milk pricing systems. The Authors are responsible for methodologies for all processors in Ireland around the A+B-C systems of milk payment. They also have developed seasonal milk payment systems for various milk processors.

6. Dissemination:

Thirteen peer reviewed publications were produced from this work. The results of the project were widely disseminated at national and international conferences and in popular press media (TResearch 2009–11 and Farmers Journal 2010). Research from the project was presented at the IDF World Dairy Summit 2009–11; the Agricultural Research Forum and the British Society for Agricultural Science 2010, 2011, 2013; Agricultural Economics Society of Ireland conferences 2010–11; Moorepark Open days, Irish Transport Research Network conferences and UCC Doctoral conferences. The A+B-C multiple component milk pricing system developed in this analysis will continue to be used in consultation with milk processors. The MPSM developed as part of this project will be used to help estimate the cost of mastitis to the milk processing sector.

http://www.agresearchforum.com/publicationsarf/2013/proceedings2013.pdf pp.43

http://www.agresearchforum.com/publicationsarf/2011/proceedings2011.pdf pp. 73

http://www.agresearchforum.com/publicationsarf/2010/proceedings2010.pdf pp. 335

Main publications:

Geary, U., Lopez-Villalobos, N., Garrick, G. and Shalloo, L. 2012. An analysis of the implications of a change to the seasonal milk supply profile in the Irish dairy industry utilising a seasonal processing sector model. *Cambridge Journal of Agricultural Science*, 150: 389–407.

Geary, U., Lopez-Villalobos, N., Garrick, G. and Shalloo, L. 2010. Development and application of a processing model for the Irish dairy industry. *Journal of Dairy Science,* 93: 5091–5100.

Quinlan, C., Shalloo L., Keane, M., O'Connor, D., Enright P. and Geary U. 2012. The interaction between economies of scale and transport costs in the Irish dairy industry. *Journal of Dairy Science* (Accepted).

Popular publications:

Geary U and Shalloo L. Mastitis and farm profitability. *TResearch*, Vol 6: Number 4. Winter 2011

Geary U and Shalloo L. A milk processing sector model for Ireland. *TResearch*, Vol 5: Number 4. Winter 2010

Geary U, Shalloo L and Hennessy T. Milk processing, utilisation and pricing. *TResearch*, Vol 4: Number 2. Summer 2009

Laepple, D., Hennessy, T. and O'Donoghue, C. 2010. Farm Demography and the Opportunities for Dairy Expansion in Food Harvest 2020, *Irish Farmers Journal*.

Hennessy, T., Kinsella, A., Moran, B. and Laepple, D. 2010. Benefits of Extending the Grazing Season, *TResearch* Vol. 5(4), pp. 26–27.

Hennessy, T., Kinsella, A., Moran, B. and Laepple, D. 2010. Benefits of Extending the Grazing Season, *Irish Farmers Journal*.

Animal and Grassland Research & Innovation Programme

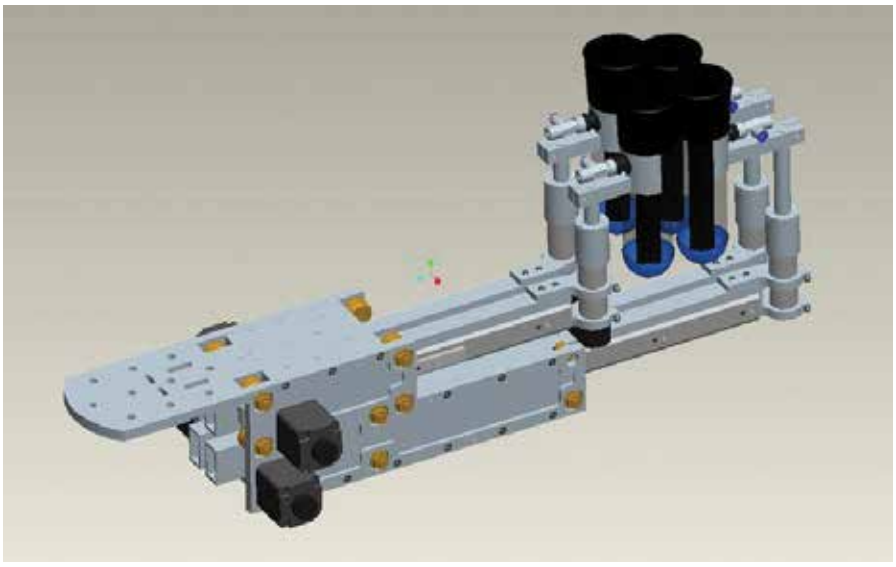
Project number:
5497

Date:
September, 2012

Funding source:
Teagasc / DCU

Project dates:
Sep 2004 – May 2012

Development of a robotic milking system for use in rotary parlours



Collaborating Institutions:
School of Mechanical Engineering, DCU

Teagasc project team:
Mr. John Upton (Pl)
Dr. Padraig French,
Dr. Pat Dillon,
Dr. Eddie O'Callaghan

External collaborators:
Dr. Harry Esmonde (Dairymaster)
Dr. Brian Corcoran (DCU)

Compiled by:
John Upton

Key external stakeholders:

Pasture based dairy farmers, milking system manufacturers, academic staff working in the area of milking technology.

Practical implications for stakeholders:

The outcome/technology is a robotic milking cup applicator suited to operation on a rotary milking parlour.

- Reduced labour costs for large scale dairy farming.
- State of the art milking technology.
- Contribution to the state of the art in the area of teat identification and robotic cup application.

Main results:

A robotic milking cup applicator has been developed which is capable of simultaneously applying milking cups to the udder of an animal. A teat sensing system has also been developed integrating thermal and optical vision systems which is suited to the rapid determination of the teat position on an animal in the milking parlour.

Opportunity/Benefit:

This technology is ideally suited for licensing to a third party such as a manufacturer of automated milking machines. Thereafter the milking system could be used on rotary milking parlours which are ideally suited for large pasture based dairy herds.

Technology

1. Project background:

The challenge for Irish dairy farmers is to increase productivity without incurring additional costs chief among which is labour. A modern automated milking parlour can allow efficient throughput of animals thereby facilitating increased animal head count and improved labour efficiency. Increasingly the rotary parlour is being adopted as an optimal solution, where herds in excess of two hundred animals are easily handled. Much of the milking process has been automated except for milking cup application. This project addresses that problem by developing a robotic milking cup applicator suitable for use on a rotary parlour.

2. Questions addressed by the project:

- Can a robotic milking cup applicator be developed for integration in a rotary milking parlour?
- Can the new system be retrofitted to existing parlours with minimal adaptation to the parlour?

3. The experimental studies:

The project was split into two aspects. Cup application and teat sensing. New techniques and devices were developed to deal with each aspect.

4. Main results:

Robotic applicator

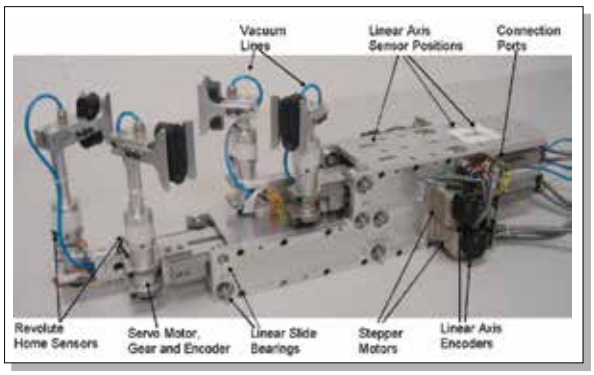


Figure 1

A multilinked robotic applicator shown In Figure 1 was designed and built at DCU. This was coupled to a six axis industrial robot arm and tested by applying milking cups simulatneously to four phantom teats. The teats were placed in arbitrary positions corresponding to typical udder configurations. The system was capable of simultaneously and independently manipulating all four cups so that they were succesfully applied to the teats in a short time frame.

Teat Sensing

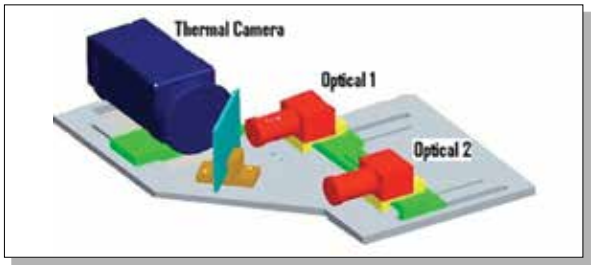


Figure 2

A hybrid sensing system incorporating a thermal camera and two optical cameras was developed to identify and then measure teat position, see Figure 2. The thermal camera was used to identify the teats from background objects. High precision optical cameras use this information so that accurate teat position values could then be determined using sereo triangulation.

5. Opportunity/Benefit:

While the project was ultimately aimed at allowing pasture based dairy farmers to benefit from the use of automation, the immediate goal was to license the technology to a manufacturer of milking systems. One major milking machine manufacturer initially expressed an interest in the technology but later declined to get involved. Due to limited funding on the part of Teagasc and DCU, further work in this area has been put on hold.

6. Dissemination:

Main publications:

Ben Azouz A., Hunt Duffy A., Corcoran B., Esmonde H., O'Callaghan E., "Development of a Teat Sensing System for Robotic Milking" 11th Mechatronics Forum Biennial International Conference, Limerick, Ireland, June 23rd-25th, 2008.

D. Christie D., White J., Corcoran B., Esmonde H., O'Callaghan E., "Design and Control of an End-Effector for Application of Milking Cups" 11th Mechatronics Forum Biennial International Conference, Limerick, Ireland, June 23rd-25th, 2008

Esmonde H., See H., "Spectral Identification of Smart Fluids", 11th Mechatronics Forum Biennial International Conference, Limerick, Ireland, June 23rd-25th, 2008.

Animal and Grassland Research & Innovation Programme

Project number:
5899

Date:
September, 2013

Funding source:
Teagasc

Project dates:
Oct 2008 – Dec 2012

Energy efficient dairying

Key external stakeholders:

Dairy farmers, dairy advisors and planners, milking system manufacturers, academic staff working in the area of milking technology.

Practical implications for stakeholders:

The outcome of this project includes baseline energy consumption data for commercial Irish dairy farms and a list of recommendations for improving energy efficiency.

- Methodologies for auditing of energy use have been developed.
- Enhanced knowledge of energy consumption trends on Irish dairy farms.
- Hotspots of energy consumption have been identified.
- Opportunities to reduce costs associated with energy consumption have been identified.

Main results:

- Electricity represents 12% of total energy use of Irish dairy farms.
- Average electricity consumption on 22 dairy farms was 3.9 mega Joules per kg of milk solids (MJ/kg MS), range 2.25 – 6.75MJ/kg MS.
- The major processes of electricity consumption were: milk cooling (31%), water heating (23%), milking machine (20%), pumping water (5%), lighting (3%), other miscellaneous consumption such as Winter housing systems, air compressors and backing gates consumed 18% of the electrical energy.

Collaborating Institutions:
Cork Institute of Technology (CIT)
Wageningen University (WU)

Teagasc project team:
Mr. John Upton (PI)
Mr. Michael Murphy (Walsh Fellow)
Dr. Padraig French
Dr. Pat Dillon

External collaborators:
Dr. Michael J. O'Mahony, CIT
Prof. Dr. Imke J. M. De Boer, WU
Prof. Dr. Peter W.G. Groot Koerkamp, WU

Compiled by:
John Upton

Technology

Opportunity/Benefit:

The results of this project describe the energy consumption trends and energy costs associated with producing milk in Ireland. Adoption of the main results of this project at farm level would result in optimised energy use strategies for integration of energy efficient technologies, minimising energy costs and maximising return on investment.

1. Project background:

In Ireland, milk production has the potential to increase by 50% by 2020 if farmers respond to national policy frameworks and are encouraged by the abolition of EU milk quotas in 2015. Milk production systems in Ireland, therefore, will continue to focus on cost control and maximising the amount of milk that is produced from grazed grass. Efficient use of energy is one way to improve the cost competitiveness of the Irish dairy sector. At this moment, electricity costs on Irish farms are around 4% of milk production variable costs, but they are expected to increase because of rising global energy prices. Besides a potential cost reduction, reducing electricity consumption has an environmental benefit, because electricity consumption has been shown to represent 25% of total energy use on pasture-based dairy farms in New Zealand. Hence, understanding electricity consumption trends will have the potential to reduce overall energy use and reduce production costs while improving sustainability.

2. Questions addressed by the project:

- What proportion of total energy use does electricity represent on Irish dairy farms?
- What is the energy consumption and energy cost associated with producing milk on Irish farms?
- What are the options for reducing energy consumption and energy costs on Irish dairy farms?

3. The experimental studies:

We selected 22 commercial dairy farms from a database of advisory clients within Teagasc. Selection criteria included availability of financial information, data on herd size and the ability and willingness of the farmer to collect and maintain accurate data.

All data were collected for 2011. All inputs and outputs necessary to compile a life cycle energy assessment were recorded using a combination of manual recording and wireless data transfer.

First, general farm data was collected using a survey, including farm area worked and detailed information on farm infrastructure (e.g. type and size of milking equipment, milk cooling equipment, manure handling equipment, machinery and Winter housing facilities).

Second, monthly questionnaires were completed by each farmer. Data collected was: quantity and type of fertiliser used, quantity of diesel or fuel oil consumed, area of land worked by contractors, amount and type of concentrate feed purchased, forage/ manure/ slurry imported or exported from the farm, quantity and type of farm chemicals used and a stock take of all animals on the farm. In order to assess actual consumption of, for example, fertiliser or feed, opening and closing balances were obtained at the beginning and end of the monitoring period. In addition to this data, milk production and composition information was gathered from the milk processors.

Third, electricity consumption was recorded using a wireless monitoring system supplied by Carlo Gavazzi. Powersoft logging and recording software was used to record cumulative energy use in kiloWatt hours (kWh) every 15 minutes for each electricity consuming process behind the farm gate. Domestic electricity use was measured separately and subtracted for the dairy farm measurements.

This comprehensive data collection process provided a database of dairy farm electricity consumption trends which was subsequently analysed to provide answers to the questions posed above.

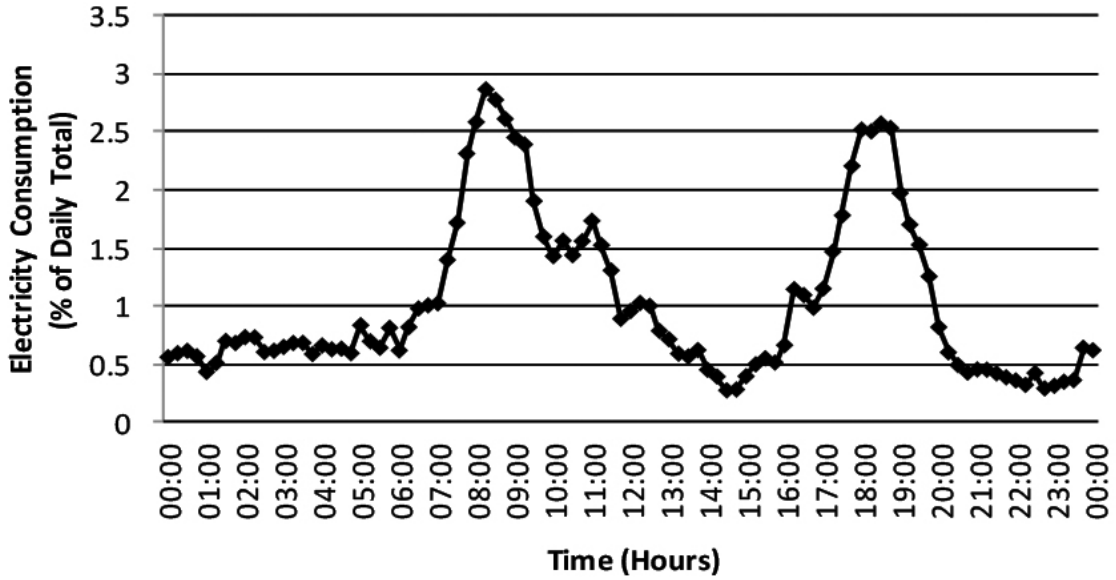


Figure 1. Average percentage of daily electricity consumption for 22 commercial farms in Ireland on the 14th June 2011, data points at 15 minute intervals

4. Main results:

The farms in this study operated grass-based milk production systems with spring calving herds and represented 0.14% of the specialised dairy farm population and supplied 0.24% of national milk in 2011.

Energy Analysis. Total energy use averaged 31.73 MJ/ kg MS, ranging from 15.28 to 49.00 MJ/ kg MS. About 57% of this energy use was accounted for by the production and transport of chemical fertilisers applied (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%).

Electrical Energy Inputs. Altogether 42.34 Wh (Watt-hours) of electricity was used per litre of milk produced (range 23.03–76.29 Wh/L). In total, 62% of all electrical energy used by the farms in this study was on the higher cost day tariff. The average cost of electricity on the study farms in 2011 was 0.51 Euro Cent per litre of milk produced (€ c/L) (range 0.26–0.87 € c/L). The major processes of electricity consumption were: milk cooling (31%), water heating (23%), milking machine (20%), pumping water (5%), lighting (3%), other miscellaneous consumption such as Winter housing systems, air compressors and backing gates consumed 18% of the electrical energy. All farms were unirrigated. Electricity used in the dairy milking shed accounted for almost 80% of the total electrical energy used.

Daily Electricity Consumption Trends. The profile of electrical energy consumption trends from day to day followed a sinusoidal pattern; large peaks in consumption were a result of the morning and evening milkings. Figure 1 shows the average electrical demand of the study farms on the 14th of June 2011. Consumption peaks were present from 7:00 to 12:00 and again from 16:30 to 19:30, these peaks can be attributed to the twice a day milking routine practiced by the farmers.

Seasonal Electricity Consumption Trends. The seasonal effect of electricity consumption follows the milk production curve due to the fact that over 80% of consumption is by equipment associated with milk harvesting. Consequently, 20% of electrical energy consumption is independent of the amount of milk produced. Electricity consumption by milk cooling equipment, water heating plant and the milking machine pumps are linked to milk production and they follow the milk production curve. Consumption of other items is decoupled from milk production and rises from November to February.

5. Opportunity/Benefit:

A two-pronged approach to minimise energy costs at farm level will be required.

Firstly, increasing the proportion of off-peak energy use by large energy users such as milk cooling and water heating systems, by shifting them to off-peak periods will be required. Milk cooling has the

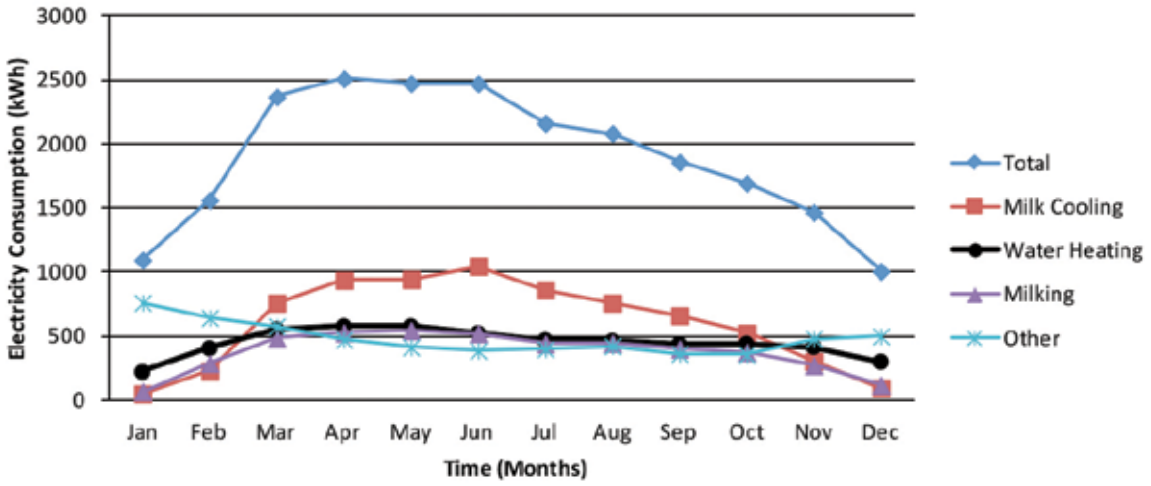


Figure 2. Monthly electrical energy consumption (kWh) for 22 farms over 12 months for all major energy consuming processes

largest electrical energy consumption (31% of total electricity consumption) on Irish dairy farms. Over 60% of milk cooling electricity consumption currently occurs on the more expensive day rate tariff (from 9am to 12 midnight). Managing the cooling of milk to ensure a high portion of off-peak electricity is utilised to cool the morning milking (in the case of direct expansion milk cooling systems) or using a milk cooling system that decouples the cooling load from these peak electricity times would be useful in mitigating the impact of rising day rate electricity prices. This practice together with optimised use of a plate cooler with ground water to milk ratio of 2:1 would reduce energy use and energy costs associated with milk cooling.

Secondly, efficiency gains and lower energy costs can be realised through application of energy efficient technology. For example, there is scope to reduce the electricity consumed by vacuum pumps, through the application of variable speed drive (VSD) technology, by 60%. Similarly, the use of solar thermal water heating systems can reduce the electricity use of the water heating system by 45%. With all these energy efficiency measures an upfront capital investment is required and the return on investment for the farmer should be computed on a case by case basis, as payback figures vary according to on-farm energy consumption.

6. Dissemination:

Main publications:

Murphy, M., O'Mahony, M. J., Upton, J. (2012). A load shifting controller for cold thermal energy storage systems. IEEE International Conference on Green Technologies (ICGT12). Trivandrum, India.

Upton, J., M. Murphy, and P. French. 2011. Lessons Learned from Teagasc Energy Audits. Proceedings of the Teagasc National Dairy Conference:101–106.

Murphy, M., O'Mahony, M. J., French, P., Upton, J. (2012). A dynamic model for the prediction of milk yields from dairy cattle. International Proceedings of Chemical, Biological and Environmental Engineering (selected for publication from the 3rd International Conference on Agriculture and Animal Science, Bangkok, Thailand).

Popular publications:

Upton J., Murphy M. (2010). 'Meeting your Hot Water Demand.' Teagasc TResearch 5(3): 26–27

Boland, A., Murphy, Paul, Upton, J., Mihailescu, E., Yang, M. and Humphreys, J. (2010). DAIRYMAN-bringing together the best in knowledge and innovation. Todays Farm 21 (4) 16–17

Animal and Grassland Research & Innovation Programme

Project number:
5404

Date:
November, 2010

Funding source:
Teagasc

Project dates:
Jan 2005 – Dec 2008

Development of a budgetary simulation model of a beef farm

Key external stakeholders:

Beef farmers, beef industry stakeholders, beef farm systems researchers, whole farm systems modellers.

Practical implications for stakeholders:

This project involved the development of a bioeconomic simulation model of suckler beef production systems. The model simulates the impact of multiple market, policy and technical scenarios and the implications of these scenarios on financial and technical performance of suckler beef production systems. Applications of the model to date have focused on replacement policies for suckler beef cow herds and the effect of turnout date to pasture and calving date in spring.

Main results:

Two applications of the model investigated (1) cow replacement strategies and (2) the effect of turnout date to pasture and calving date in spring.

(1) In Ireland, replacement breeding heifers for suckler beef production are increasingly being sourced from within the suckler herd resulting in an upgrading of many suckler beef cows to pure breeds and a subsequent reduction in cow milk production, pre-weaning growth rates and carcass weights of suckler progeny. The impact of this breeding policy on profitability of grass-based suckler beef production was investigated. Sourcing replacements from the dairy herd resulted in greater profitability (~18%) due to higher output; a consequence of heavier liveweights at sale and greater numbers of animals sold. Although, the availability of suitable breeding females from the dairy herd for suckler beef production is increasingly limited, the results highlight the importance of milk yield in suckler beef cows. Where adequate replacements are

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Teagasc project team:
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Dr. Mark McGee
Dr. Michael Drennan

External collaborators:
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Compiled by:
Paul Crosson

Technology

available, the effect of replacement rate on profitability was modest with higher replacement rates reducing profitability marginally and with the impact greater for calf-to-finishing systems than for calf-to-weanling systems.

(2) Early turnout to pasture in spring is one strategy for reducing production costs by increasing the proportion of grazed grass in the annual feed budget, replacing relatively expensive grass silage and concentrates. Where soil and weather conditions are suitable and where there is an adequate herbage supply, analysis showed that earlier calving and turnout date to pasture can lead to greater profitability in suckler beef systems by reducing slurry handling and feed costs. The impact of advancing calving date and turnout date by one day was to increase net margin by €1.75 ha^{-1} (€1.41 cow^{-1}) and €1.90 ha^{-1} (€1.54 cow^{-1}), respectively in calf-to-beef systems. For yearlings, the analysis indicated that advancing turnout to grass by one day increased net margin by €1.17 ha^{-1} (€0.95 cow^{-1}).

Opportunity/Benefit:

Economically quantified the impact of alternative replacement strategies and different turnout dates for suckler beef farms.

1. Project background:

Decoupling of EU common agricultural policy (CAP) support payments from production (Fischler reforms) means that beef production systems can now be evaluated without the constraints imposed by the previous CAP premia regime (Agenda 2000) and therefore, farmers are free to decide what production system will return the largest profit based on market returns. This study involved the development of an integrated model for evaluation of existing and prototype beef production systems from a biological and economic perspective. An integrated computer modelling system based on empirical production data generated under Irish conditions provides the opportunity to quickly, repeatedly and inexpensively evaluate different systems of beef production. The objective of this study was to develop, validate and use a bioeconomic simulation model of beef production systems.

2. Questions addressed by the project:

The overall objective was to develop an integrated modelling system for evaluation of existing and prototype beef production systems with respect to technical and economic benchmarks. Farm level models were used to identify viable systems, indicate the cause of failure of non-viable prototypes, and suggest areas where scientific research should be strengthened for various beef production systems. The project aimed to:

(1) develop a bioeconomic model which adequately reflected beef farming systems in Ireland in relation to technical inputs and outputs as well as economic indices and

(2) offer insight into the possible consequences of changing circumstances on beef farms through application of the model.

3. The experimental studies:

This was a desktop study. The constructed simulation model, the Grange Beef Systems Model (GBSM), was based on a stochastic dairy simulation model as described by Shalloo et al. (2004). The model was structured as a whole farm budgetary simulation model and was developed in MS Excel. It consists of input, planner and output worksheets. The input worksheet provides a detailed input interface and enables the user to specify the details and pricing structure of the production system to be simulated. Specifications include utilisable agricultural area, calving date, finishing strategy, forage conservation strategy, nitrogen (N) application rate on the grazing area and price and costs variables. The model structure is formulated in the planner worksheet. The primary farm activities of a typical Irish beef-cow farm are specified. Animal groupings include suckler cow, bull and heifer calf, steer and heifer yearling and a range of finishing activities. Forage production is described as monthly yields of DM and is based on N application rate and conservation strategy. The animal and forage components are coupled and the annual carrying capacity of the farm area simulated is calculated. Financial parameters relating to animal, forage and fixed cost items are specified and permit a detailed economic analysis of the simulated production system. Output worksheets include technical (average animal numbers, stocking rate, key liveweights (e.g. weaning), carcass output, feed consumption) and financial (profit and loss, balance sheet, cash flow) performance.

4. Main results:

Two applications of the model investigated (1) cow replacement strategies and (2) the effect of turnout date to pasture and calving date in spring.

(1) In Ireland, replacement breeding heifers for suckler beef production are increasingly being sourced from within the suckler herd resulting in an upgrading of many suckler beef cows to pure breeds and a subsequent reduction in cow milk production, pre-weaning growth rates and carcass weights of suckler progeny. The impact of this breeding policy on profitability of grass-based suckler beef production was investigated. Sourcing replacements from the dairy herd resulted in greater profitability (~18%) due to higher output; a consequence of heavier liveweights at sale and greater numbers of animals sold. Although, the availability of suitable breeding females from the dairy herd for suckler beef production is increasingly limited, the results highlight the importance of milk yield in suckler beef cows. Where adequate replacements are available, the effect of replacement rate on profitability was modest with higher replacement rates reducing profitability marginally and with the impact greater for calf-to-finishing systems than for calf-to-weanling systems.

(2) Early turnout to pasture in Spring is one strategy for reducing production costs by increasing the proportion of grazed grass in the annual feed budget, replacing relatively expensive grass silage and concentrates. Where soil and weather conditions are suitable and where there is an adequate herbage supply, analysis showed that earlier calving and turnout date to pasture can lead to greater profitability in suckler beef systems by reducing slurry handling and feed costs. The impact of advancing calving date and turnout date by one day was to increase net margin by €1.75 ha^{-1} (€1.41 cow^{-1}) and €1.90 ha^{-1} (€1.54 cow^{-1}), respectively in calf-to-beef systems. For yearlings, the analysis indicated that advancing turnout to grass by one day increased net margin by €1.17 ha^{-1} (€0.95 cow^{-1}).

5. Opportunity/Benefit:

- A model of suckler beef production systems was developed.
- Highlight the importance of milk yield in suckler beef cows.
- Quantified the effect of replacement rate on profitability.
- Quantified the impact of advancing calving date and turnout date by one day for suckler cows and yearling progeny.

6. Dissemination:

Conference abstracts

Crosson P. (2007) An economic comparison of replacement rates on suckler beef farms in Ireland – a modelling approach Proceedings of the International Suckler Cow Workers Group Meeting, 11–12 September 2007, Greenmount Campus, CAFRE, Antrim, Northern Ireland.

Crosson P. (2008) The impact of cow genotype on the profitability of grassland-based suckler beef production in Ireland. Proceedings of the 22nd Annual Meeting of the European Grassland Federation, Uppsala, Sweden, 9–12 June 2008, p.771

Crosson P., McGee M. and Drennan M.J. (2009) The economic impact of calving date and turnout date to pasture in spring of suckler cows. Proceedings of the Agricultural Research Forum, Tullamore, Co. Offaly, Ireland, 12–13 March 2009, p.68

Crosson P. McGee M. and Drennan M.J. (2009) The economic impact of turnout date to pasture in spring of yearling cattle on suckler beef farms. Proceedings of the Agricultural Research Forum, Tullamore, Co. Offaly, Ireland, 12–13 March 2009, p.77

Popular publications

Crosson P. (2009) The economic impact of calving date and turnout date to pasture in spring for suckler beef farms, Teagasc Beef Advisory Newsletter, Teagasc, Oakpark, Carlow, Ireland, April 2009.

Crosson P. and McGee M. (2009) Profitable beef production – the influence of calving and turnout date on farm margins, Irish Farmers Journal, 4 April, 2009

Evaluation of alternative forages for Winter feeding of spring calving dairy cows

Project number:
5401
Date:
November, 2010
Funding source:
Teagasc/Dairy Levy
Project dates:
Jan 2005 – Oct 2008

Key external stakeholders:

Dairy farmers, dairy industry stakeholders and drystock farmers.

Practical implications for stakeholders:

Forage *brassicas* and fodder beet can provide high dry matter yields and with excellent forage quality over the Winter for *in situ* utilisation. Overall, the results suggest that *in situ* utilisation of forage *brassicas* and fodder beet had no negative/deleterious effects on dry cow performance *pre* and *post partum*. The outcome of the research programme has highlighted the benefits of forage brassicas for dairying systems through potential reductions in fixed and variable costs.

Main results:

Cows Wintered outdoors on crops of forage brassicas, fodder beet and deferred grass had similar milk production and reproductive performance to cows Wintered indoors on grass silage diets.

Fodder beet can achieve significantly higher dry matter and energy yields per hectare than any other forage crop including ryegrass and therefore can potentially increase output/hectare.

Opportunity/Benefit:

Dairy farmers can reduce the fixed costs of animal accommodation with dry spring calving dairy cows grazing forage brassicas or fodder beet in situ supplemented with silage. High animal performance can be achieved by allocating animals the appropriate daily DM allowance of crop supplemented with a rough forage of 1/3 of the diet.

Collaborating Institutions:
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Teagasc project team:
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Dr. Bill Keogh

External collaborators:
Dr. Finbar Mulligan, UCD
Dr. Trevor Storey, UCD

Compiled by:
Padraig French
Bill Keogh

Technology

1. Project background:

Milk production in Ireland is dominated by seasonal, pasture-based production systems. In seasonal pasture based systems, Winter feed and housing account for a large proportion of the costs. While grazed grass is the cheapest form of feed available in temperate climates, grass utilisation during Winter may be constrained due to climatic factors and soil type and can only be managed at low stocking rates. In situ utilisation of forage brassicas is of interest within dairy production systems in Ireland because it has the potential to extend the grazing season into the Autumn and Winter and reduce both fixed and variable costs.

2. Questions addressed by the project:

There is a scarcity of published literature reporting the effects of these forages offered *in situ* on the production performance, health and metabolic status of the dairy cow in Ireland.

3. The experimental studies:

To address these issues, a series of experiments were conducted with *brassicas,* fodder beet and grass silage. Non lactating dairy cows were offered a range of these forages at different allowances from dry-off in late November until calving in mid-February and the impact on animal performance and well being was quantified. Agronomic factors such as sowing date, cultivar and nitrogen application level affecting the production of forage rape, forage oats and stubble turnips for *in situ* utilisation were also evaluated.

4. Main results:

- Dairy cows offered kale, swedes or fodder beet in-situ (outdoors) had moderate body condition score gain relative to grass silage offered indoors (0.20, 0.14 vs. 0.50 BCS units, respectively) during the Winter.
- Offering forage *brassicas in situ* to dairy cows *pre partum* had no negative effects on milk and milk compositional yields relative to offering grass silage.
- Offering *brassicas* and fodder beet *in situ pre partum* had no negative effects on *periparturient* cow performance and health (gestation length, calving difficulty, calf birth weight, somatic cell count and subsequent fertility parameters.
- Cows offered kale *in situ pre partum*, had significantly lower plasma copper and iodine concentrations *pre partum* and at *parturition* relative to those offered grass silage and fodder beet, suggesting that supplementation with copper and iodine may be essential to maintain performance and health.
- Cows offered kale *pre partum* had elevated concentrations of plasma IGF-1 immediately *post partum* relative to those offered fodder beet and grass silage, which is an important predictor of reproductive performance.
- Offering kale as the sole forage had no effect on rumen pH and total volatile fatty acid concentration. However, offering 850 g kg^{-1} DM of kale in a forage mixture with grass silage reduced rumen pH below acceptable thresholds for over seven hours potentially inhibiting cellulose digestion. Further research is warranted.
- Sowing date had a greater impact on forage rape and stubble turnip dry matter yields than nitrogen fertiliser level. The optimal sowing date for forage rape and stubble turnips was early August.
- A delay in sowing from the 1 August to 31 August led to a characterised 48% to 77% decrease in forage rape and stubble turnip DM yield.
- The ability of forage *brassicas* and fodder beet to maintain crude protein concentrations over the growing season allows considerable flexibility when utilising these forage crops *in situ*.

5. Dissemination:

Three open day events were held during the project (January 11 & 12th, 2006; January 10 & 11th, 2007 and January 6 & 7th, 2009) to provide local dairy farmers and industry representative's research information and system development technology. The objective of these events was to highlight research technologies that will increase farm profitability by extending the grazing season through reductions in fixed and variable costs and while having no deleterious or negative effects on animal performance or health.

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

Main publications:

Keogh, B., French, P., McGrath, T., Storey, T. and Mulligan, F.J. (2009). Comparison of the performance of dairy cows offered kale, swedes and perennial ryegrass herbage *in situ* and perennial ryegrass silage fed indoors in late pregnancy during Winter in Ireland. Grass and Forage Science 64:49–56.

Keogh, B., French, P., McGrath, T., Storey, T. and Mulligan, F.J. (2009). Effect of three forages and two forage allowances offered to pregnant dry dairy cows in Winter on periparturient performance and milk yield in early lactation. Grass and Forage Science 64:292–303.

Keogh, B., French, P., Murphy, J.J., Mee, J., McGrath, T., Storey, T., Grant, J. and Mulligan, F.J. (2009). The effect of dietary proportions of kale (Brassica oleracea) and grass silage on rumen pH and volatile fatty acid concentrations in dry dairy cows. Livestock Science 126: 302–305.

Keogh, B., French, P. and Mulligan, F.J. (2010). The effect of dietary proportions of kale (brassica oleracea) and grass silage on rumen pH and volatile fatty acid concentrations in dry dairy cows. In: Proceedings of the British Society of Animal Science and Agricultural Research Forum, Belfast, 12-Apr-2010, p. 27

Keogh, B., French, P., McGrath, T., Storey, T. and Mulligan, F.J. (2008). The effect of forage allowance and forage system during the dry period on the performance of dairy cows. New Zealand Society of Animal Production, Brisbane, Australia, 24-June-2008, p. 16–19.

Keogh, B., French, P., McGrath, T., Storey, T. and Mulligan, F.J. (2008). Effect of forage allowance on the performance of non-lactating dairy cows offered fodder beet, kale and perennial ryegrass silage. In: Agricultural Research Forum, Tullamore, 12-Mar-2008, p. 116.

French, P. and Keogh, B. (2009). Out-Wintering on forage crops – options for maiden heifers – Moorepark Dairy Levy Update:Components of Dairy Herd Expansion: Heifer Rearing and Herd Health. Teagasc IE p. 23–28 ISBN 18227

Animal and Grassland Research & Innovation Programme

Project number:
6026

Date:
October, 2013

Funding source:
Teagasc/ EasiFix™/ Enterprise Ireland

Project dates:
May 2010 – Oct 2013

Preventing lameness in Irish pigs

Key external stakeholders:

Pig producers, consumers, policy makers, SME's (feed companies, suppliers of products to the pig industry)

Practical implications for stakeholders:

- The sustainability of pig farming is threatened by production diseases such as lameness because it increases costs of production, reduces productivity and sow longevity and threatens pig welfare because of the associated pain.
- The environmental and dietary strategies investigated will reduce losses of young sows due to culling for lameness meaning that fewer replacement gilts need to be purchased/reared thereby reducing costs of production.
- As sows will remain in the herd for longer, herd performance can be improved through a greater number of piglets produced per sow during her productive life.
- Identification of risk factors for lameness in pigs in all stages of the production cycle associated with flooring and other management practices offers potential to improve the welfare of pigs on Irish farms and enhance the image of Irish pig farming.
- Reducing lameness may reduce the use of parenteral antibiotics on pig farms which will help to reduce the risk which antimicrobial resistance poses to human and animal health.

Main results:

- Very high prevalence of lameness in pigs and of claw lesions in sows is a welfare concern.
- Most of the risk factors identified for lameness (and limb and claw lesions in piglets) were associated with the flooring used in pig accommodation.
- Lameness in sows is set to increase with the change to group housing because of the strains placed on the locomotory system and claws by fully slatted floors.
- Rubber flooring can help to overcome the problem of lameness in fully slatted group housing systems, it also improves sow comfort and may reduce culling for lameness.

Collaborating Institutions:
University College Dublin (UCD)
University of Warwick, Coventry
EasyFix™ Rubber Products, Co. Galway
Enterprise Ireland, Dublin

Teagasc project team:
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Dr. Peadar Lawlor

External collaborators:
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Dr. Laura Green (University of Warwick)
Dr. Amy KilBride (University of Warwick)
PJ Burke (EasyFix™ Rubber products)

Compiled by:
Laura Boyle

Technology

- Farrowing house floors with a high void area (e.g. slatted steel) should be avoided to protect claw health of sows and limb health of piglets during lactation.
- In order to reduce lameness and improve longevity: replacement gilts should be housed separately from finisher stock from a young age, fed mineral supplements designed for claw health and fed a diet designed for slower growth rate to reduce joint lesions.

1. Project background:

Lameness is a major production disease of pigs. It poses a major threat to the sustainability of current pig production methods because it represents a serious welfare problem and also because it has a detrimental impact on profitability. Lameness is defined as a deviation from the normal gait caused by lesions, diseases and other factors such as nutrition and housing systems, among others. The prevalence of lameness, risk factors for lameness and ways of addressing it (focusing on replacement gilts), was the topic of this project. Claw lesions are regarded as one of the main causes of lameness. Little is known of the prevalence of claw lesions in pregnant sows but studies of finishing pigs demonstrated an overall prevalence of foot lesions of 93.8% and of adventitious bursitis of 51%. Lame pigs have very poor welfare because they are in pain, suffer discomfort, are at a disadvantage when it comes to competing for resources, are more susceptible to other diseases and fail to thrive/ reproduce. A study demonstrated that piglets with sole erosions and skin abrasions spent more time lying and less time in activities such as standing, walking, playing and fighting. These behavioural effects are indicative of reduced welfare. However, the impact of lameness on pig welfare is too often overlooked on pig units.

The root cause of most production diseases such as lameness lies in the interaction between the demands placed on animals for high productivity and the sub-optimal environment/management systems under which they are produced. This project attempted to address this complex interaction to reduce lameness, focusing on improving the environment and the nutrition of the replacement gilt to improve sow longevity. Addressing lameness in growing pigs represents an even more challenging research topic because of the clear positive relationship between growth rates and lameness and because of the ubiquitous use of fully slatted flooring which is a major risk factor for lameness.

2. Questions addressed by the project:

- What is the prevalence of lameness at each stage of the production cycle?
- What are the main causes and risks factors for lameness in Irish pigs?
- Does the change to group housing pose a risk for lameness in pregnant sows?
- What are the implications of feeding a gilt developer diet on indicators of lameness in group housed replacement gilts?
- What are the implications of housing pregnant sows in groups on rubber slat mats on their health, welfare and behaviour?

3. The experimental studies:

(i) From a questionnaire and once-off visit based **survey of 68 Irish pig farms** we established the prevalence, causes and risk factors of lameness in piglets (pre-weaners; n=2948 animals inspected), weaners (n=3368), finishers (1289), replacement gilts (n=525), pregnant gilts (n=518) and sows (n=604) and lactating sows (n=544).

(ii) **Limit feeding a developer diet:** 36 Large White × Landrace gilts were selected at 65kg, housed individually and assigned to one of 3 treatments: finisher, gestating sow or developer diets, at 65 kg. The experiment lasted 12 weeks and the gilts were then slaughtered at c. 140 kg which was the target weight that corresponded to service.

(iii) **Ad libitum feeding a developer diet:** One hundred and eighty Large White x Landrace gilts were housed in groups of 18 pens and assigned to the same finisher, gestating sow and developer dietary treatments, from 65 kg to 140 kg over a 12 week period.

In studies 2 & 3, lameness, claw, limb, body and joint lesions were scored. Bone mineral density, growth performance and pig behaviour was also measured.

(iv) **Evaluation of gestation housing system (loose vs. stall) and floor type (slatted steel vs. cast iron) during lactation** on lameness, body, limb and claw lesions and lying-down behaviour of 85 sows. Sows from 2 gestation housing systems were assigned to the experiment on transfer to the farrowing crate in which two floor types were installed.

(v) **Longitudinal study of rubber flooring in a commercial farm:** 164 replacement gilts were housed in groups of 8 during two parities in pens with rubber covered or concrete slats. Lameness, claw, limb and body lesions were scored.

(vi) **Effect of rubber flooring on the behaviour of group housed sows:** 64 sows were housed in groups of 4 in pens with solid concrete floored feeding stalls and a slatted group area from 28d after service. Sow postural and spatial behaviour was recorded.

(vii) **Effect of housing on rubber slat mats during pregnancy on the behaviour and welfare of sows in farrowing crates:** Sows from study 6 were transferred to the farrowing crate on day 110 of gestation where observations of postural and lying down behaviour were made.

4. Main results:

In study 1: Lameness prevalence was 28% in finishers at 18wks of age, 37% in finishers of 22wks of age, 39% in replacement gilts and 48% in pregnant gilts and pregnant sows. A high prevalence of limb abrasions, sole bruising and coronary band damage was observed in suckling piglets. All of the lesions recorded were associated with the presence of metal/steel slatted flooring in the farrowing crate. For finishers, replacement gilts and pregnant sows there was an increased risk of lameness associated with slat voids wider than 1.8mm.

In study 2, from the 5th week of the trial there were more lame gilts on the finisher and gestating sow treatments. All gilts on the finisher and gestating sow treatments had uneven claws by 12wk probably related to the inclusion of Availa Sow® in the developer treatment. Gilts on the developer treatment had lower joint lesion scores than gilts in the other treatments. There were differences in weight gain at weeks 4 and 10, with gilts on the developer treatment weighing less. This reduction in weight gain in the developer treatment may have contributed to the reduced joint lesion scores as fast weight gain is a known risk factor for joint lesions.

In study 3, from week 5–8 and 9–12 more gilts were lame and had more claw lesions on the finisher and gestating sow dietary treatments than on the developer treatment. Improvements in claw health could be attributable to the inclusion of the zinc, copper and manganese supplement, Availa Sow® in the developer treatment. There was no effect of treatment on joint lesion scores, bone mineral density, body weight, lying behavior or on carcass characteristics.

In study 4, 74% of group housed sows and 33% of individually housed sows were lame on transfer to the farrowing crate. The group housed sows had higher scores for claw lesions on the heel area and a higher risk of wounds on the limbs and swellings on the hind limbs (i.e. bursitis). However, individually housed sows were at greater risk of a wider range of claw lesions. These findings confirm that the problem of lameness in Irish sows will increase with the change to group housing systems. During lactation, sows kept on slatted steel floors in the farrowing crate were at higher risk of heel overgrowth and/or erosion, heel sole crack and horizontal cracks in the wall than sows on cast iron flooring.

In study 5, rubber pens were dirtier compared with pens left uncovered. Sows on rubber slat mats were at lower risk of lameness, swellings and wounds on their limbs compared to sows housed on concrete slats but at higher risk of claw lesions because of the dirtiness of the rubber flooring. The rubber slat mats were less abrasive than the concrete slats which explains the higher scores for toe length in sows housed on rubber mats.

In study 6, sows with rubber slat mats in the group area spent more time there than in the feeding stalls and stood less and lay more in the group area compared with sows housed on concrete slats. This reflects and confirms sows' preference for a comfortable surface for lying.

In study 7, flooring during gestation did not affect any of the welfare and behaviour variables recorded in the farrowing crate.

5. Opportunity/Benefit:

The findings of this project offer real solutions to pig producers to tackle the problem of lameness in their pigs with associated reductions in production costs and improved efficiencies/productivity potentially improving the profitability of their enterprise. There are real opportunities for feed companies to manufacture diets specially formulated to address the needs of the replacement gilt (developer diets) and for suppliers of products and services to the pig industry to develop new ways to overcome the risks for lameness associated with the floor types used on Irish pig farms. This project had an industry partner (EasyFix Rubber Products) who manufacture the

market leading rubber mats for pigs. Solutions and improvement to some of their current design flaws were identified and they were provided with independent evidence of welfare benefits associated with the use of rubber flooring for sows. This collaboration was facilitated by the Enterprise Ireland Innovation Partnership Programme which matched the funding provided by EasyFix.

6. Dissemination:

Main publications:

Calderón-Díaz, J.A., Fahey, A.G., KilBride, A.L., Green, L.E. and Boyle, L.A. 2013. Longitudinal study of the effect of rubber slat mats on locomotory ability, body, limb and claw lesions and dirtiness of loose housed sows. Journal of Animal Science 19: 1–15.

Calderón-Díaz, J.A., Fahey, A.G. and Boyle, L.A. Effects of gestation housing system and floor type during lactation on locomotory ability, body, limb and claw lesions, and lying-down behavior of lactating sows. Journal of Animal Science *In press*.

Calderón-Díaz, J.A. and Boyle, L.A. 2013. Effect of rubber slat mats on the behaviour and welfare of group housed pregnant sows. Applied Animal Behaviour Science *In press*.

Popular publications:

Boyle, L., Green, L., KilBride, A., Quinn, A., Fahey, A., Calderón Díaz, J. (2012). Overcoming lameness in Irish sows. TResearch Volume 7: Number 3. Autumn 2012. P 36–37

*Quinn, A., Calderón Díaz, J.A., Boyle, L. (2013). Lameness in Pigs. End of project research dissemination booklet. 26th July 2013; 30 p

**On 26th July 2013 an open day was held at Moorepark at which the findings of this project were disseminated.*

Animal and Grassland Research & Innovation Programme

Project number:
6149

Date:
October, 2013

Funding source:
EU Framework 7

Project dates:
Nov 2010 – Apr 2013

A novel transport system (*TRANSUS*) for slaughter pigs

Key external stakeholders:

Animal hauliers/transport companies, slaughter plants, pigmeat processors, pig producers, consumers, policy makers.

Practical implications for stakeholders:

- This project has shown that there is potential in the pig industry for developing alternative methods for transporting slaughter pigs.
- Alternatives to conventional transportation methods such as TRANSUS have the potential to streamline the pre-slaughter handling of pigs thereby offering potential improvements to pig welfare and meat quality.
- Under current conditions alternatives such as TRANSUS are more likely to be of interest to processors rather than pig producers or hauliers because of the initially higher costs associated with such a system.

Main results:

- In TRANSUS pigs can be kept in small, familiar social groups without the need for re-mixing and thereby avoiding the associated aggression and social stress which has negative implications for pig welfare and for meat quality.
- There was no detrimental impact on pig behaviour, welfare or meat quality of transporting in TRANSUS compared to conventional methods.
- Using the TRANSUS prototype, loading and unloading pigs took longer than with conventional methods.
- Nevertheless, refinements to the design and in the methods used to load/unload the containers could help to realise the potential for use of containers such as TRANSUS in the transportation of pigs to slaughter.

Collaborating Institutions:
Danish Meat Research Institute (DMRI), Roskilde, Denmark
The Mechanical Engineering Group of the University of Cantabria (UC), Santander, Spain
Lightweight Structures, The Netherlands
Re/gent, The Netherlands

Teagasc project team:
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Lars Blaabjerg (DMRI)
Dr. Helle Daugaard Larsen (DMRI)
Dr. Margit Dall Aaslyng (DMRI)
Dr. Fernando Viadero-Rueda (UC)
Dr. Alfonso Fernandez (UC)

Compiled by:
Laura Boyle

Technology

Opportunity/Benefit:

This project tested a prototype container TRANSUS which proved satisfactory when compared to conventional transport. Improvements to the design of the container and to the method of loading/unloading are required. There are opportunities for companies to further the development of this concept for transportation of slaughter pigs. This method of transporting pigs offers an opportunity to improve pig welfare prior to slaughter and consequently to improve meat quality. This offers benefits to the producer who could use the concept to brand his pig meat and to the processor in terms of securing markets. Individual producers selling high value breeding stock may wish to adopt this concept to reduce stresses associated with handling during transport.

1. Project background:

There is considerable concern about the effects of transport and associated handling on the welfare of animals. Consumers are now demanding better treatment of animals in the whole production chain including transport. The transport distance of pigs by road from a farm to the slaughterhouse is expanding because of the economic opportunities for long distance and international trade, improved infrastructure and increased demand for live animals for fattening and slaughtering. Within the EU, free movement of animals from one Member State to another and more uniformity in slaughter weight and quality requirements has resulted in more long distance travel to slaughter. Regulations to protect animals during transport are laid down in Council Regulation 1/2005[1] and in national legislation. A large variety of factors have been found to increase the stress levels experienced by the pig during the journey to slaughter, in particular: (a) rough treatment by staff during loading and unloading; (b) changing the pig's known and secure environment; (c) weather conditions (temperature, air velocity, humidity) during the journey; (d) the fitness of the pig; (e) unexpected truck movements during the journey; (f) mixing of pigs from different groups; (g) duration of the trip and (h) overloading of pigs on the trailer.

Using containerised transportation methods, the following advantages should be achievable:

1. Loading and unloading of individual pigs can be done offline.
2. The pigs can be brought into the transport container in sufficient time *prior to* transport so they can get used to the new environment, thus reducing stress levels in the animal.
3. Hygiene in the sector will improve because cleaning of empty containers can be done offline, and the standardisation makes it possible to develop dedicated cleaning tools and equipment.
4. The containers can be designed in a modular way, allowing optimised designs for expected group sizes, logistic handling at the farm and at the slaughterhouse, and cleaning/disinfection.

Hence, the proposed idea of this project was to develop a revolutionary new concept for the transport of a group of pigs, i.e. to use the concept of standardised container transport. To visualise the proposed concept, the container was to be developed for a small group of pigs (c. 10) of 100kg and to be of a size and weight that it could be handled by a standard forklift truck, and loaded onto a trailer from the side. Where a larger group of pigs is to be transported, a number of these containers can be stacked onto the trailer.

2. Questions addressed by the project:

The overarching goal of TRANSUS was to develop an easy-to-handle transport container that enabled the efficient transport of slaughter pigs from farm to slaughterhouse, taking into account animal welfare and hygiene requirements. The main scientific and technological objectives of TRANSUS were the following:

- To establish a set of parameters, enabling the engineering design of the transport container.
- To develop and manufacture a functional prototype.
- To validate the prototype functionality in terms of mechanics and animal behaviour, welfare and meat quality under real-world transport conditions.

1 COUNCIL REGULATION (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/971

3. The experimental study:

The main objective of Teagasc's role in this project was to evaluate the containerised transportation method (TRANSUS) from the point of view of pig behaviour and welfare and the main objective of DMRI's role in the project was to evaluate TRANSUS from the point of view of pig meat quality. In collaboration with researchers from DMRI we compared the behaviour, welfare and meat quality of pigs transported by two methods, 1) in a conventional two tier lorry and 2) in a modularised container (TRANSUS prototype) carried on the back of a flat deck truck. The study was conducted between Teagasc, Moorepark Research Centre, Fermoy, Co. Cork and Dawn Pork and Bacon Factory, Grannagh, Co. Waterford in Ireland during March 11th to 16th inclusive and March 19th to 23rd inclusive 2013. The evaluation of pig welfare during transport in the TRANSUS prototype employed a multidisciplinary approach incorporating a wide range of welfare behaviour, physiology, injury and meat quality indicators. These reflected not only the handling associated with TRANSUS (i.e. loading and unloading) but also stress levels in the pigs during transportation in the prototype.

Prior to each transport test day a number of pens of finisher pigs containing between 10 and 14 of either entire male, female or mixed gender pigs were selected. All pigs in these pens were weighed individually and the lightest and heaviest pigs available were removed from the dataset until 48 pigs (24 males and 24 females) remained. These were blocked within gender on the basis of weight and pen of origin and randomly assigned to one of four experimental groups of 12 pigs. Each experimental group was composed of 6 male and 6 female pigs coming from not more than five original home pens. The groups were randomly assigned to one of two transportation treatments: 1) TRANSUS [T, n=2/day] or 2) Conventional [C, n=2/day]. The same procedure was repeated for each of the five test days such that 20 groups of 12 slaughter pigs (240 pigs in total: 120 males and 120 females, mean live weight 97.5 ± 7.09kg) were tested. Four focal pigs were also identified in each test group (80 pigs in total; mean weight: 97.5 ± 9.12kg) based on their relationship to the mean weight of the group. At 0630h on each test day, experimental pigs were removed from their home pen and weighed individually. Skin lesions of focal pigs were scored. The non-focal test pigs were then divided into one of four pre-transport pens labeled T1 (TRANSUS 1), T2 (TRANSUS 2), C1 (Conventional 1) and C2 (Conventional 2) depending on the experimental group to which they'd been assigned. Focal pigs were fitted with heart rate monitors. Once these were fitted, their skin temperature was recorded. Once all the groups were assembled, pigs were left undisturbed in the pre-transport pens for 25 ± 10 minutes prior to loading. Five minutes before the start of loading the skin temperature of the 16 focal pigs was measured again. Thereafter the first group of 12 pigs was moved the short distance to the loading area, where they were loaded either directly into the first TRANSUS box (T1) at ground level or into the upper deck of the conventional lorry by the ramp (C1) depending on the schedule shown below. A protocol for moving the pigs was strictly adhered to so that differences between systems could not be attributed to handling. The same handler was used throughout the experiment, and pig boards were used to herd the animals as rapidly as possible but with the minimum of coercion. Goads were not used. Once the first group was loaded, the second group from the same treatment was loaded. Thereafter, groups 1 and 2 of the 2nd treatment were loaded. During loading and unloading, one person recorded pig behaviour and a second recorded the loading times. During transport pig behaviour and environmental conditions were recorded. Pigs were unloaded at the factory and once HR monitors were removed and skin lesions scored, they were slaughtered immediately. Blood samples were collected at exsanguination for later determination of haematological parameters and during blood collection the blood temperature was measured. Meat quality measures were taken by DMRI personnel in the chill room 45 mins post slaughter and 22 hours later.

4. Main results:

Loading and unloading of TRANSUS pigs took significantly longer than loading/unloading of Conventional pigs (Figure 1). This was because of the necessity to lift the TRANSUS boxes onto the back of the flat deck truck. However, when the time taken to lift the TRANSUS box onto the truck was removed from the data, loading times between TRANSUS and Conventional were similar (Figure 1). It took significantly longer to position the TRANSUS box on the truck than it did to remove the TRANSUS box from the truck.

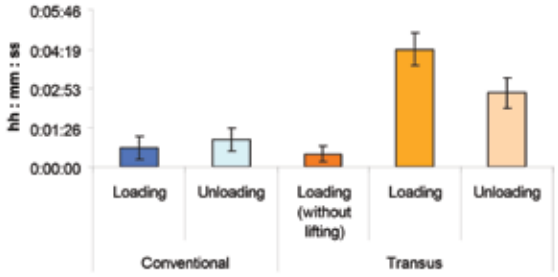

Figure 1. Loading and unloading times for pigs transported by TRANSUS or Conventional means

In TRANSUS a maximum of two pigs were observed in a dog sitting position at any one time during transport in four of 10 test groups. In the Conventional treatment six pigs were observed in a dog sitting position simultaneously in one test group and 4 pigs were observed in this position simultaneously in another two test groups during transportation. There was never more than one pig seen lying down in either treatment (in 5 Conventional groups and in three TRANSUS groups).

In the conventional truck more incidences of aggression were seen compared to TRANSUS, however, in TRANSUS more incidences of mounting and hitting the ceiling were seen compared to the conventional truck. A key difference between both transportation methods was that the ceiling was much lower in TRANSUS (90cm) and this probably influenced these findings for pig behaviour during transportation.

There was no significant effect of treatment on skin temperatures of the focal pigs in the home pens, prior to or post loading (P>0.05). The total and front body skin lesion scores of all pigs increased significantly between the pre and post transport measurements (P<0.05). This reflected the fighting which occurred at mixing. However, there was no significant effect of treatment on the skin lesion scores (P>0.05).

There was a considerable amount of technical difficulties associated with use of the heart rate monitors. There were problems with lost belts and belts loosening and therefore losing the signal. Hence, missing data points meant that statistical analysis could only be conducted during the transport and loading periods. There was no statistical difference between TRANSUS and the conventional transportation treatment in the mean heart rate of focal pigs at these two stages (P>0.05). There was no effect of treatment on any of the blood parameters (P>0.05) although there tended to be an effect of treatment on glucose with Conventional pigs being slightly higher than TRANSUS pigs (7.29mM *vs.* 6.97mM, s.e.=0.133; P=0.088). There was a significant effect of day on albumin, glucose and lactate (P<0.001). There was no effect of treatment on blood temperature but there were significant differences between test days (P<0.001). There was no treatment effect on carcass weight (overall mean: 74.3 ± 5.87kg [SD]; P>0.05) but there was an effect of test day (P<0.001). There was no interaction between treatment and test day (P>0.05). There was a weak tendency for an effect of treatment on lean meat percentage (overall mean: 58.7 ± 1.77 [SD] %; P=0.096) as well as a significant test day effect (P<0.05). There was no effect of treatment or day on kill out % (overall mean: 49.2 ± 4.06 [SD] %; P>0.05). There was a significant effect of treatment on fat percentage (overall mean: 10.4 ± 1.94 [SD] %; P<0.05) and a tendency for an effect of test day (P=0.068).

In the cold storage room, the temperature at the region of the loin centre ranged from 6.0 to 6.3°C while the temperature at the region of the centre of the hams ranged from 5.3 to 5.6°C.

There was no effect of treatment on the temperature of the longissimuss dorsi 40 minutes after exsanguination (P>0.05). However, there was a significant effect of test day and an interaction (not shown) between treatment and test day (P<0.001). There was a significant effect of test day on the pH of the longissimuss dorsi 40 minutes post slaughter (P<0.05) but no effect of treatment (P>0.05).

pH 22 hours post slaughter

There was a significant effect of test day on the pH of the longissimuss dorsi 22 hours post slaughter and an interactive effect (P<0.01, data not shown) but no effect of treatment (P>0.05). There was a significant effect of treatment, day and an interaction between treatment and day (P<0.05, data not shown) on the pH of the semimembranosus 22 hours post slaughter. Conventionally transported pigs had higher values for this measure compared to

TRANSUS pigs. However, in the absence of any other differences in physiological/meat quality measurements, it is difficult to suggest a biologically plausible explanation for this difference.

There was no effect of treatment on drip loss (C: 2.41 *vs.* T: 2.24 s.e. 0.259; P>0.05). However, there was a significant effect of position on the truck (P<0.01) and sex (Male: 2.75 *vs.* Female: 1.82, s.e. 0.283; P<0.001).

5. Opportunity/Benefit:

Butina is a moderate to large company which was given special dispensation by the EC to be involved in the project as an SME. Butina manufactures equipment/machinery for use in pig slaughter plants and they may be interested in carrying the concept forwards to develop it commercially. This research was for the benefit of SMEs and so the information is readily available to all the SMEs which were involved, to use as they see fit to develop the concept.

6. Dissemination:

Main publications:

Reports produced as per deliverable requirements for TRANSUS – 262312 (Research for SMEs): A Novel Transport System for Slaughter Pigs.

Boyle, L.A., Lykke, L. and Blaabjerg, L. 2011. Deliverable No: D2.1: Pig and Technology Research – Literature review. 61 pgs.

Boyle, L.A., D., Lykke, L. and Blaabjerg, L. 2013. Deliverable No: D2.1: Pig and Technology Research – Welfare requirements. 14pgs.

Boyle, L.A., Lemos Teixeira, D., Lykke, L. and Blaabjerg, L. 2013. Deliverable No: D4.3 Pig welfare, behaviour and meat quality test report. 51pgs.

Testing the safety of genetically modified (GM) feed ingredients in pigs

Project number:
5822
Date:
March, 2013
Funding source:
EU Framework 7
Project dates:
Aug 2008 – Sep 2012

Key external stakeholders:

EU Commission, farmers, feed compounders, EFSA, FSAI, consumers, policymakers, agricultural advisers.

Practical implications for stakeholders:

The main outcomes of this study are:

- Bt MON810 did not have harmful effects on growth, intestinal health or organ function of pigs.
- Bacteria within the digestive systems of pigs are tolerant of the GM maize.
- The *cry1Ab* gene as well as the protein itself did not migrate from the digestive tract and the gene was broken down as it progressed through the digestive tract.
- Feeding GM maize to pigs of different ages and for extended periods of time is as safe as its conventional counterpart with respect to potential effects on animal health.
- In a 30 day feeding study using weaned pigs, GM α-amylase inhibitor (αAI) peas were as safe as their conventional counterpart with respect to potential effects on animal health.
- Multiple conventional comparators should be used during safety assessment of GM ingredients.

Collaborating Institutions:
Waterford Institute of Technology (WIT)
University College Dublin (UCD)
MUW, Austria
CSIRO, Australia
NVH, Norway
CFRI, Hungary

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Compiled by:
Peadar Lawlor

Technology

Main results:

GM maize did not have harmful effects on growth, intestinal health or organ function of pigs. Bacteria within the digestive systems of pigs are tolerant of the GM maize. In addition, the *cry1Ab* gene, as well as the protein itself, was shown not to migrate from the digestive tract and the gene was broken down as it progressed through the digestive tract. It was concluded that feeding GM maize to pigs of different ages and for extended periods of time is as safe as its conventional counterpart with respect to potential effects on animal health. Furthermore, our results did not reveal any reason for concern regarding the safety of the αAI peas tested. The latter experiment highlights the need to include multiple conventional comparators of the same feed ingredient during safety assessment.

Opportunity/Benefit:

It was concluded that feeding Bt MON810 maize to pigs of different ages and for extended periods of time is as safe as its conventional counterpart with respect to potential effects on animal health. In addition, our results did not reveal any cause for concern regarding the safety of the αAI peas tested. These results can better inform all stakeholders regarding the safety of GM feed ingredients.

1. Project background:

Teagasc was a partner in the EU GMSAFOOD project whose principle objective was to determine the safety of GM food/feed ingredients. The consortium focused its work on Bt (MON810) maize and αAI peas, both of which were bred for their insect-resistant properties and grown in Spain. The work conducted by the consortium included:

- The production of αAI peas (CSIRO, Australia)
- Long-, medium- and short-term pig feeding studies (Teagasc, Ireland)
- Salmon feeding studies (NVH, Norway)
- Human immune response to potential allergens in GM peas using human-SCID mice (MUW, Austria)
- Food chain studies in which rats were fed pork and fish that had been raised on Bt maize (NVH, Norway)
- Epitope mapping and antibody determinations (CFRI, Hungary)

2. Questions addressed by the project:

- Is the growth performance and/or health of pigs affected following long-, medium- and short-term consumption of Bt (MON810) maize?
- Is the growth performance and/or health of pigs affected following short-term consumption of αAI peas?
- Is there an inflammatory or allergic-type immune response to the transgenic protein?
- Is the gastrointestinal microflora affected by consumption of the GM feed ingredients?
- What is the fate of the *cry1Ab* gene and the Cry1Ab protein once consumed?
- Will inclusion of multiple comparators (conventional varieties) to the GM ingredient being tested, in animal feeding studies, enable improved interpretation of the data obtained?

3. The experimental studies:

1. Bt (MON810) maize

Weaned pigs were fed diets containing non-GM or GM (Bt MON810) maize for 31 or 110 days. A trans-generational experiment was also conducted, whereby pregnant sows were fed non-GM or GM maize diets with the progeny of both groups being fed non-GM or GM maize diets to commercial slaughter weight. These experiments investigated the effects of GM maize on growth performance, intestinal histology, immune response, intestinal microbiology and organ weight and function. Analyses were also performed to determine if the gene encoding the protein responsible for the genetic modification of the maize, or the protein itself, migrated from the animal's digestive tract.

2. α-amylase (αAI) inhibitor peas

In a 31-day experiment weaned pigs were fed diets containing:

- Non-GM commercial field peas (*Pisum sativum* L.)
- Non-GM parent line peas (*Pisum sativum* L.)
- GM peas (*Pisum sativum* L.) expressing αAI-1 from the common bean (*Phaseolus vulgaris*).

This experiment investigated the effects of the αAI peas on pig growth, blood haematology, organ weight and function.

4. Main results:

1. Bt (MON810) maize

The main results from this work include:

- Feed intake, growth rate and feed conversion efficiency of pigs were not adversely affected when pigs were fed GM maize.
- As an indicator of toxicity, the effect of GM maize consumption on the structure and function of the liver, heart, kidneys and spleen of the pigs was determined. Organ pathology and organ function were similar for pigs fed GM or non-GM maize.
- There was no adverse effect of feeding GM maize on small intestinal morphology.
- Comparison of the immune response of pigs fed GM maize or non-GM maize failed to reveal differences of biological importance. Antibodies specific to the GM maize protein (Cry1Ab) were not detected in the pigs' blood, indicating the absence of an allergic-type immune response to the protein.
- In addition to conventional culturing techniques, gene sequencing was used to determine if feeding GM maize influenced the bacterial profile within the digestive tract. Counts of selected culturable bacteria were unaffected by feeding GM maize. High-throughput gene sequencing revealed that GM maize consumption had only minimal impact on microbial community structure in the caeca of pigs, resulting in statistically significant differences in abundance of only 2 of 39 bacterial families and 3 of 54 genera detected. Furthermore, the taxa affected were detected at low abundance and frequency and their role within the intestine is not fully understood. Therefore, the differences observed are not believed to be of major biological importance and in addition, were not associated with any adverse health effects.
- Neither the *cry1Ab* gene nor the Cry1Ab protein was found in the blood, organs or muscle of pigs fed the GM maize. These findings indicate that the gene or protein did not migrate from the digestive system of the animal into other body tissues. Our results also indicate that the cry1Ab gene was broken down as it moved through the digestive system, being found in the stomach contents but not in the colon. As anticipated, fragments of the Cry1Ab protein were found throughout the gastrointestinal tract.

2. α-amylase inhibitor peas

Feed intake, growth rate and feed conversion efficiency of pigs were similar regardless of treatment. Likewise, there was no difference in the weight of the heart, kidneys, liver or spleen between treatments and evidence of pathology was absent from the organs of pigs fed all of the pea treatments. Differences were observed in haemoglobin concentration and hematocrit between treatments; however, the differences were only found between pigs fed the non-GM parent pea diet and pigs fed the other two pea treatments with no difference between the non-GM commercial field pea and the GM pea being found. Differences in mean platelet volume were also found between treatments; however, the GM pea was not different to the non-GM parent counterpart but was different to the non-GM commercial field pea. These results highlight the importance of correctly interpreting data on GM ingredients. Even a comparison between two conventional varieties of any feed ingredient is likely to yield differences in some parameters of interest. Therefore, it is important that feeding trials investigating the safety of GM ingredients should also include a comparison to conventional varieties of the same feed ingredient.

5. Opportunity/Benefit:

The study concluded that feeding Bt MON810 maize to pigs of different ages and for extended periods of time was as safe as its conventional counterpart with respect to potential effects on animal health. In addition, our results did not reveal any cause for concern regarding the safety of the αAI peas tested. These results can better inform all stakeholders regarding the safety of GM feed ingredients. In addition the results indicate that a comparison to a number of conventional varieties of the same feed ingredient should be included in future feeding trials investigating the safety of GM ingredients to enable better interpretation of the data obtained.

6. Dissemination:

Twelve peer reviewed publications resulted from this work. The results of this project were widely disseminated. A final project conference was held in the Medical University of Vienna on March 6–8, 2012 www.gmsafoodproject.eu/Sections.aspx?section=463

The talks from this conference and the press conference were videoed and are available at www.youtube.com/user/GMSAFOOD Results of the project were presented at the Teagasc pig farmers conferences, European Federation of Animal Science Annual Conference, American Society of Animal Science Annual Meeting, Society for Feed Technologists Pigs Conference, Agricultural Research Forum and Symposium on Digestive Physiology in Pigs.

Main publications:

Buzoianu, S.G., Walsh, M.C., Rea, M.C., Cassidy, J.P., Ryan, T.P., Ross, R.P., Gardiner G.E., and Lawlor P.G. (2013). Trans-generational effects of feeding genetically modified maize to nulliparous sows and offspring on offspring growth and health. Journal of Animal Science 91: 318–330.

Walsh, M.C., Buzoianu, S.G. Gardiner, G.E. Rea, M.C., O'Donovan, O., Ross, R.P., and Lawlor, P.G. (2013). Effects of feeding Bt MON810 maize to sows during first gestation and lactation on maternal and offspring health indicators. British Journal of Nutrition 109: 873–881.

Buzoianu, S.G., Walsh, M.C., Rea, M.C., O'Donovan, O., Gelencsér, E., Ujhelyi, G., Szabó, E., Nagy, A., Ross, R.P., Gardiner, G.E., and Lawlor, P.G. (2012). Effects of feeding Bt maize to sows during gestation and lactation on maternal and offspring immunity and fate of transgenic material. PLoS ONE 7(10): e47851.

Popular publications:

Lawlor, P.G. (2008). GM feed ingredients. In: Proceedings Teagasc, Pig Farmers Conferences. October 20th-22nd 2008, Cavan, Kilkenny and Fermoy, p. 10–20.

Lawlor, P. G. and Walsh, M. (2009). The GM debate and the Irish pig meat sector. T-Research 4(4): 26–27.

Lawlor, P.G. (2008). GM feed ingredients. In: Proceedings Teagasc, Pig Farmers Conferences. October 20th-22nd 2008, Cavan, Kilkenny and Fermoy, p. 10–20.

Buzoianu, S.G., Walsh, M.C., Gardiner, G.E., O'Sullivan, L., Rea, M.C., and Lawlor, P.G. (2011). Investigating transfer of genes from genetically modified maize to the pig intestinal microbiota: one of the steps in determining the safety of GM feed. Society for Feed Technologists Pigs Conference, Coventry, UK, November 10th 2011.

Lawlor, P.G., Walsh, M.C., Buzoianu, S.G., Rea, M.C., Ross, R.P. and Gardiner, G.E. (2012). Short, medium and long-term studies of pigs fed GMOs. GMSAFOOD Conference – Genetically Modified Organisms Safety & Post market Monitoring, Medical University of Vienna, Austria, March 6th – 8th 2012.

Lawlor, P.G., Walsh, M.C., Buzoianu, S.G., Rea, M.C., Ross, R.P. and Gardiner, G.E. (2013). Testing the safety of genetically modified (GM) feed ingredients in pigs. T-Research Volume 8(1):36–37.

Effect of maternal backfat levels and feed allowance during gestation on offspring growth

Project number:
5510
Date:
March, 2013
Funding source:
Teagasc
Project dates:
Jan 2006 – Sept 2012

Piglet birth weight and growth to slaughter is influenced by sow condition and feed allowance during gestation.

Collaborating Institutions:
Royal Veterinary College, University of London

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External collaborators:
Prof. Neil Stickland, RVC London

Compiled by:
Peadar Lawlor
Linda Giblin

Key external stakeholders:

Pig farmers, advisers, animal and human nutritionists, infant formula companies.

Practical implications for stakeholders:

The main outcomes from this project are:

- P_2 backfat of gilts should be targeted at ~19mm by the time of first insemination.
- During gestation a daily feed allowance of ~2.5kg of gestation diet (6.2 g/kg lysine, 13.0 MJ DE /kg) should be provided between day 25 and 90 of gestation.
- Following these guidelines will maximize growth to slaughter in offspring.

Technology

Main results:

Feed-restricted gilts had higher salivary cortisol levels during gestation and gave birth to lighter piglets. This response to restricted feeding was greatest for the fat gilts. Body condition of gilts and feed level during gestation altered the fat percentage and profile of sows' milk, with thin gilts having higher levels of saturated fat than fat gilts. Weaning weights were heavier and average daily gain from birth to weaning was greater in piglets born to fat gilts. Body condition of gilts at insemination had a greater influence on offspring post-weaning growth than feed level during gestation. Gilts with a backfat depth of ~19mm at insemination, which is close to current recommendations, gave birth to pigs that were heavier and fatter at ~158 days of age than those born from gilts with ~ 12mm backfat depth at insemination. Only transitory effects of gestation feed allowance were observed for ADG and FCE of offspring and when considering these the control feed allowance of 2.5kg/day which is close to current recommendations appeared optimum. Manipulating maternal body condition and feed allowance during gestation did not eliminate the poor growth performance associated with low birth weight piglets.

Opportunity/Benefit:

P_2 backfat of gilts should be targeted at ~19mm by the time of first insemination. During gestation a daily feed allowance of ~2.5kg of gestation diet (6.2 g/kg lysine, 13.0 MJ DE /kg) should be provided between day 25 and 90 of gestation. Following these guidelines will maximize growth to slaughter in offspring.

Maternal food intake and weight play an important role in susceptibility to obesity and insulin resistance in children. The pig model developed here is a tool to examine diet and intake of the pregnant mother and the outcome for the offspring. Such a tool could be useful in developing formulations for pregnant women to benefit the health of the child.

1. Project background:

Inadequate prenatal nutrition can negatively influence both the birth weight and subsequent development of offspring. Altering feeding levels at different time points during the gestation period of the sow can influence piglet growth rates and subsequent sow reproduction both of which are key factors for efficient and profitable pig production. As a commercial pig spends nearly half its life *in-utero*, optimum nutrition and environmental conditions during this time are essential to maximise pig productivity. Body composition of the mother during gestation may also affect offspring development. In humans, babies born from obese mothers had increased body fat percentage, higher rates of diabetes and higher rates of insulin resistance. However, little is known about maternal feed level and body condition interactions during pregnancy and how they influence offspring growth and development. Our hypothesis was that postnatal growth in pigs is influenced by both the mother's body condition and her gestation feed allowance. This hypothesis was tested in a 2 x 3 factorial design experiment which examined the effect of backfat depth at service (Thin, 12 ± 0.6 mm P2 backfat and Fat 19 ± 0.6 mm P2 backfat) and feed allowance (1.8kg/d, 2.5kg/d and 3.5kg/d) between d25 and d90 of gestation in gilts on the lifetime growth and carcass quality of offspring at 158d of age.

2. Questions addressed by the project:

- Does maternal feed allowance during gestation influence the growth and development of offspring pigs?
- Does Maternal back-fat thickness at insemination influence the growth and development of offspring pigs?
- Are there maternal feed allowance and maternal back-fat thickness interaction effects on the growth and development of offspring pigs?

3. The experimental studies:

Gilts (Large White x Landrace) were selected as replacement breeding stock at birth on a commercial breeding company's (Hermitage AI, Sion Road, Kilkenny, Ireland) multiplier farm and were exposed to the same housing and feeding regime up to 22 weeks of age. At this time backfat depth of gilts was measured at the last rib and 65 mm from the back bone using an ultrasound scanner (Lean-meater, Renco Corporation, Minneapolis, Minnesota, USA) on both the left and right side and the mean value was recorded.

One hundred and forty gilts were selected based on their backfat depth at 22 weeks of age and Thin (N=68; P2 backfat ~ 8 mm) and Fat (N=72; P2 backfat ~ 12 mm) groups were formed. The difference in backfat depth between groups was accentuated by feeding different diets up to service at 32 weeks. The Thin gilts were restricted to 1.8kg/d of gestation diet (13.0MJ DE/Kg and 6.2g/kg Lysine) and the Fat gilts were provided with *ad-libitum* access to a gilt developer diet (14.3MJ DE/Kg and Lysine 5.9g/kg) up to 2 weeks before service. All gilts were provided with *ad-libitum* access to a lactation diet (14.2MJ DE/kg and 9.1g/kg Lysine) for flushing for two weeks prior to insemination (30 to 32 wk). To allow each gilt to exhibit at least one standing oestrus before insemination, they were provided with constant boar contact from an adjoining pen for four weeks before planned mating. Gilts were synchronised to oestrus and artificially inseminated at onset of standing oestrus and again 24 hours later using semen pooled from eight closely related Hylean Large White boars (Hermitage AI, Sion Road, Kilkenny). At Insemination back-fat depth was 12 ± 0.6 mm and 19 ± 0.6 mm for the Thin and Fat gilts, respectively.

Immediately after insemination, pregnant gilts were moved to individual gestation pens (2.4 m x 0.6 m; O'Donovan Engineering, Coachford, Ireland) and fed once per day 1.8 kg/d (23.4 MJ DE/d) of a gestation diet (Table 1) until d 25 of gestation. On d 25 of gestation, pregnant gilts from each body condition group (Thin or Fat) were blocked according to weight and expected farrowing date and allocated at random to one of three feeding allowances of the gestation diet: (a) Restricted (1.8 kg/d), (b) Control (2.5 kg/d) or (c) High feed level (3.5 kg/d), until d 90 of gestation. The experiment was a 2 x 3 factorial design with 2 factors for gilt backfat and 3 factors for gestation feed allowance. From d 90 to weaning at 28 days all gilts were treated the same.

Three same gender pigs (light birth weight, medium birth weight and heavy birth weight) were selected within litter at weaning, with litter representation balanced for the treatments so that in total 270 pigs were allocated to individual pens to be followed through to slaughter at d 130 post-weaning. From weaning, these pigs were individually fed 2 kg of commercial starter diet (16.25 MJ DE/ kg; 16 g/Kg lysine I), until consumed followed by 5 kg of a commercial link diet (15.4 MJ DE/kg; 15.0 g/kg lysine) until consumed after which a weaner diet (14.1MJ DE/Kg and 13.1g/kg Lysine) was fed to d 49 post-weaning. A finisher diet (13.7 MJ DE/kg; 11.1/Kg lysine) was fed from d 49 post-weaning to slaughter. At all times feed was available on an *ad-libitum* basis. Pig weights were recorded at birth, weaning, d 14, d 28, d 49, d 91 post-weaning and at slaughter. Feed disappearance was measured between d 0 (weaning) and d 14, d 14 and d 28, d 28 and d 49, d 49 and d 91 and between d 91 and d 130 postweaning. Average daily gain (ADG) and average daily feed intake (ADFI) were calculated for each of the growth stages above.

4. Main results:

During gestation restricted gilts had higher levels of cortisol than high and control fed animals. Piglets born to fat gilts had higher average daily gain during the lactation period and higher weaning weights at day 28 than piglets born to thin gilts. Gilts on a high feed level during gestation had heavier piglets than those provided with restricted and control allocations. Fat gilts had less saturated fat in their milk at day 21 of lactation and higher unsaturated fat levels. No differences were found in the n-6:n-3 PUFA ratio in the milk between thin and fat gilts.

At day 80 of gestation (d 80), Thin Restricted gilts had lower serum IGF-1 concentrations than Thin High or Thin Control fed gilts ($P < 0.001$). Pigs born from Fat gilts had greater backfat depths ($P < 0.05$), a lower lean mean yield ($P < 0.05$) and were heavier ($P < 0.05$) at slaughter than pigs born from Thin gilts. Gilt gestation feed allowance had only transitory effects on average daily gain and feed conversion efficiency and had no effect on pig weight at slaughter ($P > 0.05$) or lean meat yield ($P > 0.05$).

5. Opportunity/Benefit:

P2 backfat of gilts should be targeted at ~19mm by the time of first insemination. During gestation a daily feed allowance of ~2.5kg of gestation diet (6.2 g/kg lysine, 13.0 MJ DE /kg) should be provided between day 25 and 90 of gestation. Following these guidelines will maximise growth to slaughter in offspring.

We offer an animal model to food companies to investigate foods for the pregnant mother and to examine the outcome for her child (growth, weight management, diabetes, cardiovascular health).

6. Dissemination:

Main publications:

Amdi, C., Giblin, L., Hennessy, A.A., Ryan, T., Stanton, C., Stickland, N.C., and Lawlor, P.G. (2013). 'Feed allowance and maternal backfat levels during gestation influence maternal cortisol levels, milk fat composition and offspring growth' *Journal of Nutritional Science* 2(e1): 1 – 10. doi:10.1017/jns.2012.20

Amdi, C., Giblin, L., Hennessy, A.A., Ryan, T., Stanton, C., Stickland, N.C., and Lawlor, P.G. (2013), 'Maternal backfat depth has a greater influence than maternal feed level during pregnancy on growth performance and insulin-like growth factor-1 concentrations in pig offspring'. *Animal* (Accepted)

Amdi C., Stickland NC., Giblin L., McNamara L., Ryan T., Walsh M & PG Lawlor (2010) Effect of piglet birth weight on serum triglyceride levels at weaning and at slaughter. Advances in Animal Biosciences 1:185

Popular publications:

Amdi, C., Giblin, L., Stickland, N.C. and Lawlor, P. G. (2011). Influence of body condition and feed allowance on the cortisol levels of pregnant sows. In: International Oskar Kellner Symposium. Metabolic flexibility in animal and human nutrition, Warnemunde, Germany, 9th Sept, 2011

Amdi, C., Giblin, L., Stickland, N. and Lawlor, P.G. (2011). Influence of body condition and feed level of pregnant sows on prenatal muscle development. In: 2nd Workshop meeting of the former COST Action 925: The importance of prenatal events for postnatal muscle growth in relation to the quality of muscle based foods, Fribourg, Switzerland, 22nd Aug, 2011

Amdi, C., Stickland, N., Walsh, M., Ryan, T, Mc Namara, L., Giblin, L. and Lawlor, P. G. (2010). The effect of sow back fat and gestation feeding level on serum IGF-I levels of progeny. In Proceedings "The Power of Programming" International Conference on Developmental Origins of Health and Disease, Munich, 6th May, 2010, p.102

Amdi, C., Stickland, N.C., Giblin, L., McNamara, L., Ryan, T., Walsh, M., and Lawlor, P.G. (2010). Effect of piglet birth weight on serum triglyceride levels at weaning and at slaughter. In: 'Advances in animal Biosciences'. Proceedings of BSAS and the Agricultural Research Forum, Belfast, 12-Apr-2010, p. 185.

Alternative uses for pig manure

Project number:
5823
Date:
March, 2013
Funding source:
DAFF
Project dates:
May 2008 – Apr 2012

Key external stakeholders:

Pig farmers, pig advisers and consultants, policy makers, the scientific community.

Practical implications for stakeholders:

Despite restrictions and difficulties relating to the land spreading of pig manure, it is likely to be the most cost effective method of pig manure disposal in Ireland for the foreseeable future. While our cost analyses showed that the alternative technologies investigated in this project are not currently cost effective in Ireland, they may have potential in particular scenarios. For example, anaerobic digestion would be cost effective on large pig units (+2000 sows integrated) or if the renewable energy feed in tariff for energy sold to the grid was to increase in the future.

Main results:

This project demonstrated the technological feasibility and effectiveness of several alternative technologies for using and treating pig manure in Ireland. These include: anaerobic digestion of pig manure and grass silage, composting of the separated solid fraction of pig manure, use of the solid component of manure as a feedstock in pyrolysis and treatment of the liquid fraction of pig manure through integrated constructed wetlands (ICW) and woodchip biofilters. However, cost analyses of all technologies examined found all to be uneconomic, with conventional land spreading of pig manure for its fertiliser value found to be the most economic use for pig manure currently.

Collaborating Institutions:
NUI Galway
Agri-Food and Biosciences Institute (AFBI)
Waterford Institute of Technology (WIT)
University of Limerick (UL)

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Compiled by:
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Technology

Opportunity/Benefit:

The economic analysis performed on all of the technologies employed in this study allows examination of their economic feasibility now and in future scenarios. The results show land-spreading of pig manure for its fertiliser value to be the most economic use for pig manure currently, thus preventing farmers from making unwise financial decisions. Nonetheless, information on the effectiveness of and design guidelines for each technology examined are now available for adoption by stakeholders should economic conditions change in the future.

1. Project background:

The Nitrates Directive Action plan introduced by S.I. No.378 (2006) and updated by S.I. No. 610 (2010), prompted this research into non landspread options for pig manure. The spiraling cost of fossil fuel also means that the potential of pig manure as a renewable energy source should be examined.

2. Questions addressed by the project:

- Is anaerobic digestion of pig manure feasible?
- Can the separated solid fraction of pig manure be used for composting or as a biofuel?
- Are ICW and woodchip biofilters suitable for treating the separated liquid fraction of pig manure ?
- What is the energy balance of the technologies studied?
- Do the manure treatment strategies examined stack up economically?

3. The experimental studies:

Anaerobic Digestion: A total of nine experiments were carried out as part of the investigation into AD of pig manure. The researchers designed and constructed three identical continuously stirred single stage reactors (3l capacity), as well as six additional identical leaching bed reactors (2l capacity) to study the AD of pig manure with and without grass silage and maize silage. Two additional reactors were set up to investigate hydrolysis and acidogenesis of the mixture of pig manure and biomass. After these laboratory studies, a pilot scale digester was commissioned and installed at Moorepark to validate the main findings of the small scale units. Greenhouse gas (GHG) emissions were also measured during the storage of pig manure.

Composting of Manure Solids: The separated solid fraction of pig manure was composted using different bulking agents (straw, sawdust, shredded green waste and woodchips) at different ratios. The composting process was monitored through physical, chemical and microbiological analyses.

Use of Solid Manure as a Fuel: A small scale pyrolysis reactor in UL was used to study the suitability of producing energy from pig manure. The use of all three end products of pyrolysis (biochar, bio-oil and gases) to generate energy was evaluated. Experiments were carried out on the separated solid fraction of pig manure before and after composting. The biochar produced by the pyrolysis process was also analyzed for its value As a soil addendum.

Integrated Constructed Wetlands (ICW): Sixteen meso-scaled ICW systems, each comprising 4 cells, were constructed at Teagasc Moorepark in order to assess treatment of the separated diluted liquid fraction of pig manure. Different application rates and flow rates were investigated and microbiological analyses were conducted to investigate the removal of pathogenic micro-organisms.

Woodchip biofilters: Laboratory scale woodchip biofilters were designed, constructed and used to assess the suitability of using this technology to remove nutrients and pathogenic micro-organisms from the separated liquid fraction of pig manure. Twelve aerobic woodchip biofilters of 0.6 m depth were constructed to treat separated raw pig manure liquid (SR) and separated anaerobically digested pig manure liquid (SAD) at two hydraulic loading rates. Following on from this, six pilot-scale biofilters consisting of 1 m aerobic woodchip and 0.5 m saturated woodchip layers were constructed at Moorepark to verify results from the laboratory and to demonstrate effects of scale, variations in temperature and rainfall when used to treat the SR and SAD.

Energy Balance: An energy balance was performed on some of the technologies studied in the project. The energy balance was based on a case study of a 500 sow integrated pig unit producing 10,500 m^3 of liquid manure/year with a dry matter (DM) of 4.3%.

Economics: A cost-benefit analysis of the technologies investigated was performed based on the same criteria used for the energy balance study.

4. Main results:

Anaerobic Digestion: Using the laboratory-scale continuously stirred single stage reactors, it was found that grass silage could be co-digested with pig manure at a volatile solids ratio of 1.5 (manure/silage) in the feedstock and this was found to be feasible without reducing the specific methane yield. When the reactors were operated under an organic loading rate of up to 3 kg volatile solids/m^3/day and a grass silage volatile solids ratio of up to 40%, the system was found to be stable. However, the post methane production potential increased to 183–197 ml CH_4/g volatile solids and the volumetric post-methane production potentials increased to 9.96 ml CH_4/ml digestate. In subsequent pilot-scale experiments the specific methane yield increased from 154 ml CH_4/g volatile solids added with mono-digestion of manure to 251 ml CH_4/g volatile solids added with anaerobic co-digestion of manure and grass silage. Volatile solids removal rates increased from 41.4% (manure alone) to 53.9% (manure + silage). The results show that co-digestion of pig manure and grass silage is preferable to mono-digestion of manure alone.

Composting of Manure Solids: Results demonstrated that addition of a carbon-rich bulking agent is required when composting the separated solids of pig manure. Of the bulking agents investigated sawdust produced the best quality compost. When composting the separated solids of pig manure with sawdust, stable compost can be produced using a Carbon to Nitrogen ratio as low as 16. This corresponds to a separated manure solids to sawdust ratio of 4:1 (fresh weight). In addition, microbiological analyses showed that pig manure-derived compost meets microbiological criteria for marketable processed manure products, as set out in EU regulations, as *E. coli* and *Enterococcus* were below limits and it was *Salmonella*-free.

Use of Solid Manure as a Fuel: The small scale pyrolysis reactor studies showed that the proportion of biochar, bio-liquid and gas produced, and the physical and chemical characteristics of these products were influenced by both sawdust addition and feedstock composting. Increasing the sawdust content in the wood/manure mixture decreased the biochar yield and increased the bio-liquid yield. The biochar showed increased heating values, but reduced nutrient concentrations with increasing sawdust addition. The heating value of the gases produced also increased, while that of the bio-liquid was decreased with sawdust addition. Composting of the feedstock before pyrolysis increased the biochar and bio-liquid yield, but decreased the gas yield. The biochar showed reduced heating values, while the bio-liquid heating values were increased with composting. The biochar produced by the pyrolysis process was also analyzed as a soil addendum in laboratory columns. The addition of biochar to the soil increased N_2O emissions when pig manure was also added and CO_2 emissions also increased. The GHG emissions in this study were examined over a one month period following manure application. Longer term studies would be necessary to give a true picture of the overall effect of biochar addition on soil GHG emissions.

Integrated Constructed Wetlands: The meso-scaled ICW study demonstrated the potential of this technology to treat the separated liquid fraction of pig manure. However due to the system's high sensitivity to ammonium, the separated liquid fraction of pig manure had to be greatly diluted before entering the ICW. This may render this technology unviable for pig farmers due to the high land area required to construct such systems. Flow through the cells reduced mean counts of coliform, yeasts and moulds and spore-forming bacteria across all treatments but there were no effects on *Enterococcus* or *E. coli* counts. As *Salmonella* was undetectable in the influent material, its removal could not be investigated. As a result, microbial removal was also investigated in large-scale on-farm ICW systems treating agricultural wastewater. Overall, reductions in enteric indicator bacteria counts were found across nine ICW systems treating dairy and piggery wastewater, with *E. coli* and *Enterococcus* non-detectable in the final effluent. Furthermore, *Salmonella*, when present in the influent material, was absent in the ICW effluent.

Woodchip biofilters: The SR pilot-scale woodchip biofilters were successful in removing 49% DM, 71% CODt, 87% 5-day biochemical oxygen demand (BOD5), 89% TN and 91% total phosphorous (TP). Reductions of 54% DM, 80% CODt, 93% BOD5, 86% TN and 79% TP were achieved in the SAD pilot scale woodchip biofilters. The results confirm the occurrence of nitrification in the aerobic woodchip layers and denitrification in the submerged layers as previously found in the laboratory scale tests. When different chemical treatments were investigated for polishing of the pilot-scale biofilter effluent aluminium sulphate was found to be better than lime. It removed 71% turbidity, 63% CODt and 50% TP from the SR woodchip biofilter effluent, and 84% turbidity, 76% CODt and 99.6% TP from the SAD biofilter effluent. The measurement of GHG (CH_4, N_2O and CO_2) emissions from the pilot-scale woodchip biofilters using a chamber based flux measurement indicated that the average GHG equivalent emissions from the

woodchip biofilters were 264 kg CO_2e/ha/day and 217 kg CO_2e/ha/day from the SR and SAD woodchip biofilters, respectively. Microbiological analyses showed that *E. coli* and *Enterococcus,* although detectable in the biofilter influent were almost always below the limit of detection in the effluent and *E. coli* counts also appeared to be reduced. Furthermore, *Salmonella*, although detected in the influent on some occasions, was never found in the biofilter effluent.

Energy Balance: Anaerobic digestion was shown to be a net energy producer, with 277 MJ energy generated per t of input manure. For the separation process after AD a total of 4 MJ/ t input manure is necessary. The composting process is also an energy consumer with 16.5 MJ/ t manure input (plus the energy necessary for separation). The pyrolysis of pig manure was considered under different conditions: with and without the addition of different amounts of sawdust as well as before and after composting. The highest energy yield (496 MJ/ t manure input) was achieved when non-composted manure + sawdust at a 3:2 ratio was used as a feedstock and all three pyrolysis products were used as fuel source. The only energy input necessary for the ICW and the woodchip biofilter treatments is the energy necessary to separate the manure beforehand (4 MJ/ t input manure), as the material will be gravity-fed to the systems.

Economics: The AD of pig manure and grass silage (1:1; volatile solids basis) is unviable under the current tariffs, with costs at €4.8/m^3 manure. The solid-liquid separation of the digestate would cost an additional €12.4/m^3 manure. Subsequent treatment of the separated solid fraction by composting would add €2.1/m^3 manure. The use of ICW to treat the separated liquid fraction would add €4.5/m^3 manure to the treatment costs, while the use of woodchip filters would add €2.8/m^3 manure. The costs presented showed that the technologies analyzed are currently not cost effective. Transport and spreading of raw manure, at €4.9/m^3 manure (15 km maximum distance from farm) is the most cost effective option. For distances of up to 14km from the customer's farm the tractor and vacuum tanker scenario is the most cost effective option (€4.7/m^3). For longer distances it becomes more cost effective to use a truck, with the cost of transporting and spreading manure within a distance of 50 km to the customer's farm calculated at €7.7/m^3 manure.

5. Opportunity/Benefit:

The economic analysis performed on all of the technologies employed in this study allows examination of their economic feasibility now and in future scenarios. The results show land-spreading of pig manure for its fertiliser value to be the most economic use for pig manure currently, thus preventing farmers from making unwise financial decisions. Nonetheless, information on the effectiveness of and design guidelines for each technology examined are now available for adoption by stakeholders should economic conditions change in the future.

6. Dissemination:

A total of 17 referred journal papers and 49 conference papers/abstracts were generated. An open day 'Research Results on Alternative Uses for Pig Manure' was held in Moorepark on the 8th June 2011 to update stakeholders on the main results of the project.

Main publications:

1. Nolan T., Troy S., Gilkinson S., Frost P., Xie S., Zhan X., Harrington C., Healy M. G., and Lawlor, P. G. (2012). Economic analyses of pig manure treatment options in Ireland. Bioresource Technology. 105, 15–23.

2. Troy, S.M., Nolan, T., Kwapinski, W., Leahy, J.J., Healy, M.G. and. Lawlor, P.G. (2012) Effect of sawdust addition on composting of separated raw and anaerobically digested pig manure. Journal of Environmental Management, 111, 70–77

3. Xie S., Lawlor P., Frost P., Hu Z. and Zhan X. (2011). Effect of pig manure to grass silage ratio on methane production in batch anaerobic co-digestion of concentrated pig manure and grass silage. Bioresource Technology 102, 5728–5733.

Popular publications:

Proceedings of Pig Development Department research dissemination day, 'Research results on alternative uses for pig manure'. Wednesday 8th June, 2011. 82pp.

http://www.teagasc.ie/publications/2011/1021/Moorepark_AlternativeUsesForPigManure.pdf

Crops Environment & Land Use Programme

Agricultural Catchments Programme – socio-economic studies

Key external stakeholders:

Policy makers including Department of Agriculture, Food and the Marine, Department of the Environmental and Local Government, Environmental Protection Agency and Teagasc research and advisory colleagues.

Practical implications for stakeholders:

This project explored a range of socio-economic issues associated with nutrient management across farms and the implementation of EU Nitrates Directive based regulations.

- Dissemination of new and existing information on the scientific rationale behind certain EU Nitrates based measures may help to embed considerations on diffuse pollution and associated nutrient loss into the decision making processes of farmers.
- More efficient inorganic fertiliser applications and imported feed purchase has the potential to deliver a double dividend, win-win situation by reducing the risk of nutrient loss from agricultural land thereby assisting in the achievement of environmental water quality objectives while improving economic margins at farm level.

Project number:
5870
Date:
October, 2013
Funding source:
DAFM
Project dates:
Sep 2007 – Dec 2011

Collaborating Institutions:

None

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Expert Steering Group

Compiled by:
Cathal Buckley

Main results:

- Farmers are sceptical of the validity of certain Nitrates Directive based measures, especially in the area of temporal farm practices, however, there is acceptance among some farmers of environmental benefits deriving from the regulations.
- Results from a nationally representative sample of specialist dairy and tillage farms indicate that compared to the most efficient benchmark in the sample the average farm had over application of chemical fertilisers ranging from 22.8 to 32.8 kg N ha^{-1} and 2.9 to 3.51 kg P ha^{-1}.
- 53% of catchment farmers surveyed indicated a negative preference for provision of a 10 metre riparian buffer zone. The mean willingness to accept was estimated at €1.51 per linear metre for willing adopters.
- Results from a nationally representative survey of farmers indicate that between 26–43 per cent of farmers indicated a willingness to import organic pig or poultry manures either on a payment or free of charge basis.

Opportunity/Benefit:

The analysis conducted and published in this project is helping support agricultural policy formulation in the Republic Ireland in the area of the EU Nitrates Directive based regulations. Results from this study helped inform the Teagasc submission on the review of the EU nitrates Directive regulations and are available to Irish policymaker to use in policy negotiations at EU level.

1. Project background:

The Agricultural Catchment Programme (ACP) integrates bio-physical with socio-economic processes in the evaluation of the impacts of EU Nitrates Directive measures. ACP socio-economic research aims to provide information on and analysis of the socio-economic impact of the implementation of the measures contained in the National Action Programme (for EU Nitrates Directive implementation) on farms in selected catchments (and nationally) with particular emphasis on – the attitudes and awareness of the farming community to water pollution issues, the measures used to address them and the economic impact of changing agricultural practises to comply with the measures.

2. Questions addressed by the project:

- What are farmer opinions on EU Nitrates Directive implementation in the Republic of Ireland?
- Is there room to improve nutrient management efficiency at farm level?
- Are farmers willing to import pig and poultry manures onto their farms?
- Are farmers willing to engage with riparian buffer zones?
- What are farmers manure application and storage practices?

3. The experimental studies:

Within the ACP framework Q methodology was used to investigate farmer subjective opinions of the operation of the EU Nitrates Directive regulations after the first four year National Action Programme phase and explores the level of acceptance and refutation of measures from the view of farmers own knowledge and experience of land stewardship.

Using data generated from a survey of catchment farmer with land adjacent to a watercourse the willingness of farmers to adopt a riparian buffer zone was investigated. The research was based on a proposal to install a 10 metre deep riparian buffer zone on a five year scheme and the analysis was based on principal components analysis, contingent valuation methodology and a generalized tobit interval model.

Using Teagasc National Farm Survey (NFS) data, research was undertaken to investigate whether there is room to reduce chemical nitrogen and phosphorus fertiliser applications and imported feeds by exploring the extent to which application rates may have exceeded optimum levels using data envelopment analysis productivity analysis methodology. The investigation concentrates on specialist dairy and tillage farms in the Republic of Ireland stratified by land use potential.

Using NFS data and a multinomial model the willingness of the farming population to import pig and poultry manures was investigated.

Finally a survey of manure application and storage practices was undertaken across farms in the National Farm Survey in 2009.

4. Main results:

Results from Q methodology analysis indicate four main opinion groups. A "Constrained Productionists" group remain unconvinced about the appropriateness of certain EU Nitrates Directive measures from a farm management, environmental and water quality perspective. A second group "Concerned Practitioners" share these concerned but are generally more positive regarding other farm management and environmental benefits accruing from the regulations. A third group, "Benefit Accepters", indicated quite an environmentalist position and are generally very positive towards regulation implementation and associated environmental and farm management benefits. The final group "Regulation Unaffected" have some concerns but are mostly unaffected by the regulations. Results suggest scepticism remains around the validity of certain measures, especially, in the area of temporal farm practices, however, there is acceptance among some farmers of environmental benefits accruing from the regulations.

Results indicated that famers' willingness to supply a riparian buffer zone depended on a mix of economic, attitudinal and farm structural factors. A total of 53% of the sample indicated a negative preference for provision. Principle constraints to adoption include interference with production, nuisance effects and loss of production in small field systems. Of those willing to engage with supply, the mean willingness to accept based cost of provision for a 10 metre riparian buffer zone was estimated to be €1,513 ha^{-1} per annum equivalent to €1.51 per linear metre of riparian area.

Results across specialist dairy and tillage farms in the NFS demonstrate some inefficiency in the utilisation of nitrogen and phosphorus fertilisers compared to benchmark farms across these systems. Average over application of chemical fertilisers ranged from 22.8 to 32.8 kg N ha^{-1} and 2.9 to 3.51 kg P ha^{-1} in 2008. Potential cost savings on chemical fertilisers across all systems on average ranged from €38.9 ha^{-1} to €48.5 ha^{-1}. Additionally, potential cost reductions on imported feeds of €65 to €84 per livestock were indicated for dairy farms versus efficient cohort benchmark farms. Average excess of imported feedstuffs equated to 5.82–7.44 kg LU^{-1} of N and 0.92–1.17 kg LU^{-1} of P.

Based on a nationally representative survey (NFS) between 9 and 15 per cent of farmers nationally would be willing to pay to import poultry and pig manures manure respectively and a further 17 to 28 per cent would import if offered on a free of charge basis. Demand is strongest among arable farmers, younger farmer cohorts and those of larger farm size with greater expenditure on chemical fertilisers per hectare and who are not restricted by an EU Nitrates Directive derogation.

An NFS based nationally representative survey of manure application and storage practices on farms in 2009 estimated that 52 percent of all slurry was applied between the end of the closed period in January and April 30th in total volume terms. This contrasts with a 2003 survey which found that 35 percent of slurry was applied in the spring season. Across all farm systems approximately 71 percent of slurry was estimated to be applied to conservation ground (hay/silage), 26 percent to grazing land with the remaining 3 percent applied to maize or tillage crops. These figures indicate a trend toward greater slurry application on land used for livestock grazing compared to a 2003 survey where 80 percent of the slurry applications was to hay or silage land and 16 percent was on grazing land. The report also indicates an increasing number of farmers are starting to engage with newer slurry application technologies. A total of 6 per cent of dairy farmers reported using the trailing shoe method of slurry application.

5. Opportunity/Benefit:

The principle stakeholders for this research are policy makers in the Republic of Ireland. This includes officials within government (DAFM, DEHLG), state organizations such as the EPA as well as farm and agri-food industry representatives and colleagues within Teagasc research and advisory directorates. The research conducted is helping informed policy debate on the review of the EU Nitrates Directive based regulations.

Phase 1 of the ACP explored a range of socio-economic issues and laid the groundwork for longer term studies concerning farmer attitudes, economic impacts and uptake of nutrient management new practices which will be completed through the analysis of data to be collected in Phase 2.

6. Dissemination:

Main publications:

Buckley, C., Carney, P., (2013). The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level. Environmental Science and Policy, 25, 118–126.

Buckley, C., Hynes, S. and Mechan, S., (2012). Supply of an ecosystem service – Farmers' willingness to adopt riparian buffer zones in agricultural catchments. Environmental Science and Policy, 24,101–109.

Buckley, C., (2012). Implementation of the EU Nitrates Directive in the Republic of Ireland – A view from the farm. Ecological Economics, 78, 29–36.

Buckley, C., Fealy, R.M., (2012). Intra-national importation of pig and poultry manure: acceptability under EU Nitrates Directive constraints. International Journal of Agricultural Management, 1, 41–47.

Hennessy, T., Buckley, C., Cushion, M., Kinsella, A and Moran, B., (2011). National Farm Survey of Manure Application and Storage Practices on Irish Farms. Teagasc, Athenry, Ireland.

Popular publications:

Jordan P., Melland A., Mellander P-E., Wall D., Murphy P., Buckley C., Mechan S. and Shine O. (2011). Nutrient loads from agri-catchments: environmental risk or economic write-off? TResearch, 4(6), 12–13.

Agricultural Catchments Programme – nutrient pathways

Project number:
5869A
Date:
October, 2013
Funding source:
DAFM
Project dates:
Sep 2007 – Dec 2011

Key external stakeholders:

Policy makers including Department of Agriculture, Food and the Marine, Department of the Environmental and Local Government, Environmental Protection Agency and Teagasc research and advisory colleagues.

Practical implications for stakeholders:

This project contributes with information that will help policy makers to target mitigation measures.

Main results:

- Hydrological connectivity by surface (overland) or near-surface flow might not be as important in nitrogen (N) and phosphorus (P) transfer from land to water as is often assumed in some catchments of high permeability soils and aquifers.
- There are likely to be significant lag-times between implementation of a source measure and impact on water quality due to long time-scales that can be involved in below-ground nutrient transfers.
- Current Nitrates Action Programme (NAP) measures targeted at nutrient sources (soil nutrient status and nutrient inputs) may provide a more effective mitigation of nutrient loss over time in landscapes of high permeability, than supplementary measures such as buffer strips which target overland flow pathways (notwithstanding the multi-functional nature of such features).
- A method of quantifying N and P transfer to streams was developed using high-resolution hydro-chemistry data.

Collaborating Institutions:
None

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External collaborators:
Expert Steering Group

Compiled by:
Per-Erik Mellander

Technology

- Higher P exports were attributed to lower soil permeability, leading to flashier runoff (and P mobilisation into fast pathways), more so than to landuse or the magnitude of the P source (soil P status).
- Between 29% and 40% of the P exports from two grassland and two arable catchment occurred during the closed period for slurry spreading, supporting the utility of the closed period to avoid incidental losses.
- Emerging high P concentrations during sensitive low flow summer periods were attributed to loss of dilution of rural point sources.
- In a karst spring zone of contribution high P source (soil P status) and aquifer vulnerability did not elevate P in the emergent groundwater.
- Definitions of risk and vulnerability for P delivery in karst systems need further evaluation.

Opportunity/Benefit:

The output from this project contributes to the scientific evaluation of the effectiveness of the measures through an improved understanding of the nutrient pathways and will also provide a basis for any modifications to the measures.

1. Project background:

The Agricultural Catchment Programme (ACP) evaluates the impacts of European Union (EU) Nitrates Directive measures. The NAP in Ireland constrains the magnitude of the nutrient source pressure (through limits on livestock numbers and fertiliser use, for example) and minimises mobilisation potential (through closed periods for nutrient application and ploughing and slurry/ manure handling and storage requirements, for example). This closed period takes account of the fact that diffuse nutrient mobilisation and transport is more prevalent in times of greatest hydrological action. Within the ACP pathway project we aim to provide information on when, where and how much of the nutrient is transferred to groundwater and stream water.

There are uncertainties in the definition of N and P transfer pathways within agricultural river catchments due to spatiotemporal variations such as water recharge and the farming calendar, or catchment soil and hydrogeological properties. A holistic insight into processes and spatiotemporal variability is thus required when estimating nutrient transfer pathways in catchments.

In Ireland many karst aquifers are classified as having poor status; contributing to the eutrophication of receiving waters and this status had been identified by the EU Commission and other authorities as being of particular concern. Therefore, to evaluate the efficacy of the NAP measures a karst spring zone of contribution was included in the ACP.

2. Questions addressed by the project:

- When and where are nutrients (N and P) mobilized and transferred from source to groundwater and surface water?
- How do nutrient pathways respond to different land management, soil, geology and season?
- Can we define the risks and vulnerability of P delivery in a karst spring zone of contribution?
- How can we target and improve mitigation strategies with our insight to nutrient pathways?

3. The experimental studies:

This study combined site specific pathway studies on focused study sites with catchment integrated studies in the catchment outlets in order to characterise N and P transfer pathways from four agricultural river catchments (two grassland and two arable) with different land management, soil drainage and geology as well as from a karst spring zone of contribution.

Data from four ACP river catchments were used to compare the magnitude and seasonality of N and P transfers using data from the catchment outlets where synchronous chemistry and hydrology data were gathered at high resolution (sub-hourly time scales). Monthly sampling of groundwater chemistry and high resolution monitoring of groundwater hydraulic gradients (gathered from representative focused study sites), together with onsite weather data, allowed a coupling of surface and groundwater.

In a karst spring zone of contribution the soil P source and pathway components of the nutrient transfer continuum were defined at a high spatial resolution and the inferred risk of P transfer was evaluated using observed P delivery to the primary emergent spring at a high temporal resolution. This was achieved by surveying soil P status in fields as well as mapping of all surface karst features and depth to bedrock, by sub-hourly monitoring of P concentrations and water discharge in the emergent spring, and by monitoring weather within the zone.

The approach involved monitoring, surveying, data analysis and modeling. The challenges are the complexities of scale involved that arise from the spatial variability of soil physical/chemical properties that determine the pathway, the temporal variability of rainfall and the nutrient transformations that occur in the soil.

4. Main results:

For a major summer flow event in two river catchments with well drained soils, below-ground delivery pathways of N represented up to 97% of the total load, and up to 63% of the total reactive P and total P load. In these catchments, hydrological quick flow pathways were only 2–8% of total event flow but were efficient in delivering P to the stream. In two other catchments, with poor to moderately drained soils, up to 55% of the hydrological pathways were quick flow during a summer storm flow event. This quick flow delivered up to 88% of the event flow P load. Background groundwater flows were apparently mixed with point source inputs.

Even though quick-flow P transfer pathways (largely surface and shallow subsurface or artificial drain flow) appeared to dominate catchments with poorly drained soils and below-ground N transfer pathways dominated in catchments with permeable soils, a substantial P loss below-ground was found in the catchments with permeable soils. There was some evidence for N loss via ephemeral surface ditches in catchments with predominantly moderate to poorly drained soils.

Annual total phosphorus exports were low to moderate and not defined by landuse as is usual in models which use export coefficients. For example, the two grassland catchments exported 0.541 kg/ha/yr and 0.701 kg/ha/yr and the two arable catchments exported 0.175 kg/ha/yr and 0.785 kg/ha/yr.

Assuming that P exports during the closed period for slurry spreading comprise mostly of residual soil P (*i.e.* not incidental losses from recently applied P), the proportion of annual P exported in this period was mostly related to the hydrological flashiness of the catchments. As these exports represented 29% to 40% of the annual exports (in approximately 25% of the time), the results support the utility of a closed period for avoiding incidental losses – or avoiding spreading times of higher runoff risk.

The data also show that the runoff flashiness is synonymous with soil permeability – a factor not accounted for in the regulations as a limitation to nutrient mobilisation and fast runoff flowpaths.

In a karst spring zone of contribution with a moderate to intensive grassland agriculture, a high proportion of soil P Index 4 fields (considered agronomically and environmentally excessive) and a high karstic connectivity potential, P concentrations in the emergent groundwater were low and indicative of being insufficient to increase the P status of receiving surface waters.

Episodic P transfers *via* the karst conduit system did increase the P concentrations in the spring during storm events but not above 0.035 mg total reactive P/L. This process is similar to other catchments where the predominant transfer is *via* episodic, surface flow pathways, but here the high buffering potential of the karst system delayed and attenuated the infiltrated runoff. Spring hydrographs indicated a large proportion of small fissure flow within the limestone bedrock, thus inferring a high potential for P attenuation.

In a karst spring zone of contribution, capture of conduit flows in datasets of intermittent water quality assessment may over-emphasise the influence of conduit flows on the overall status of the groundwater body.

Current definitions of risk and vulnerability for P delivery to receiving surface waters should be re-evaluated as high source risk (soil P status) need not necessarily result in a water quality impact due to the nature of transport pathways and attenuation processes.

5. Opportunity/Benefit:

The principle stakeholders for this research are policy makers in the Republic of Ireland. This includes officials within government (DAFM, DEHLG), state organizations such as the EPA as well as farm and agri-food industry representatives and colleagues within Teagasc research and advisory directorates. The research conducted is helping informed policy debate on the review of the EU Nitrates Directive based regulations and a changed risk assessment.

6. Dissemination:

Main publications:

Mellander P-E., Melland A.R., Jordan P., Wall D.P., Murphy P.N.C. and Shortle G. (2012). Quantifying nutrient transfer pathways in agricultural catchments using high temporal resolution data. Environmental Science and Policy, 24, 44–57.

Jordan P., Melland A.R., Mellander P-E., Shortle G. and Wall D.P. (2012). The seasonality of phosphorus transfers from land to water: implications for trophic impacts and policy evaluation. Science of the Total Environment, 434, 101–109.

Mellander P-E., Wall D.P., Jordan P., Melland A.R., Meehan R., Kelly C. and Shortle G. (2012). Delivery and impact bypass in a karst aquifer with high phosphorus source and pathway potential. Water Research, 46, 2225–2236.

Popular publications:

Melland A. and Mellander P-E. (2011). Everyone wins by reducing nutrient loss. Today's Farm, Jan/Feb 2011.

Jordan P., Mellander P-E. and Melland A. (2011). Considerations of nutrient status in river systems. Geological Survey of Ireland, Groundwater Newsletter NO. 49 2011, ISSN-0790–7753.

Jordan P., Melland A., Mellander P-E., Wall D., Murphy P., Buckley C., Mechan S. and Shine O. (2011). Nutrient loads from agri-catchments: environmental risk or economic write-off? TResearch, 4(6), 12–13.

Agricultural Catchments Programme – nutrient delivery and impacts

Key external stakeholders:

Farmers, policy makers including Department of Agriculture, Food and the Marine, Department of the Environment and Local Government, Environmental Protection Agency and Teagasc research and advisory colleagues.

Practical implications for stakeholders:

The Good Agricultural Practice (GAP) measures introduced under the Nitrates Directive aim to reduce the risk to water quality from agriculture. Results from this research have implications for stakeholders in planning to achieve this objective.

- The impact of nutrient contributions from point sources needs to be considered when tackling impacted surface waters especially in less well-drained catchments.
- Evidence that current farm practices (influenced by regulation and schemes) are contributing to recovery in lake water quality, against a background of increasing farming intensity, suggests that further evaluation of the impact of the GAP measures on water quality is required.

Project number:
5869B
Date:
October, 2013
Funding source:
DAFM
Project dates:
Sep 2007 – Dec 2011

Collaborating Institutions:
None

Teagasc project team:
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Mrs. Sarah Mechan
Mr. Oliver Shine
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Dr. Paul Murphy
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Mr. Noel Meehan
Mr. Brian O'Connor
Mr. Mark Treacy
Dr. Avril Rothwell
Mr. David Ryan
Mr. Pat Flannery
Mr. Sean Murphy
Mr. John Colgan
Mr. Frank Lennon

External collaborators:
The Agricultural
Catchments Programme
Expert Steering Group
Dr. Barry O'Dwyer, UCC

Compiled by:
Ger Shortle
Phil Jordan
Alice Melland

Technology

Main results:

- Annual stream exports of P (0.12 kg/ha to 0.83 kg/ha) were low to moderate despite high rainfall and stream nitrate concentrations were below the maximum acceptable drinking water concentration of 11.3 mg/L in two representative arable catchments, monitored over two years using high resolution techniques.
- The phosphorus (P) Environmental Quality Standard (EQS) was impacted by a chronic signal of poor water quality during low flows (summer) which was likely to have a significant non-agricultural contribution.
- Meeting water quality targets is likely to be more challenging in the catchments with lower soil permeability due to lower summer dilution of point sources and higher diffuse nutrient losses during storms.
- Disproportionately high nitrate exports during winter confirmed that the closed period is synchronous with the period during which risks of incidental nutrient losses to water are highest.
- Sedimentary evidence from a drumlin lake suggests that since the late 1990s there has been a decrease in P enrichment of the lake water despite a local increase in agricultural intensification during this time.
- This decoupling of (increasing) external P source and (decreasing) P impact is proposed to be due to an increase in agri-environmental measures in this catchment and surrounding area.

Opportunity/Benefit:

Eliminating point sources offers an opportunity to reduce ecological impacts in streams and rivers from nutrient enrichment (particularly P). The evidence of a decrease in P enrichment of a lake despite a local to regional increase in agricultural intensification in recent years supports the comprehensive implementation of the GAP measures as an effective means to mitigating the impact of agriculture on water quality.

1. Project background:

The first four-year phase of the Agricultural Catchments Programme (ACP) was completed at the end of 2011. This phase was concerned with the establishment of an extensive catchment scale experiment, and providing an agri-environmental baseline of agricultural activity and water quality response in the years following the implementation of the Nitrates Action Programme (NAP).

The NAP is concerned with mitigating the risk of loss of nitrogen and P to groundwater and surface waters and additionally the suite of measures in the NAP are recognised as the agricultural contribution towards helping to implement the Water Framework Directive objectives in Ireland. The hypothesis tested in the ACP is that the NAP is addressing these issues satisfactorily. The first phase of the ACP has provided significant evidence to support this hypothesis; assertions which will require validating in Phase 2.

The ACP integrates the bio-physical with the socio-economic processes in the evaluation of the impacts of the NAP measures. Conducted at the catchment scale, the evaluation was more concerned with the water quality response of the package of NAP measures in agricultural catchments, rather than individual measures. However, the status of some of the individual measures, as obligated under the NAP, was investigated. Six catchments were instrumented to monitor nutrient sources and loss pathways to surface and groundwater bodies. Intensive biophysical monitoring was conducted according to a common experimental design, with the aim of evaluating the effect of changes in farm management practices on the transfer of nutrients from source to water and their impact on water quality. Measurements, modelling and socio-economic studies were used to evaluate the efficacy of the measures and aspects of their cost effectiveness and economic impact.

2. Questions addressed by the project:

- Does catchment soil type influence P attenuation and loss?
- How much P is exported annually from the two arable catchments in the ACP?
- How are nutrient losses distributed over the year in these two catchments?
- How have P levels changed in a drumlin lake over the past century and a half?
- What evidence is there of the impact of changes in farm practices on P enrichment of the lake?

3. The experimental studies:

Export rates of nutrients and sediment are not regulated to standard thresholds but are considered to be important determinants of downstream water quality. Efficacy of the NAP measures at the catchment scale were evaluated by comparing end of catchment stream chemistry with water quality targets, and included measurements of phosphorus, nitrogen and suspended sediment in two hydrologically contrasting and intensively cropped catchments.

Ecological surveys have been conducted in all the ACP catchment streams in spring (May) and late summer (September) since September 2009 and will continue during Phase II of the ACP. These data are used to identify the link between land management and biological water quality and to identify water quality status according to WFD inter-calibrated chemical, hydromorphological and biological indicators. Macro-invertebrate analysis was conducted seasonally in all catchments except the karst limestone catchment in Mayo where sites downstream of the spring emergence were not suitable. Benthic diatom (siliceous unicellular algae) analysis was conducted seasonally in all six catchments. River hydromorphology was measured at each site once and a fish survey was conducted in summer 2010. Associated water chemical analysis was conducted on a monthly basis during low flow at each site.

Sreenty Lough is a small (0.17km2) lake in the Sreenty-Corduff paired catchments, Co. Monaghan. The lake catchment is 2.5km2. Despite being smaller than the 50ha WFD requirement for monitored lakes, it is representative of typical inter-drumlin lakes that are a characteristic feature of a large area of North-Central Ireland. Many of these lakes have shown susceptibility to eutrophication via P transfers from impermeable soils over several decades and especially post 1950. Two short 50cm sediment cores were extracted from the central deep basins of the lake and dated using standard techniques (Pb210 and Cs137). Core slices (1cm) were analysed in the laboratory for diatom sub-fossil remains and these results were used in an Irish lakes diatom-inferred total phosphorus (DI-TP) model.

4. Main results:

For two representative arable catchments monitored over two years using high resolution techniques:

- Annual stream exports of P (0.12 kg/ha to 0.83 kg/ha) and suspended sediments (3 t/km2 to 15 t/km2) were low to moderate despite high rainfall.
- Stream nitrate concentrations were below the maximum acceptable drinking water concentration of 11.3 mg/L.
- Disproportionately high nitrate exports during winter confirmed that the closed period is synchronous with the period during which risks of incidental nutrient losses to water are highest.
- Phosphorus loads were higher and the chemical Environmental Quality Standard (EQS; 0.035 mg/L) was exceeded in the arable catchment with lower soil permeability despite lower annual rainfall.
- The P EQS was also impacted by a chronic signal of poor water quality during low flows which was likely to have a significant non-agricultural contribution.
- Meeting water quality targets is likely to be more challenging in the catchment with lower soil permeability due to lower summer dilution of point sources and higher diffuse nutrient losses during storms.

Monitoring of in-stream ecology in all the catchment streams showed that:

- The ‘potential’ WFD macro-invertebrate status ranged from Poor to High (Q-value 3 to 4–5) across sites, seasons (late spring and late summer) and years. At least good WFD status was achieved in at least one year and site in four of the five surveyed catchments.
- During the September samplings, when pressures on in-stream biology are greatest, the Small Stream (macro-invertebrate) Risk Score showed that 80–100% of the sites surveyed across 5 catchments were ‘potentially’ at risk of not reaching good water quality status by 2015.
- During spring samplings there was an overall improvement in macro-invertebrate health, despite these samplings following the winter periods of proportionately highest nutrient loss to streams, but 50–60% of sites remained ‘at risk’.

- A stream algal-growth indicator (the trophic diatom index) showed that the karst limestone catchment was the only catchment (on average) without trophic impact. Seasonal variation at some sites in some catchments was also observed.
- Juvenile brown trout were found in the three southern catchments and not in the two North-Eastern catchments where downstream physical and/or water quality barriers to trout migration were identified.
- The 'potential' WFD river hydromorphological status ranged from Bad to Good across sites.

An investigation into lake impact and recovery showed that:

- Sedimentary reconstructions of historical lake water quality in Sreenty Lough show trophic impacts by P to be broadly coincident with other similar sized lakes in the region from the 1950s to 1960s.
- Most recently, since the late 1990s and especially post-2007, sedimentary evidence suggests a decrease in aquatic enrichment despite a local to regional increase in agricultural intensification during this time.
- The decreased impacts were noted despite this lake having a high potential for internal P loading through seasonal anoxia and also a small apparent increase in soil in-wash.
- This decoupling of (increasing) external P source and (decreasing) P impact is proposed to be due to an increase in agri-environmental measures in this catchment and wider locale.

5. Opportunity/Benefit:

The disproportionately large impact of point sources, many of which are non-agricultural, presents an opportunity to reduce pressure on stream ecology by reducing or eliminating these sources. In many cases this would pose a lesser challenge than reducing diffuse losses from agriculture especially in less permeable catchments where the hydrological risk is high and agricultural source pressure is low.

P enrichment of Sreenty Lough has declined since the late 1990s and especially post-2007, despite a local to regional increase in agricultural intensification. This supports the contention that the implementation of the GAP measures by farmers has been effective in mitigating nutrient loss from farmland to water. This supports the comprehensive implementation of the GAP measures as the principal means of mitigating the impact of agriculture on water quality.

6. Dissemination:

Main publications:

Melland, A.R., Mellander, P.-E., Murphy, P.N.C., Wall, D.P., Mechan, S., Shine, O., Shortle, G. and Jordan, P. (2012). Stream water quality in intensive cereal cropping catchments with regulated nutrient management. Environmental Science & Policy, 24; 58–70.

O'Dwyer, B., Crockford, L., Jordan, P., Hislop, L. and Taylor, D. (in press). A palaeolimnological investigation into nutrient impact and recovery in an agricultural catchment. Journal of Environmental Management, doi. 10.1016 / jenvman / 2013.01.034.

Shortle et al., 2013 Agricultural Catchments Programme Phase 1 Report.

Teagasc. May 2013. ISBN1–84170–594–2

Popular publications:

Jordan P., Melland A., Mellander P-E., Wall D., Murphy P., Buckley C., Mechan S. and Shine O. (2011). Nutrient loads from agri-catchments: environmental risk or economic write-off? TResearch, 4(6), 12–13

Melland, A.R. & Mellander, P-E. Everyone wins by reducing nutrient loss. Teagasc Today's Farm Vol 22 Number 1 Jan/Feb 2011

Agricultural Catchments Programme – nutrient sources

Key external stakeholders:

Farmers, policy makers including Department of Agriculture, Food and the Marine, Department of the Environmental and Local Government, Environmental Protection Agency and Teagasc research and advisory colleagues.

Practical implications for stakeholders:

To reduce the risk to water quality the Good Agricultural Practice (GAP) measures introduced under the Nitrates Directive aim to reduce soil phosphorus (P) levels where they are excessive to the optimum for farming. Results from this research have implications for achieving this objective.

- Expectations for water quality improvement through mitigating diffuse P from farming must also factor in lag time between implementation of soil P mitigation regulations and the reduction in soil P levels, P decline model uncertainty, land management variability, and time for P to transfer to and within river networks.
- The wide variability in soil P levels found at farm and field scale indicates scope to correct imbalances with better nutrient management.
- A better farm scale nutrient management tool, accounting for the influence of soil type and landscape hydrology could be useful to improve the spatial distribution of nutrients on-farm.

Project number:
5868
Date:
October, 2013
Funding source:
DAFM
Project dates:
Sep 2007 – Dec 2011

Collaborating Institutions:
None

Teagasc project team:
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Mr. Frank Lennon

External collaborators:
The Agricultural Catchments Programme Expert Steering Group

Compiled by:
Ger Shortle
David Wall

Technology

Main results:

- In four ACP catchments (two grassland-dominated and two arable-dominated) at a field P deficit scenario of 7 kg per hectare per year it was predicted that an average of between 5 and 20 years would be required for all Index 4 soils to reach index 3. At a deficit of 30 kg it was predicted to take between 2 and 10 years.
- In 5 ACP catchments, between 6 and 26% of soils had excessive P status, showing the legacy of historic P surpluses.
- Significant differences in P attenuation and loss were found between the catchments, reflecting different soil types. Regulations do not currently reflect these differences.

Opportunity/Benefit:

Improved nutrient management and use on Irish farms has the potential to deliver a 'win/win' outcome of better economic returns on fertiliser costs and reduced risk to water quality from nutrient loss to water. There is an opportunity for further gains in improved nutrient management if soil type and landscape hydrology were considered.

1. Project background:

The first four-year phase of the Agricultural Catchments Programme (ACP) was completed at the end of 2011. This phase was concerned with the establishment of an extensive catchment scale experiment, and providing an agri-environmental baseline of agricultural activity and water quality response in the years following the implementation of the Nitrates Action Programme (NAP).

The NAP is concerned with mitigating the risk of loss of nitrogen and P to groundwater and surface waters and additionally the suite of measures in the NAP are recognised as the agricultural contribution towards helping to implement the Water Framework Directive objectives in Ireland. The hypothesis tested in the ACP is that the NAP is addressing these issues satisfactorily. The first phase of the ACP has provided significant evidence to support this hypothesis; assertions which will require validating in Phase 2.

The ACP integrates the bio-physical with the socio-economic processes in the evaluation of the impacts of the NAP measures. Conducted at the catchment scale, the evaluation was more concerned with the water quality response of the package of NAP measures in agricultural catchments, rather than individual measures. However, the status of some of the individual measures, as obligated under the NAP, was investigated. Six catchments were instrumented to monitor nutrient sources and loss pathways to surface and groundwater bodies. Intensive biophysical monitoring was conducted according to a common experimental design with the aim of evaluating the effect of changes in farm management practices on the transfer of nutrients from source to water and their impact on water quality. Measurements, modelling and socio-economic studies were used to evaluate the efficacy of the measures and aspects of their cost effectiveness and economic impact.

2. Questions addressed by the project:

- How long can it be expected to take, after the implementation of the GAP, measures for soils with excessive P levels (Index 4) to reach the optimum level for farming (Index 3)?
- What level of variability was there in soil P across and within the catchments and within catchment farms?
- Does catchment soil type influence P attenuation and loss?
- Is there scope to achieve more balanced spatial distribution of nutrients on farms?

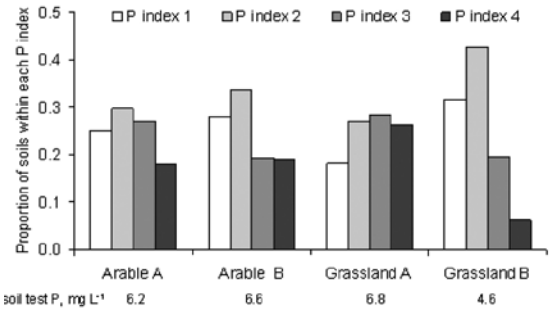
3. The experimental studies:

Two catchments representing a range of intensive grassland agriculture (beef and dairy production) with contrasting soil drainage characteristics (well-drained and poorly-drained) and two catchments with contrasting soil drainage characteristics representing intensive cereal production were selected to evaluate soil P changes in soils with high soil test P (STP) following the implementation of the GAP measures. Catchment fields were digitized and larger fields subdivided into soil sampling units of ca. 2 ha to account for differences in soil type, topography and management practices. The soils were analysed for Morgan's available P; national standard for plant available soil test P used in Ireland. The soils in each catchment were placed into the appropriate index for grassland or arable production using the Irish index system: index 1 (very low), index 2 (low), indexes 3 (medium) and index 4 (sufficient/excess). A model for predicting the trajectory of STP decline as a function of field P-balance, initial Morgan's P and initial total soil P was applied to the individual soil sampling units at P index 4 in each catchment.

Trajectories of soil P decline were assessed under three realistic field-scale P balance scenarios under different limitations affecting P inputs (high, medium and low P deficit) and used to calculate the rate of P decline.

4. Main results:

Soil P status in the catchments reflects management history, with the intensive dairy farming catchment (Grassland A – Timoleague) having the highest number of soil sampling units in Index 4 and a higher mean P concentration of these Index 4 soils (19.74 mg l-1) than the less intensive grassland catchment (Grassland B – Ballycanew) (10.44 mg l-1). The two arable catchments had similar numbers of Index 4 soil sampling units and mean Index 4 P concentrations (14.27 and 15.68 mg l-1). Current soil P status reflects the legacy of historical management practices. High soil P status fields (Index 3 and 4) mostly occur in dryer fields or fields adjacent to farm yards.



Three field P deficit scenarios were modelled; at -30 kg P ha^{-1} there are no limitations to reduce STP (e.g. silage fields or arable fields with P applications withheld), at -15 kg ha^{-1} there are some limitations to reducing STP (e.g. silage fields or arable fields with only slurry P applications) and at -7 kg P ha^{-1} there are severe limitations to reducing STP (e.g. a grazed field on a farm with all fields in Index 4, a reasonably high stocking rate and with slurry recycled evenly across the farm). At a field P deficit scenario of -7 kg P ha^{-1} it was predicted that an average of between 5 and 20 years would be required for all Index 4 soils to reach Index 3 (< 8 mg l^{-1}). At -30 kg P ha^{-1} it was predicted to take between 2 and 10 years. For the intensive dairy catchment (Timoleague), the model predicted that there will still be soils in Index 4 in 2015 (WFD reporting year), even at a deficit of -30 kg P ha^{-1}, reflecting the higher number of soils with very high STP values in this catchment.

A number of points were highlighted regarding the current NAP measures and their effects. On non-derogation farms, if no soil test is available, fertiliser P can only be applied at a replacement rate which limits the P inputs and potential build up. However, where soils have sub-optimal STP levels (Index 1 and 2) the restriction of P application may have a negative impact on yield and quality of crops. Nevertheless, P additions at replacement rates on soils already above optimum (Index 4) may present a further P transfer risk. While the less intensive grassland catchment has a lower proportion of Index 4 fields and these are predicted, on average, to decline rapidly, other evidence (see Jordan et al., 2012) suggests that this Grassland B catchment is more risky due to soil hydrological properties rather than soil chemical properties. The current NAP measures do not explicitly account for these other factors affecting P loss risk.

The decline to optimum soil P status remains a desirable aim for both agronomic efficiency and environmental risk objectives. Expectation of soil P decline can be realised under P deficit scenarios but concerted effort on management and advice needs to be focussed to realise these deficits without losing production.

At the farm level, whole farm P balances for 5 sample farms (one in each catchment) in 2010 showed that the dairy farm in the lowest intensity grassland catchment had the highest farm gate surplus (16.5 kg ha-1), while the beef-tillage farm in the winter-wheat dominated arable catchment had the highest farm gate deficit (-12.6 kg ha-1). The tillage-lamb farm in the spring barley-dominated arable catchment (1.7 kg ha-1), the dairy farm in the intensive dairy catchment (1.9 kg ha-1) and the beef-lamb farm in the grassland catchment of intermediate intensity (-0.7 kg ha-1) were closer to being in balance. However, when the soil P requirement is considered (level of fertiliser P required to build-up and maintain agronomic soil P levels), these balances become negative, even for the highest dairy farm surplus above. An intensive dairy farm with an N derogation in the intensive dairy catchment had just 4 % of the farm area requiring soil P additions and low P fertiliser imports on this farm resulted in an overall farm P deficit of -4.5 kg P ha-1.

At the field scale, large spatial variability was found, indicating scope to correct imbalances with better nutrient management on farms and redistribute P to lower status soils, potentially increasing P use efficiency and decreasing P loss risk. Trends in soil P

status, fertiliser P inputs and surplus P availability can be misrepresented at larger scales (national, catchment, farm scale) and may be better represented at smaller scales (field, soil process scale) where management and soil factors can be considered.

5. Opportunity/Benefit:

The outcomes of this project can be used by policy makers and regulators to reassess their expectations for water quality improvement through diffuse P source mitigation and they can now factor in additional time for P decline model uncertainty, land management variability and time for P to transfer to and within river networks.

The results also indicate that a better farm scale nutrient management tool, accounting for the influence of soil type and landscape hydrology could be useful to improve the spatial distribution of nutrients on-farm.

6. Dissemination:

Main publications:

Jordan, P., Melland, A.R., Mellander, P.-E., Shortle, G. and Wall, D. (2012). The seasonality of phosphorus transfers from land to water: Implications for trophic impacts and policy evaluation. Science of the Total Environment, 434, 101- 109.

Wall, D.P., Jordan, P., Melland, A.R., Mellander, P-E., Mechan, S., and Shortle, G. 2012a. Forecasting the decline of excess soil phosphorus in agricultural catchments. Soil Use and Management. Doi: 10.1111/j.1475–2743.2012.00413.x

Wall, D.P., Murphy, P.N.C., Melland, A.R., Mechan, S., Shine, O., Buckley, C., Mellander, P-E., Shortle, G. and Jordan, P. 2012b. Evaluating agricultural nutrient source regulations at different scales in five Irish catchments. Environmental Science and Policy 24, 34–43. Doi:10.1016/j.envsci.2012.06.007

Popular publications:

Treacy, M., Nutrient Management is a sweet success, Today's Farm, Vol.22 No.3 p.34–35 May-June 2011

Wall, D.P., & Shortle, G,. 2011. Securing Irelands N derogation: the Agricultural Catchments Programme. TResearch, Vol 6: Number 1. Spring 2011.

Crops
Environment
& Land Use
Programme

Generation of marker tools towards the mapping and isolation of key agronomic traits in *Lolium perenne* L.

Project number:
5244
Date:
September, 2013
Funding source:
Teagasc
Project dates:
Sep 2003 – Apr 2013

Key external stakeholders:

Plant geneticists, grass breeders, general public.

Practical implications for stakeholders:

The outcome of this project is of strategic nature. Main stakeholders at this time point are plant geneticists trying to unravel phenomena related to biomass accumulation and self-incompatibility in plants.

Also a number of genomic and population resources have been created during the lifetime of this project which are in use in Teagasc and other research institutions to further the understanding of perennial ryegrass trait genetics.

- A resource of genetic markers for perennial ryegrass has been created.
- A large mapping population (F2 biomass population) has been developed and utilised for the mapping of biomass related traits, segregation distortion and global metabolites.
- Research on the position and nature of the *S* and *Z* incompatibility loci has been advanced.

Collaborating Institutions:
University of Birmingham
Aberystwyth University/ IBERS
Aarhus University (AU)
University of Leicester

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Professor Pat (JS) Heslop-Harrison, University of Leicester
Dr. Trude Schwarzacher, University of Leicester

Compiled by:
Susanne Barth

Technology

Main results:

- Teagasc has contributed in a consortium to the development of expressed sequenced tag (EST) microsatellites (SSRs) for perennial ryegrass.
- A large mapping population in perennial ryegrass has been developed, characterised and utilised for the mapping of key agronomic traits.
- The main self-incompatibility loci S and Z which exist in all grasses have been fine mapped in perennial ryegrass.

Opportunity/Benefit:

The project is of strategic nature. Outcomes of the project are detailed genetic maps of the F2 biomass population which have been used to identify quantitative trait loci (QTL) for biomass related traits and agriculturally important metabolites (e.g. including fatty acids) under field and glasshouse conditions. Also the two major loci, S and Z, involved in self-incompatibility in grasses have been fine mapped and candidates for these two loci identified. In the course of these works molecular markers for perennial ryegrass have been developed, useful as a resource to study the genetics and physiology of traits in perennial ryegrass and related species.

1. Project background:

Perennial ryegrass (*Lolium perenne*) is an important pasture grass species for the temperate regions of the world. It is especially important for Ireland since a vast majority of Irish agriculture depends on the productivity of this species to produce feed for ruminants. Perennial ryegrass in its natural state is an outbreeding species. For this project we also used inbred lines developed in a previous breeding programme in Teagasc Oak Park to develop a F2 biomass population. This is an approach to study hybrid vigor and biomass related traits. Since high resolution mapping populations are also very useful for trait genetics we have developed up to the F5 generation a recombinant inbred line population which can be used to study in detail agronomic traits and phenomena like hybrid vigor. In its natural state perennial ryegrass is self-incompatible to maintain heterozygosity and viability of the species. This is a very common phenomenon in many plant species. Amongst the grasses a two loci self-incompatibility system based on the so called loci S and Z is conserved. The directed control of this system would be very useful for hybrid breeding. To date these loci have not been cloned. The research is of a public good nature. In the long term the outcomes of this research will support sustainable agricultural production practices, through the production of improved varieties.

2. Questions addressed by the project:

The overall project objectives were to study quantitative trait loci (QTL) for biomass related traits and the genetics of self-incompatibility in perennial ryegrass. Questions addressed were:

- Can we develop populations which are useful to study agronomic traits in perennial ryegrass?
- How great is the extent of hybrid vigor in an experimental population of perennial ryegrass?
- Is this population useful to study other agronomically important traits?
- Can any candidate loci for self-incompatibility be identified?
- To what level of detail can the self-incompatibility loci in grasses be mapped?

3. The experimental studies:

A F2 biomass population was developed from Teagasc perennial ryegrass inbred lines. ~400 individuals of this population have been used to study biomass related quantitative trait loci in replicated glasshouse and field trials. We developed molecular markers, including EST-SSRs, which can be easily applied in selection and breeding. For this population a high density genetic map has been developed using the markers developed during the course of his project. The inbred lines which are the grandparents of the F2 biomass mapping population were also characterised with genomic in-situ hybridization (GISH) and fluorescence in-situ (FISH) hybridization. To study self-incompatibility in perennial ryegrass high resolution mapping populations were developed for each locus, S and Z, respectively to study in approximately 10,000 segregating individuals. Molecular markers were developed around the S and Z loci and bacterial artificial clone (BAC) sequencing was carried out to study the regions containing the S and Z loci.

4. Main results:

A number of genomic resources were developed to study agronomically important traits in perennial ryegrass in detail. They included EST-SSRs as they are an easily applicable molecular marker type. Major quantitative trait loci for biomass yield under field and glasshouse conditions were identified. Identical positions for fresh weight and dry weight QTL were consistently detected on LG 2, 3 and 7 with one additional QTL for fresh and dry weight on LG 5, which was found in the field but could not be found in the greenhouse experiment. The QTL explained 28% and 50% in the greenhouse and the field experiment, respectively, of the variance in fresh weight and 29% and 53% in the greenhouse and field experiment, respectively, of dry weight. The broad sense heritability for the field data was 0.7. A recombinant inbred line population from the F2 biomass population has been developed by further generations of selfing and is awaiting immortalisation by seed production.

Through fine mapping of *Lolium perenne* by genotyping 10,177 plants, from six different populations segregating for the *S*-locus its region was reduced to 0.11cM. There appears to be low recombination frequency in this region as the first fine mapping of 1,393 plants identified exactly the same region as the large-scale fine-mapping. The genetic distance of the region was reduced but no additional recombinants were found. It is possible to determine the *S* and *Z* allelic diversity in a population by using closely few linked markers coupled with the high resolution melting (HRM) method. Allelic diversity, at both *S* and *Z* loci, is maintained in breeding population even within recurrent selection breeding programmes. However, the allele frequency is uneven.

5. Opportunity/Benefit:

The project is of strategic nature and will benefit mainly strategic research with a view to using the knowledge gained in plant breeding, which will ultimately result in increased rates of genetic improvement in ryegrass and productivity per hectare on grassland farms.

6. Dissemination:

The project resulted in a number of scientific publications and presentations at meetings including the plant breeding sector. The project was also presented to visitor groups, at Open Days in Oak Park and at Food Harvest in Athenry in 2008.

Main publications:

Barth S & Milbourne D (eds) (2012) Breeding Strategies for sustainable forage and turf grass improvement, Springer, Dordrecht, 2012 (ISBN 978–94–007–4554–4)

Anhalt UCM, Heslop-Harrison JS(Pat), Piepho HP, Byrne SL & Barth S (2009) Quantitative trait loci mapping for biomass yield traits in a *Lolium* inbred line derived F_2 population, Euphytica, 170: 99–107

Yang B, Thorogood D, Armstead I, Franklin FCH & Barth S (2009) Identification of genes expressed during the self-incompatibility (SI) response in perennial ryegrass (*Lolium perenne* L.). Plant Molecular Biology, 70: 709–723

Popular publications:

Barth S, Byrne S, Anhalt U & Yang B (2007) Applying 'omics' technologies to grassland improvement. TResearch 2 (2), p 22–23

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Future low emission biomass combustion systems

Collaborating Institutions:
Technical University of Graz (TU Graz)

Teagasc project team:
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Dr. John Carroll

External collaborators:
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Compiled by:
John Finnan
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Key external stakeholders:

Biomass producers, Consumers, Boiler Manufacturers, Policy Makers, Scientific Community.

Practical implications for stakeholders:

Substantial reductions in gaseous and particulate emissions from biomass combustion are possible through the use of a range of strategies which include:

- Air staging.
- The use of mixtures and additives.
- The use of electrostatic precipitators.

Main results:

- Emissions of oxides of nitrogen (NOx) and particulates can be minimised by optimising the air ratio in the primary combustion chamber as well as by the use of lower temperatures in the primary combustion chamber.
- Particulate emissions can be minimised by the addition of peat to bioenergy feedstocks although NOx emissions will increase as a result.
- Significant reductions in particulate emissions are attainable when 4% of kaolin, a clay-type material, is added to miscanthus and tall fescue bioenergy feedstocks.

Technology

- Precipitation efficiencies of greater than 70% are possible in an inline Electrostatic Precipitator (ESP) system with automated cleaning, while in a chimney top, manual cleaning system high efficiencies can be achieved for willow (86%) and wood (69%) on a short term basis. However, for medium (willow >100 mg/Nm^3) and high (tall fescue > 300mg/Nm^3) emission fuels, the use of an automated cleaning system is necessary to maintain precipitation efficiencies at acceptable levels.

Opportunity/Benefit:

This project has shown that combustion emissions from a wide range of bioenergy feedstocks can be reduced. Thus, this project has improved the potential environmental footprint of biomass combustion. The project has also increased the utility and attractiveness of a range of energy crops by demonstrating that there are several ways by which the emissions from these feedstocks can be reduced.

1. Project background:

Rising oil prices and increasing concern about the impact of greenhouse gas emissions from the use of fossil fuels has stimulated interest in renewable forms of energy including biomass. Combustion is the most mature technology for biomass utilisation but emissions from biomass combustion are typically greater in comparison to the combustion of natural gas or light fuel oil and can contribute significantly to concentrations of particulate matter, ozone and nitrogen dioxide in ambient air. Nitrogen in the fuel is the principal source of NO_x emissions as during combustion fuel nitrogen is almost entirely converted into gaseous nitrogen and nitrogen oxides. Particles of solid carbon (soot) may emanate from incomplete biomass combustion. However, under conditions of complete burnout, particle emissions primarily result from the release of inorganic material from the fuel, such particles consist mainly of K,Cl, S and Na although the principal element is K.

Epidemiological studies have demonstrated a relationship between negative health effects and air pollution. However, increasing demand for biomass together with limited wood supplies are forcing markets to consider non-woody forms of biomass such as agricultural crops. Such fuels differ in their chemical composition to wood as they typically have a higher ash content and higher concentrations both of ash-forming elements and of elements which produce elevated levels of gaseous emissions such as nitrogen and sulphur. Thus, emissions from the combustion of agricultural fuels are likely to be higher than those from the combustion of wood fuels. There is increasing concern that pollutant emissions from biomass combustion will reduce the benefit of the principal environmental driver for biomass utilisation, that of reducing emissions of greenhouse gases.

2. Questions addressed by the project:

- Can emissions from biomass combustion be reduced?
- Can a range of energy crops be used as feedstocks for biomass combustion without significant effects on air quality?

3. The experimental studies

Experimental Equipment

The combustion experiments were conducted at Oak Park, Carlow. An ETA Hack35 (ETA Heiztechnik GmbH, Hofkirchen, Austria) tilting grate biomass boiler with a rated output of 35kW and the capability to recirculate flue gas beneath the combustion grate was used for the combustion tests. The boiler was ignited and the temperature limited to 900°C at steady state using flue gas recirculation before the commencement of tests. The boiler was then run for one hour in this state, during which the particulate and gaseous emissions were monitored. This test was repeated 5 times for each of the pellet types.

Gaseous emissions were measured using a Horiba portable gas analyser with a heated sampling line. Particulate emissions were measured using a Dekati 3 stage low pressure impactor with 10 µm, 2.5 µm, 1 µm and filter collection stages. This method of particulate sampling involves a known quantity of flue gas being drawn across the impacter under isokinetic conditions and the weighing of impacter plates and filter before and after testing.

Feedstocks

Five bioenergy feedstocks were used in the experiments although not all feedstocks were used in all experiments. The five bioenergy feedstocks were: wood, willow, miscanthus, tall fescue and cocksfoot. Wood, willow and miscanthus were generally combusted in chip form while tall fescue and cocksfoot were pelleted prior to combustion.

Experiments

Air Staging Experiments: Three separate air staging experiments were carried out to determine the effect of the following parameters on particulate and gaseous emissions:

Test 1: Primary lambda (0.4, 0.6, 0.8, 1.0 and 1.2)

Test 2: Primary Combustion Chamber Temperature (900, 1000 and 1100 ^{0}C).

Test 3: Overall excess air ratio (4, 6, 8, 10, 12%).

Air Staging Experimental Set-up

Mixture and Additive Experiments: Peat was added to miscanthus and tall fescue feedstocks in percentages from 0 to 100%, both components of the mixture were mixed before being pelleted prior to combustion. A clay-based additive called Kaolin was also mixed with either miscanthus or tall fescue in percentages of 0, 1, 4, and 7% prior to pelletisation. The peat for blending tests was harvested in Ireland and was received in milled form with a particle size of less than 3 mm. The kaolin for additive tests was in powdered form with a particle size less than 1 mm. Miscanthus and tall fescue were firstly milled for ease of mixing in a Jiangsu Dehui hammer mill with a 3 mm screen size.

Electrostatic Precipitator Experiments: Two different types of electrostatic precipitator; an inline and a chimney top system, were tested using three different fuels which gave a range of particulate matter emission values ranging from very low (wood), medium (willow) and very high (tall fescue). The Schrader Al-Top (Schrader, Hemsack, Kamen, Germany) works on the principle of using a high voltage electrode (28kV) at the flue gas inlet to impart a negative charge to the particles. An automated cleaning system is used by this system. The Oekosolve “Oekotube” (Oekosolve AG, Industriestrasse, Ruggell, Liechtenstein) is a chimney top type ESP. A long electrode (1.3m) is inserted into the chimney and the control system is mounted outside. The electrode imparts a charge to the particulates which are collected either on the electrode or on surrounding surfaces.

AL-TOP Oekotube

4. Main results:

- It was shown that by varying the lambda value in the primary combustion chamber, NO_x emission reductions of between 15% (wood) and 30% (miscanthus) and particulate emission reductions of between 16% (cocksfoot) and 26% (wood) are possible. For all fuels, both NOx and particulate emissions were minimised at a primary lambda of 0.8. Particulate emissions from miscanthus increased with increasing temperature in the primary combustion chamber, NOx emissions from miscanthus and from willow also increased with temperature. Overall excess air ratio has no effect on emissions as no significant differences were found for any of the fuels at any of the different excess air ratios.
- Peat has a diluting effect on particulate emissions with a very strong linear relationship between percentage peat addition and particulate emission reduction demonstrated for both miscanthus (r^2 – 0.98) and tall fescue (r^2 – 0.99).
- For both miscanthus and tall fescue it was found that a kaolin addition rate of 4% gave significant reductions in particulate emissions. For miscanthus, a reduction of over 50% in particulate emissions (from 50 mg/Nm^3 to 24 mg/Nm^3) was demonstrated, particulate emissions from tall fescue fell by over 40% (from 340 mg/Nm^3 to 200 mg/Nm^3) after kaolin addition. Ash sintering temperature increased while potassium release decreased with increasing peat/kaolin addition.
- For all fuels, testing showed that precipitation efficiencies of greater than 70% are possible in an inline ESP system with automated cleaning, while in the chimney top, manual cleaning ESP system high efficiencies can be achieved for willow (86%) and wood (69%) on a short term basis.
- It was shown, that for low emission fuels such as wood (< 10mg/Nm^3), acceptable precipitation efficiencies (approx. 70%) could be achieved and maintained over a long time period on both automated and manual ESP systems. For medium (willow >100 mg/Nm^3) and high (tall fescue > 300mg/Nm^3) emission fuels it was found that the use of an automated cleaning system is necessary to maintain precipitation efficiencies at acceptable levels.

5. Opportunity/Benefit:

This project has shown that combustion emissions from a wide range of bioenergy feedstocks can be reduced. Thus, this project has improved the environmental footprint of biomass combustion. The project has also increased the utility and attractiveness of a range of energy crops by demonstrating that there are several ways by which the emissions from these feedstocks can be reduced.

6. Dissemination:

Future Low Emission Biomass Combustion Systems – Final Report

Low Emissions Operation Manual for Chimney Stove Users

Guidelines for Low Emission Chimney Stove Design

Design and Operation Concepts for Low Emission Biomass Grate Furnaces based on Advanced Air Staging

Guidelines for the Design and Application of Particle Precipitators for Residential Biomass Combustion

Reports available on http://www.teagasc.ie/energy/research/BiomassCombustion.asp

Project number:
5769 (B)
Date:
November, 2012
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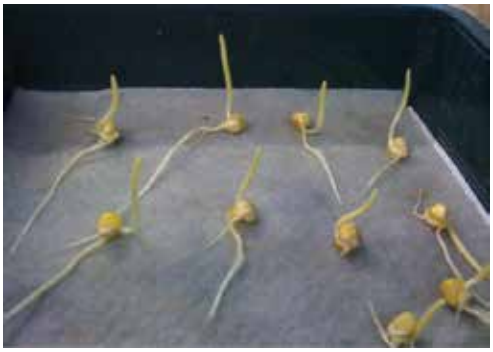
Project dates:
Dec 2007 – Dec 2012

Physiological and genetic response of maize to low temperature conditions



Collaborating Institutions:
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Compiled by:
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Key external stakeholders:

Maize breeders, agronomists, plant science research community.

Practical implications for stakeholders:

The outcome of this research informs agronomists and breeders on the impact of cold stress on the performance of maize varieties at early developmental stages.

- For both root and shoot tissues the effect of cold stress on the growth of a variety varies depending on the time of treatment. The differential responses of the varieties could not be explained by either kernel type or maturing time, however, the two varieties with the highest level of cold tolerance were very early maturing, flint types.
- From the 46K maize array, genes involved in chilling tolerance were identified. These could be targets for the improvement of cold tolerance of varieties.

Main results:

- In the physiological experiments the genotypes presented a wide range of cold tolerance, which was dependant on the time point of the cold treatment.
- The analysis of the microarray showed significant changes in gene expression between controlled conditions and cold treatment for the cold tolerant varieties studied, but not for the cold sensitive varieties. These differentially expressed transcripts could be followed up in marker assisted breeding programmes for the development of cold tolerant varieties.

Opportunity/Benefit:

Maize is a desirable crop for the production of high quality animal feed. Due to its origin in warmer climates the crop is not well adjusted to cooler temperate climates. Progress has been made to develop novel maize cultivars better adapted to temperate climates, especially in terms of tolerance to cold spring temperatures and chilling shocks. This project examined the genetic causes of cold tolerance/susceptibility of a range of maize cultivars. An improved understanding of the underlying causes of cold tolerance can help in the production of better adapted maize varieties.

Technology

1. Project background:

This project is part of a multidisciplinary project with the aim of providing a functional evaluation of the potential of maize (*Zea mays*) for use in low-input, sustainable production systems that are better suited to temperate conditions. But also to provide a basis for the further exploitation of maize as an alternative, more widely used fodder and bioenergy crop. A wide range of maize varieties and breeding lines were examined in laboratory-based experiments using comparative genomics, supported by physiological methods of assessing plant performance. A particular focus was placed on the impact of low soil temperatures during early seedling establishment. A detailed genetic study of the genes involved in cold stress tolerance in maize has been made available by a publicly accessible 46K maize array. The development of maize hybrids able to grow with high performance at low temperatures would result in improved establishment of the crop in cool climate regions like Ireland.

2. Questions addressed by the project:

- How large are varietal differences in the response to chilling shock in root and shoot tissues of maize?
- Can we identify the major genes underlying cold tolerance using a high density maize microarray?

3. The experimental studies:

Twelve varieties, differing in kernel type and maturation time, were provided by the seed companies Caussade, Pioneer and Codisem. Of the 12 cultivars, one (Fergus) is included in the Irish Recommended List 2012 suitable for growing in the open without plastic and Justina and PR39d60 are included in the Irish Recommended List 2012 suitable for growing covered/with plastic. The other 9 cultivars had all shown a high yield performance under Irish climate conditions. The varieties also differed in kernel type (flint, dent and flint-dent) and maturation time. The physiological experiments were to establish suitable temperature regimes for seed germination and root and shoot growth. Germination was classified as, when either the radicle or shoot emerged from the meristems, and these were at least 1 mm long. Three different light/dark temperature regimes were set up. A high temperature cycle was set at 22°C for 16 hours in the light and 18°C for 8 hours in the dark, a medium temperature cycle at 18°C for 16 hours in light and 12°C for 8 hours in dark, and a low temperature cycle at 10°C for 16 hours in light and 4°C for 8 hours in dark. Maize seeds were arranged on a surface of capillary matting lying over two layers of blotting paper to keep the environment moist without excess free water. The trays were placed in Snijder Microclima controlled environmental chambers at the three different temperature regimes described above. The layers of blotting papers and capillary matting were kept constantly moist by the addition of 100 ml of water every 24 hours. The individual seed trays were distributed in the cabinets according to a randomised block design and their arrangement was changed each time measurements were taken. Seed germination was determined every 24 hours. All experiments were carried out in triplicate. The goal of the experiment was to determine the germination rate and the growth performance of the genotypes, in terms of primary root and shoot elongation, under the cold treatment.

Samples from root and shoot tissues were taken for macro and micro array experiments. A custom cDNA macro array with known cold tolerance genes was constructed in UCD. A maize 46K array with 70-mer oligos was available from the University of Arizona (http://www.maizearray.org/index.shtml) which also supplied a hybridisation service. Four varieties were selected from the physiological experiment on the basis of the percentage of growth reduction, and used for the microarray analysis. One of the main objectives of the project was to identify expression patterns associated with temperature tolerance at the establishment stage in maize varieties adapted for NW European conditions. An understanding of such expression changes can provide tools for marker assisted breeding programmes. Analysis of variance was used to determine significant gene effects. Macroarray analysis was initially conducted, on cDNA of known maize cold resistance genes, in order to test if it was possible to detect changes, between the two experimental conditions, in the gene expression pattern of the varieties included in the Irish Recommended List, before the samples of interest were employed for microarray analysis. The macroarray analysis was performed by preparing a custom array consisting of ~300 cDNAs with a set of testing probes.

Four varieties selected from the physiological experiment on the basis of the percentage of growth reduction, were used for the microarray analysis. Roots were collected from seedlings grown under the same experimental conditions (18°C/16 hours for the control temperature regime and 12°C/8

hours for the low temperature regime, in dark conditions). Root samples were harvested at day 4, 5, 6, 7, and 8 days post-germination. At each time point, three biological replicates of root samples per variety were collected. The three biological replicates from day 4 were used for microarray analysis. An interwoven loop design (Kerr & Churchill, 2001) was applied to microarray analysis. The microarray analysis results showed that the two varieties with the highest degree of cold tolerance each had a set of differentially expressed genes (up and down regulated, p-value <0.05; variety 1, 39 out of 46K genes, variety 2, 29 out of 46K genes), while no genes appeared to be up or down regulated for the two cold sensitive varieties. Four of the differentially expressed genes were shared by 2 cold tolerant varieties, although not with the same degree of regulation. In particular, one of the genes was regulated in the opposite direction in two genotypes.

The outcomes of the microarray work were verified in a time series experiment with 5 time points (day 4 to day 8 post-germination). The gene expression was not maintained across the time series, but it was subjected to fluctuation. Nevertheless, except for one gene, the expression pattern was similar between the two varieties.

4. Main results:

Cold tolerance in maize root growth at early developmental stages is not dependant on the kernel type and maturing time, but varies according to the genotype and the time point at which measurements are made.

Four genes were significantly regulated under cold stress conditions in both cold tolerant varieties, but only three presented a similar expression pattern between the two genotypes, indicating a common mechanism for coping with the low temperatures.

5. Opportunity/Benefit:

Although directed specifically at maize the results will have applicability to other crop plants. The availability of detailed information on the maize genome will allow us to identify common genes/ gene products that are a feature of plant responses to cold stress. An understanding of the genetic basis of plant response to low temperature is a key requirement if we are to increase the availability of crops/products suitable for temperate regions.

6. Dissemination

The project resulted in a number of scientific publications and presentations at meetings. The project was also presented to visitor groups and as a poster at the Tillage Conference in 2010.

Main publications:

Di Fenza M. (2013) Examining the physiological and genetic response of maize to low temperature conditions. PhD thesis, National University of Ireland.

Di Fenza M., Gallagher T.F., Hogg B. and Barth S. (2010) Examining the physiological and genetic response of maize to low temperature conditions. *Proceedings of the Irish Plant Scientists' Association Meeting* 2nd to 4th June 2010, UCD Dublin.

An integrated biosciences platform for the future control of potato late blight on the island of Ireland

Project number:
5758
Date:
September, 2013
Funding source:
DAFM
Project dates:
Dec 2007- Sep 2012

Key external stakeholders:

Potato farmers, potato consumers, supermarkets, potato packers, agrochemical industry.

Practical implications for stakeholders:

Potato blight, caused by *Phytophthora infestans*, is the most destructive disease of potatoes worldwide. This project evaluated the structure of the Irish population of *P. infestans* compared to other worldwide populations and the practical consequences of this for potato growers and consumers. A migration event which introduced novel aggressive strains of *P. infestans* was detected. One of these new genotypes exhibits resistance to phenylamide fungicides and has the ability to overcome varietal resistance in current cultivars. This arrival represents a significant challenge to commercial potato production in Ireland. In addition, these new genotypes have demonstrated in both laboratory and polytunnel conditions an ability to genetically recombine with native strains to produce new strains. The durability of novel blight resistance sources in potato and the adaptation of the new and existing genotypes of *P.infestans* to currently available cultivars was also investigated. The project also began the process of characterising areas of the potato genome associated with resistance to blight and other pathogens with a view to producing DNA markers for use in conventional breeding of blight resistant varieties.

Collaborating Institutions:
Agri-Food & BiosciencesInstitute (AFBI)
Sarvarai research trust; USDA

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Compiled by:
Denis Griffin

Technology

Main results:

New aggressive genotypes of blight migrated to Ireland in 2008 and were responsible for severe blight epidemics over the following years. These strains are sexually compatible with native strains and have demonstrated an ability to genetically recombine; hence demonstrating the likelihood that new genotypes may emerge over time. The detection of the migrating genotypes resulted in the revision of disease control strategies. A quantitative PCR to detect latent infection of late blight was also developed during the project. The project also contributed to the international initiative to sequence the potato genome, with a special focus on a region of chromosome 4 harbouring a cluster of genes conferring resistance to late blight and other diseases. This information is being used to increase the capacity for marker assisted selection (MAS) for disease resistance in potato breeding.

Opportunity/Benefit:

Understanding the *P. infestans* population allows the implementation of improved disease control strategies such as fungicide choice and variety selection.

Characterisation of the efficacy and durability of novel resistance sources in potato allows these to be used in conventional breeding programmes with confidence the resistance will last.

The development of DNA markers for resistance to late blight improves the efficiency of the breeding process for new varieties and will lead to resistant varieties in the future.

1. Project background:

Late blight remains the biggest constraint to global potato production, and season-long control of late blight is essential to secure both yield and quality of the crop. This is the case in most potato growing regions worldwide, but particularly on the island of Ireland where the climate is very favourable to late blight in most years. As *P. infestans* can complete its lifecycle in as little as five days the potential exists for new genotypes to become established quickly. This can have immediate and dramatic effects on control strategies. The migration of novel aggressive strains (e.g. 13_A2, 6_A1) of *P. infestans* with altered fungicide sensitivity and the ability to overcome varietal resistance in current cultivars represents a significant challenge to commercial potato production in Ireland. At the outset of this project it was not known how new strains detected elsewhere might impact on the Irish blight population, how aggressive the new strains would be and whether they would have the potential to mate with pre-existing strains, resulting in the emergence of novel sexual recombinants. Future control of these strains depends on both fungicides and the continued development of potato varieties with genetically based resistance. Conventional breeding supplemented with marker assisted selection would vastly improve the efficiency of the development of resistant varieties, but the poor state of characterisation of the potato genome at the outset of the project limited the possibilities for adopting this approach.

The central rationale for the work was to secure the development of sustainable disease control strategies by gaining an in-depth knowledge of current pathogen populations and how they might develop in the future and how they interact with available fungicides and genetic resistance to the disease.

2. Questions addressed by the project:

This project adopted a multi-stranded approach to:

1 Understand the changes in the late blight (*Phytophthora infestans*) pathogen population in Ireland following the arrival of new aggressive strains including its ability to overcome fungicides and resistance in potato varieties.
2. Examine the potential future evolutionary path of the blight pathogen in terms of its interaction with older strains of blight, the potential for sexual recombination.
3. Contribute to the international effort to provide a platform for biotechnology-based strategies for developing disease resistance cultivars by developing a high quality draft sequence of the entire potato genome.

3. The experimental studies:

1. Pathogen Monitoring:

With the assistance of potato inspectors from the Department of Agriculture, Food and the Marine, the Department of Agriculture and Rural Development of Northern Ireland, the Teagasc Advisory Service and the general public, field populations of *Phytophthora infestans* were sampled each season for four years (2008–2011). Culture collections representative of the populations in both the Republic of Ireland (ROI) and Northern Ireland were subsequently established at both Teagasc Oak Park and AFBI respectively. These collections were characterised both molecularly (SSR genotyping and

mtDNA haplotyping) and phenotypically (phenylamide resistance, allozyme and mating type). Additional characterisations (RG57 RFLP profiling and CAA fungicide sensitivity) were also performed on a subset of isolates. The ability of the prevailing *P. infestans* population to overcome host plant resistance was tested by exposing potato plants carrying known R-genes (R-gene differentials) and varieties exhibiting partial blight resistance to natural infection at sites in Carlow and Belfast in successive years.

2. Adaptability and aggressiveness studies:

A combination of both classical pathology skills and biotechnology (e.g. qPCR, microsatellite marker analysis, cloning, amplicon sequencing) were adopted to characterise the novel strains of blight appearing in Ireland and to determine their impact on native strains and existing potato germplasm.

3. Potato Genome Sequencing:

Teagasc contributed to the development of a draft sequence of the potato genome as part of the international Potato Genome Sequencing Consortium (www.potatogenome.net). The sequencing initiative adopted emerging next generation sequencing technologies to sequence an experimental doubled monoploid clone of potato referred to as "DM", and also performed extensive sequencing in a highly adapted dihaploid potato clone referred to as RH. Teagasc's main roles in the PGSC project were to carry out a series of sequencing experiments demonstrating the accuracy of the novel sequencing approaches relative to the traditional approaches previously adopted, and to help identify the chromosomal origin of the large stretches of sequence generated during the project. Teagasc also focused on developing a higher quality sequence of several potato genotypes at a locus on chromosome 4 harbouring an important cluster of disease resistance genes.

4. Main results:

1. Pathogen Monitoring

Monitoring of Blight populations took place in 2008, 2009 and 2011. Blight was extremely rare in 2010. In 2008 the 13_A2 (Blue 13) genotype of blight (A2 mating type, phenylamide-resistant) was detected here for the first time. This genotype has subsequently been shown to be more aggressive than the previous population. Two other new genotypes 6_A1 (Pink-6) and 12_A1 were also identified. In addition to the older genotypes (8_A1 and 5_A1) 13_A2 was identified at the start of the 2009 season indicating an absence of the fitness penalty previously associated with phenylamide resistance. The populations remained stratified with the new A2 strains dominating the east coast and older genotypes on the west coast. When detailed monitoring resumed in 2011, the population had experienced a potential bottleneck effect; the new genotypes virtually disappeared to be replaced by the original genotypes 8_A1 and 5_A1. Characterisation of the 6_A1 genotype revealed a rare verision of the pathogens mitochondrial genome known as Ib haplotype. This haplotype has been almost absent from both the Irish and U.K. *P. infestans* populations since the early 1980s indicating this genotype is a migrant. The new *P. infestans* population is capable of overcoming all Solanum demissum resistance genes except R8, but Sárpo Mira remained resistant. The limited population diversity and absence of rare genotypes indicate sexual recombination is not currently a factor in population epidemiology.

2. Adaptability and aggressiveness studies:

A qPCR assay was developed using the PiYt gene from *P. infestans*. This diagnostic test can be applied to detect latent infection of *P. infestans* in tubers. A polytunnel study carried out with the University of Wales, Bangor, has confirmed the potential for sexual mating between the aggressive 13_A2 genotype and older A1 genotyopes. Laboratory studies concluded that while the newer *P. infestans* genotypes are more aggressive collectively, there are individual isolates of the older genotypes that are as aggressive as the newer Blue 13 and Pink 6 strains. A population of *P. infestans* recombinants (n = 55) was isolated from recovered oospores from the above mentioned polytunnel experiment. Microsatellite analysis of the F1 recombinant progeny confirmed significant genetic segregation and the presence of triallelic alleles in up to seven F1 progeny. Aggressiveness testing of the recombinants indicated that the parental isolates remained the most aggressive, compared to the progeny studied in this experiment. This study demonstrates that while there is currently no evidence from the field of sexual recombination, *P. infestans* isolates present in Ireland are capable of viable sexual recombination and the possibility of fitter genotypes and soil-borne oospore inoculum cannot be ruled out in the future.

3. Potato Genome Sequencing:

The potato genome is approximately 840 million nucleotides long. Using a hybrid approach involving Illumina and 454-based next generation sequencing (NGS), data for a draft sequence of the potato genome were generated. This was subsequently assembled, annotated, and several key biological

and evolutionary features of the genome were examined. Teagasc contributed to the main sequencing initiative by demonstrating the accuracy of the novel methodologies through re-sequencing of several regions, and by performing genetic mapping to anchor sequenced regions to their respective chromosomes. Chromosome 4 is of particular interest to the Teagasc potato breeding programme because germplasm containing resistance genes that confer resistance to late blight and potato cyst nematode has been identified in this region. The development of genetic markers from chromosome 4 is a high priority in order to deploy marker assisted selection in the breeding programme. Because the genome sequence is at "draft" level, with possible local inaccuracies in any one region, we carried out a careful manual reassembly and annotation of the region to develop an accurate picture of the gene content which is critical for the development of genetic markers linked to genes in the region.

5. Opportunity/Benefit:

It is important that the industry is aware of the continuously changing nature of the *P. infestans* population and this knowledge will also inform breeding programmes as to the most relevant R genes to deploy. Improved knowledge of population changes within *P. infestans* including changes in fungicide resistance spectrum allows growers and advisers to target fungicide programmes more effectively. Rapid dissemination of this information to the industry through the Teagasc and AFBI knowledge transfer systems facilitates this.

The information developed by participating in the genome sequencing initiative will allow the development of genetic markers, which, in the longer term, will help develop potato varieties exhibiting resistance to diseases such as late blight, via a process of marker assisted selection.

6. Dissemination:

The project received much public interest at open days, the annual national potato conference and in radio, television and newspaper interviews with the project team members. Results from the project were presented at several international conferences.

Main publications:

The Potato Genome Sequencing Consortium* 2011. Genome sequence and analysis of the tuber crop potato. Nature, Volume: 475, Pages: 189–195. * (including Marialaura Destefanis, Istvan Nagy and Dan Milbourne Teagasc Oak Park).

S Kildea, L Quinn, J Mehenni-Ciz, DEL Cooke, FM Perez, KL Deahl, D Griffin and LR Cooke. 2013. Re-emergence of the Ib mitochondrial haplotype within the British and Irish *Phytophthora infestans* populations. European Journal of Plant Pathology 135, 237–242.

Sanjeev Kumar Sharma, Daniel Bolser, Jan de Boer, Mads Sønderkær, Walter Amoros, Martin Federico Carboni, Juan Martín D'Ambrosio, German de la Cruz, Alex Di Genova, David S. Douches, Maria Eguiluz, Xiao Guo, Frank Guzman, Christine A. Hackett, John P. Hamilton, Guangcun Li, Ying Li, Roberto Lozano, Alejandro Maass, David Marshall, Diana Martinez, Karen McLean, Nilo Mejía, Linda Milne, Susan Munive, Istvan Nagy, Olga Ponce, Manuel Ramirez, Reinhard Simon, Susan J. Thomson, Yerisf Torres, Robbie Waugh, Zhonghua Zhang, Sanwen Huang, Richard G. F. Visser, Christian W. B. Bachem, Boris Sagredo, Sergio E. Feingold, Gisella Orjeda, Richard E. Veilleux, Merideth Bonierbale, Jeanne M. E. Jacobs, Dan Milbourne, David Michael Alan Martin, and Glenn J. Bryan 2013.

Construction of Reference Chromosome-Scale Pseudomolecules for Potato: Integrating the Potato Genome with Genetic and Physical Maps
G3 (In press)

Popular publications:

The onward march of potato blight. Kildea, S., Cooke, L.R., Griffin, D. Tresearch Vol.4 No.3 Autumn 2009, pp. 24–25.

Changing blight populations in Ireland. Kildea S. Proceedings of the National Potato Conference and Trade Show 2010, 9th of February, Dublin, pp. 35–37.

Is the blight threat increasing? Kildea, S., Griffin, D. Irish Farmers Journal Crop Protection Magazine April 2009, pp. 8–10.

Population shifts and weather reduce effectiveness of late blight control – Kildea, S., Griffin, D. Irish Farmers Journal 25–06–2011.

Combined heat and power from biomass

Project number:
5915
Date:
October, 2013
Funding source:
Teagasc
Project dates:
Jan 2009 – Dec 2012

Collaborating Institutions:
Stirling Denmark

Teagasc project team:
Dr. John Finnan (PI)
Padraig Brett
Tom Ralph

External collaborators:
Stirling Denmark

Compiled by:
John Finnan

Key external stakeholders:

Commercial and industrial users with high energy costs, biomass suppliers, local and national government/government agencies and the scientific community.

Practical implications for stakeholders:

Small scale combined heat and power production from biomass is now possible. This project has shown that this concept is feasible but that some of the technologies entering the marketplace require further development. Such technologies are likely to work best where there is a constant demand for heat.

Main results:

- A small biomass CHP plant (200 kw) based on stirling engine and gasifer technology was operated over three heating seasons and produced 36.3 MWh of electricity and 268.5 MWh of heat over 2157 hours of plant operation.
- Electrical efficiency (12%) was low due to the fact that the plant was not operated continuously and was only operated at part load.
- The Stirling engine did not give any problems until its seals failed and needed to be replaced after 2108 hours of operation.

Technology

- Gasification proved difficult to control and most of the problems of the plant were associated with the gasifier.
- Energy efficiency increased when the plant was operated continuously.

Opportunity/Benefit:

Technologies for small scale (<500 kw) co-generation of heat and electricity from biomass are now becoming available for commercial users. This project has shown that such technologies can work although, in the case of this technology, further development is needed.

1. Project background:

Co-generation of heat and power in rural areas using biomass as a feedstock offers the attraction of a high overall plant efficiency, reduced transmission losses, closer proximity to feedstock materials and the use of an indigenous energy source in addition to mitigation of the effects of climate change. It would also assist in achieving the renewable electricity targets set out in the 2007 White Paper on Sustainable Energy. Development of the sector has been constrained to date by the lack of suitable plant, especially for applications less than 200 kW.

A wide range of technologies may be considered for the co-generation of heat and electricity from biomass. For example, the biomass may be burned in grates or fluidised beds, or gasified using up- or down-draft systems. Power may be generated by an internal- or external-combustion engine, or by a turbine. A number of new technologies for small scale biomass CHP have recently become available:

- Organic Rankine-cycle (ORC) plant where steam is replaced by an organic working medium with a lower boiling point.
- Grate boiler with air-to-air and air-to-water heat exchangers which transfer heat first to recirculating air driving a micro-turbine and then to water for heating (e.g. Talbott CHP system)
- Grate boiler or gasifier operating an external-combustion Stirling engine (e.g. Stirling Denmark)

A review of the state of development of small-scale technologies concluded that ORC plants were most suited to demands between 400 and 1500 kWe, with Stirling engines offering most promise between 10 and 150 kW. The Stirling engine unit, though having a low electrical efficiency, was felt to be most suitable for small installations with a suitable heat-power profile. Small scale (< 500 kw) biomass CHP plants are now becoming available and the objective of this study was to evaluate a small (200 kw) biomass CHP plant based on gasification and stirling engine technology.

2. Questions addressed by the project:

To evaluate a small (200 kw) biomass CHP based on gasifer and stirling engine technology to determine if this technology is suitable for small scale combined heat and power production from biomass.

3. The experimental studies:

The biomass CHP plant at Oak Park has an electrical output of 35 KWe (Kilowatts electrical) and 140 KWth (Kilowatts thermal). The overall process of the plant is shown in the Figure below. The plant uses wood chips at 40% moisture as a fuel, the chips are augered into the gasifier where gasification occurs in an atmosphere containing a partial measure of oxygen. The gasifier in the plant at Oak Park had a total capacity of 800 kw to allow for further expansion of the system. The gas from the gasifier is taken from the top of the gasifier at a temperature of between 70 and 80 degrees C before being conducted into a combustion chamber where it is burned. The heat from combustion is used to heat water in a water jacket around the combustion chamber but also to turn the Stirling engine attached to the combustion chamber. The Stirling engine is cooled by the return water circuit of the plant. Part of the flue gas stream from the combustion process is used as a gasification agent for the gasification process and is conducted to the bottom of the gasifier after its oxygen content has been adjusted by the addition of air. The remainder of the flue gas stream is passed through a heat exchanger (economizer) before exhaustion to the atmosphere.

Electricity from the Stirling engine is fed into the sub-station at Oak Park and subsequently used around the Oak Park campus. The hot water from the plant is used to heat water in buffer tanks, this water is then used to heat buildings and glasshouses around the campus via a district heating system.

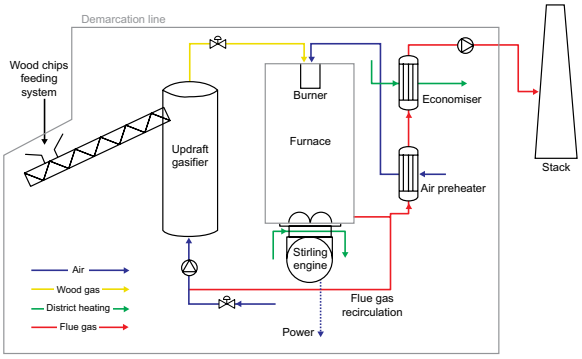
Gasification

Gasification is a form of incomplete combustion in which a fuel is burnt in an atmosphere which is deficient in oxygen. During gasification, an energy rich gas consisting principally of methane, carbon monoxide and hydrogen is formed but only a limited

amount of heat is released. In contrast, carbon dioxide, water vapour and heat are released during combustion when a fuel is burnt in an atmosphere which is not deficient in oxygen.

Stirling Engine

A Stirling engine is an example of a closed cycle engine in which the expansion and contraction of a working fluid is used to turn a crankshaft. In the CHP plant in Oak Park, the Stirling engine is bolted onto the combustion chamber where gas produced in the gasifer is burnt, heat from the combustion of the gas is absorbed by the working fluid of the stirling engine through heat exchangers. The engine starts to rotate once it's working fluid (helium) absorbs sufficient heat, a generator on the crankshaft of the engine starts to produce electricity once the engine rotates.



The plant was installed at Oak Park during 2009 and 2010 and was first run during the 2010/2011 heating season. It was subsequently run during the 2011/2012 and 2012/2013 heating seasons.

Initially, the plant was only run for a relatively small number of hours (4–8) on working days (Monday to Friday). Heat was supplied initially via a district heating system to two buildings in the campus which required heat between 8am and 4 pm from Monday to Friday. The district heating system from the plant was eventually expanded to include five large glasshouses in Oak Park which need to be supplied with heat during nighttime and at weekends in addition to during the daytime.

The expansion of the heatload of the plant in addition to improvements in the reliability of the plant allowed the plant to be run continuously when there was sufficient heat load.

4. Main results:

- **Plant:** The plant was operated over three heating seasons and was run for a total of 2157 hours during the study. The plant was run at full load (35 KWe) on several occasions without any problems but was generally operated on part load (15 KWe to 25 KWe) due to limitations in heat demand. Energy efficiency reached 81% when the plant was operated continuously under partial load.
- **Energy Generated:** 36.3 MWh of electricity and 268.5 MWh of heat were generated during this period.
- **Electrical Efficiency:** The average electrical efficiency of the plant was 12%. This figure is low and is attributable to the fact that the plant was not in continuous operation during this period and because the plant was only operated at part load.
- **Stirling Engine:** The Stirling engine did not give any problems during this period but its seals failed and needed to be replaced after 2018 engine hours and this effectively ended the study.
- **Gasifier:** Most of the problems encountered during the study period were related to the operation of the gasifier. The gasifier ran at a high temperature during the first heating season due to the fact that the concentration of oxygen supplied to the gasifier was too high (18%). This problem was eliminated once the oxygen concentration was reduced to 13%. High temperature operation caused considerable damage to the bottom of the gasifier and to the ash scrapers although this problem was partially attributable to the fact that these components were not covered with a sufficiently deep layer of ash before plant operations commenced.

- **Tar Formation:** No problems were encountered with tar formation during the course of the study. The pipe conducting product gas from the gasifier to the combustion chamber was almost totally clean at the end of the study (shown below). This is most probably attributable to the use of moist wood chips as a fuel for the plant. The resulting high moisture content of the product gas ensured that the tar did not lodge in pipes but was conducted to the combustion chamber and burned there along with the other constituents of the product gas.

- **Wood Chip Usage:** Wood chip usage was dependant on the operating cycle of the plant and the moisture content of the wood chips. Wood chip usage varied between 55 and 70 kgs of wet chips per hour during periods when the plant was operating continuously.
- **Manpower Requirements:** The plant proved to be manpower intensive and a part time operator would be needed to run such a plant. Manpower was needed on a regular basis to supervise chip loading, ash removal and for regular checking of plant operation. Additionally, a significant amount of time was found to be required for repair, annual maintenance and cleaning.

5. Opportunity/Benefit:

Technologies for small scale (<500 kw) co-generation of heat and electricity from biomass are now becoming available for commercial users. This project has shown that such technologies can work although, in the case of this technology, further development is needed.

6. Dissemination:

Finnan J, Brett P, Ralph T (2012) Producing Electricity and Heat from Biomass. TResearch, 7(4), 18–19.

Producing Biomass from Hemp (*Cannabis sativa*)

Project number:
5788
Date:
March, 2013
Funding source:
Teagasc
Project dates:
Jan 2008 – Sep 2012

Key external stakeholders:

Farmers, industrial users, scientific community.

Practical implications for stakeholders:

Farmers: can benefit from new knowledge on growing hemp in Ireland, specifically on the fertiliser requirements of hemp as well as on harvesting techniques for hemp. Hemp is an effective break crop, additional break crops are urgently needed in Ireland since the demise of the sugar beet industry.

Industrial Users: benefit from the knowledge that hemp can be grown in Ireland with relatively low inputs to produce high yields of biomass. Potential industrial users include the building industry, industries which produce insulation products as well as the bioenergy industry.

Scientific Community: benefits from this project as new information is now available on the fertiliser requirements of hemp as well as on the optimum harvesting techniques for hemp crops.

Main results:

- Highest yields were obtained from the variety with the latest maturation date.
- Hemp yields increased with applied nitrogen up to an application rate of 120 kg N/ha.
- There was no response to applied potassium, irrespective of initial soil potassium level or variety.
- Finger bar mowers and disc mowers can be used for mowing hemp.

Collaborating Institutions:
None

Teagasc project team:
Dr. John Finnan (PI)
Brendan Burke

External collaborators:
None

Compiled by:
John Finnan

Technology

- Once cut, hemp stalks rapidly loose moisture even during changeabl weather periods.
- Hay rakes which feature a cam-type action can be used successfully to rake the mown hemp crop into windrows.
- Baling can be problematical if hemp is cut as whole stalks but can be simplified considerably if hemp is cut into lengths by, for example, a tiered mowing bar system.
- Yield increases in succeeding cereal crops can be expected after hemp is included in an arable rotation.

Opportunity/Benefit:

This project has shown that relatively low fertiliser inputs are required to produce high yields of hemp. Thus, this project has demonstrated that hemp can be used as a low input break crop if suitable markets exist.

1. Project background:

The use of biomass as a source of energy forms a significant part of government strategy to reduce fossil fuel dependence and to mitigate the impact of climate change. The most significant targets include the use of biomass to replace 30% of the peat burned for electricity, the use of biomass to produce 12% of the heat market and the expansion of biomass fuelled CHP (combined heat and power). A bioenergy action plan has also been produced. Future markets for biomass may arise from the production of second generation biofuels. However, energy crops and short rotation coppice have not been grown in this country to any significant extent and relatively little research work has been carried out in Ireland.

The most popular energy crops are all perennial species which, after establishment, remain in the ground for a long number of years. Growers unable or unwilling to invest in such a long term commitment may wish to consider an annual energy crop such as *Canabis sativa* (Hemp). Hemp has been periodically grown in Ireland since the 18th century and was identified as an energy crop with high yield potential. An annual crop which produces high biomass yields under low input conditions is of interest as a combustion feedstock for the production of heat and electricity. Additionally, hemp as a species exhibits unusually high concentrations of cellulose which can make up >60% of the stem (Struick et al., 2000). The species should therefore be an excellent feedstock for the production of second generation ethanol by enzymatic hydrolysis. Additionally, hemp can also be used as an insulation product in both the building and automotive industries. Thus, there are a number of potential markets for hemp.

In previous research, hemp was grown over a three year period and achieved respectable yields (12.5t/ha) without the use of agrochemicals and with a relatively low fertiliser input. The work established, however, that the highest biomass yields could be achieved at low seeding rates. Further research was however needed to optimise the production of hemp. In particular, no research had previously been carried out in Ireland on the harvesting and the fertilisation requirements of hemp crops. The objective of this current project was to carry out research on these areas of hemp production in order to ensure that best practise advice was available on all aspects of hemp production.

2. Questions addressed by the project:

- What are the nitrogen fertiliser requirements of hemp crops grown for biomass?
- What are the potassium fertiliser requirements of hemp crops grown for biomass?
- What are the most efficient ways to harvest hemp crops?

3. The experimental studies:

Nitrogen fertilisation trials were carried out at a number of sites over a three year period. The only input used to grow hemp over this period was fertiliser, hemp crops were grown without any agrochemicals. The response to nitrogen of hemp varieties with different maturation dates was studied in the first year of the study (2008). These varieties were sown on both light and heavy soils on which crops had previously been grown as well as on an organic soil previously in grassland, all varieties received nitrogen application rates from 0 to 150 kg N/ha. The experiments were harvested by hand in September 2008.

Nitrogen response experiments in 2009 and 2010 concentrated on a late maturing variety of hemp (Futura 75), experiments in 2008 had confirmed that the highest biomass yields are produced by late, maturing varieties. In 2009 and 2010, Futura 75 was grown on two sites (heavy and light soil). Nitrogen was applied at rates between 0 and 150 kg N/ha, all nitrogen treatments were applied at sowing but some treatments were also applied either at emergence, after emergence or split between a


Left: **Windrows of whole stalks of hemp after raking with a swather rake.** *Right*: **Round bale of whole stalks of hemp**

number of application dates. The experiments were harvested by hand in September.

Potassium response experiments were conducted in 2011 on four different sites with different levels of soil potassium. Three varieties with different maturation dates were grown at each site, potassium fertilisation rates between 0 and 150 kg K/ha were used. The experiments were harvested by hand in September 2011. A range of conventional agricultural l machinery was used to harvest the hemp crops during the course of the study with the objective of determining the optimum harvesting procedures for hemp crops. Additional, post-cutting drying rates were also quantified. Winter barley was grown after hemp at one site in 2012, grain yields were quantified and compared to an adjoining site where winter barley was grown after a preceding cereal crop.

4. Main results:

Biomass yields increased with increasing maturation date from 11.1 to 12.2 tonnes of dry matter per hectare. Highest yields were obtained from the variety with the latest maturation date.

Hemp yields increased with applied nitrogen up to an application rate of 120 kg N/ha after which there was no further response to higher levels of nitrogen application. This result was obtained at all sites in all years irrespective of soil type, previous cropping history or soil nitrogen level.

Yield was not increased by applying nitrogen after sowing (ie at emergence or after emergence) or by splitting nitrogen between a number of application dates. Late applications of nitrogen were found to reduce initial growth in comparison to the growth produced when nitrogen was applied at sowing although late season growth was enhanced when late applications of nitrogen were used.

There was no response to applied potassium, irrespective of initial soil potassium level or variety.

Finger bar mowers and disc mowers can be used for mowing hemp. Drum mowers and conditioner mowers are unsuitable, however, as hemp stalks will readily wrap around the drums and conditioners respectively. Baling can be problematical if hemp is mown as whole stalks, the baling operation becomes much easier if hemp stalks are cut into a number of sections during mowing. When baling hemp crops cut as whole stalks, round balers typically perform better than square balers while belt balers or variable chamber balers typically perform better than roller balers.

Tiered mowing systems offer a superior method for mowing hemp, drying rates are enhanced with the use of such machines and subsequently the baling operation is less problematical.

Once cut, hemp stalks rapidly loose moisture even during changeable weather periods. Hemp stalks can decrease in moisture content from 65% to 35% in the first week after cutting and can reach a moisture content as low as 16% after a number of weeks.

Hay rakes which feature a cam-type action (swather rakes) can be used successfully to rake the mown hemp crop into windrows.

Hemp crops can be cut and chipped in one

operation using self-propelled harvesters with kemper headers. However, the fresh chips need to be ensiled immediately to avoid heating.

Yield increases can be expected in cereal crops grown after hemp. The magnitude of the increase will depend on previous cropping history and soil type.

5. Opportunity/Benefit:

This project has shown that only relatively low fertiliser inputs are required to produce high yields of hemp. Thus, this project has demonstrated that hemp can be used as a low input break crop if suitable markets exist.

6. Dissemination:

Main publications:

Finnan, J. and Burke, B. (2012) Potassium Fertilisation of Hemp (Cannabis sativa). Industrial Crops and Products 41, 419–422.

Finnan, J. and Burke, B (2013) Nitrogen fertilisation to optimise the greenhouse gas balance of hemp crops grown for biomass. Global Change Biology Bioenergy. Doi 10.111 1/gcbb12045

Genomics of the biomass crop Miscanthus: characterising variation in the plastid genome and assessing nuclear ploidy variation

Project number:
5763
Date:
November, 2012
Funding source:
Teagasc
Project dates:
Oct 2007 – Sep 2011

Collaborating Institutions:
Trinity College Dublin (TCD)

Teagasc project team:
Dr. Susanne Barth (PI)
Dr. John Finnan
Dr. Mariateresa de Cesare

External collaborators:
Prof. Trevor Hodkinson, TCD

Compiled by:
Susanne Barth

Key external stakeholders:

Miscanthus breeders, agronomists, plant science research community, general public.

Practical implications for stakeholders:

Miscanthus is a genus of perennial C4 grasses that has raised interest as a non-food crop for energy and fibre production. Currently mostly one clone of *Miscanthus x giganteus* is used in most of the field trials. More genetic diversity is required to have accessions available suitable for different geographical areas.

- A field collection of ~150 Miscanthus genotypes has been established in Oak Park.
- The genetic diversity of a collection of 164 *Miscanthus* genotypes and 26 related species of the subfamily Panicoideae has been characterised using newly developed nuclear and chloroplast SSR markers.
- Morphological and agronomical characteristics of this field collection have been recorded.

Main results:

An Irish field collection of *Miscanthus* spp. genetic resources accessions was established in Oak Park. This field collection was characterized by morphology and by molecular means. Novel molecular markers have been developed for this purpose.

Technology

Opportunity/Benefit:

Energy crops, unlike food crops are grown largely to maximize their biomass without concern for the details of nutritional quality or flavor. The product is largely lingo-cellulosic material that is used to generate energy either directly by combustion or by conversion to other fuels such as bio-ethanol. Fossil fuels are becoming depleted and evidence is growing on the negative impacts of greenhouse gases on global climate. It is generally believed that alternative energy sources such as biomass, including Miscanthus, are required to facilitate a transition from non-renewable carbon resources to renewable sources. Advances in genetics/genomics are essential to breed the next generation of agroenergy crops. Since the Miscanthus enterprise is built around a very narrow genetic basis, more genetic diverse materials for certain geographical and environmental end uses.

1. Project background:

Miscanthus species are perennial, C4 grasses capable of tremendous biomass growth under a wide range of climatic conditions. Attention has focused on biomass crops because of the need for alternative energy sources for sustainable living. Very few Miscanthus genotypes have been assessed for their biomass potential but work is underway to develop new genotypes. The overall aim of this project is to gather essential genomic information required for plant breeding in this poorly understood genus. The focus will be on the characterization of the nuclear and cytoplasmic gene pools.

We will assess the cytoplasmic gene pools available for breeding by developing and applying molecular markers suitable for rapid screening of diversity. We will quantify diversity, group haplotypes and study infra-generic variation. We will also assess if cpDNA is maternally inherited in Miscanthus.

Miscanthus species form a polyploid complex including several other genera (including Saccharum). For polyploid complex assessment we will use flow cytometry. The aim is to study nuclear DNA content and ploidy variation in the breeding genepools and to compare these to the assessments of plastid genome variation. We will determine crossability groups and gather essential information for future ploidy manipulation.

2. Questions addressed by the project:

The projects aims to gather essential genomic information required for breeding in this poorly understood biomass crop. Cytoplasmic and nuclear gene pools will be assessed by developing molecular markers for the chloroplast and nuclear genomes. Ploidy variation data for the nuclear genome are being gathered and the morphological variability in the Oak Par field collection recorded.

- How large is the cytoplasmic and nuclear diversity in the Oak Park field collection?
- How variable the is the Oak Park field collection in its morphology?

3. The experimental studies:

A field collection of approximately 150 accessions was gathered from different sources and planted in two replications in the field in Oak Park with the aim to provide at least medium term storage of these genetic resources. The majority of this collection was donated by the botanic Gardens in Trinity College Dublin and by Svaloef Weibull/ Sweden to provide a safety duplication of their collections. The collection was evaluated for morphological and agronomic characteristics. Reproductive morphological traits were recorded in detail to help in the identification of Miscanthus species. Nuclear microsatellite markes (nSSRs) and chloroplast microsatellite markers (cpSSRs) were developed from de novo and applied to the collection and further grass DNA samples. Genetic diversity for the chloroplast and nuclear genomes was calculated. Also the nuclear DNA contents of the accessions was determined using flow cytometry. Crossability studies were conducted in the greenhouse.

4. Main results:

Different traits were scored during the second growing season for the newly established collection of *Miscanthus* in Oak Park. A high level of variation was found for all the traits, with only a few of them showing a normal distribution in the multi-species dataset. When the same traits were measured in herbarium specimens from nine different species of *Miscanthus*, it was observed that mean values and standard deviation among species varied considerably, thus explaining the non-normal behaviour of a collection with mixed species. The ploidy level estimated in the collection ranged from diploid to tetraploid, with the genotypes almost equally divided between di- and triploid, with a few

tetraploid. All the *M. sacchariflorus* were found to be tetraploid, and, as expected, the individuals classified as *M. ×giganteus* were triploid. Diploids were only recorded in *M. sinensis* and *M. condensatus*. The comparison between the ploidy levels and the data from the inflorescences showed that all the diploids that produced inflorescences had *sinensis*-like spikelets, while in the triploid group, the accessions identified as *M. sinensis* 'goliath' had *sinensis*-like spikelets, whereas among the *M. sacchariflorus× M. sinensis* hybrids, some carried *sinensis*-like inflorescences and some the *sacchariflorus*-like ones. None of the plants identified as *M. ×giganteus* or *M. sacchariflorus* flowered.

Starting from the complete sequence of the *Saccharum officinarum* chloroplast genome, a close ally to *Miscanthus,* a total of 30 primer pairs were designed to amplify regions containing SSRs. With one exception, they all proved to be transferable to the genus *Miscanthus*. PCR products for the twelve primer pairs that performed better and amplified DNA reliably were sequenced to verify the presence in *Miscanthus* of microsatellite regions and possible polymorphism. Six markers showed length polymorphism of the repeats, with a species-specific preference in alleles. The six newly developed cpSSR primers were used to genotype the collection of *Miscanthus*. Their cross-amplification was also tested in closely related taxa. The results of the cpSSR genotyping revealed a high number of different haplotypes but with a clear bias in allele composition between *M. sinensis* and the two species *M. sacchariflorus* and *M. ×giganteus*, thus confirming *M. sacchariflorus* as the maternal lineage of the hybrid *M. ×giganteus*. The newly bred *M. sacchariflorus×M. sinensis* hybrids on the contrary shared their haplotype with *M. sinensis*.

New primer pairs for the amplification of nineteen nuclear SSRs loci were developed from the sequences of 192 clones from a microsatellite enriched library. The enrichment of the library was obtained by screening clones for sequences of TC_n, TG_n and $GATA_n$ simple sequence motifs. The newly developed primers were used to characterize the genetic diversity in the *Miscanthus* collection and test their cross-amplification in closely related taxa. All nineteen markers showed high levels of polymorphism with an average number of alleles of 27.5 per locus.

5. Opportunity/Benefit:

The main objectives of this work were to develop new molecular markers for the genus *Miscanthus* and to characterize morphological and molecular diversity in a genetic resource collection of *Miscanthus* established in Oak Park, Carlow. Such characterization is essential pre-breeding work necessary to define gene pools, identify taxa, establish inter-relationships of the accessions and develop markers suitable for association studies, quantitative trait loci mapping and marker-aided selection.

6. Dissemination:

The project resulted in scientific publications and presentations at meetings. The project was also presented to visitor groups and at Open Days in Oak Park.

Main publications:

Hodkinson T.R.H., de Cesare M., Prickett R., Jones M.B. and Barth S. (2012) Genetic variation in *Miscanthus x giganteus* (Poaceae) a bioenergy and fibre crop. Irish Plant Scientists' Association Meeting 3rd to 5th April 2012, National Botanic Gardens Dublin.

de Cesare M., Hodkinson T.R. and Barth S. (2010) 'Chloroplast DNA markers (cpSSRs, SNPs) for *Miscanthus, Saccharum* and related grasses (Panicoideae, Poaceae)' *Molecular Breeding* 26: 539–544 (DOI: 10.1007/s11032–010–9451-z).

de Cesare M., Hodkinson T.R., Barth S. (2010) **'**Development and use of nuclear microsatellite markers (SSRs) for genetic diversity evaluation in Miscanthus (Panicoideae, Poaceae). Irish Plant Scientists' Association Meeting 2nd to 4th June 2010, UCD Dublin.

Barth S. (2009) Genetic improvement of bioenergy crops (ed. Wilfried Vermerris) book review by S. Barth. Springer. Annals of Botany 103: viii-ix.

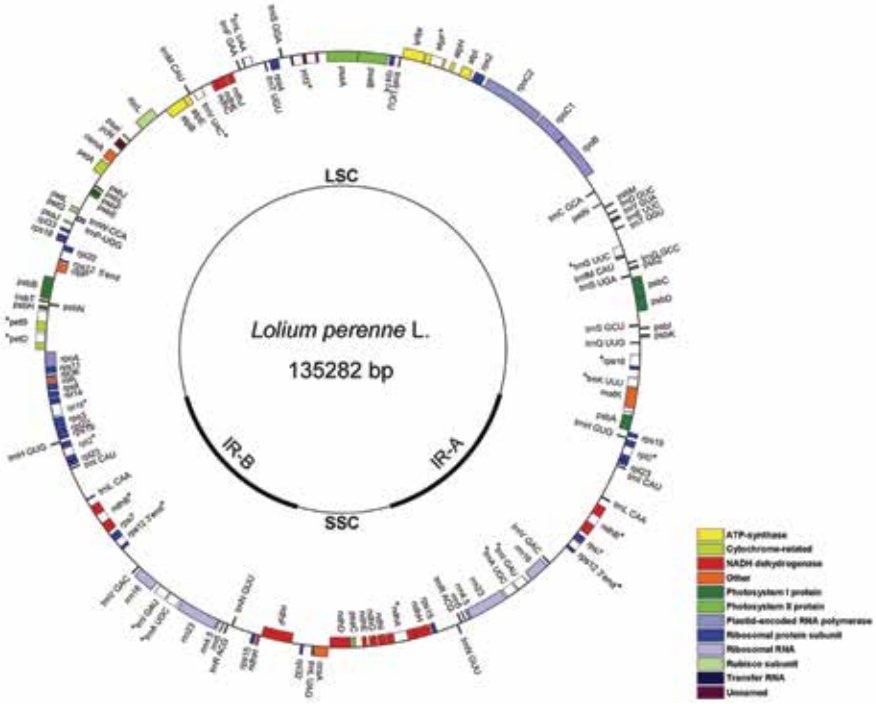
de Cesare M., Hodkinson T.R., Barth S. (2009) Phylogenetic analyses and ploidy variation in the biomass crop *Miscanthus*. Agricultural Research Forum 2009, Tullamore, p. 125 (ISBN 1–84170–538–1).

de Cesare M., Hodkinson T.R. and Barth S. (2009) Development of cpSSR markers in Miscanthus (Poaceae) Irish Plant Scientists' Association Meeting 19–20 March 2009, Trinity College Dublin.

de Cesare M., Hodkinson T.R. and Barth S. (2008) Use of cpSSRs markers and phylogenetic analyses in genus *Miscanthus*. ABIC conference, Cork August 2008, Ireland.

Perennial ryegrass organelle genomics

Project number:
5532
Date:
October, 2012
Funding source:
Teagasc
Project dates:
Feb 2006 – Dec 2010



Collaborating Institutions:
National University of Ireland (NUI) Maynooth
Trinity College Dublin (TCD)

Teagasc project team:
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Compiled by:
Susanne Barth

Key external stakeholders:

Plant geneticists, grass breeders, general public.

Practical implications for stakeholders:

The outcome of this project is of strategic nature. Main stakeholders at this time point are plant geneticists trying to unravel phenomena related to the organelle genomes of plants. Outcomes of this project form the basis for these studies.

Information gained on both perennial ryegrass organelle genomes is now available to carry out more applied research.

Technology

Main results:

- A high quality assembly of the perennial ryegrass chloroplast genome has been produced and made publically available.
- A high quality draft assembly of the perennial ryegrass mitochondrial genome has been produced.
- Molecular chloroplast markers have been developed which are useful to distinguish grass species and to assess genetic diversity in grass species. These markers are available to the breeding community.
- A robust regeneration protocol for perennial ryegrass amenable for genetic engineering studies was developed.
- Evidence for horizontal gene transfer between perennial ryegrass and a rhizosphere fungus was found.

Opportunity/Benefit:

The project is of strategic nature. To date only very few mitochondrial genomes of monocot plant species have been sequenced. Phylogenetic studies at high taxonomic ranks can be conducted and structural rearrangements and sequence evolution to understand patterns and processes of molecular evolution of the mitochondrial genome in grasses can be studied. The project results will allow investigation of the interaction with, and susceptibility to, endophytic fungi of perennial ryegrass in connection to plant nuclear and mitochondrial gene transfer or horizontal gene transfer between the fungus and the plant. The most studied plant mitochondrial mutation causes cytoplasmic male sterility (CMS), a tool widely used in plant breeding which prevents the formation of viable pollen.

1. Project background:

Perennial ryegrass (*Lolium perenne*) is an important pasture grass species for the temperate regions of the world. It is especially important for Ireland since a vast majority of Irish agriculture depends on the productivity of this species. It is grown mainly in the United States, Europe, Australia and New Zealand as a forage crop and it is also an important turf grass. Perennial ryegrass belongs to the family Poaceae and is related to the other economically important and extensively studied crop species like wheat, rice and maize. Perennial ryegrass has a nuclear genome size of about 2300 Mbp which is distributed over seven haploid chromosomes. The organelle genomes of perennial ryegrass, chloroplast and mitochondria, have not been sequenced yet. These genomes are small in comparison to the nuclear genome (estimated size of chloroplast genome 150kbp; mitochondrial genome 400kbp), however they are both important in their biological functions. Modifications in both genomes are amenable to enhance productivity of grasslands by genetic engineering of the chloroplast genome and via the more directed exploitation of heterosis via cytoplasmic male sterile (cms) lines which are based on incompatibilities between the nuclear and the mitochondrial genome. The research is of a public good nature. In the long term the outcomes of this research will support sustainable agricultural production practices.

2. Questions addressed by the project:

The overall project objectives were to sequence the whole genome of the perennial ryegrass chloroplast and mitochondrial genomes. Questions addressed were:

- How completely can the chloroplast and mitochondrial *Lolium perenne* genomes be assembled? -How can the sequence information of both genomes be described and exploited?
- Can we better understand the molecular evolution of these genomes and is there evidence of horizontal gene transfer?
- How useful are the genomes for examining the molecular evolution of chloroplast and mitochondrial genes in comparison to other grasses?
- Can we develop a robust regeneration protocol for perennial ryegrass to facilitate the transformation of *Lolium perenne* chloroplasts?

3. The experimental studies:

The perennial ryegrass chloroplast genome was shotgun sequenced and assembled using the cultivar 'Cashel'. It was necessary to develop a chloroplast DNA extraction protocol for grasses. Molecular markers from the chloroplast genome were developed and tested on a number of related grass species. The perennial ryegrass mitochondrial genome from cultivar 'Shandon' was shotgun sequenced and a high quality draft assembly was made. Evidence for horizontal gene transfer between *Glomus intraradices* and *Lolium perenne* was investigated. A robust regeneration protocol for perennial ryegrass was developed. RNA editing in the chloroplast genome of stressed and non-stressed plants from different genotypes was studied.

4. Main results:

A robust protocol to extract highly purified chloroplast DNA from grasses was developed. A complete chloroplast genome draft was obtained and molecular markers from this genome were developed and tested on *Lolium perenne* and related grass species. Several of the markers developed proved to be useful to distinguish *Lolium perenne* from *Lolium multiflorum* and other grass species and to assess genetic diversity in *Lolium*. The influence of stress on RNA editing in the chloroplast genome was conducted in several gentypes, genotype was found to be more influential on RNA editing than environmental stress (drought). A high quality draft assembly of the perennial ryegrass mitochondrial genome was made and evidence for horizontal gene transfer was found. The sequence information can be used now for a multitude of studies on the strategic and applied side of science.

A robust regeneration protocol for *Lolium perenne* was established and can be used in the future for genetic engineering of the chloroplast genome of *Lolium perenne*.

5. Opportunity/Benefit:

The project is of strategic nature and will benefit mainly strategic research with a view to using the knowledge gained in plant breeding. The sequence information of the *Lolium perenne* chloroplast genome provides the opportunity to study the specific modes of gene expression, including cis- and trans splicing and RNA editing. The interaction with and susceptibility to endophytic fungi of perennial ryegrass particularly in connection to plant nuclear and mitochondrial gene transfer or horizontal gene transfer between the fungus and the plant can now be investigated. Phylogenetic studies at high taxonomic ranks can be conducted and structural rearrangements and sequence evolution to understand patterns and processes of molecular evolution of the mitochondrial genome in grasses can be studied. The project also provides the bioinformatics basis for the construction of chloroplast transformation vectors to use plants as cell factories for the production of recombinant proteins. The expression of severe and effective changes in phenotypes can be a result of the high recombination rate in the mitochondrial genome. The most studied plant mitochondrial mutation causes cytoplasmic male sterility (CMS), which prevents the formation of viable pollen. CMS is a valuable and economic tool to create directed heterosis (hybrid vigor) and to reproduce identicle genetic line constitutions.

6. Dissemination:

The project resulted in a number of scientific publications and presentations at meetings including the plant breeding sector. The project was also presented to visitor groups, at Open Days in Oak Park and at Food Harvest in Athenry in 2008.

Main publications:

Diekmann K, Hodkinson T.R. and Barth S. (2012) New chloroplast microsatellite markers prove to be suitable for assessing genetic diversity of *Lolium perenne* and other related grass species. *Annals of Botany* 110: 1327– 1339 (DOI:10.1093/aob/mcs044).

Diekmann K., Hodkinson T.R., Wolfe K.H. and Barth S. (2012) First insights into the mitochondrial genome of perennial ryegrass (*Lolium perenne*) in '*Breeding Strategies for sustainable forage and turf grass improvement*' (Barth S and Milbourne D eds) Springer, Dordrecht, 2012 p 141 – 146 (ISBN 978–94–007–4554-4) (DOI 10.1007/978–94–007–4555–1)

Diekmann K., Hodkinson T.R., Wolfe K.H., van den Bekerom R., Dix P.J., and Barth S. (2010) The complete chloroplast genome sequence of perennial ryegrass (*Lolium perenne* L.) reveals useful polymorphisms among European ecotypes. In: *Sustainable use of genetic diversity in forage and turf breeding* (Huyghe C ed), 409–413, Springer, Berlin (DOI: 10.1007/978–90–481–8706–5_59).

Diekmann K., Hodkinson T.R., Wolfe K.H., Bekerom R.v.d., Dix P.J. and Barth, S. (2009) Complete chloroplast genome sequence of a major allogamous forage grass species, perennial ryegrass (*Lolium perenne* L.), *DNA Research* 16(3): 165–1 76.

Diekmann K., Hodkinson T.R., Fricke E., and Barth S. (2008) An optimized Chloroplast DNA Extraction Protocol for Grasses (Poaceae) Proves suitable for Whole Plastid Genome Sequencing and SNP Detection. *PloS One* 3(7): e2813. DOI:10.1371/journal.pone.0002813.

Investigations into the biological and genetic control of fatty acid levels in perennial ryegrass

Project number:
5620
Date:
November, 2012
Funding source:
DAFM
Project dates:
Oct 2007 – Jun 2010

Key external stakeholders:

Grass breeders, agronomists, plant science research community, general public.

Practical implications for stakeholders:

The outcome of this research informs agronomists and breeders on the effects of management factors influencing fatty acid levels in different perennial ryegrass cultivars.

- Management practices influence the fatty acid composition of perennial ryegrass.
- A perennial ryegrass proteome map has been constructed under contrasting fatty acid levels which can be used for further genetic studies on this topic.

Main results:

The field study component of this project identified the range and extent, along with the seasonality, of variation in fatty acid levels in varieties of perennial ryegrass recommended for use in Irish agriculture. A proteome map of perennial ryegrass under contrasting fatty acid levels was constructed. This work will inform further genetic studies in the fatty acid genetics in perennial ryegrass.

Collaborating Institutions:
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External collaborators:
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Compiled by:
Susanne Barth

Technology

Opportunity/Benefit:

This research is of strategic nature and the results obtained are not currently directly exploitable in a commercial sense. But they will help to inform breeding strategies in the future not only in terms of enhancing fatty acid levels but also in the approach taken to improve other important quality parameters.

1. Project background:

Ireland has a grassland based agricultural system with over 80% of the total agricultural area dedicated to grassland. Grass is the cheapest source of feed available to ruminants and so the objective is to optimise grazed grass in the diet. Considerable advances have been made in recent years in breeding more productive and persistent varieties of perennial ryegrass but less emphasis has been placed on the quality of these varieties. Fatty acids in grass are the main precursors for conjugated linoleic acid and polyunsaturated fatty acids in ruminant products. These have well documented associated human health benefits. In order to promote sustainable and profitable agricultural systems by increasing the content of beneficial fatty acids in ruminant products, increasing fatty acid intake from grazed grass is the most appropriate strategy in an Irish context. There is little information on the genetic control of fatty acid levels in grass although a number of management strategies are known to alter grass content. The focus of this study is to profile the variation in fatty acid levels in grass cultivars and determine the biological and genetic control of this variation using new technologies such as real time PCR and 2D protein gels.

Breeding of perennial ryegrass varieties has improved DM yield, persistency, digestibility and water soluble carbohydrate content of the sward but fatty acid levels have received little attention. As grass is the cheapest source of ruminant feed and is maximised in ruminant diets, quality parameters should not be neglected. Grass breeders and producers require information on the genetic control of fatty acid content of perennial ryegrass (PRG) if progress is to be made in breeding varieties with increased fatty acid contents. Grass based diets are known to increase the a-linolenic acid content (18: 3n-3) levels in beef muscle and milk. Therefore there is a need to improve the fatty acid content of PRG and the first step in this is developing an understanding of the genetic control of this important quality trait.

2. Questions addressed by the project:

Internationally there are a small number of groups working on management strategies to augment fatty acid levels in PRG. Shading or extended wilting of fresh grass prior to ensilage will reduce the fatty acid levels in the silage. Fatty acid levels in PRG have been shown to be under genetic control with variation between PRG cultivars in linolenic acid contents identified throughout the growing season and fatty acid profiles were distinctive to species when grasses received the same management. Genetic control of herbage quality traits have been assessed although fatty acid levels were not included in this assessment. Because of the lack of more detailed insights into the genetics of the fatty acid genetics this project was necessary to collect information and data on this subject.

- How large is the variation in fatty acid levels in different perennial ryegrass cultivars under different management regimes grown under field conditions in Ireland?
- Is it possible to correlate fatty acid levels with genetic information gained from candidate genes of the fatty acid pathway?
- Is it possible to construct a 2D proteome map of perennial ryegrass based on a differential response of fatty acid levels?

3. The experimental studies:

Perennial ryegrass varieties used in recommended list testing were grown under different management regimes at Lyons Estate Research Farm and at DAFM Backweston Farm. For a period of three years samples were taken at each harvest and processed for fatty acid quantity and quality testing by gas chromatography.

In the last decade the analysis of RNA expression via Real time PCR has opened up new venues for the accurate determination of the number of transcripts. Furthermore, proteomics has gained new interest with recent advances in protein analysis which allow the generation of complete 2D proteome maps for different cellular compartments. At the time of project application submission very few perennial ryegrass nucleotide sequences had been submitted to public nucleotide databases.

Sufficient genetic variation is the prerequisite to work on the genetics of fatty acid pathways. In perennial ryegrass significant variation has been found for fatty acid contents in different genetic backgrounds applicable to Irish agriculture. For the Poaceae in general a larger number of sequences

involved in the fatty acid pathway have been submitted to genebank. From these a number deemed to be worthwhile testing as candidate genes in expression experiments using Real time PCR were selected. These sequences were from *Lolium rigidum* (a close relative of perennial ryegrass), which were likely to amplify without too much difficulty in perennial ryegrass. For other candidate genes degenerate primers were designed. These genes could prove valuable markers if a tight correlation between the expression of those genes and enhanced fatty acid levels could be found.

4. Main results:

The field study component of this project identified the range and extent along with the seasonality of variation in fatty acid levels in the recommended varieties of perennial ryegrass for use in Irish agriculture. The potential to exploit this natural variation through management practices was then investigated under controlled circumstances on Lyons research farm. This work further identified the extent to which natural variation could be augmented by agronomic practices.

For the Poaceae in general several nucleotide sequences involved in the fatty acid pathway have been submitted to genebank (http://www.ncbi.nlm.nih.gov/nuccore). From these a number have been identified to be worthwhile testing as candidate genes in expression experiments. The strategy of using genomic information from other grass or monocotyledonous species was necessary due to the limited number of publicly available perennial ryegrass sequences. We worked with sequences from closer to more distant related grasses. This approach gave us a chance to amplify those sequences in perennial ryegrass. With the identified sequences multiple sequence alignments were done using the program MEGA (S Kumar, K Tamura, and M Nei (2004) MEGA3: Integrated software for Molecular Evolutionary Genetics Analysis and sequence alignment. Briefings in Bioinformatics 5:150–1 63). Areas of conserved sequences were identified which were then used as template regions for primer design. Primers were designed using the program PriFind (http://cgi-www.daimi.au.dk/cgi-chili/PriFi/main) which is software specialised to design degenerate primers from sequences of other species. Primers were successfully designed for the following genes lipocalin, lipoxygenase, oleate desaturase, fatty acid hydroxylase and the accase gene. In total we optimised seven PCR assays for fatty acid candidate genes in perennial ryegrass; (1) four independent assays from different sequence gene regions for the key regulatory fatty acid gene accase, (2) two independent assays for the lipocalin gene, and (3) one assay for the oleate desaturase gene. Two working assays for the accase gene, one assay for the oleate desaturase, and one assay for the lipocalin gene are available for real time PCR work in perennial ryegrass. The expression of the genes Accase and lipocalin was quantified using real-time PCR. Quantification was achieved on the LC480 (Roche) using SYBR Green I chemistry. Relative expression was normalised to two housekeeping genes, namely β-actin and GAPDH. Amplification efficiency values (E) were calculated by generating standard curves and incorporated into final calculations. Analysis was performed using the software Qbase (Ghent University, Belgium). Finally correlation analysis between the phenotypic fatty acid data and expression profile data were calculated using the statistical package SAS. The main outcome of this task was the correlations between the levels of expression of the two candidate genes, ACCase and lipocalin, and fatty acid content. A positive correlation was found for the gene expression level of the candidate gene ACCase and C18:0 content ($P<0.05$) for samples from October 2007, while a negative correlation was found for the expression of the same gene and C18:3 content ($P<0.05$) for samples from July 2008. While the relationship appears inconsistent it presents evidence of a relationship between the target genes and the fatty acid levels in the varieties tested. This presents strong evidence for future research in this area.

For the perennial ryegrass fatty acid proteome map initial work was focused on the optimisation of protein extraction methods to obtain a high quantity and quality of proteins for 2D SDS-page analysis. The extraction method of Gorg *et al.* (2002) with O'Farrell's lysis buffer was retained as the best working extraction method. For the comparative proteome map two perennial ryegrass varieties, two treatments, two protein ranges, three replications and each gel in technical duplicates were used. The two varieties were picked based on their statistically significant high and low polyunsaturated fatty acid contents. The pH ranges 3–10 and 4–7 were included in the experiments. Gels were stained using Sypro Ruby and digitalized using the Typhoon GE Healthcare scanner. The software package 'Progenesis' (UCD Conway Institute) has been used to compare the 2-D protein gels. A comparative proteome map of differentially expressed proteins for perennial ryegrass with contrasting fatty acid profiles has been built.

5. Opportunity/Benefit:

The outcomes of this research have an impact on the advancement of plant sciences for the forage grass perennial ryegrass. When the grant application for this project was written little research on the molecular aspects of the fatty acid pathway in perennial ryegrass had been published. This project also increased collaboration between Teagasc and UCD. While this research is at the basic level of the research spectrum and the results obtained are not currently directly exploitable in a commercial sense, they will help to inform breeding strategies in the future not only in terms of enhancing fatty acid levels but also in the approach taken to improve other important quality parameters.

6. Dissemination:

The project resulted in a number of scientific publications and presentations at meetings. The project was also presented to visitor groups and at Open Days in Oak Park.

Main publications:

Cristilli M. (2012) Investigations into the biological and genetic control of fatty acid levels in perennial ryegrass. *PhD. thesis National University of Ireland,* in preparation.

Cristilli M., Lynch M.B., Barth S., McGilloway D., Boland T.M. (2010) Effect of variety, nitrogen fertilisation and regrowth interval on fatty acid levels of perennial ryegrass post establishment. *Proceedings of British Society of Animal Science and the Agricultural Research Forum 2010*, p 145 Belfast, Northern Ireland.

Cotecchia L. (2010) Development and testing of assays for the expression of candidate genes involved in the fatty acid pathway in perennial ryegrass. *MSc. thesis National University of Ireland.*

Cotecchia L., Boland T.M., Lynch M.B., McGilloway D., Mullins E., Byrne S. and Barth S. (2009) Investigations into the biological and genetic control of fatty acid levels in perennial ryegrass. *Proceedings of the Irish Plant Scientists Association*, 19th – 20th March 2009 Trinity College Dublin.

Cristilli M, Lynch MB, Barth S, McGilloway D, Kenny DA and Boland TM (2009). Effect of cutting date on fatty acid levels of different perennial ryegrass varieties throughout the growing season. *Proceedings of the Agricultural Research Forum* p. 96.

Cristilli M, Lynch MB, Barth S, McGilloway S, Kenny DA and Boland TM. (2009). Comparison and optimisation of fatty acid extraction methods for high throughput perennial ryegrass sample screening. *Proceedings of the Agricultural Research Forum* p. 104.

Cotecchia L., Boland T, Yang B, McGilloway D., Lynch B. and Barth S. (2008) Investigations into the biological and genetic control of fatty acid levels in perennial ryegrass. *Proceedings of the Irish Plant Scientists Association Meeting*. March 2008

Development of metabolomics based methods to benefit marker assisted breeding in perennial ryegrass

Project number:
5622
Date:
November, 2012
Funding source:
DAFM
Project dates:
Dec 2006 – Jun 2010

Key external stakeholders:

Plant geneticists, grass breeders, general public.

Practical implications for stakeholders:

This project has demonstrated that metabolomics is a suitable technique for application to outbreeding forage species.

- In combination with targeted physiological experiments we have identified key metabolites involved in several abiotic stress conditions in perennial ryegrass. This metabolomics work on nitrogen and phosphorus acquisition and usage efficiency has lead to in depth initial insights into plant metabolism under deficient conditions.
- Follow up work would need to investigate the effect of toxic concentrations of phosphorus on plant metabolism and also how genotypes cope with low nutrient situations. This future work should be coupled with genomics techniques and modelling approaches to maximise the gain in information acquired which could lead in the longer term to cultivars with improved nutrient efficiency.
- Also an investment into the genetics of crown rust resistance and to sources and strains of crown rust would help with the development of cultivars with an improved resistance to this economically important disease.

Collaborating Institutions:
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The University of Dundee, Scotland Biomathematics and Statistic Scotland

Teagasc project team:
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Dr. Christine Hackett, Biomathematics and Statistic Scotland

Compiled by:
Susanne Barth

Technology

Main results:

- Key metabolites and transcripts in the response of perennial ryegrass to low phosphorus supply and drought stress were identified.
- Key metabolites in the response of perennial ryegrass to different levels of nitrogen supply were identified.
- Key transcripts in the response of perennial ryegrass to toxic levels of selenium were identified.
- A metabolite quantitative trait loci (mQTL) study identified and genetically mapped QTL associated with quality traits.

Opportunity/Benefit:

The research completed in this project is of a 'public good' and strategic nature. The outcomes of this project provide an excellent base to study in greater depth insights into plant metabolism under deficient conditions for nitrogen and phosphorus acquisition and usage efficiency.

1. Project background:

Perennial ryegrass is of economic importance to both Irish agriculture (90% of the agricultural land) and the leisure industries. The breeder's objective is to produce cultivars with a diverse range of characteristics for a range of specific uses. Major breeding goals include; improving the nutritive quality as an animal feed, nitrogen and phosphate use efficiency for a more safe and sustainable use of resources, tolerance to selenium a localized problem in many areas of Ireland, and adaptability to changing environmental factors including susceptibility to drought and disease resistance. Conventional selection during breeding puts a limit on the efficiency of introducing desirable combinations of traits due to the large resource required to phenotype the breeding germplasm. This constraint severely limits the ability of plant breeders to target specific environmentally valuable traits in new cultivars. The development of functional molecular markers to select for these specific traits may reduce the need for costly phenotypic selection at certain times during the breeding cycle. The development of functional marker technologies can be accelerated by the application of metabolomics technology to understand a plants response to these environmental changes.

2. Questions addressed by the project:

The project aimed to investigate if metabolomics methods can be used as a suitable technique to be applied to outbreeding forage species to aid the identification of key metabolites affected under environmental stress conditions. This was achieved by asking two key questions:

- Is it possible to identify key metabolites and transcripts for environmental stress conditions such as drought stress, nitrogen and phosphorus deficiency in the outbreeding plant species perennial ryegrass?
- Is it possible to place key metabolites on a genetic map to make those accessible for further molecular marker assisted breeding strategies?

3. The experimental studies:

The primary objectives of this project was to apply metabolomics technology to understand the response of perennial ryegrass to environmental change, and combine this data with both transcriptomic and genomic data with the purpose of developing functional markers for perennial ryegrass breeding.

A stepwise approach was applied to investigate the genetic basis of phenotypic and metabolic plasticity to abiotic stress factors for perennial ryegrass inbred lines, a segregating population and wildtype accessions. The stress testing (water stress, nitrogen, phosphorus and selenium) was carried out in hydroponics to enable the targeted application of one stress factor at a time. Hydroponics allowed the genetic characterization and metabolite profiling of above and below ground biomass (roots and shoots). The single biotic stress studied (crown rust infection) was monitored under field conditions and natural infection.

In the first strand of the project transcriptomics and metabolomics approaches were used to characterise the response of perennial ryegrass to the stress factors described above. Subtractive hybridization libraries (SSH) were constructed for the stress factors of drought and nitrogen. These libraries were enriched for genes regulated by the stress factor. Candidate genes were subsequently selected to carry out expression profiling via real-time PCR. To study the response of perennial ryegrass to selenium toxicity we modified the SSH screening technique by using next generation sequencing technology (NGS) to sequence the entire libraries of

selenium stress regulated genes. Using this approach we were able to identify genes and gene families regulated upon selenium stress. A different approach was taken for the stress factor phosphorus, where we tested the possibility of using a 44K barley micro array to study gene expression in perennial ryegrass. This proved possible and we subsequently used the array to characterize changes in the transcriptome under low phosphorus. For metabolomics analysis, plant material grown under various stress conditions were harvested, flash frozen in liquid nitrogen and polar and non-polar extracts were analysed using a range of metabolomics techniques at the Hutton Institute. Plant materials for these approaches used were ecotypes and inbred lines of perennial ryegrass. The inbred lines did not show wide differences in response to stress conditions and work was stopped on the diallel crosses of inbred materials after one year of crossing.

In a second strand of the project the segregation within an F2 population to rust resistance was studied in order to identify QTL associated with the trait. The F2 population was previously used to map biomass QTL and we had an existing genetic linkage map. In order to enhance this existing genetic map we employed DArT marker technology to improve marker density. We looked at the metabolomics profiles of each plant within the entire F2 population under field conditions, with the goal of mapping individual metabolites as quantitative traits (mQTL). In this way the genetic location of QTL responsible for variation in individual metabolite levels within the F2 population could be identified. These include many of the metabolites identified as responsive to the environmental stresses which were imposed in strand one of the project.

4. Main results:

Metabolic profiling was carried out in perennial ryegrass to uncover mechanisms involved in the plants response to water stress. When leaf and root materials from two genotypes, with a contrasting water stress response, were analysed by GC-MS, a clear difference in the metabolic profiles of the leaf tissue under water stress was observed. Differences were principally due to a reduction in fatty acid levels in the more susceptible Cashel genotype and an increase in sugars and compatible solutes in the more tolerant PI 462336 genotype. Sugars with a significant increase included: raffinose, trehalose, glucose, fructose and maltose. Increasing the ability of perennial ryegrass to accumulate these sugars in response to a water deficit may lead to more tolerant varieties. The metabolomics approach was combined with a transcriptomics approach in the water stress tolerant genotype PI 462336, which identified perennial ryegrass genes regulated under water stress.

Selenium is an essential micronutrient for animals and humans, but can be toxic at high concentrations. Manipulation of Se metabolism in plants may enable plants to be tailored to enhance Se content for human and animal consumption and to decontaminate Se polluted soils. In this project, we generated subtracted cDNA libraries from perennial ryegrass roots and leaves, enriched for genes whose expression is enhanced under toxic levels of selenium. The libraries were sequenced using next generation sequencing technologies to characterize the pool of enriched genes. Within these subtracted libraries, there were a large number of genes involved in the calcium-calmodulin signaling network. Furthermore, in the leaf subtracted cDNA library, we identified 28 ABC transporters. Subsequent expression analysis by quantitative RT-PCR demonstrated the significant accumulation of these transcripts in the leaf tissue of perennial ryegrass under toxic levels of Se. These results suggest a role for ABC transporters in selenium movement and accumulation in perennial ryegrass.

Improving phosphorus (P) nutrient use efficiency in *Lolium perenne* (perennial ryegrass) is likely to result in considerable economic and ecological benefits. To date, research into the molecular and biochemical response of perennial ryegrass to P deficiency has been limited, particularly in relation to the early response mechanisms. This study performed as part of this project aimed to identify molecular mechanisms activated in response to the initial stages of P deficiency. A barley microarray was successfully used to study gene expression in perennial ryegrass and this was complemented with gas chromatography-mass spectrometry metabolic profiling to obtain an overview of the plant response to early stages of P deficiency. After 24 h of P deficiency, internal phosphate concentrations were reduced and significant alterations were detected in the metabolome and transcriptome of two perennial ryegrass genotypes. Results indicated a replacement of phospholipids with sulfolipids and the utilisation of glycolytic bypasses in response to P deficiency in perennial ryegrass.

Crown rust caused by the fungal biotroph, *Puccinia coronata*, is an economically destructive disease of perennial ryegrass. To identify genetic loci associated with resistance to this disease, Quantitative trait loci (QTL) mapping was performed in an existing F2 mapping population segregating for natural crown rust infection under Irish field conditions. The F2 population, consisting of 325 genotypes was saturated with DArT markers to improve map coverage and density. This high density map was used to locate QTL associated with the differences in crown rust susceptibility identified within the population. QTL on linkage groups 2, 3, 4, and 7 were successfully identified, with the QTL on linkage group 2 explaining the largest percentage of the phenotypic variance (13.9%).

Nitrogen use efficiency (NUE) is a key objective in perennial ryegrass breeding in order to produce economically and environmentally sustainable varieties. We performed an in depth study looking at the changes in the phenotype and metabolism of seven perennial ryegrass genotypes to altering concentrations of nitrogen. This allowed us to identify biochemical processes being altered as external nitrogen concentrations were altered.

The primary metabolome of perennial ryegrass was mapped into a high resolution genetic map of an F2 inbred derived mapping population. This work has lead to the identification of quantitative trait loci controlling the accumulation of individual metabolites. This allows us to look at the genetic control of these metabolites, including the metabolites we have identified above as being responsive to environmental change. This work is forming the basis of further studies at Oak Park. The publication of the outcomes of this work is in preparation.

5. Opportunity/Benefit:

The research completed in this project is of a public good' nature. As such it will deliver a direct economic benefit to the forage sector. While the research has not delivered patents or intellectual property it has demonstrated that significant research outputs can be achieved in a small frame.

6. Dissemination:

The project resulted in a number of scientific publications and presentations at meetings including the plant breeding sector. The project was also presented to visitor groups and at Open Days in Oak Park.

Main publications:

Foito A., Byrne S.L., Hackett C., Hancock R.D., Stewart D. and Barth S. (2012) Short-term response in leaf metabolism of perennial ryegrass (*Loliumperenne*)to alterations in nitrogen supply' Metabolomics (DOI: 10.1007/s1 1306–012–0435–3)

Tomaszewski C., Byrne S.L., Foito A., Kildea S., Kopecký D., Doležel J., Heslop-Harrison P.(J.S.), Stewart D. and Barth S. (2012) Genetic linkage mapping in an F2 perennial ryegrass population using DArT markers' *Plant Breeding*, 131: 345—349 (DOI: 10.111 1/j.1439–0523.201 1.01 944.x)

Byrne S, Foito A, Hedley P, Morris J, Stewart D and Barth S. (2011) Early response mechanisms of perennial ryegrass to phosphorus deficiency' *Annals of Botany*, 107: 243–254.

Byrne S, Durandeau K, Nagy I and Barth S (2010) Identification of ABC transporters from *Lolium perenne* that are regulated by toxic levels of Selenium' *Planta* 231: 4, 901 – 911.

Foito A, Byrne S, Shepard T, Stewart D, Barth S (2009) Transcriptional and metabolic profiles of *Lolium perenne* L. genotypes in response to a PEG induced water stress' *Plant Biotechnology Journal* 7:8, 719–732.

Popular publications:

Byrne S., Foito A., Stewart D. and Barth S. (2010) Omics' for better breeding. *TResearch* 5: 24–25.

Barth S., Byrne S., Anhalt U. and Yang B. (2007) Applying omics' technologies to grassland improvement. *TResearch* 2 (2), p 22–23.

Byrne S., Barth S. and Foito A. (2007) Stress Test. *TResearch* 2 (2), p 21.

Evaluating the hybrid soil moisture deficit model as a tool for indicating suitability for machinery traffic

Image courtesy of Met Eireann (www.met.ie)

Project number:
5808
Date:
January, 2013
Funding source:
DAFM
Project dates:
Feb 2008 – Jan 2013

Collaborating Institutions:
University College Dublin (UCD)
Met Eireann
University of Ulster

Teagasc project team:
Mr. Stan Lalor (PI)
Ms. Sara Vero (MSc student)
Dr. Diogenes Antille

External collaborators:
Prof. Nick Holden, UCD

Compiled by:
Stan Lalor
Sara Vero

Key external stakeholders:

Advisors, farmers, agricultural contractors, policy makers.

Practical implications for stakeholders:

This research showed that the hybrid soil moisture deficit model, which is currently calculated and made available on a daily basis from Met Eireann, is a useful indicator of the suitability of soil conditions to receive machinery traffic for slurry application.

Main results:

Traffic by slurry application machinery had greater long term negative impact on soil bulk density and grass growth when the soil moisture deficit (SMD) was < 10 mm.

Opportunity/Benefit:

This study has shown the SMD model is a useful tool that could be applied in decision support to assist in determining whether traffic of soils on a given day will result in long-term negative impacts on the soil.

1. Project background:

Compaction is regarded as one of the main causes of degradation of agricultural soils. The vulnerability of a soil to compaction depends on the soil moisture content. Slurry application is one of the machinery operations in grassland that involves high axle loads and ground pressure, and can result in soil compaction if conducted under wet conditions. Soil compaction following slurry application is of particular concern given the potential for reduced grass growth, nutrient

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uptake and overland flow from compacted soils, resulting in reduced utilisation of slurry nutrients. Slurry application in early spring has been shown to be particularly advantageous for increasing the nitrogen fertiliser value. However, opportunities for slurry application in spring have also been shown to be restricted by soil conditions that are suitable for damage-free traffic. Therefore, a decision support tool to help identify days where soil conditions are suitable for machinery traffic may assist in optimising slurry spreading opportunities on farms.

2. Questions addressed by the project:

The aim of this study was to investigate the use of the hybrid soil moisture deficit (SMD) model as a proxy for volumetric soil water content to determine the suitability of grassland soils to support vehicle traffic with slurry spreading equipment.

3. The experimental studies:

Three experimental sites at Teagasc Johnstown Castle (Wexford) were selected, to represent well, moderate and poorly drained soils. Each site comprised 32 plots (4m x 5m) divided into four replicated blocks. Treatments were assigned randomly within each block. The hybrid SMD model was used to make daily predictions of SMD, based on the soil drainage class and weather data recorded at Johnstown Castle. Trafficking treatments were targeted at SMD = 0, 5, 10 and 20mm. Measurements in each plot were made of soil bulk density (n=8) and rut profiles (n=4). Measurements were taken prior to and after trafficking with a single axle slurry spreading tanker equipped with a splashplate (total weight c.18 tonnes) both in and between the wheel tracks. At 30 and 60 days subsequent to trafficking, these measurements were repeated, and herbage yield measurements were made within the wheel rut and the non-trafficked area. Statistical analyses were conducted using GenStat (14th Ed) and included ANOVA and repeated measurement of ANOVA, using the LSD to compare the means with a 5% probability level. Factors tested under these analyses included soil bulk density, rut cross-sectional area and herbage dry matter yield.

4. Main results:

The soil bulk density within the wheel rut increased significantly (P<0.05) by 8% to 22% compared with pre-traffic values depending on the SMD at the time of trafficking. The changes in soil bulk density recorded in the non-trafficked area were not significant (P>0.05). This suggests that the compaction incurred during slurry spreading is largely confined to within the wheel ruts. Soil bulk density in the wheel rut decreased significantly over time (P<0.05) by 8% to 17% depending on SMD. Where field traffic was conducted at SMD greater than 10mm, soil bulk density in the wheel rut decreased to near pre-traffic levels at 60 days post-trafficking (Figure 1).

Rut dimensions were significantly (P<0.05) influenced by the SMD; relatively larger ruts were formed at SMD 0 and 5mm compared with SMD 10mm or greater. The area of the rut profiles decreased over time (P<0.05), however, regardless of the SMD, the soil surface was not restored to its pre-traffic condition. Grass dry matter yield (DMY) was significantly reduced in the wheeled compared to the non-wheeled area (P<0.05). Trafficking at SMD 10mm or higher did not have a significant effect (P>0.05) on DMY as recorded 60 days subsequent to trafficking (Figure 2).

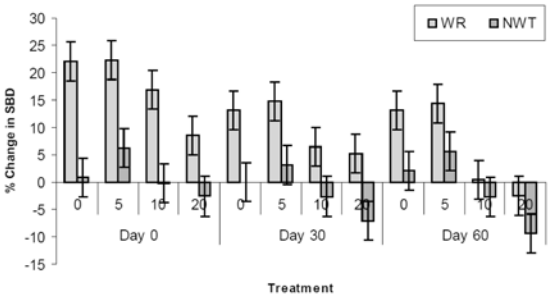

Figure 1. Changes in soil bulk density in wheel tracks (WR) compared to non-wheel track (NWT) areas subsequent to trafficking at 0, 5, 10 and 20mm SMD.

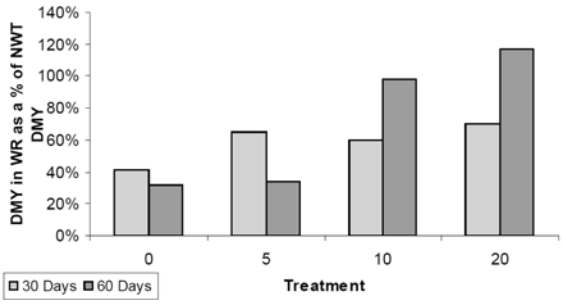

Figure 2. DMY in the wheel track (WR) relative to the non-wheel track (NWT) area in the 30 and 60 day period after traffic.

5. Opportunity/Benefit:

The results of this study suggested that a guideline value of SMD of 10mm will be suitable to indicate the limit for trafficability with standard slurry spreading equipment. This guideline value could be used to minimise the risk of long-term soil compaction and to maximise the opportunities for safe slurry spreading.

6. Dissemination:

The results of this study have been presented at Scientific Conferences and have been submitted for peer review publication.

Main publications:

Vero, S.E., Antille, D.L., Lalor, S.T.J. and Holden, N.M. (2012) 'Soil moisture deficit as a predictor of grass field trafficability.' *Agmeteorology 2012 – Science and Practice.*

Vero, S.E., Antille, D.L., Lalor, S.T.J. and Holden, N.M. (2012) 'The effect of soil moisture deficit on the susceptibility of soil to compaction as a result of vehicle traffic.' *ASABE Annual International Meeting 2012.*

Vero, S.E., Antille, D.L., Lalor, S.T.J. and Holden, N.M. (2012) 'The potential of soil moisture deficit as a predictor of soil compaction following machinery traffic.' *Sino-European Symposium on Environment and Health 2012.*

Vero, S.E., Antille, D.L., Lalor, S.T.J. and Holden, N.M. (2013) 'Determining threshold values for grass field trafficability using the hybrid soil moisture deficit model. *Agricultural Research Forum 2013.*

Project number:
5785
Date:
September, 2012
Funding source:
DAFM
Project dates:
Dec 2007 – Jun 2013

New biodegradable hydrogel materials for the delivery of nitrification and urease inhibitors

Biodegradable hydrogel beads containing DCD

Collaborating Institutions:
NUI Maynooth

Teagasc project team:
Dr. Karl Richards (PI)
Dr. Eddy Minet

External collaborators:
Dr. Denise Rooney
Prof. Carmel Breslin (NUI Maynooth)

Compiled by:
Karl Richards

Key external stakeholders:

All farmers, Department of Agriculture, Food & Marine, Environmental Protection Agency, Industry.

Practical implications for stakeholders:

Dicyandiamide (DCD) is an effective nitrification inhibitor that reduces nitrate production in soil and associated environmental losses of nitrogen, and increases nitrogen use efficiency. The efficacy of DCD is variable in soil and this has been linked to leaching and microbial degradation of DCD from soil. Hydrogels provide a slow release mechanism that could improve the efficacy of DCD released in soil and improve its efficacy as a tool to increase the utilisation of nitrogen in soil.

- Farmers: Hydrogels are a viable potential tool to improve the efficacy of DCD by prolonging its presence in soil.
- Policymakers: DCD is an effective nitrification inhibitor but it degrades in soils at different rates. Hydrogels slowly release DCD from a protective biodegradable porous matrix.
- Scientific: DCD degradation is a soil specific process that relates to soil chemical and microbial properties. Hydrogels slow DCD release and this could be a potential tool to increase DCD efficacy.

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Main results:

- Soil type had a significant effect on the breakdown of DCD over time and this could result in reduced efficacy when DCD degrades quickly in soil.
- For DCD to efficiently mitigate N losses to the environment, soil type specific application timings and rates need to be established.
- Alternatively, the use of a chitosan hydrogel has shown some potential to slowly release DCD in soil under moderate moisture conditions, but more research is needed to improve this new technology.

Opportunity/Benefit:

Chitosan hydrogel is a potential tool for increasing the efficacy of DCD on nitrification in soil.

1. Project background:

Reactive nitrogen (N) losses and greenhouse gas emissions from agricultural soils are a source of concern for animal/human health and the environment. To mitigate agriculture's environmental footprint, a commercially available nitrification inhibitor dicyandiamide (DCD) has been used with some success to slow down NO3- production and reduce N2O emissions. However, inhibitors have a limited life-span in soils and repeated applications are required to maintain efficiency. The objective of this research was i) to estimate the impact of DCD degradation on nitrification inhibition across soils with contrasting physical and chemical characteristics, and ii) to test the potential of an alternative application method whereby inhibitor DCD is encapsulated in a protective slow-release matrix of biodegradable polymeric hydrogel.

2. Questions addressed by the project:

This research addressed the following questions:

- What are the factors driving DCD degradation in soil?
- How does DCD degradation impact nitrification inhibition in soil?
- Can the encapsulation of DCD in slow-release chitosan hydrogel be a viable method of DCD field application (as opposed to repeated spray applications)?

3. The experimental studies:

The impact of DCD degradation was studied on twenty-one soil types (Ireland and UK) that received two treatments: 20 kg/ha NH4-N ± DCD (15 kg/ha DCD). Soil units arranged in a randomised block design were incubated in triplicate at 15°C for 6 times (between 2 days and 64 days). Samples were then extracted with 2M KCl and analysed for DCD (HPLC analysis) and NO3-N content (colorimetry). Based on these measurements, two response variables were calculated: DCD degradation constant (from an exponential decay model) and % nitrification inhibition. Regression analysis was carried out for each incubation time. Chitosan hydrogel beads were formed by precipitation of a chitosan gelling solution and covalent crosslinking with glyoxal (excess glyoxal was partly removed (C beads) or allowed to polymerise upon drying (CG beads)). Slow-release of DCD was tested with twenty beads dropped on compacted soil (equivalent to 15 kg DCD/ha). The experiment was conducted investigating the effect of time, rainfall, soil moisture (expressed as % of water holding capacity (WHC)) and partial removal of excess glyoxal from the beads.

4. Main results:

Soils used in the first part of the experiment (DCD degradation) contained between 0.89 and 9.4 % organic C. % sand, silt and clay ranged between 21 and 68, 20 and 51, 11 and 30, respectively. Soil pH varied between 4.6 and 7.6. DCD degradation was equally variable. A 24% DCD loss was observed after 64 days from the soil with the lowest constant k (1.8), whereas a 93% DCD loss was observed from the soil with the highest k (18.8). For most soils, % nitrification inhibition increased sharply until incubation day 8 or 16 and stabilised or slightly decreased thereafter. There was a significant ($p < 0.05$, day 64 not significant) negative correlation between DCD degradation constant k and % nitrification inhibition. In other words, the higher the degradation rate of DCD, the lower the % nitrification inhibition. These results suggest that some soils with faster DCD degradation will possibly require more frequent/higher rates of application. This could be dealt with more conveniently (and possibly more efficiently) if small amounts of DCD were consistently delivered over long periods of time.

In the second part of the study, the incubation of beads in soil resulted in a delayed release of DCD. DCD soil release significantly increased with time ($p \leq 0.0001$). Treatment also had a significant effect ($p \leq 0.0001$): rainfall caused more DCD release than soil moisture (WHC). Finally, higher rates of rainfall or WHC significantly ($p \leq 0.0001$) increased DCD bead release. After seven days, incubation of C beads caused the release of 74 to 98% of the total DCD bead content. Some of the DCD remaining in the beads has been shown to be more durably trapped inside the beads. In comparison with the C beads (219 µg DCD loaded per bead), CG beads contained less DCD (43 µg DCD per bead), but DCD release was much slower (33% of total DCD bead content released after seven days under high rainfall conditions). These results suggest that a combination of C and CG beads could be used to fit two purposes: a quick release of DCD with C beads necessary after fertiliser (urea or ammonium based) or slurry application, and a slower release of DCD with CG beads to sustain nitrification inhibition.

5. Opportunity/Benefit:

Soil properties affect the efficacy of DCD on nitrification and this relates to DCD degradation. Chitosan beads are a viable method to reduce DCD release rate in soil and increase its efficacy on nitrification.

6. Dissemination:

The results of the project have been presented at national and international conferences. There is one scientific paper published and a number of other papers in preparation. The outputs from the project have been sent to relevant national policy makers.

Main publications:

Minet E.P., O'Carroll C., Rooney D., Beslin C, McCarthy C.P., Gallagher L. and Richards K.G. (2013) Slow delivery of a nitrification inhibitor (dicyandiamide) to soil using a biodegradable hydrogel of chitosan. Chemosphere In Press.

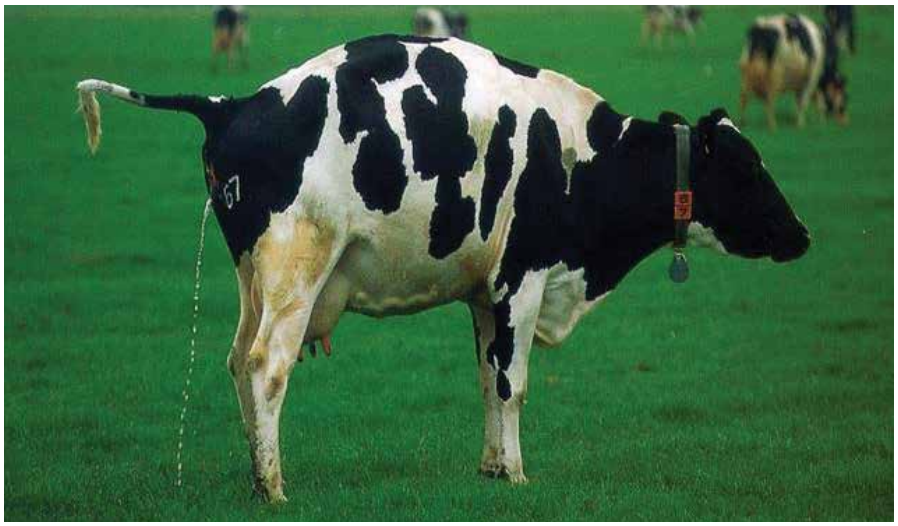
Minet E., Richards K.G., Rooney D., Breslin C., O'Carroll C. and Gallagher L. (2012) Slow delivery of nitrification inhibitor to soil using a biodegradable hydrogel: testing of a novel approach to mitigate N losses and GHG emissions, Agricultural Research Forum Tullamore, Ireland, 12–13 March 2012, p.13.

Popular publications:

Richards, K.G., Selbie, D., Cahalan, E., Dennis, S., Ernfors, M., Minet, E., Lanigan, Gary, Lalor, S., Murphy, J.B., Watson, C., Laughlin, R., McGeough, K., Mueller, C., Rooney, D., Cameron, K., Di, H., Khalil, I. and Hennessy, D. (2011). Reducing N loss using inhibitors. Tresearch 6 (2) p. 12–13 (Summer 2011)

Nutritional and management strategies to reduce nitrogen excretion, ammonia and nitrous oxide emissions

Project number:
5786
Date:
September, 2012
Funding source:
DAFM
Project dates:
Nov 2007 – Jun 2013



Key external stakeholders:

All farmers, Department of Agriculture, Food & Marine, Environmental Protection Agency.

Practical implications for stakeholders:

There is a strong relationship between urine nitrogen (N) content and both N losses to water (nitrate leaching) and air (nitrous oxide emissions). As a result, the use of dietary manipulation could be an important mitigation measure for reducing both nitrate leaching and nitrous oxide (N_2O) emissions. In addition the nitrous oxide emission factor (amount of N_2O emitted per kg N applied) was observed to be <0.4%, which is considerably lower than the IPCC default value (2%) suggesting that soil type specific emission factors would greatly improve the assessment of sustainable farm systems. Benign di-nitrogen (N_2) is the main environmental loss pathway of N deposited in urine.

- **Farmers:** Optimising cow diet reduces N excretion and this directly reduces both nitrate leaching and nitrous oxide emissions at little or no cost.
- **Policymakers:** Dietary manipulation results in lower reactive N loss to the environment. The measured nitrous oxide emission factor is considerably lower than the default value. DCD was highly effective at reducing N_2O emissions and leached N. Reduced cost application techniques could make it a viable mitigation option.
- **Scientific:** Di-nitrogen gas (N_2) was the main environmental loss pathway observed of nitrogen deposited in urine.

Collaborating Institutions:
Lincoln University (New Zealand)
University College Dublin (UCD)

Teagasc project team:
Dr. Karl Richards
Dr. Gary Lanigan
Dr. Diana Selbie

External collaborators:
Dr. Karina Pierce, UCD
Prof. Hong Di,
Prof. Keith Cameron
and Dr. Jim Moir of Lincoln University, New Zealand

Compiled by:
Karl Richards

Technology

Main results:

- Nitrous oxide emissions and nitrate leaching were strongly related to urine N content. This suggests that dietary N manipulations can substantially reduce environmental nitrogen losses.
- The main loss of nitrogen from grazing animals is benign di-nitrogen gas emissions which accounted for close to 25% of the urine nitrogen applied.
- The nitrification inhibitor DCD reduced N_2O emissions and N leaching by up to 70% and 50% respectively. Increased pasture N uptake was also observed particularly in year one. However, the response to DCD was variable.
- The N_2O emission factors (EF_3 values) were below 0.4% from urine N applied in all treatments during both years, which is considerably lower than the current IPCC default value. In addition the N_2O emission factor decreased with increasing urine N rate.

Opportunity/Benefit:

Dietary manipulation can be used to substantially reduce nitrogen loss to the environment from grazing cows. Nitrous oxide emission factors for this free draining Irish soil are considerably lower than the IPCC default value.

1. Project background:

Losses of nitrogen from agricultural production systems to the environment are of concern, particularly in the context of dairy expansion envisioned in Food Harvest 2020. Principally lost as ammonia (NH_3), nitrous oxide (N_2O) these emissions are deleterious to aquatic and terrestrial ecosystems and contribute directly or indirectly to climate change. Ireland, along with other countries has committed to reducing national emissions of these gases under the EU Climate and Energy Package and Gothenburg Agreement. As Irish agriculture, and in particular, animal production, contribute to large portions of national N_2O and NH_3 emissions, there is a requirement to examine strategies that reduce these emissions, of which dietary manipulation to reduce animal N excretion offers great potential. In addition to gaseous losses, nitrogen can be lost to water via nitrate leaching, contributing to deterioration of freshwater and estuarine ecosystems, drinking water quality and also contributing to indirect N_2O emissions. This project examined the potential of reducing urine N excretion by dietary manipulation on the fate of urinary N in the soil.

2. Questions addressed by the project:

This research addressed the following questions:

- Is there a relationship between urine N content and nitrous oxide emissions and nitrate leaching?
- What proportion of the urine N applied is utilised by grass?
- What is the fate of urine N when applied to soil?
- Can nitrification inhibitors reduce losses of nitrogen to the environment?

3. The experimental studies:

Intact monolith lysimeters (0.5 diameter by 0.7m deep) were collected from intensively managed grassland in Teagasc Moorepark and installed in a new facility in Johnstown Castle. Urine was collected from cows at milking a few days before the experiments started and was stored in a cold room prior to application. Urine was applied at 5 rates of nitrogen, 0, 300, 500, 700 and 1000 kg N ha^{-1} to the lysimeters in late autumn. Dicyandiamide (DCD), a nitrification inhibitor was applied in solution form at 30 kg DCD ha^{-1} in two split applications following urine. Measurements of gaseous N emissions, nitrate leaching and pasture N uptake were made for a calendar year following urine application in two consecutive experiments. The fate of urine N in soil was investigated using ^{15}N labeled urine at the 1000 kg/ha rate which enabled urine partitioning between plant uptake, nitrate leaching and the denitrification end products of N_2O and N_2 to be quantified.

4. Main results:

Increasing urine nitrogen loading rate resulted in an increase in the cumulative nitrous oxide (N_2O) emissions, N leaching and pasture uptake. The relationships between urine N rate and N_2O emissions and N leaching were curvilinear, with the increase in N recovered in each fraction diminishing at the higher N rates. The exception was with pasture N uptake, where the relationship with urine N rate was curvilinear with an exponential increase at the higher N rates. The main driver for these responses was thought to be the increase in the supply of N in the soil with increasing urine N loading rate, which was able to be denitrified, leached or taken up by the pasture. Application of the nitrification inhibitor DCD reduced N_2O emissions and N leaching, and increased pasture N uptake, particularly in year one. However, the response to DCD was variable,

and no consistent interaction between DCD and urine N rate was found. It is likely that at least some of the DCD was removed from the soil via leaching, which explained the reason for the variable response in N_2O emissions, N leaching and N uptake between urine N rates, and between years. As a percentage of the N applied, the mass recovery of N in N_2O emissions, N leaching and N uptake did not change significantly. The 'missing' N was recovered in soil immobilisation and N_2 emissions, using the ^{15}N isotopic balance method at the 1000 kg N ha^{-1} urine rate. The use of mass balance and ^{15}N balance methods highlighted the significance of mineralisation-immobilisation turnover processes in a urine patch and their contribution to N loss pathways. This study showed that the largest loss of nitrogen was removal via environmentally benign N_2 which has major implications for N balance studies in pastoral soils.

5. Opportunity/Benefit:

Nitrogen loss to the environment can be reduced through reducing N excretion via dietary manipulation and the use of DCD. Nitrogen losses from urine patches are dominated by environmentally benign N_2 emissions.

6. Dissemination:

The results of the project have been presented at national and international conferences. There are two scientific papers under review in high impact international journals. The outputs from the project have been sent to relevant national policy makers.

Main publications:

D.R. Selbie, G.J. Lanigan, H.J. Di, J.L. Moir, K.C. Cameron, K.G. Richards (2010) Importance of urinary N content on nitrous oxide emissions from grassland soil lysimeters. Ecotrons & Lysimeters conference, 29–31 March 2010, Nancy, France.

D.R. Selbie, K.G. Richards, G.J. Lanigan, H.J. Di, J.L. Moir, K.C. Cameron, M.I. Khalil (2010) Manipulating N excretion – effect on N_2O emissions from grassland soil. A Climate for Change conference, 24–25 June 2010, Dublin, Ireland.

D.R. Selbie, G.J. Lanigan, H.J. Di, J.L. Moir, K.C. Cameron, K.G. Richards (2011) Improving nitrogen efficiency using a nitrification inhibitor on urine-affected soil – a grassland lysimeter study. Agricultural Research Forum, 14–15 March 2011, Tullamore, Ireland.

D.R. Selbie, K.C. Cameron, H.J. Di, J.L. Moir, S. Whelan, K. Pierce, G.J. Lanigan, K.G. Richards (2011) Improving nitrogen efficiency from urine applied to grassland lysimeters in Ireland. Nitrogen and Global Change conference, 11–14 April 2011, Edinburgh, Scotland.

D.R. Selbie, K.C. Cameron, H.J. Di, J.L. Moir, G.J. Lanigan, K.G. Richards (2012) The effect of urinary nitrogen content and DCD nitrification inhibitor on nitrogen emissions from grassland lysimeters in Ireland. Joint SSA and NZSSS Conference, 2–7 December 2012, Hobart, Australia.

D.R. Selbie, K.C. Cameron, H.J. Di, J.L. Moir, G.J. Lanigan, R.J. Laughlin, K.G. Richards (2012) The fate of urine nitrogen with use of a nitrification inhibitor. 17th International Nitrogen Workshop, 26–29 June, Wexford, Ireland.

D.R. Selbie, K.C. Cameron, H.J. Di, J.L. Moir, S. Whelan, K. Pierce, G.J. Lanigan, K.G. Richards (2013) Improving nitrogen efficiency from urine applied to grassland lysimeters in Ireland. Greenhouse Gases and Animal Agriculture Conference, 23–26 June 2013, Dublin, Ireland.

Selbie D.R., K.C. Cameron, Di H.J., Moir J.L., Lanigan G., Richards K.G.(In review) The effect of urinary nitrogen loading rate and DCD nitrification inhibitor on nitrous oxide emissions from an Irish grassland soil, J. Agricultural Sciences

Popular publications:

Richards, K.G., Selbie, D., Cahalan, E., Dennis, S., Ernfors, M., Minet, E., Lanigan, Gary, Lalor, S., Murphy, J.B., Watson, C., Laughlin, R., McGeough, K., Mueller, C., Rooney, D., Cameron, K., Di, H., Khalil, I. and Hennessy, D. (2011). Reducing N loss using inhibitors. Tresearch 6 (2) p. 12–13 (Summer 2011)

Project number:
6094
Date:
December, 2012
Funding source:
Teagasc
Project dates:
Aug 2010– Dec 2012

Cattle slurry variability: tools for improving precision of nutrient advice

Key external stakeholders:

Advisors, farmers, Agri-contractors.

Practical implications for stakeholders:

The nutrient content of cattle slurry is known to be highly variable. Knowledge of the slurry nutrient content through laboratory analysis helps to improve the precision of slurry nutrient applications. However, obtaining a representative slurry sample is difficult without complete agitation of the tank, due to stratification of slurry in storage. Slurry agitation is usually carried out immediately prior to land spreading and this means that laboratory results would not be available in time for spreading. A reliable method of sampling slurry prior to agitation would facilitate more timely availability of laboratory results.

The results of this project provide an increased understanding of the variability in cattle slurry on farms, and aid in identifying tools that can help to better quantify slurry nutrient content and to improve the precision of slurry allocation within a nutrient management plan.

Main results:

1. The nutrient concentrations in samples of slurry taken from unagitated slurry tanks using a tube sampler were not significantly different than those of samples taken with conventional sampling methods after agitation. A tube sampler can be used to take a representative slurry sample prior to agitation so that laboratory analysis results can be received in time to make slurry application rate adjustments based on actual nutrient values, rather than relying on imperfect average values.
2. The adoption of quick tools on farms can permit on-the-spot estimates of nutrient concentrations in slurry. Farmers perceived the slurry hydrometer to be the most useful quick tool and the one they would be most likely to purchase.
3. Cattle slurries on Irish farms have a wide range of nutrient contents, and the average nutrient contents found in slurry were lower than those assumed in previous advice and in the GAP regulations. The farm system, management system and diet did not predict slurry nutrient content based on the data collected. However, slurry dry matter content was a good predictor; therefore the slurry hydrometer shows potential to improve the estimation of slurry nutrient content on farms.

Collaborating Institutions:
Agri-Food Biosciences Institute (AFBI)
Queen's University Belfast (QUB)

Teagasc project team:
Stan Lalor (PI)
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External collaborators:
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Compiled by:
Stan Lalor
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Technology

Opportunity/Benefit:

Sampling pre-agitation for laboratory analysis using a tube sampler, or assessing dry matter and nutrient concentration on site using a quick tool such as the slurry hydrometer has potential to improve the precision with which slurry can be utilised within a nutrient management plan.

1. Project background:

The nutrient content of cattle slurry is known to be highly variable. This affects the precision and reliability of nutrient management planning on farms in terms of nutrient supply requirements for crops when chemical fertilisers are replaced with slurry applications. Slurry nutrient advice is usually based on standard average values of total nutrient concentrations. The standard total nutrient content values assumed by the Good Agricultural Practice (Nitrates) Regulations are higher than slurry often contains in reality.

Knowledge of the slurry nutrient content through laboratory analysis helps to improve the precision of slurry nutrient applications. However, obtaining a representative slurry sample is difficult without complete agitation of the tank, due to stratification of slurry in storage. Slurry agitation is usually carried out immediately prior to land spreading and this means that laboratory results would not be available in time for spreading. A reliable method of sampling slurry prior to agitation would facilitate more timely availability of laboratory results.

2. Questions addressed by the project:

The objective of this study was to investigate methods for improving the estimation of total nutrient content in slurry. Three issues were investigated as follows:

1. Sampling methods for laboratory analysis allowing farmers to overcome the time delay between sampling and the availability of laboratory results.
2. On-farm quick assessment tools for analysing slurry enabling the estimation of slurry nutrient content quickly and on-site.
3. Factors affecting nutrient content in slurry to improve the accuracy of assumed average nutrient contents.

3. The experimental studies:

1. Comparing slurry sampling methods

The nutrient content in slurry sampled post agitation (using a bucket inserted into the tank and retrieved using an attached rope) was compared with a 'tube-sampler' method used a number of days prior to agitation (Figure 1). Seven slurry tanks were sampled in/near Teagasc, Johnstown Castle, Co Wexford. The tube sampler consisted of a 6 cm diameter plastic pipe which was inserted to the full depth of the unagitated slurry tank. A ball stopper attached to a rope was then applied to the base of the pipe as a seal by pulling the rope up through the centre of the pipe. Three full columns of slurry were extracted from the tank and sub-sampled for analysis.

Figure 1. 'Tube sampler' consisting of a 6 cm diameter plastic pipe with a rubber ball stopper attached to a rope that runs through the centre of the pipe (a). The tube is inserted to the full depth of the unagitated slurry tank (b) and the ball stopper is applied to the end of the pipe by pulling the rope. The full column of slurryis then extracted from the tank by securing the rope to hold the ball stopper in place. The extracted column of slurry can be collected in a vessel by releasing the ball stopper (c).

2. On-farm quick assessment tools

Having a tool for making a quick, on-the-spot assessment of slurry nutrient content would help farmers to adjust slurry application rates on the move, and to achieve better utilisation of the available nutrients. In this study, three commercially available tools were demonstrated to groups of farmers. These farmers were subsequently surveyed for their opinions on the usability and/or value to them of each tool. The tools selected were: a slurry hydrometer that estimates the slurry dry matter content (Figure 2), and two tools that estimate the ammonium-N content of slurry.

3. Factors affecting nutrient content

A total of 75 slurry samples were collected from dairy and beef farms along with supporting data on animal type, animal housing and animal diet. Samples were collected by Teagasc advisors.

4. Main results:

1. Comparing slurry sampling methods

There was a wide range in nutrient and slurry dry matter contents between the seven tanks sampled in the study. For example, the dry matter content ranged from 1.7 to 10.3 %. The sampling method did not have a significant effect on the dry matter or nutrient content within each tank. This shows that the tube sampler can be used to take a representative slurry sample in advance of agitation leaving enough time for laboratory analysis results to be available on the day of slurry application.

2. On-farm quick assessment tools

Of the tools selected, the slurry hydrometer (Figure 2) showed the highest potential for adoption on farms, as the slurry dry matter could be used to estimate the concentrations of all nutrients (N, P, K), whereas the other two tools only gave an estimate for ammonium-N.

Figure 2. Slurry hydrometer with graduated scale used to estimate the slurry dry matter content in a well mixed slurrysample.

3. Factors affecting nutrient content

The mean and range of dry matter, N, P and K contents in the 75 samples are shown in Figure 2. The mean content of N, P and K were lower than those assumed by the GAP regulations and in previous advice. Analysis of this dataset found no definitive relationships between slurry nutrient content and the farming system variables that were recorded. However, the slurry nutrient content was correlated with slurry dry matter content (Figure 3), indicating that the slurry dry matter can be used to estimate the nutrient content.

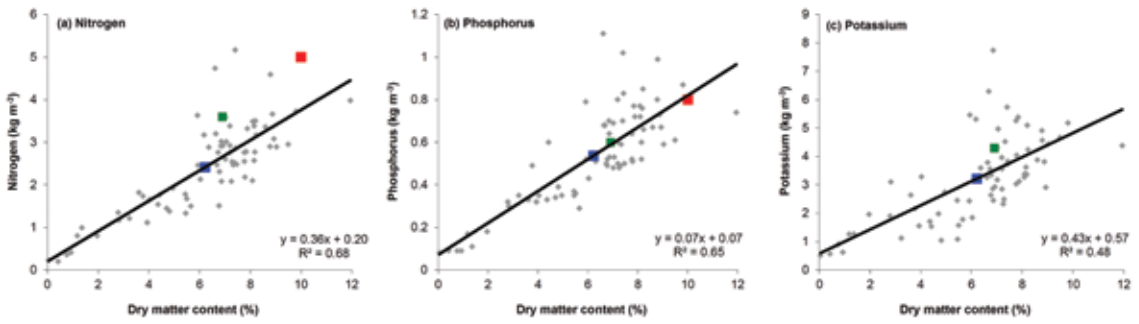

Figure 3. Relationship between slurry dry matter and nitrogen (a), phosphorus (b) and potassium (c) in the 75 slurry samples collected on farms. Values assumed in previous nutrient advice and current GAP regulations are also shown. (Note that no value is assumed for potassium in the GAP regulations).

5. Opportunity/Benefit:

The following opportunities and benefits can be concluded based on the results of this study:

1. A tube sampler can be used to take a representative slurry sample prior to agitation so that laboratory analysis results can be received in time to make slurry application rate adjustments based on actual nutrient values.
2. The adoption of quick tools on farms, is more likely if the tool can estimate a range of nutrients. Farmers perceived the slurry hydrometer to be the most useful quick tool and the one they would be most likely to purchase.
3. Cattle slurries on Irish farms have a wide range of nutrient contents, and the average nutrient contents found in slurry were lower than those assumed in previous advice and in the GAP regulations. The farm system, management system and diet did not predict slurry nutrient content based on the data collected. However, slurry dry matter content was a good predictor; therefore the slurry hydrometer shows potential to improve the estimation of slurry nutrient content on farms.

6. Dissemination:

The work of this project has been disseminated to farmers and advisors through the demonstrations and surveys of quick assessment tools. The results of this study have been presented at the Agricultural Research Forum, 2012, and published in TResearch.

Main publications:

Berry, P.B., Lalor, S.T.J., Wall, D.P., Quinn, J.P. and Frost, J.P., 2012b. Comparison of different methods for obtaining representative samples of cattle slurry, Agricultural Research Forum, Tullamore. pp. 31.

Popular publications:

Berry, P., Lalor, S., Wall, D., Frost, P. and Quinn, J., 2012a. Cattle slurry variability: tools for improving precision of nutrient advice, TResearch Vol. 7, No. 4. Teagasc. 22–23 pp.

Project number:
5784
Date:
October, 2013
Funding source:
DAFM
Project dates:
Jan 2008 – Jun 2012

Assessment of the vulnerability of groundwater to pesticide inputs from Irish Agriculture

Figure 1 Installing groundwater monitoring points.

Collaborating Institutions:
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Teagasc project team:
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Compiled by:
Karl Richards

Key external stakeholders:

All farmers; Department of Agriculture, Food & Marine; Environmental Protection Agency.

Practical implications for stakeholders:

This is the first specific project on pesticide occurrence in Irish groundwater. The project aimed to determine a large range of currently active and banned pesticide active ingredients and their degradation products from several locations across Ireland with contrasting physical characteristics e.g. soil type, subsoil type, and aquifer type.

The project found some active ingredients and their degradation products in groundwater at concentrations in breach permitted limits detailed in the European Union drinking water and groundwater directives. These substances were found in locations with both well drained soils, karst geology and poorly drained soils.

- Farmers: Pesticides occurred in karst geologies, as expected, due to little overburden material but also in poorly drained areas likely due to a delayed breakdown of pesticides.
- Policymakers: Mecoprop (-p), 2,4-D, and MCPA were the most frequently found active ingredients in groundwater. Degradation products were also present: usually in quantities higher than those found for active ingredients and more frequently across the catchment scale sites.
- Scientific: The degradation products of active ingredients were discovered in groundwater but the toxicity or persistence of these compounds is unknown.

Technology

Main results:

- The active ingredients mecoprop (-p), 2,4-D, and MCPA were frequently found both at the catchment- and national- scale (EPA data).
- The degradation products phenoxyacetic acid (PAC), dichlorbenzoic acid (DBA), and 4-chloro-2-methylphenol (4C2MP) were most frequently found in groundwater.
- Soil association, soil drainage class, subsoil type, subsoil thickness, subsoil permeability, groundwater vulnerability, and aquifer type were significantly associated with pesticide occurrence in groundwater.
- The study has highlighted that the risk of groundwater pesticide occurrence varies nationally and that mitigation measures may be required in arable farming areas dominated in high risk catchments.
- Two new analytical methods were developed to quantify for 22 substances in groundwater.

Opportunity/Benefit:

- National groundwater vulnerability databases can be used to identify areas of higher risk.
- Many compounds analysed for were not frequently detected in groundwater indicating these compounds may be less of a concern to groundwater sources e.g. bentazone and bromoxynil.

1. Project background:

The widespread use of agricultural pesticide compounds has been of growing concern in the area of groundwater protection. The Drinking Water Directive (EC, 1998) and Groundwater Directive (EC, 2006) has imposed an upper limit of 0.1 µg/L for concentrations of individual pesticides (both active ingredients and degradation products) in these waters. Recent EPA reports highlighted the presence of pesticides in water samples at levels greater than 0.1 µg/L, which may have negative implications for human health. An assessment of factors influencing groundwater contamination with pesticides in Ireland was therefore urgently required. Such an assessment needed to assess the influence of pesticide mobility, adsorption, absorption and preferential flow characteristics, all of which may vary according to each pesticide's characteristics and site-specific conditions. The need for data specific to Irish agricultural conditions that can be used in a risk assessment framework to help inform policy makers of high risk compounds and regions was evident. The key objective of this research was to provide knowledge to assist in the development and implementation of policy actions to reduce the impact of pesticide usage on the environment, and in particular on groundwater quality.

2. Questions addressed by the project:

This research addressed the following questions:

- How widespread is pesticide occurrence in groundwater in Ireland?
- What pesticide compounds are most commonly detected in Irish groundwater?
- What factors influence the occurrence of pesticides in Irish groundwater?

3. The experimental studies:

Groundwater pesticide occurrence was investigated within agricultural catchments and at the national scale across Ireland. Seven intensive agricultural catchments were selected, each with different physical characteristics representing common scenarios within Ireland. Six catchments were dominated by arable farming and one by grassland. At each site monitoring points were installed to target groundwater at different depths (Figure 1). Springs, drains, and streams were also monitored where present, to gain insight into potential pesticide transport pathways. Groundwater was sampled monthly between March 2010 to March 2012, using low-flow purging methods. Water quality parameters were measured in-situ and samples collected to quantify for physico-chemical variables and pesticides.

Two in-house methods were developed using gas chromatography (GC)- and liquid chromatography (LC)- mass spectrometry (MS) and validated according to European Union legislation (SANCO/10232/2006). These methods could quantify for four organochlorine pesticides, 16 phenoxyacetic acid herbicide parent active ingredients and six of their relevant degradation products, and two benzonitrile degradation products. 22 pesticide compounds in groundwater, including degradation products, from 835 samples, were analysed throughout the study. Samples from March 2012 were also sent to an external laboratory in the UK and analysed for organophosphorous herbicides.

4. Main results:

The most frequently detected parent active ingredients in groundwater from these agricultural catchments were mecoprop and 2,4-D which were present in 35% and 26%, of all samples collected. The most frequently detected degradation products in groundwater within all seven agricultural catchments were PAC and 4-chloro-2-methylphenol (4C2MP) in 33% and 26% of samples, respectively (Figure 2). The method developed to determine mecoprop and mecoprop-p in groundwater using LC-MS was unable to differentiate between the two, thus the detection of either of these compounds is referred to as mecoprop(s). No detections of organophosphorous herbicides were found in March 2012. The most commonly detected compounds in breach of the European Union drinking water standard of 0.1 µg/L for individual compounds (98/83/EC) were the degradation products 2,6-dichlorobenzoic acid (DBA) and PAC. This is the first report on the widespread occurrence of these two degradation products in groundwater. The toxicity, persistence and source of these products in groundwater are unknown. The FOOTPRINT PPDB indicates that PAC degrades from MCPA and 2,4-D, DBA degrades from dichlobenil and 3,5-dichlorobenzamide (BAM), and 4C2MP degrades from MCPA, mecoprop, and mecoprop-p.

The effect of land use on pesticide occurrence was investigated by comparing pesticide occurrence on karst dominated by arable and grassland farming. The results suggest that groundwater pesticides were more associated with arable land use compared to grassland farming due to higher pesticide usage in arable areas.

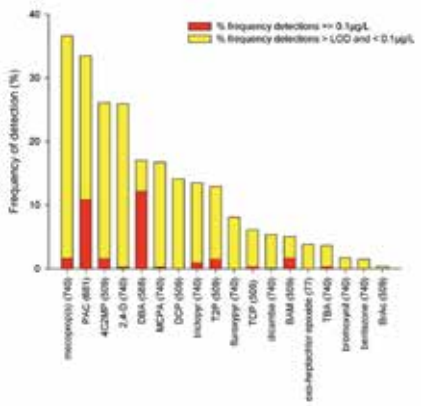

Figure 2: Percentage frequency of detection for all seven sites sampled monthly from March 2010 to March 2012. The total number of samples analysed for each compound is stated in brackets. LOD = method detection limit.

The relationship between groundwater pesticide occurrence and physico-chemical groundwater parameters was statistically evaluated. Significant positive associations were found between pesticide occurrence in groundwater and calcium, manganese, sodium, magnesium, and total nitrogen. Significant negative associations were found with redox potential, turbidity and pH. Groundwater pesticide occurrence at the national and catchment scales was found to be significantly associated with several site physical characteristics: monitoring point type, aquifer type, subsoil type, and soil drainage class were all significantly associated with pesticide occurrence at the national scale. At the catchment scale pesticides were associated with sample type, sample depth, soil association, soil texture, soil drainage class, subsoil type, subsoil thickness, subsoil permeability, aquifer type, and groundwater vulnerability. Risk of pesticide occurrence was associated with groundwater vulnerability as classified by the national methodology, providing a useful risk assessment tool. This project has highlighted that the risk of groundwater pesticide occurrence varies nationally and that mitigation measures may be required in arable farming areas dominated in high risk catchments. One high risk site of the seven studies at the catchment scale had the highest detection of compounds. This was an aerobic sand and gravel aquifer with well drained soil. The high effective porosity of the material is allowing pesticides to leach to groundwater.

At the national scale, a two year database from the Environmental Protection Agency's groundwater monitoring campaign for pesticides was analysed, reported and interpreted. The main pesticide compounds detected were MCPA and mecoprop. Comparing this national monitoring campaign with the catchment scale campaign revealed more detections during the catchment scale study (Table 1). There were also more detections in breach of the European Union drinking water standard for individual compounds during catchment scale monitoring.

Table 1 Differences in sample detection frequency between national- and catchment- scale monitoring.

Concentration category	National Scale	Catchment Scale
Number of samples analysed	845	835
≥ 0.5 µg/L	0%	8%
≥ 0.1 µg/L	3%	18%
< 0.1 µg/L	24%	41%
Non-detections	73%	41%

The overall project conclusions are summarised below:

1. The most frequently detected compounds in descending order of frequency of occurrence in Irish groundwater from catchment scale sites were: mecoprop(s), phenoxyacetic acid (PAC), 4-chloro-2-methylphenol (4C2MP), 2,6-dichlorobenzoic acid (DBA), MCPA, 2,4-dichlorophenol (DCP), triclopyr, and 3,5,6-trichloro-2-pyridinol (T2P).
2. Currently in Ireland mecoprop, 2,4-D, MCPA, and triclopyr are active ingredients permitted in plant protection products. Throughout the two year catchment scale monitoring campaign, the maximum observed concentrations of these four substances were 1.46 µg/L, 0.24 µg/L, 1.05 µg/L, and 0.07 µg/L, respectively.
3. Degradation products were not only found to be present in detectable concentrations in groundwater, but at concentrations in breach of the EU Drinking Water Standard for individual compounds. The most frequently detected TPs were PAC, 4C2MP, DBA, DCP, and T2P. DBA and PAC regularly exceeded the Drinking Water Standard. DBA had never been monitored for in Irish groundwater, while monitoring data for PAC in groundwater has never been published internationally. The maximum observed concentration of DBA and PAC was 120 µg/L and 4.15 µg/L, respectively.
4. The physical characteristics of zones of contribution surrounding each monitoring point which were most associated with pesticide occurrence in groundwater were the type of monitoring point, sample depth, soil association and texture, soil drainage class, subsoil type, thickness and permeability, aquifer type, and also the groundwater vulnerability index.
5. Comparing the only two available pesticide monitoring datasets on Irish groundwater for the physical characteristics most associated with pesticide occurrence revealed that monitoring point type, aquifer type, and subsoil type were associated at both monitoring scales. National scale monitoring also detected MCPA and mecoprop as some of the most frequently observed compounds. However, national scale monitoring did not quantify for any degradation products in groundwater or any other active ingredients which were frequently detected at the catchment scale (e.g. triclopyr and fluroxypyr).

European Commission (1998) 98/83/EC, Official Journal of the European Communities.
European Commission (2006) 2006/118/EC, Official Journal of the European Communities.

5. Opportunity/Benefit:

The monitoring carried out by this project represents the first analysis of pesticide groundwater quality under Irish specific conditions and can be used to assist the government in responding to EU protocols. New analytical methods were established for organochlorine, phenoxyacetic acid and benzonitrile compounds at research laboratories at Teagasc Johnstown Castle, Wexford and the Teagasc Food Research Centre, Ashtown. These may be used for future projects. New degradation products PAC, 4C2MP and DBA were widely detected in Irish groundwater monitored at the seven study sites. These compounds are relatively unknown and little is known about their toxicity or persistence in the environment in Ireland, Europe or globally. The seven sites selected and used across Ireland are now fully instrumented and could be used in the future to gain further insight into groundwater contamination. From the seven sites selected and monitored monthly, parent active ingredients from pesticide products did not exceed the 0.1 µg/L permitted limit for drinking water and groundwater as often when compared to degradation products.

6. Dissemination:

The results of the project have been presented at national and international conferences. Two papers were published and there are a further tow papers currently under review in high impact scientific journals to date. The outputs from the project have been sent to relevant national policy makers.

Main publications:

McManus S-L, Coxon C.E., Richards K.G., Danaher M. (2013) Quantitative solid phase microextraction – Gas chromatography mass spectrometry analysis of the pesticides lindane, heptachlor and two heptachlor transformation products in groundwater, *Journal of Chromatography A*, 1284: 1–7.

Herve Labite, Nick M. Holden, K.G. Richards, Gaelene Kramers, Alina Premrov, Catherine E. Coxon, Enda Cummins (2013) Comparison of pesticide leaching potential to groundwater under EU FOCUS and site specific conditions, *Science of the Total Environment* 463–464: 432–441.

McManus S-L, Richards K.G., Grant J., Mannix A., and Coxon C.E. (*In review*) Pesticide occurrence in Ground Water and the factors contributing to these detections in Ireland, *Journal of Environmental Monitoring and Assessment*

Popular publications:

McManus, S-L., Richards, K.G & Coxon, C.E (2009) Pesticide occurrence in Irish groundwaters. GSI groundwater newsletter, December 2009.

McManus, S-L., Richards, K.G & Coxon, C.E (2009) Investigating pesticide occurrence in groundwater in Ireland. Ireland's rural Environment: Research Highlights from Johnstown Castle, August 2009, Teagasc, Wexford.

Chemical amendment of slurry to control phosphorus losses in runoff

Project number:
5669
Date:
December, 2011
Funding source:
Teagasc
Project dates:
Jun 2007 – Dec 2011

Key external stakeholders:

International research community and practitioners using chemically amended slurry or considering using it in the future.

Practical implications for stakeholders:

This research provides important data on the effectiveness and feasibility of using chemically amended slurry and dirty water to decrease incidental losses of phosphorus and nitrogen.

- This research highlights that the current management practice for dairy slurry and dirty water application should not include chemical amendment. Their potential use is in identified critical source areas to protect losses during episodic rainfall events.
- In chemical amendment research both effectiveness, feasibility and pollution swapping at field scale must be taken into account.

Main results:

- In laboratory agitator and simulated runoff experiments, chemical amendments were effective at controlling phosphorus losses in runoff. When combined with feasibility criteria (e.g. cost and handling considerations) whole scale application was not advised due to cost restrictions.
- Using chemical amendments also has implications for nitrogen in the runoff phase. Solubility is increased leading to greater runoff volumes and therefore greater loads of nitrate and ammonium are lost.

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Teagasc project team:
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Ray Brennan, Walsh Fellow

External collaborators:
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Dept. of Civil Engineering,
NUI Galway

Compiled by:
Owen Fenton

Technology

- Chemical amendments also effect gaseous emissions following slurry application. Ammonia emissions were reduced by Alum, ferric chloride (FeCl2), poly-aluminium chloride (PAC) and biochar, but were increased by lime. Cumulative N2O emissions were increased when amended with alum and FeCl2 and reduced when amended with lime, PAC and charcoal. The release of CO2 form soil was not significantly affected by any of the amendments. Methane emissions followed a similar trend for all of the amended slurries applied with an initial increase in losses followed by a rapid decrease and then steady release for the duration of the study. All of the amendments examined reduced the initial peak in CH4 emissions compared to the slurry only treatment. There was no significant effect of any amendment of slurry on global warming potential (GWP) caused by land application of dairy cattle slurry, with the exception of charcoal.
- After considering pollution swapping in conjunction with amendment effectiveness from best to worst, the amendments recommended for further field study are PAC, alum and lime. This study has also shown that charcoal has potential to reduce GHG losses arising from land application of dairy cattle slurry.

Opportunity/benefit:

Data obtained in this research provides an improved understanding of the effectiveness and feasibility of chemical amendment to dairy slurry and dirty water. It has identified that chemical amendment of slurry may have a place in critical source areas which are connected to a surface waterbody. The laboratory experiments in this study were useful to identify amendments suitable for field scale studies.

1. Project background:

Land application of dairy slurry and dirty water can result in incidental losses of phosphorus (P) and nitrogen (N) to runoff where land application is followed by a heavy rainfall event. The risk of P loss from soil can also be increased as a result of a high buildup in soil test P. Fenton et al. (2008) proposed that preliminary laboratory tests (e.g. beaker agitator and runoff box tests) should be conducted to investigate the effectiveness and feasibility of chemically amended slurry and dirty water to control incidental losses. As part of this process a variety of amendments were chosen in agitator, flume and runoff studies which included ochre, ferric chloride, aluminium chloride, charcoal, alum, lime, poly-aluminium chloride hydroxide (PAC) and alum (aluminium sulphate) water treatment residuals.

2. Questions addressed by the project:

- Is chemical amendment of slurry and dirty water an effective way to control incidental losses of P and N and do other losses (pollution swapping) occur when they are used?
- Is chemical amendment of slurry and dirty water feasible within the current management process?

3. The experimental studies:

- Agitator effectiveness study – involved adding slurry mixed with various amendments (mixed in a beaker using a jar flocculator at 100 rpm), to intact soil samples at field capacity. Slurry was applied with a spatula, submerged with overlying water and then mixed to simulate runoff. Feasibility here was judged on cost and handling. The same experiment was conducted with dirty water.
- The flume study – intact grassed soil samples were placed in lab runoff boxes and simulated rainfall fell on this setup for 30 minutes.
- Gas experiment – incubation experiments with chemically amended dairy slurry and its affects on losses of NH3, CH4, N2O, and CO2.

4. Main results:

In laboratory agitator and simulated runoff experiments, chemical amendments were effective at controlling P losses in runoff. When combined with feasibility criteria (e.g. cost and handling considerations) whole scale application was not advised due to cost restrictions. As an example alum (aluminium sulphate) would cost €7.4 per m3 of treated slurry or €66.7 per kg of P reduction. A summary of the results is shown in Table 1.

Table 1. Summary of results from agitator and column experiments. (Abbreviations: a-pig slurry, b-dairy dirty water, c-dairy slurry, d-pig slurry column, NL-no leaching losses found, AFWMC-average flow weighted mean concentration decrease, TDP-total dissolved P, DRP-dissolved reactive P, SS-suspended sediment, TP-total P).

Agitator/Column

Amendment	P	N
Alum	DRP (86%)[a], DRP down 83%[c], minor decrease[d]	NL[d]
PAC	DRP (73%)[a], minor decrease[d]	NL[d]
Ferric Chloride	DRP (71%)[a], DRP down 88%[c], minor decrease[d]	NL[d]
Fly-ash	DRP (58%)[a], DRP down 72%[c]	
Biochar		
Lime	DRP (54%)[a], DRP down 81%[c]	NL[d]
Flue gas by-product	DRP (74%)[a], DRP down 72%[c]	

Using chemical amendments also has implications for nitrogen in the runoff phase. Solubility is increased leading to greater runoff volumes and therefore greater loads of nitrate and ammonium are lost. A summary of results form the run-off experiment is shown in Table 2.

Table 2. Summary of results from run-off experiments. (Abbreviations: a-pig slurry, b-dairy dirty water, c-dairy slurry, d-pig slurry column, NL-no leaching losses found, AFWMC-average flow weighted mean concentration decrease, TDP-total dissolved P, DRP-dissolved reactive P, SS-suspended sediment, TP-total P).

Runoff

Amendment	P
	AFWMC of TP to 1.08 mg/L (56% PP)[a], SS down[a], P+SS down[b], SS down 88%[c]
Alum	TP down 94%[c], PP down 95%[c], TDP down 81%[c], DRP down 88%[c]
PAC	AFWMC of TP to 0.64 mg/L (42% PP)[a], SS down[a], DRP down 86%[c]
Ferric Chloride	AFWMC of TP to 0.91 mg/L (52% PP)[a], SS down[a], P+SS down[b]
Fly-ash	
Biochar	
Lime	P down SS up[b]

Chemical amendments also effect gaseous emissions following slurry application. Alum, ferric chloride (FeCl2), poly-aluminium chloride (PAC) and biochar reduced ammonia (NH3) emissions by 92, 54, 65 and 77%, respectively, compared to the slurry control. Lime increased emissions by 114%. Cumulative N2O emissions of dairy cattle slurry increased when amended with alum and FeCl2 by 202 and 154% compared to the slurry only treatment. Lime, PAC and charcoal resulted in a reduction of 44, 29 and 63%, respectively, in cumulative N2O loss compared to the slurry only treatment. Addition of amendments to slurry did not significantly affect soil CO2 release during the study while CH4 emissions followed a similar trend for all of the amended slurries applied with an initial increase in losses followed by a rapid decrease and then steady release for the duration of the study. All of the amendments examined reduced the initial peak in CH4 emissions compared to the slurry only treatment. There was no significant effect of any amendment of slurry on global warming potential (GWP) caused by land application of dairy cattle slurry, with the exception of charcoal. After considering pollution swapping in conjunction with amendment effectiveness from best to worst, the amendments recommended for further field study are PAC, alum and lime. This study has also shown that charcoal has potential to reduce GHG losses arising from land application of dairy cattle slurry. The summary of the results form gaseous emissions experiments are shown in Table 3.

Table 3. Summary of results from gaseous emissions experiments. (Abbreviations: a-pig slurry, b-dairy dirty water, c-dairy slurry, d-pig slurry column, NL-no leaching losses found, AFWMC-average flow weighted mean concentration decrease, TDP-total dissolved P, DRP-dissolved reactive P, SS-suspended sediment, TP-total P).

Amendment			Gas	
Alum	NH_3	Cumulative N2	soil CO_2	CH_4
PAC	Down 92%[c]	Up by 202%[c]	No effect	No difference from slurry
Ferric Chloride	Down 54%[c]	Down 29%[c]	No effect	No difference from slurry
Fly-ash	Down 65%[c]	Up by 154%[c]	No effect	No difference from slurry
Biochar				
Lime	Down 77%[c]	Down 63%[c]	No effect	No difference from slurry
Flue gas by-product	Up 114%[c]	Down 44%[c]	No effect	No difference from slurry

5. Opportunity/Benefit:

Use of chemical amendments needs to be tested at field scale in a holistic way e.g. runoff, leaching and gaseous losses for N&P needed to be considered.

6. Dissemination:

Main publications:

Brennan, R.B., Fenton, O., Rodgers, M., Healy, M.G. 2011. Evaluation of chemical amendments to control phosphorus losses from dairy slurry. Soil Use & Management, 27, 238–246

Brennan, R.B., Fenton, O., Grant, J., M., Healy, M.G. 2011. Impact of chemical amendment of dairy cattle slurry on phosphorus, suspended sediment and metal loss to runoff from a grassland soil. Science of the Total Environment, 409: 5111–5118.

Fenton, O., Serrenho, A., Healy, M.G. 2011. Evaluation of amendments to control phosphorus in runoff from dairy soiled water. Water Air and Soil Pollution, 222, 185–194.

O Flynn, C.J., Fenton, O., Wilson, P., Healy, M.G. 2012. Impact of pig slurry amendments on phosphorus, suspended sediment and metal losses in laboratory runoff boxes under simulated rainfall. Journal of Environmental Management. In press.

O Flynn, C.J., Fenton, O., Healy, M.G. 2012. Evaluation of amendments to control phosphorus losses in runoff from pig slurry applications to land. CLEAN – Soil, Air and Water 40: 164–170.

Popular publication:

Fenton, O., Healy, M.G., Brennan, R.B., Serrenho, A.J., Lalor, S.T.J., OhÚallacháin, D., Richards, K.G. 2011. Agricultural Wastewaters. Waste Water Edited by Fernando S. Garcia. Intech Publishers.

Quantifying subsurface denitrification across contrasting agri-environmental settings

Project number:
5605
Date:
September, 2012
Funding source:
DAFM
Project dates:
Oct 2006 – Dec 2011

Installing groundwater investigation wells.

Key external stakeholders:

All farmers, Department of Agriculture, Food & Marine, Environmental Protection Agency.

Practical implications for stakeholders:

The fate of nitrate leaching from agricultural soils is not well known internationally and subsoil/groundwater denitrification could potentially reduce nitrate transport to sensitive receiving waters. Our project has shown that subsurface denitrification is an important sink for nitrate and nitrous oxide during transport in subsoil and groundwater.

- **Farmers:** This research demonstrates that nitrate leached from the root zone can be reduced substantially through denitrification and this supports allowing higher nitrate leaching on soils with higher denitrification potential.
- **Policymakers:** There is considerable potential for nitrate leaching reduction through denitrification on lower permeability soil/aquifers. Indirect N2O emission factors were potentially considerably higher than the IPCC default value.
- **Scientific:** This research quantifies nitrate reduction, indirect nitrous oxide, methane and CO2 emissions from groundwater for the first time in Ireland and provides valuable international data in a much ignored process.

Collaborating Institutions:
Trinity College Dublin (TCD)
NUI Galway

Teagasc project team:
Dr. Karl Richards (PI)
Dr. Ibrahim Khalil
Dr. MMr. Jahangir

External collaborators:
Prof. Vincent O'Flaherty and Dr. Maria Barrett (NUIG)
Mr. Paul Johnston and Dr. Catherine Coxon (TCD)
International Steering Group

Compiled by:
Karl Richards

Technology

Main results:

- Subsoil denitrification rates are low and predominantly releases environmentally benign di-nitrogen.
- Groundwater denitrification resulted in nitrate leaching reductions on lower permeability sites was 57% compared to 6% on high permeability sites with di-nitrogen the main end product.
- Groundwater denitrification was negatively associated with groundwater oxygen and redox potential.
- Groundwater can be an important source of indirect greenhouse gas emissions with emission factor (EF5g) ranged 0.0029–0.0041.

Opportunity/Benefit:

- Identification of areas with high and low groundwater denitrification potential could provide an important N management tool in agricultural systems for decreasing nitrate delivery to rivers and indirect N2O emissions to atmosphere.
- Indirect GHG emissions from groundwater are an important part of farm and national inventories.

1. Project background:

Internationally, subsurface denitrification has received only limited attention, due to methodological limitations that have more recently been overcome. Denitrification may prove to be the key process in determining nitrate occurrence in receiving waters. The indirect emission of nitrous oxide via subsurface denitrification has large uncertainties and little data is available nationally or internationally. These indirect emissions can account for up to 70% of direct emissions from soil and further data is needed for global greenhouse gas budgeting. Understanding the microbial denitrification process within subsoil/groundwater will lead to a better understanding of the fate of nitrate delivery to groundwater and may also lead to management procedures for reducing both nitrous oxide emissions and nitrate leaching.

2. Questions addressed by the project:

This research addressed the following questions:

- Is subsurface denitrification an important process for reducing nitrate transport to ground and surface waters?
- Do agricultural practices and soil type/ hydrogeology influence the denitrification rate?
- Is subsurface denitrification a sink or source of indirect greenhouse gas emissions?

3. The experimental studies:

An integrated multidisciplinary team assessed the fate and transport of nitrate at a range of depths beneath the rooting zone. The research approach used the most up to date, state of the art methodologies, for the quantification of denitrification in subsoil, groundwaters and the microbial community responsible for denitrification. Within the subsoil zone, the rates of denitrification and the partitioning between N2 and N2O were assessed ex-situ. Groundwater denitrification was quantified by the measurement of actual denitrification products (N2 and N2O) in a range of agricultural/hydrogeological situations and potential groundwater denitrification quantified using the “push-pull” method. The project used novel, direct methods to study the rates and distributions of denitrifying bacteria in soils and aquifer samples. This project established Irelands only Membrane Inlet Mass Spectroscopy unit for the quantification of argon and di- nitrogen gases. The project established protocols for the extraction and analysis of dissolved nitrous oxide, carbon dioxide and methane concentrations in water by gas chromatography. In addition the project quantified, for the first time, the microbial community in soil and groundwater response to N inputs.

4. Main results:

Soil carbon concentration strongly positively influenced denitrification rate. Soil denitrification rates reduced significantly with soil depth and were 25, 12 and 3% in the soil A, B and C horizons (Jahangir et al 2012a). Addition of carbon to soil increased denitrification rates in the A and B horizons by 100% and by 600% in the C horizon. Although the rate of denitrification is lower in the subsoil, due to carbon availability, the ratio of N2:N2O is much higher. Thus subsoil denitrification is a sink for the emission of N2O and nitrate. The coupling of low rates of denitrification with long

residence times in subsoil is likely to consume considerable quantities of nitrate. Denitrification will be considerably reduced in free draining aerobic soils with rapid flow paths to groundwater.

Landuse and hydrogeological settings are both important variables in determining groundwater nitrate occurrence. Mean groundwater nitrate concentrations were high on the two free draining sites. Groundwater nitrate concentrations were correlated with physiochemical parameters such as DO, redox potential and saturated hydraulic conductivity. Sites with low groundwater DO and redox potentials had low nitrates and vice versa (Jahangir et al. 2012b). The chemical data suggest that denitrification could be responsible for the low groundwater nitrate concentrations observed at two sites.

Our results indicated that groundwater N2O can leach to the water table with recharge. The push-pull experiments, using in situ ^{15}N tracer, showed that N2O was also produced in the groundwater and identified in-situ ammonia generation from dissimilatory nitrate reduction to ammonium (DNRA). The fate of groundwater N2O requires further research to quantify the actual emissions to the atmosphere during groundwater transport.

Groundwater denitrification (N2+N2O) was a significant pathway of groundwater nitrate depletion resulting in 45, 70, 7 and 3% losses of NO3-N (Figure 1). The main end product of denitrification (N2) was significantly higher in the less well drained sites than the well drained sites. Across the sites, the mean indirect N2O emission factors were considerably higher (0.0048–0.0259) than the IPCC default value of 0.0025 (EF5g). The results also identified groundwater can be an important source of CO2 and CH4 emissions to the atmosphere. Denitrification functional genes, nitrous oxide reductase nosZ' and nitrite reductase nir', were observed across all soil types and groundwaters. The abundance of nirK and nirS gene varied across the six sites tested, whereas the nosZ gene concentration remained relatively constant, suggesting that bacterial populations with nosZ gene are less opportunistic. N2 and N2O emissions were found to be significantly correlated with gene copy number.

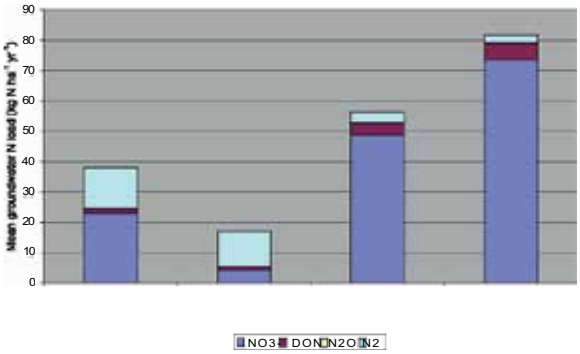

Figure 1 Mean annual nitrogen load in groundwater disaggregated in to nitrate (NO3 -) dissolved organic N (DON), nitrous oxide (N2O) and excess di-nitrogen (N2) across 4 sites. Sites 1&2 had lower permeability soil/aquifers and sites 3&4 had higher permeability soil/aquifers (Jahangir et al. 2012c)

Subsurface denitrification has been found to be an important process that can substantially reduce nitrate leaching but can contribute to indirect greenhouse gas emissions. Further research is needed to refine indirect greenhouse gas emissions and to further evaluate denitrification as groundwater discharges to surface water. Indirect emissions need further consideration in the carbon foot printing of Irish agricultural systems.

5. Opportunity/Benefit:

The primary stakeholders for this research are both farmers and policy makers. Policy makers will be interested in the potential for denitrification to reduce nitrate leaching and achievement of water quality targets particularly in lower permeability settings. In addition indirect greenhouse gas emissions from groundwater is important and the first Irish emission factors have been produced by the project. For farmers there is justification for having higher acceptable nitrate leaching rates on lower permeability soils. This unique national research has led to a capacity for quantifying indirect emissions.

6. Dissemination:

The results of the project have been presented at over 30 national and international conferences. There are four scientific papers under review in international journals and five papers have been published in high impact scientific journals to date (see below). The outputs from the project have been sent to relevant national policy makers.

Main publications:

Jahangir, M.M.R., Khalil, M.I., Johnston, P., Cardenas, L., Hatch, D., Butler, M. and Richards, K.G. (2012a) Total denitrification potential in subsoils: a mechanism to reduce nitrate leaching to groundwater, *Agriculture Ecosystems and the Environment* 147: 13–23.

Jahangir, M.M.R., Johnston, P., Khalil, M.I. and Richards, K.G. (2012b) Linking hydrogeochemistry to the abundances of nitrate in groundwater at diverse landscape settings, *Journal of Hydrology* 448–449, 212– 222.

Jahangir, M.M.R., Johnston, P., Khalil, M.I., Hennessy, D., Humphreys, J. Fenton, O., Richards, K.G. (2012c) Groundwater: A pathway for terrestrial C and N losses and indirect greenhouse gas emissions, *Agriculture, Ecosystems and Environment* 159: 40– 48.

Jahangir, M.M.R., Johnston, P., Khalil, M.I., Grant, J., Sommers, C. and Richards, K.G. (2012d) Evaluation of headspace equilibration methods for quantifying greenhouse gases in groundwater, *Journal of Environmental Management* 111: 208–212.

Jahangir, M.M.R. (2012e) Denitrification in subsoils and groundwater in Ireland, *PhD Thesis*, Trinity College Dublin, Dublin 2.

Khalil, M. I. and Richards, K.G. (2011) Denitrification enzyme activity and potential of subsoils under grazed grasslands assayed by membrane inlet mass spectrometer, Soil Biology and Biochemistry 43, 1787–1797.

Popular publications:

Richards, K.G., Khalil, M.I., Fenton, O., Haria, A., Barrett, M., Jahangir, M.M.R., Johnston, P., O'Flaherty, V. (2009) Discovering subsurface denitrification, Tresearch 4 (3) 26–27.

Crops Environment & Land Use Programme

An evaluation of existing and potential measures to sustain an increased biodiversity and water quality on Irish farms

Project number:
5584

Date:
September, 2012

Funding source:
DAFM

Project dates:
Oct 2006– Jun 2011

Key external stakeholders:

Agri-environment policymakers, participants in agri-environment schemes and extensive farmers, environmental NGOs.

Practical implications for stakeholders:

Intensification of agriculture over the last number of decades has resulted in a loss of ecological heterogeneity and has contributed to the loss of biodiversity, resulting in significant implications for wild species of flora and fauna.

Biodiversity conservation on farmland is critical to international, EU and CAP policy objectives and will mainly depend on effective agri-environment schemes. Measures involving field and watercourse margins affect almost all farmers who join Agri-Environment Schemes. This study evaluated the effectiveness of existing and potential field and watercourse margin measures from a biodiversity and water quality point of view.

Field margin measures developed by this project have now been included in the new Agricultural Environment Options Scheme (AEOS). Furthermore, results relating to the impact of cattle access drinking points on water quality will inform policy-makers when designing future prescriptions for AE schemes or cross-compliance regulations.

Collaborating Institutions:
University College Dublin (UCD)
University College Cork (UCC)

Teagasc project team:
Dr. Daire Ó hUallacháin (PI)
Dr. John Finn, Johnstown Castle

External collaborators:
Dr. Helen Sheridan (University College Dublin)
Dr. Simon Harrison (University College Cork)
A steering committee was established for this project

Compiled by:
Daire Ó hUallacháin
John Finn

Technology

Main results:

- Minimal-change management approaches (currently adopted in many agri-environment schemes), such as fencing and/or the cessation of nutrient inputs, are unlikely to produce swards of conservation value.
- Current guidelines in relation to fencing of riparian management are not promoting and enhancing farmland biodiversity. A variety of grassy, scrubby and woody habitats in these margins appropriately managed would benefit the biodiversity of riparian margins and associated habitats.
- There is no one solution to appropriate management for all field and watercourse margins. Site specific management is required to conserve existing species and habitat diversity and promote new habitat development.

Opportunity/Benefit:

Details from this study will aid policy-makers with the design of future agri-environment schemes and measures. A measure demonstrated in this study relating to the temporary fencing of field margins has been included in the new Agricultural Environment Options Scheme (AEOS).

The results from this study indicate that current AEOS prescriptions in relation to watercourse margins are not promoting riparian biodiversity. Our results relating to the impact of cattle access drinking points on water quality and biodiversity could help inform policy-makers when designing prescriptions for AE schemes or cross-compliance regulations.

The results from this study will also be of benefit to the scientific community in giving a greater insight into the biodiversity associated with field and water-course margins. Furthermore, a number of species new to Ireland have been recorded which will help scientists when trying to map the distribution of certain species.

1. Project background:

Intensification of agriculture over the last number of decades has led to a dramatic change in agricultural production methods. This in turn has resulted in a loss of ecological heterogeneity and has contributed to the loss of biodiversity, resulting in significant implications for wild species of flora and fauna. In an effort to halt the decline in biodiversity, the Rural Environmental Protection Scheme (REPS) was initiated in Ireland in 1994 as the Irish government's response to the EU Agri-environmental Regulation. Since its establishment over 4 billion euro has been paid to farmers under REPS (and Agri-Environment Options Scheme).

Carey et al, (2003) stated that agri-environment schemes need to be accountable and provide value for money. A study by Kleijn and Sutherland (2003) into the effectiveness of European agri-environment schemes found that 46% of studies found few or no benefits associated with the scheme.

REPS addressed the protection and maintenance of field and watercourse margins by incorporating a number of measures (1, 2, 3, 5, 6, 9, SM4). Measures involving field and watercourse margins affect almost all farmers who join REPS. Despite this, little empirical research has been undertaken in Ireland examining the effect these measures have on biodiversity and environmental factors such as water quality.

Field margin measures are a popular option in agri-environment schemes. However, most research on field margins to date has been conducted on arable systems. Grassland field margins in Ireland are not well researched.

Fencing watercourses to prevent bovine access became mandatory under REPS, for water quality and biodiversity reasons. However, despite being a compulsory measure since the early 1990s, little research has been undertaken in relation to evaluating the effectiveness of such a measure under Irish conditions.

The present study aimed to evaluate the effectiveness of existing field and watercourse margin measures from a biodiversity and water quality point of view. This was achieved through both theoretical and practical studies. The study was a combination of relevant existing Irish and European studies and new knowledge based on an Irish context.

2. Questions addressed by the project:

- Are existing field and watercourse margin measures protecting and sustaining biodiversity and water quality?
- Are there potential new measures which could facilitate increased biodiversity within grassland field margins and watercourse margins on Irish farms?
- How feasible is it to implement and manage newly developed measures in an Irish context?

3. The experimental studies:

This project consisted of a number of concurrent experiments:

Grassland field margin experiment

The field margin experiments investigated a combination of establishment and management methods to enhance botanical and invertebrate diversity of experimental field margins in intensively managed grasslands (over a seven year period).

Three methods of field margin establishment were investigated (fencing, rotavation, or reseeding with a variety of seed mixtures). Subsequent sward management by either continuous grazing, periodical grazing or mowing was tested on a number of margin widths and designs.

The experiments were conducted on a number of sites within the research farm at Johnstown Castle, as well as on eight commercial farms in Wexford and Meath.

Plant abundance and diversity was assessed using quadrats and the Braun-Blanquet scale. Carabid and spider diversity and abundance were sample using pit-fall traps over a number of sampling periods. Earthworm abundance and diversity was assessed using a combination of mustard oil extraction and hand- sorting.

Riparian margin experiment

This experiment assessed the impact of vegetation type and subsequent management on riparian biodiversity. Farms in SE Ireland were selected for study with up to 42 sites being selected. Each site was dominated by grass, scrub or woodland vegetation, and was adjacent to a 1st or 2nd order stream.

The abundance and diversity of plants, carabid, spiders, earthworms and small mammals was assessed. Changes in riparian biodiversity as a result of experimental cattle exclusion were also assessed.

This final part of the riparian experiment evaluated the impact of cattle access drinking points on in-stream biodiversity and water quality. Variables such as, land-use, stream physical attributes, riparian vegetation etc. were recorded at each of 40 stream sites. Water chemistry measurements (total phosphorus, total nitrogen, ammonium, nitrate, dissolved oxygen, conductivity and temperature) were recorded at each site (up-stream and downstream of each access point), along with details in relation to sediment characteristics. Aquatic insects were sampled using a kick-sampling technique at riffle points up and down-stream of the access points.

4. Main results:

Grassland field margin experiments

Our results highlight that reseeding field margins with a wildflower mixture was the most successful establishment method to enhance plant species richness, with this effect persisting throughout the seven years of the experiment.

Grazing led to a significant, increase in plant species richness and had a positive effect for earthworm abundance and diversity. However, a reduction in grazing pressure resulted in an increase in abundance and species richness of most invertebrate groups studied.

Corner margins were slightly more effective than linear margins in enhancing botanical diversity. Spider species richness also showed a trend towards higher species richness in corner plots compared to linear plots.

Although margin width was not found to significantly influence plant species richness, there was increased herb cover and reduced abundance of noxious weeds in the wider seeded margins.

No single establishment treatment was best for overall invertebrate abundance and richness, as each taxon responded differently. Use of a range of establishment methods and subsequent grazing methods supports the highest diversity and abundance of plants and invertebrates.

Riparian margin experiment.

Our study highlighted the highly modified nature of streamside habitats in many agricultural catchments. Because of this modification there was little difference in the carabid communities between the three vegetation types, despite distinct floristic differences.

Riparian margins were found to be important habitats for a variety of species. Twenty of the 28 known Irish earthworm species, including rare and recently recorded species, were found during the survey of riparian margins highlighting the importance of riparian zones as habitats for earthworms. Riparian margins provide breeding and feeding sites for a number of small mammals. Significantly more mammals were caught in woodland dominated margins as opposed to those dominated by grass or scrub. The diversity of small mammals was lowest in woodland dominated margins. These results highlight the important role riparian margins play in farmland ecology and in agri-foodwebs.

The management practice of fencing agricultural streams at this scale is unlikely to significantly enhance riparian diversity at the farm, or the regional scale.

Removing the disturbance of cattle by fencing is unlikely to enhance the numbers or diversity of riparian specialists, because the colonisation of riparian habitats by specialists is hindered by the low diversity of species in adjacent areas.

Fencing of riparian margins (with no subsequent management) will likely lead to streamsides being dominated by woody and scrubby vegetation, rather than grassy vegetation. Our results indicate that this would be unlikely to cause a significant reduction in the number of grassland specialist species. There could however be implications for other taxa (plants, small mammals, spiders etc.).

Our study found that cattle drinking access points did not have a significant impact on stream water quality or biological community structure in the sample of study streams. Cattle drinking access points were unlikely to further impact negatively on water quality in streams where water quality was of Q3 or less.

Complete exclusion of cattle from watercourses might not be the most cost-effective or environmentally effective measure in more intensive agricultural grassland systems, where water quality might already be impacted (≤Q3).

Heterogeneity of habitats results in greater faunal and floral diversity. REPS riparian management guidelines do not promote heterogeneity of riparian habitats.

5. Opportunity/Benefit:

Details from this study will aid policy-makers with the design of future agri-environment schemes and measures. To date, a measure demonstrated in this study relating to the temporary fencing of field margins to promote biodiversity has been included in the new Agricultural Environment Options Scheme (AEOS).

The results from this study indicate that current AEOS prescriptions in relation to watercourse margins are not fulfilling their full potential in promoting riparian biodiversity. Our results relating to the impact of cattle access drinking points on water quality and biodiversity could help inform policy-makers when designing prescriptions for AE schemes or cross-compliance regulations.

The results from this study will also be of benefit to the scientific community in giving a greater insight into the biodiversity associated with field and water-course margins. A number of species new to Ireland have been recorded during this study. These records will help scientists when trying to map the distribution of certain species.

6. Dissemination:

Main publications:

Fritch, R.A., Sheridan, H., Finn, J.A., Kirwan, L. and Ó hUallacháin, D. (2011) Methods of enhancing botanical diversity within field margins of intensively managed grassland: a 7-year field experiment. *Journal of Applied Ecology*, 48, 3, 551–560.

Ó hUallacháin, D. and Madden, D. (2011) Riparian vegetated margins and small mammal communities: Implications for agri-environment schemes. *Tearmann, The Irish Journal for Agri-Environmental Research*, Vol 8, 15–24.

Ó hUallacháin, D. and Finn, J. (2011) Report from Teagasc Biodiversity Conference "Conserving Farmland Biodiversity: lessons learned and future prospects". *Tearmann, The Irish Journal for Agri-Environmental Research*, Vol 8, 77–90.

Regan, E., Nelson, B., McCormack, S., Nash, R., and O'Connor, J.P. (2010) Can we assess Ireland's insect species diversity and loss. *Biology and Environment*, vol 110b, 109–117.

Madden, D., McCormack, S, Ó hUallacháin, D. (2010) Ground beetles (Carabidae) from field margins in southeastern Ireland. *The Coleopterist* 19(2): 100

McCormack, S. (2010) *Medon apicalis* (Kraatz) (Staphylinidae) new to Ireland. *The Coleopterist*, 19; 102.

McCormack, S. & Guinan, M. (2010) *Oedemera nobilis* (Scopoli) (Oedemeridae) in Co. Waterford. *The Coleopterist*, 19; 103.

McCormack, S., Fritch, R., Madden, D., Leyvastre, A. and Ó hUallacháin, D. (2009) Bembidion quadrimaculatum (Linnaeus) (Carabidae) new to Ireland. *The Coleopterist*, 18; 201.

Popular publications:

Over 50 practical, popular and scientific presentations were completed throughout the study. A number of open days were also organized.

A Biodiversity Conference "Conserving farmland biodiversity: lessons learned and future prospects" was organised in Wexford (25th-26th May, 2011). Over 140 delegates registered for the conference and included a mixture of researchers, policy-makers, advisors and farmers (http://www.teagasc.ie/publications/201 1/996/index.asp).

Project number:
5721
Date:
November, 2013
Funding source:
Teagasc
Project dates:
Mar 2007 – Dec 2010

Inhibitory effect of barley straw on algal growth

Key external stakeholders:

Farmers and land-owners, water managers, freshwater scientists.

Practical implications for stakeholders:

Barley straw can be an effective low cost method for controlling problematic algal growth on lake systems, however, strict protocols in relation preparation and location straw booms should be adhered to in order to ensure optimal water quality and ecological results.

The key to unlocking the algal inhibitory capabilities of barley can be obtained by using specific barley strains, commercially available algal assays and modern investigative techniques.

Main results:

In order to control the growth of problematic algae in eutrophic surface waters the following recommendations should be followed:

- Optimal rates of barley addition are 10 g m^{-2} and 25 g m^{-2} (lake surface area) in areas with average and severe algal problems respectively.
- To facilitate the even distribution throughout the water system of the compounds which prevent algal growth (i.e. algistatic compounds) derived from barley, a number of loosely packed straw booms of varied length should be randomly located throughout the target water system.
- Installation of straw booms should occur in April, before the peak algal growing season.
- Prevention of algal growth may result in an increase in the growth of other aquatic plant species. This is due to increased light penetration in the water system.

Collaborating Institutions:
None

Teagasc project team:
Dr. Owen Fenton
Dr. Daire Ó hUallacháin

External collaborators:
None

Compiled by:
Owen Fenton
Daire Ó hUallacháin

Technology

The key to unlocking the algal inhibition properties of barley lies in the protocols used in laboratory experiments. A review of the literature highlighted a number of inconsistencies in the barley variety used, algal species tested, barley liquor preparation and phenol extraction methodologies. This led to differences in the growth responses for the same species of algae tested. This project highlighted several successful forms of investigation:

- using commercially available compounds i.e. with known shikimate pathway producing phenols and acids, which can then be combined with algal assays of different algal species.
- using commercially available algal species from which batch cultures are grown, which are then added to barley liquor of different ages.
- using in-vivo fluorescence whereby the filtrate can then be analysed via HPLC/MS.

The identification of allelochemicals, which range from phenolics to quinones within the Poaceae family is extremely important for determining the optimal algistatic properties of compounds.

Opportunity/Benefit:

Interested stakeholders can liaise with the project researcher to develop laboratory and field protocols for successful inhibition of algal species using barley.

There is a commercial opportunity here to develop barley liquor as a viable product to prevent algal growth on surface waterbodies.

1. Project background:

Declining ecological water quality in freshwater ecosystems has been linked to an increase in planktonic algae growth, cyanobacteria and higher forms of macrophytes. The use of organic and inorganic fertilisers and soil test phosphorous can result in incidental losses to a surface waterbody. Such nutrient losses can result in surplus nutrients being washed into waterbodies, ultimately providing suitable conditions for excess growth of algae, cyanobacteria and macrophytes. These water systems can become eutrophic, i.e. rich in nutrients and capable of supporting dense plant populations. When the dense plant populations decompose, they use up oxygen in the water column, resulting in a lack of oxygen for freshwater flora and fauna, and ultimately resulting in a reduction in biodiversity and water quality.

The Water Framework Directive stipulates that waterbodies in the Republic of Ireland must achieve 'Good Ecological Status' by 2014. Currently, however, 14% of the Republic of Ireland's land area has been determined to be of "poor" status, i.e. the groundwater bodies exceed the annual median phosphate concentration of 30 µg L^{-1} molybdate-reactive phosphorus (cited as the limit to prevent eutrophication in surface waters).

Slow abatement occurs in many lake systems, due to internal nutrient loading of the lake system and because many lake ecosystems can often be resistant to improvement measures. A number of studies have been undertaken in recent decades to investigate the inhibitory effect of compounds derived from barley straw on algae. Experimental set-up and outcomes have varied between studies.

The aim of the current research was to undertake a small field study to determine optimal barley application rates and appropriate construction and placement of barley booms in a water system. A second aim of the project was to compare the methodologies used in previous national and international algal inhibitor studies in order to identify optimal application rates and laboratory preparation methods.

The final aim of the study was to propose a way forward to achieve a better understanding of the inhibitory capabilities of barley on algal growth.

2. Questions addressed by the project:

- What are the optimal application rates, construction methods and placement of barley booms to prevent excess algal growth in eutrophic surface waters?
- Investigate the causes of algal inhibition by barley in the field and laboratory respectively? What are the differences in methodologies used in previous algal inhibitor studies?
- What are the gaps of knowledge that need to be addressed in order to achieve a better understanding of the inhibitory capabilities of barley on algal growth?

3. The experimental studies:

- A field experiment utilising the three artificial lakes at Johnstown Castle.
- A review of all available literature regarding algal inhibition using barley.

4. Main results:

The amount of straw to place on a lake is dependent on the severity of the algal problem and the flow within the lake. The minimum quantity of barley should be 10 g m^{-2} (surface area of lake) with a rate of 25 g m^{-2} in areas with severe algal problems. It is important to note that overloading the lake with barley can also cause environmental and ecological problems. The micro-organisms which colonise the decomposing straw absorb oxygen from the surrounding water. If too much straw is added, it can increase the demand for dissolved oxygen and lead to de-oxygenation of the water column resulting in loss of freshwater flora and fauna. For a specific case study in Johnstown Castle, taking the surface area and the flow of water through the lake into account, coupled with the severity of the algal problem, a rate of 25 g m^{-2} was deemed appropriate.

The most appropriate method of adding barley to a lake is to create a number of straw booms and place them in a variety of locations throughout the lake. This method allows for a greater dispersal of algistatic compounds from the straw. Furthermore, this method allows specific areas of problematic algal growth to be directly targeted. Constructed straw booms are more loosely packed than conventional barley bales; therefore they undergo decomposition at a faster rate and result in earlier dispersal of algistatic compounds.

Round straw bales (weighing on average 170 kg per bale) were rolled out on mesh netting. This netting was used to loosely wrap the straw. Floats were incorporated within the straw at regular intervals to ensure that the straw would remain afloat and therefore undergo aerobic decomposition. Each bale resulted in 9 to 12 cylindrical booms, 10 to 20 m in length. These straw booms were then placed at a distance of 15 to 25 m from each other on the lakes and anchored at one end. This allowed the straw booms to move with the wind and currents and hence increase the area affected by the released algistatic compound. Smaller straw booms (1 to 3 m) were placed in areas with particularly severe algal problems e.g. areas around islands and areas of stagnant water.

A lake system follows seasonal trends, with phosphorous and nitrogen becoming limiting at different times. This cycle occurs naturally, but can be altered slightly following barley bale installation. With an increase in the size of the lake the effect of phosphorous limitation is delayed. In addition, the barley booms act as sediment traps and water breakers, which improve the turbidity of the lake system. It should be noted that barley bale amelioration methods alone will not be sufficient to control problematic algal growth in water-systems that have received high nutrient inputs over a prolonged period of time. If such instances occur, it is recommended that some mechanical control measure be undertaken first, to remove the nutrients e.g. dredging. Barley bales may then be used as an on-going control measure.

A direct result of appropriate barley bale installation is a reduction in the growth of algae, along with an improvement in the turbidity of the water column. This can result in more light being available for aquatic plants to grow and prosper. In many artificial lake systems, introduced plants such as Canadian Pondweed *Elodea canadensis* are common. In the present study, the prevention of algal growth afforded pondweed an opportunity to dominate the water column. It is important to note that pondweed dominance does not necessarily have negative environmental implications, however, if pondweed dominance occurs in water-systems that are open to and used by the public, problems may be encountered from an aesthetic point of view, and in relation to pursuits such as fishing and boating.

Barley bale amelioration on its own will not affect the trophic status of the lake. If a lake was previously considered to be eutrophic (e.g. containing a high nutrient content), this will still be the case, unless issues in relation to the nutrient cycling within the lake are tackled.

The positioning of barley booms is also highly important. The booms may interrupt the natural flow of the water system which in turn can have either positive or negative implications. Barley booms may result in water flow being directed to areas that previously were stagnant thus improving water quality. Alternatively, it may result in the channelling of the water flow through the lake system. This can result in large areas of the lake receiving a reduced flow of water and as such lead to them becoming more stagnant and thus giving rise to problematic species such as algae.

Many field and laboratory studies have attempted to explain the inhibitory effect of rotting barley on algae. Such studies offer practical information on barley bale field construction and application rates. However, early field studies lacked controls and replication and results typically depended on subjective visual observations and therefore discrepancies occurred. In the laboratory, discrepancies occurred between studies, particularly in relation to the barley variety used,

algal species tested, barley liquor preparation and phenol extraction methodologies. Inconsistencies have led to different growth responses for the same species of algae tested i.e. with some studies finding an inhibitory response and other studies reporting an accelerated growth response of algae.

Two successful forms of investigation have been identified:

a) using commercially available compounds i.e. with known shikimate pathway producing phenols and acids, which can then be combined with algal assays of different algal species and
b) using commercially available algal species from which batch cultures are grown, which are then added to barley liquor of different ages.

Algal growth may then be investigated using in-vivo fluorescence and the filtrate can be analysed via HPLC/MS. The identification of allelochemicals, which range from phenolics to quinones within the Poaceae family of which barley is a member, has received a lot of attention in recent years.

5. Opportunity/Benefit:

Further research or co-operation with a commercial company is needed to create species-specific barley liquor to limit growth of specific problematic algal species.

6. Dissemination:

Main publications:

Fenton, O. and Ó hUallacháin (2012) Growth of third generation biomass (microalgae) for biofuel production using agricultural nutrient surpluses: a review. *Algal Research*, Vol 1, 49–56.

Ó hUallacháin, D. and Fenton, O. (2010) Barley (Hordeum vulgare) induced growth inhibition of algae: A review. *Journal of Applied Phycology*. Vol 24, 651–658

Ó hUallacháin, D. and Fenton, O. (2011) "Barley as a method of Algal control" in *Barley: Production, Cultivation and Uses*. Eds Steven B. Elfson. (14pgs)

Popular publications:

Ó hUallacháin, D. and Fenton, O. (2008). Artificial lake amelioration: implications for submerged aquatic vegetation, *18th Irish Environmental Researchers Colloquium,* Dundalk, February, 2008

Fenton, O., Hyde, B., Ó hUallacháin, D., Healy, M., Regan, J., Rodgers, M. (2008). Tackling nutrient loss head on: catching the nutrients that got away, *TResearch*.

Crops
Environment
& Land Use
Programme

Project number:
5508
Date:
December, 2011
Funding source:
DAFF
Project dates:
Oct 2005 – Sep 2009

An evaluation of strategies to control ammonia emissions from the land – spreading of cattle slurry and cattle wintering facilities

The experimental slurry tanker and ammonia flux gradient mast

Collaborating Institutions:
University College Dublin (UCD)
ADAS Wolverhampton
Rothamstead – North Wycke
Westlakes Scientific

Teagasc project team:
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David Ryan
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Dr. Owen Carton
Dr. Bernard Hyde

External collaborators:
University College Dublin (Tom Curran)
ADAS Wolverhampton (Ken Smith)
Rothamstead – North Wyck (Tom Misselbrook)
Westlakes Scientific (Richard Hill)

Compiled by:
Gary Lanigan

Key external stakeholders:

Livestock farmers, Department of Agriculture, Food & Fisheries, Environmental Protection Agency.

Practical implications for stakeholders:

This research demonstrates the effectiveness of altered timing and application technique on ammonia emissions abatement. This will enable stakeholders to make informed decisions as to which strategy to adopt in order to reduce N losses to the atmosphere.

Farmers: This research demonstrates that N losses to the atmosphere can be reduced without any outlay in terms of new machinery simply by targeting application either early in the season or be evening application. This will increase the N-fertiliser efficiency of slurry (demonstrated in RMIS 5512).

Policymakers: This research has quantified the abatement benefits of adopting trailing shoe technology and altered timing. Results are also feeding into a revision of the national ammonia inventories which should lead to reduced estimates of housing emissions.

Scientific: This research quantifies ammonia emissions from out-wintering pads in Europe for the first time.

Technology

Main results:

- On average, 54% of total ammoniacal nitrogen (TAN) was lost when slurry was applied by splashplate. Emissions were highest on hot, dry days. Application was targeted for cooler periods, particularly during spring, reduced emissions by over 30%. Emissions were also reduced by application in evening.
- The adoption of trailing shoe technology reduced ammonia emissions by an average of 36%. Under low emission weather conditions, there was no significant difference between application techniques.
- Ammonia emissions from slatted sheds were lower than those used by the EPA in the national ammonia inventories such, indicating a substantial overestimation of cattle housing emissions within the inventory. By comparison, emissions from an outwintering pad (OWP) were higher, particularly dry periods. Emissions were substantially reduced (90%) if pads were regularly cleaned. However, OWP's are in general, *not* an effective ammonia abatement technique.

Opportunity/Benefit:

Application technique and timing are both effective measures for reducing ammonia emissions following landspreading. Therefore, farmers can reduce emissions without the requirement to adopt more expensive machinery. Ammonia emissions from slatted cattle housing is towards the low end of European figures and lower than default values derived from UK data. In addition, it was also demonstrated that whilst out- wintering facilities be advantageous in terms of animal welfare, ammonia emissions per animal were higher.

1. Project background:

Irish agriculture faces considerable challenges in reducing N inputs both in terms of financial sustainability and complying with future emissions targets. The loss of N via ammonia volatilisation represents a challenge both in terms of atmospheric pollution and a loss of resource for the farmer. Under the terms of the National Emissions Ceilings Directive (2001) ammonia (NH3) emissions are limited to 116,000 tonnes by 2010; with further, more stringent, reductions currently under discussion. Agriculture comprises 98% of national ammonia emissions, with cattle accounting for 80% of this total. In terms of agricultural practices, the land spreading of slurry and animal housing comprise 47% and 34% of total emissions, respectively; whilst the remainder is split between manure storage and animal deposition. In terms of atmospheric pollution, ammonia is both a local and trans-boundary pollutant, and also indirectly contributes to greenhouse gas emissions. Ultimately, however, these emissions represent a considerable loss of N to the farmer. Indeed, the economic cost associated N loss via volatilization is c. €60 million. As a result, there is an urgent need to develop abatement strategies to reduce these losses.

2. Questions addressed by the project:

This project had two principle research goals. The first was to assess the effect of timing and application technique on ammonia emissions. The second objective was to assess the emissions from housing and to evaluate the efficacy of Out-Wintering Pads (OWP's) as a housing control measure.

3. The experimental studies:

Landspreading: Eight land-spreading experiments were carried out between July 2006 to August 2008 with slurry applied to grassland on a loamy soil using either splashplate or trailing shoe application methods. On all plots, application rates were 33 m^3 per hectare. All slurry used for application came from the slatted beef unit at Teagasc Environmental Research Centre, Johnstown Castle, was agitated in the shed 1–3 days prior to application and spread using the same purpose built tanker (Abbey Machinery Ltd, Nenagh, Co. Tipperary). The tanker had a capacity of 7 m^3 and had a valve which allowed slurry to be circulated inside the tank. The slurry was forced through the pipes to the 24 applicators. Each applicator had a valve to allow the selection of splashplate or trailing shoe application. In order to accurately assess the effect of timing and spreading technique on ammonia emissions, measurements were performed using the flux-gradient technique. This method measured ammonia emissions at various heights (from 0.1 to 2.2m) above the ground, with the sum of the all heights representing the emissions for an area of ground (dependent on the mast height and windspeed). Thus it provided a non-invasive technique and provided an integrated measurement over a large area (100m^2). The masts contained passive flux samplers which were coated with acid to trap the ammonia. This trap was subsequently washed and the ammonium content analysed. Experimental data was used to parameterize a statistical model.

Housing Systems: A comparative assessment of emissions from both slatted sheds and OWPs was undertaken using of direct measurements from acid traps placed at 1 m intervals on each side and roof of the building. In addition, emissions plumes arising from housing sources were simulated using atmospheric dispersion models, which simulate the ammonia plume emitted from the housing system. This plume modeling was undertaken as direct emissions measurements from open out-wintering pads and lagoons were impractical.

4. Main results:

- On average, 54% of total ammoniacal nitrogen (TAN) was lost when slurry was applied by splashplate. However, there was significant variation in emissions depending on the prevailing weather conditions for the first four hours after application, with up to 78% of TAN lost on hot, dry days. However, if application was targeted for cooler periods, particularly during spring, emissions were reduced by over 30%. In addition, dusk application during summer halved emissions with only 24% TAN lost.
- The adoption of trailing shoe technology reduced ammonia emissions by an average of 36%. In addition the range of ammonia emissions across weather conditions was more consistent. However, under low emission conditions, there was no significant difference between application technique.
- Ammonia emissions from slatted sheds were 8 $gNH3\text{-}N\ LU^{-1}\ day^{-1}$. This value is considerably lower than the values (38 $gNH3\text{-}N\ LU^{-1}\ day^{-1}$) used by the EPA in the national ammonia inventories and as such, indicating a substantial overestimation of cattle housing emissions within the inventory. By comparison, OWP emissions were 62 $gNH3\text{-}N\ LU^{-1}\ day^{-1}$ with periods of higher emissions occurring during dry periods. Emissions were substantially reduced (90%) if pads were regularly cleaned. However, OW P's are in general, *not* an effective ammonia abatement technique.

5. Opportunity/Benefit:

This research demonstrates the effectiveness of both changing application technique and timing. In particular, statistical models generated in this study will provide a starting point for the construction of an Application Timing Management System for Ireland. This would allow farmers to reduce emissions without the requirement to adopt more expensive machinery.

In terms of housing, this research indicates that ammonia emissions from slatted cattle housing is towards the low end of European figures and lower than default values derived from UK data. In addition, it was also demonstrated that whilst out-wintering facilities be advantageous in terms of animal welfare, ammonia emissions, expressed on a per head basis were much higher than housing.

6. Dissemination:

The primary stakeholders for this research are both farmers and policy makers.

Main publications:

Dowling, C., Hill, R., Curran, T. & Lanigan, G.J (2010) Ammonia emissions associated with cattle housed on Out-Wintering Pads. Biosystems Engineering (accepted)

Meade, G., Pierce, K., O'Doherty, J.V., Muller, C., Lanigan, GJ and McCabe, T. (2010). Ammonia emissions following land application of high and low nitrogen manures to winter wheat at three growth stages. Agriculture, Ecosystems & Environment (in press).

Dowling, C., Hyde, B., Carton, O., Curran, T. and Lanigan G.J. (2010) Ammonia emissions associated with the landspreading of cattle slurry in Ireland. Atmospheric Environment (submitted).

Dowling, C., Curran, T. and Lanigan G.J. (2008) The effect of application technique and climate conditions on ammonia emissions from cattle slurry. In: 13th Int. RAMIRAN Proceedings, Albena, 4pages ISBN 978- 954–9067671–6–3

Lalor, S. and Lanigan, G. (2010). The potential of application timing management to reduce

ammonia emissions following cattle slurry application. In: 14th Int. RAMIRAN Proceedings, Portugal.

Popular publications:

Dowling, C., Curran, T. and Lanigan G.J. (2009) Reducing Ammonia Emissions. TResearch. 4(1): 40–43

BROADFORM: Shaping and tending of broadleaves

Project number:
5106
Date:
May, 2013
Funding source:
COFORD and Teagasc
Project dates:
Jan 2002 – July 2010

Key external stakeholders:

Farm-forest owners, forestry contractors/consultants, policymakers.

Practical implications for stakeholders:

- Formative shaping can improve the stem form of young broadleaf tree species but the improvement diminishes over time since the operation was conducted as new-growth branches form, leading to the conclusion that shaping needs to be carried out frequently.
  - Will result in greater proportion of stems with good form from which to select potential crop trees later in the rotation.
- Thinning and pruning ash can increase stem diameter annual increment by 50%.
  - Increases the volume of timber produced.
  - Timber properties of ash benefit from fast growth rates.
  - Reduces rotation length.

Main results:

- Formative shaping had no effect on tree height or stem diameter.
- Formative shaping can improve the stem form of young broadleaf tree species but the improvement diminishes over time since the operation was conducted as new-growth branches form, leading to the conclusion that shaping needs to be carried out frequently, possibly biennially.
  - Will result in greater proportion of stems with good form from which to select potential crop trees later in the rotation.
- Thinning of ash, in conjunction with artificial pruning, can increase stem diameter annual increment by approximately 50%.
  - Increase in volume of quality timber produced.
  - Reduced rotation length.

Collaborating Institutions:
None

Teagasc project team:
Dr. Ian Short
Jerry Campion
Mike Bulfin
Toddy Radford

External collaborators:
Enda Cullinane
Kirklands Forestry

Compiled by:
Ian Short

Technology

Opportunity/Benefit:

Farm forest owners of young broadleaf plantations can formatively shape their trees to increase the proportion of high quality stems. Thinning and high pruning of older ash plantations can increase stem diameter and hence volume.

1. Project background:

The area of broadleaf afforestation has substantially increased over the past two decades, mostly through planting on farms. There has been a fear that the management of many sites is neglected after the 4-year grant has been paid (Bacon). Neglect can lead to poor stem form, leading to reduced volume of quality timber and reduced income from timber sales.

2. Questions addressed by the project:

The objective of the BROADFORM project was to develop some silvicultural methods and protocols for the early management of broadleaved plantations, up to and including pre-commercial thinning, for quality hardwood timber production. The project has investigated formative shaping of young broadleaves and pre-commercial thinning, in conjunction with artificial pruning of ash.

3. The experimental studies:

Experiments to assess the effect of formative shaping of ash (*Fraxinus excelsior*), beech (*Fagus sylvatica*) and oak (*Quercus robur*) were initiated in 2003 and monitored until end 2006. Six experimental sites [one ash, two beech, one oak/Scot's pine (*Pinus sylvestris*) mixture and two oak] at four locations. Six treatments were investigated:

1. Control: No shaping done;
2. Yellow: Shape focusing on the tree leader. Remove up to 50% of the foliage as required;
3. Blue: Remove all branches that interfere with the leader to a maximum of 90% of the canopy;
4. Blue Blue: Remove only disproportionately large branches greater than one-third of the diameter of the main stem;
5. Red: Shape only those trees above mean height; and
6. Red Red: Shape only those trees above mean height and with stem form ≤ 3 i.e. equal to or better than category 3.

Not all the treatments were represented at each trial site. Tree height, stem diameter and stem form were assessed.

An experiment was installed into 10-year old ash plantations at two locations in 2003 and monitored until the completion of the project. There were three treatments:

1. Control: Approximately 850 potential crop trees selected per hectare. No thinning and no pruning carried out.
2. 33% thin: Approximately 850 potential crop trees selected per hectare. Thinning carried out as per recommendation in "Growing Broadleaves" publication (i.e. 33% of stems removed). Pruning of potential crop trees as required.
3. 50% thin: Approximately 850 final crop trees selected per hectare. 50% of stems removed. Pruning of potential crop trees as required.

Tree height, stem diameter, stem form, incidence of live defects and height to first prunable defect were assessed.

4. Main results:

- Formative shaping had no effect on tree height or stem diameter.
- Formative shaping can improve the stem form of young broadleaf tree species but the improvement diminishes over time since the operation was conducted as new-growth branches form, leading to the conclusion that shaping needs to be carried out frequently, possibly biennially.
  - Will result in greater proportion of stems with good form from which to select potential crop trees later in the rotation.
- Thinning of ash, in conjunction with artificial pruning, can increase stem diameter annual increment by approximately 50%.
  - Increase in volume of quality timber produced.
  - Reduced rotation length.

5. Opportunity/Benefit:

Teagasc provides advice derived from the project to the forest industry. Formative shaping of broadleaves became a requirement for payment of the Afforestation Maintenance grant.

6. Dissemination:

Formative shaping protocols were produced by the project and disseminated. Formative shaping of broadleaves is a requirement for payment of 4-year grant. A grant is also available for the second formative shaping of broadleaves. The project had input to the formulation of the protocol for the new Tending and Thinning of Broadleaves grant available under the Forest Service Woodland Improvement Scheme.

Numerous very successful and well-attended demonstration days were held which included active participation from the audience. The objective of these demonstration days was to highlight best practice in thinning of broadleaves and provide farm-forest owners and the industry the procedures for selecting and marking potential crop trees and thinnings.

'Tending and Thinning of Broadleaves' National Demonstration days

- 21st April, 2010. Summerhill, Co. Meath.
- 22nd October, 2009. Fourmilehouse, Co. Roscommon.
- 20th May, 2009. The Rower, Inistioge, Co. Kilkenny.
- 17th September, 2008. Moroe, Cappamore, Co. Limerick.
- 9th April, 2008. Crookedwood, Co. Westmeath.

Outdoor presentations

- 30th June, 2010. 'Broadleaf Thinning, Marking and Presentation of Felled Timber'. National Small-Scale Harvesting and Extraction Demonstration Day. Mount St. Joseph's Abbey, Roscrea, Co. Tipperary.
- 11th May, 2010. Farm Forest Management Walk. Mountmellick, Co. Laois.
- 27th May, 2009. 'Broadleaf Thinning and Marking'. National Small-Scale Harvesting and Extraction Demonstration Day. Teagasc Ballyhaise College, Co. Cavan.
- 18th April, 2008. 'Tending and Thinning of Ash'. ITGA/SIF field-day. Teagasc, Johnstown Castle, Co. Wexford.
- 20th June, 2007. 'Ash Tending and Thinning'. Wood Energy Demonstration Day, Stradbally, Co. Laois.
- 6th July, 2007. 'Tending and Thinning of Ash'. Morning session of the ITGA/COFORD/FDA/SIF/ Teagasc field-day. Kilmeague, Co. Kildare.
- Dr Ian Short and Jerry Campion organised the Farm Woodland Forum 2010 Annual Meeting, held at Teagasc Kinsealy, June 21st – 23rd 2010.
- Short, I., Radford, T. and Campion, J. (2010) Broadleaf Thinning and Knowledge Transfer. Presentation at the Farm Woodland Forum Annual Meeting, 21st June 2010, Teagasc Kinsealy.
- Short, I. and Radford, T. (2009). Tending and Thinning of Broadleaves. Invited presentation to the IFA, 18th June 2009.

A new five-year project, co-ordinated by Dr Ian Short and in conjunction with Dr Conor O'Reilly (UCD) has been funded by COFORD which builds upon the work carried out by this project.

Main publications:

Short, I. and Radford, T. (2008) *Silvicultural Guidelines for the Tending and Thinning of Broadleaves*. Teagasc. http://www.teagasc.ie/forestry/docs/research/Teagasc_silvicultural_guidelines_Broadleaves.pdf

Popular publications:

Anon. (2008) 'Tending and Thinning of Broadleaf Forests'. Factsheet No. 15, *Farm Forestry Series*. Teagasc. http://www.teagasc.ie/forestry/docs/technical_info/leaflets/Teagasc_Tending_Thinning_Broadleaves_15.pdf

Anon. (2005) 'Shaping Young Broadleaves for Quality Timber'. Factsheet No. 3 (Revised), *Farm Forestry Series*, Teagasc. http://www.teagasc.ie/forestry/docs/technical_info/leaflets/teagascshaping3.pdf

Short, I., Bulfin, M. and Radford, T. (2006) 'Formative Shaping of Broadleaf Trees'. Today's Farm 17(6): 26. http://www.teagasc.ie/forestry/docs/research/Todays%20Farm%20article,%20Nov_Dec%202006.pdf

Short, I. (2010) 'Tending and Thinning of Broadleaves'. Teagasc Forestry Newsletter, June 2010.

Short, I. (2009) 'The 2-Stick Method for Marking Trees'. http://www.teagasc.ie/forestry/docs/research/Teagasc%202-stick%20method%20tending_thinning_broadleaves.pdf

Project number:
5469
Date:
August, 2013
Funding source:
Teagasc
Project dates:
Jan 2006 – Jan 2013

Improving strawberry 'tray plant' production technology in Ireland

Collaborating Institutions:
UNIVPM, Italy
University College Dublin (UCD)

Teagasc project team:
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Mr. Oliver Sheridan
Mr. Ted Cormican

External collaborators:
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Dr. Alan Hunter, UCD

Compiled by:
Eamonn Kehoe

Key external stakeholders:

Strawberry plant propagators, strawberry producers, commercial horticultural researchers, substrate suppliers, commercial horticulture students.

Practical implications for stakeholders:

- High quality strawberry 'tray plants' can be grown very successfully in both protected cropping and outdoor in Ireland.
- Very high yields of marketable quality can be achieved using these plants.
- Less plant disease risks by using Irish plants.
- Substantial cost savings and added security by growing and using your own 'tray plants'.
- Plant dissection and flower analysis provides a very good indicator of plant quality and future cropping patterns.

Main results:

- 'Elsanta' and 'Sonata' tray plants were grown very successfully both indoors and outdoors. Yields of ≥ 600g per plant were obtained from both cultivars in the first and second year of cropping. Quality parameters were also very good.
- Time of runner harvest is critical with early to mid July being the optimum. Other parameters including runner grade, runner size and substrates used can also influence yield and quality.

Technology

Opportunity/Benefit:

Strawberry growers now have the technology to propagate their own plants. They have less reliance on imported plants where plant disease risks and costs are higher. This information can be accessed by all growers through the Teagasc Horticultural Development Unit. The work can be used as a foundation for future strawberry propagation work.

1. Project background:

The fruit growing season in Ireland has changed fundamentally over the last decade. In the past, the strawberry season lasted from June to July. Today, through new technology the season has been extended from April to November. The strawberry industry has grown by over 190 percent in the last decade and is now worth an estimated €35 million. Unfortunately, the Irish strawberry propagators are limited in their supply of plants for extended season production. There is now a demand for the use of strawberry 'tray' plants in protected strawberry production. Tray plants have gained popularity and have formed an important part of the growing system among growers in the Netherlands, Belgium and in surrounding countries such as France, the UK and Italy.

Tray plants are replacing 'waiting bed' and A+ plants. They offer many advantages over soil grown 'bare root' plants. Runners and cuttings are grown on substrates, reducing the risk of infection by root diseases to a minimum. Plant nutrition can be controlled completely; plants can be more easily lifted during frost and wet conditions and the roots remain intact in comparison to 'bare root' plants. This improves plant storability and establishment after cold storage. Tray plants also produce 10 to 20 percent more large fruits than 'bare root' plants which reduces picking costs substantially.

When the project began, the knowledge in regard to tray plant production technology in Ireland was scarce. Research was undertaken to establish and test a tray plant production system for the Irish strawberry propagators who wished to set up such production. Research was also conducted to better understand strawberry growth and flowering. Strawberry flower induction is sensitive to temperature and photoperiod and to several agronomic and nutritional factors. The aim of this research was also to improve the cultural knowledge and understanding of the physiological control of axillary meristems, which can enhance strawberry fruit production. It may be possible to programme axillary meristems to a particular grower's requirements/part of the growing season.

2. Questions addressed by the project:

- Would it possible to grow high quality strawberry plants (cv. 'Elsanta' & 'Sonata') in Ireland and to produce satisfactory yields and quality from the same?
- What effect would strawberry runner harvest date have on subsequent yield and quality of the plant?
- Would runner grade (size) and runner order have any effect on plant yield and quality?
- Would tray-plant substrate type influence subsequent tray plant quality attributes and or yield and strawberry quality parameters?
- What role does strawberry plant dissection and architecture analysis serve for a tray-plant producer? And is this information of use for the final strawberry producer?

3. The experimental studies:

All strawberry runners' cv. 'Elsanta' and 'Sonata' were grown from 'super elite' stock planted in unheated glasshouses. Runner tips were harvested from these mother plants and planted into peat modules and grown in a glasshouse. Runner tips were harvested on different dates in July and early August. On one occasion they were graded into three different grades, small, medium and large and in other experiments they were graded according to primary, secondary and tertiary runner order. Different substrates were also used in the propagation of the tray plants including a number of peat grades, composted green waste (CGW) and cocoa peat (coir). Measurements of plant crown size and root biomass were conducted.

Plants were grown both in an unheated glasshouse and outside in beds. Nutrition was carefully controlled. Strawberry tray plant crowns were dissected throughout the growing season. The flowering stage of the primary flower in the main crown and in lateral crowns was determined using a stereo microscope. A photographic chart showing the nine stages of strawberry flower development was used to aid this work. A total plant flower count was also conducted as part of the dissection. When the plants were finally harvested they were placed into cold store. They were subsequently planted as per industry norms at a final density of 10 plants per m^2.

4. Main results:

- Tray plants were grown very successfully both inside and outside. There were very few plant deaths. Crown size diameters of between 15 and 19 mm were obtained.
- Total yields of 12.73 kg/m^2 and 13.2 kg/m^2 were obtained with cv. 'Elsanta' and 'Sonata' respectively. 'Sonata' also had a significantly higher score for marketable quality.
- During runner production the mean total number of primary, secondary, tertiary and quaternary runner cuttings from 'Elsanta' and 'Sonata' were 31 and 38 per plant respectively. The time of runner harvest had a significant effect on the subsequent yield of the tray plant. Early July is the optimum time to harvest and plant runners. This is to maximise crown diameter, initiated flower number and development stage together with leaf number and crop yield.
- Runner size (grade) has a significant effect on fruit yield and quality parameters. Average fruit yield was highest where larger runners were used for propagation earlier. Yield reduced significantly for those harvested later in the season (19th July).
- When fruit yield was assessed, there was no significant difference effect between primary, secondary or tertiary runners which were planted for rooting at the three different dates.
- As regards peat substrate (coarse & fine) this has no effect on the yield and quality in the early runner harvest date. However, the yield and quality parameters of the large runner grade were highest when this was propagated using the finer peat substrate later in the season (19th July).
- Primary runner plants propagated in 100% peat, a 1:1 cocoa peat (coir)-peat mix and a 1:1 composted green waste (CGW)-peat mix gave the highest yields and marketable quality. Crown diameters were also highest in these treatments.
- Highest root dry weight was obtained from plants propagated in peat or a 1:1 peat cocoa-peat (coir) mix.
- Strawberry crown dissection resulted in a very clear picture of the various stages of flower formation that the plant goes through. This could be used as a method to further determine plant flower quality characteristics throughout the whole growing cycle in the nursery. Using strawberry flower 'architecture analysis' can help further in the development of specific flower quality attributes which are demanded now by the industry.

5. Opportunity/Benefit:

The primary stakeholders for this research are the Irish strawberry producers and the Irish strawberry plant propagators. Propagators now have a dedicated protocol for the production of their own 'high quality' plants. The fruit yields and quality produced in these trials were excellent and were equal to or better than those seen in more advantageous climates. Some propagators have already invested heavily to produce plants for their own use, for the Irish market and perhaps for export in the future.

A number of propagators have recently started to propagate their own plants based on this Teagasc research and are also achieving excellent results e.g.≥ 600g/plant. All of this means less reliance on imports where plant disease risks are higher. This is a low risk country as regards plant disease. This is a major advantage in regard to intensively grown plants. There is also added security in producing your own plants as well as a substantial cost saving in doing do.

6. Dissemination:

The results of this research have been presented at both Teagasc (http://www.teagasc.ie/publications) and International conferences including the COST 863 'Euroberry' group (www.euroberry.it). The results were also presented in Beijing, China. Growers have also visited the facility at Teagasc Kinsealy and further advice is given through the advisory-research service. Results have also been reported through some national and international media channels.

Main publications:

Beyene, G.T., Kehoe, E., Hunter, A. and MacSiúrtain, M. (2012). Effect of Different Substrates on Rooting and Flower Development of Primary and Tertiary Runners of Strawberry tray-plants cv. 'Elsanta'. Proceedings of the 7th International Strawberry Symposium, Beijing, Peoples Republic of China. 18–22 February, 2012. (In print)

Beyene, G.T., Kehoe, E., Hunter, A. and MacSiúrtain, M. (2010). Effect of Different Transplanting Dates and Runner Types on Quality and Yield of 'Elsanta' strawberry. 28th International Horticultural Congress on Science and Horticulture for People (IHC2010). International Symposium on Berries: From Genomics to Sustainable Production, Quality and Health. *Acta Horticulturae*, 926: 483–489.

Kehoe, E., Savini, G. and Neri, D. (2009). The Effects of Runner Grade, Harvest Date and Peat Growing Media on Strawberry Tray Plant Fruit Production. Proceedings of the 6th International Strawberry Symposium. *Acta Horticulturae*, 842: 699–702.

Popular publications:

Kehoe, E. (2007) Designing the perfect strawberry plant. T-Research.2 (2) 28–29.

Kehoe, E. (2010) Designing the perfect strawberry plant. T-Research 5 (2) 22–23.

Kehoe, E. (2006–2012). Proceedings of the Teagasc National Soft Fruit Conference and Trade Show. www.teagasc.ie/publications

Thesis:

Beyene, G.T. (2012). Improving Strawberry Module Plant Production Technology in Ireland. Ph.D. Thesis. University College Dublin. 226pp.

Project number:
6355
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June, 2013
Funding source:
Teagasc
Project dates:
Dec 2012 – Jun 2013

Spent mushroom compost – nutrient content for application to agricultural crops

Teagasc project team:
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Key external stakeholders:

Policy makers, advisors, farmers, composters.

Practical implications for stakeholders:

Spent mushroom compost (SMC) is a valuable source of major and minor nutrients as well as organic matter. Over the last decade, the composting process has changed and higher mushroom yields are now harvested from the compost compared to previously, resulting in lower phosphorus (P) levels in spent mushroom compost.

In 2011 and 2012, Teagasc analysed a number of SMC samples taken from a large random sample of commercial mushroom units. The results indicate (Table 1) that the P content is lower when compared to the previous study by Maher in 2003. The characteristics of mushroom compost and SMC have changed over time with lower levels of P due in part to lower P usage and high crop yields. These more recent analyses will help improve nutrient management planning on farms where SMC is applied to replace alternative sources of N, P and K for crop requirements.

The P content of SMC as stated in The Good Agricultural Practice (Nitrates) regulations (SI 610/2010) is higher than the average P levels in SMC currently being land spread. In practice, the producer of the compost is generally not the end user of the SMC, which is mostly utilised as a fertiliser NPK source on livestock and tillage farms. If the average P value for SMC is taken to be what is currently stated in the Nitrates regulations, then it will result in under supplying the P requirement of crops where SMC is applied as a replacement for chemical fertilisers.

Main results:

This study indicates that the N content in SMC is still similar to the previous study in 2003. The P levels have declined from 2.5 kg P/tonne in 2003 to 1.45kg P/tonne in 2012. Results also indicate that the K levels are more variable, which is in agreement with previous SMC studies.

Technology

Opportunity/Benefit:

Changes in modern composting techniques, and higher crop yields at harvest time, have resulted in lower P levels in SMC. SMC is a good source of several key nutrients and can effectively replace expensive fertilisers. The P content as determined in recent studies over the last 5 years is a more precise measure of the actual P value of SMC, which will improve its use as a replacement for artificial fertiliser in grass and tillage crops. These updated analyses of SMC will ensure that nutrient management plans deliver better nutrient advice where SMC is used to supply crop N, P and K requirements.

1. Project background:

Spent mushroom compost (SMC) is a valuable source of major and minor nutrients and organic matter when applied to crops. Over the last decade several changes have occurred that impact on the characteristics of SMC. Firstly, less poultry manure is added to mushroom compost to reduce odour during the composting process, thereby further reducing the phosphorus (P) content in compost. Secondly, higher mushroom yields (+10%) are now harvested from mushroom compost compared to previously. Consequently, the P content of typical SMC may have decreased over time. As a result, the average P content as stated in The Good Agricultural Practice (Nitrates) regulations may over-estimate the actual P content that is present in the SMC as a fertiliser source when applied to land. In practice, the producer of the mushroom compost is generally not the end user of the SMC. If the average P values for SMC are taken as what is stated in the Nitrates Regulations, this could result in under-supplying the crops requirement for P where SMC is used to replace chemical fertilisers.

2. Questions addressed by the project:

Has the level of P and other nutrients in SMC declined in recent years due to changes in compost ingredients and practices and higher mushroom yields?

3. The experimental studies:

Fresh spent mushroom compost samples were taken nationally from 23 randomly selected farms in 2011 and 20 farms in 2012. Sampling times (December) were the same on each occasion. Each sample consisted of 7 to 10 core samples taken at random from different shelves in each house and mixed together. The mixed bulk sample was then sub sampled and placed in a clean plastic bag and labeled. Each sample was approximately 1 kg in weight. Samples were analysed for dry matter (DM) and total content of nitrogen (N), P, potassium (K), calcium (Ca), magnesium (Mg), sulphur (S) and organic matter (OM). The data were statistically tested by analysis of variance (ANOVA), using SAS statistical software, and the results of the 2011 and 2012 surveys were compared to results from analysis of 20 SMC samples taken in 2003 (Maher, 2003).

4. Main results:

The results (mean and standard deviations) of the laboratory and statistical analysis of the samples taken in 2003, 2011 and 2012 are shown in Table 1. There were statistical differences between years in DM, N, P, K, and Ca. In the case of N, the mean content from 2011 samples was significantly lower than 2003 and 2012. There has been a significant trend of decreasing K content. However, the standard deviation of the mean is high in the case of K, indicating a high variability in the material in terms of K content.

Table 1. Laboratory analysis of mean dry matter, nutrient, and organic matter concentrations in SMC samples. (Standard deviations of the mean values are shown in parenthesis. Letters in superscript indicate years with statistically significant differences in concentration).

Year	n	DM (%)	N (kg/t fresh)	P (kg/t fresh)	K (kg/t fresh)	Ca (kg/t fresh)	Mg (kg/t fresh)	S (kg/t fresh)
2003	20	33 (2.4)[a]	8.0 (0.92)[a]	2.5 (0.39)[a]	9.7 (1.68)[a]	Not analysed		
2011	23	35 (5.3)[b]	5.9 (1.38)[b]	1.3 (0.30)[b]	7.9 (3.04)[b]	21 (6.5)[a]	2.2 (0.64)	6.8 (1.55)
2012	20	36 (5.1)[b]	8.6 (1.40)[a]	1.5 (0.35)[b]	5.4 (2.18)[c]	13 (3.1)[b]	1.9 (0.39)	6.3 (1.59)
Effect of Year[1]		*	***	***	***	***	NS	NS
SI 610 of 2010			8.0	2.5				
2007/2009[2]			6.9 – 7.4	1.86 – 1.98	6.6 – 8.4			

[1] Significant differences between years are indicated as: * = < 0.05; ** = < 0.01; and *** = < 0.001
[2] Results for outdoor stored SMC (up to 12 months old) from Velusami (2013)

The largest difference between years was found with P content, with the samples in 2011 and 2012 being 1.3 and 1.5 kg/t, respectively, compared with 2.5 kg/t in 2003. This represents a significant decrease in P content of over 40% since 2003, as was expected due to changes in compost manufacture and mushroom production practices. These results indicate that the current value of P content, assumed in the Nitrates regulations, over-estimates the actual P content in SMC.

Analysis of Ca, Mg and S were not available for the 2003 samples. There was a significant difference between 2011 and 2012 in the case of Ca, but there was no significant difference in Mg or S contents.

The results of these surveys are in agreement with analysis of other samples of SMC following outdoor storage, taken between 2007 and 2009, in a study by Velusami (2013) (Table 1). In that study, the N and K contents measured were in the range of 6.9–7.4 kg/t for N, and 6.6–8.4 kg/t for K. The P content ranged from 1.9–2.0 kg/t which is intermediate between the 2003 data and the 2011/2012 data.

5. Opportunity/Benefit:

1. The nutrient content of all organic manures, including SMC, is variable. The mean P content of SMC in 2011 and 2012 is lower than the average values reported by Maher (2003) as shown in Table 1. Under the current Nitrates regulations, the P value of SMC is assumed as 2.5 kg P/t. This study indicates that the nutrient value of SMC from modern mushroom units has declined to 1.3–1.5 kg/t of P, due to modern composting and production techniques, resulting in an overall reduction in the level of P in spent mushroom compost as a consequence.
2. The lower mean P content of SMC detected in recent surveys provide a better, more accurate, estimate of the actual nutrient content of SMC and will ensure more precise fertiliser planning where SMC is used to replace artificial fertilisers in crop production.

6. Dissemination:

All Ireland Mushroom conference, Monaghan, 20th October, 2011 http://www.teagasc.ie/publications/2011/1056/index.asp

Teagasc Mushroom Newsletter, April, 2012 http://www.teagasc.ie/publications/2012/1166/Mushroom_April12.pdf

Main publications:

Maher, M.J., Magette, W.L., Smyth. S., Duggan, J., Dodd, V.A., Hennerty, M.J. and McCabe, T. (2000). Managing spent mushroom compost,Teagasc End of Project Report No. 4444. http://www.teagasc.ie/research/reports/horticulture/4444/eopr4444.pdf

Maher, M.J (2003). The Challenge Ahead. All-Ireland Mushroom Conference& Trade Show, Hillgrove Hotal Monaghan, Thursday 16th October, 2003.

Velusami, B. (2013). Stored Spent Mushroom Compost- Measurement of Hydrogen Sulphide Emissions and Material Characteristics. PhD thesis, School of Biosystems Engineering, UCD. Dublin 4 (submitted).

Popular publications:

Making best use of spent mushroom compost, Teagasc factsheet (Teagasc T NET, 2013), Tillage Specialist Unit.

Rural Economy & Development Programme

Rural Economy and Development Programme Modelling the economics of forestry in Ireland (FIRMEC)

Project number:
5698
Date:
December, 2012
Funding source:
COFORD, DAFM
Project dates:
Jan 2008 – Dec 2012

Key external stakeholders:

Forest Service, Department of Agriculture, Food and the Marine, Farmers interested in planting forests, other land-owners seeking to invest in forestry.

Practical implications for stakeholders:

Forestry has the potential to meet many of the goals of National and EU policies for sustainable rural development.

- Many Irish farmers would benefit financially from planting some land with commercial forestry – cattle farmers would benefit most.
- Larger farms and those in less-intensive farm systems were more likely to enter into forestry during the period 1995–2009.
- A comprehensive valuation tool for forestry in Ireland was developed as part of this project.
- A negative attitude towards forestry still exists amongst some farmers and may be a barrier to planting.
- Soil quality plays an important role in the economics of land-conversion.
- Land availability is likely to be an important factor in reaching afforestation goals.
- The Irish public value forest recreation and other non-market forest benefits and travel cost valuation methods offer a way to capture this value.

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Compiled by:
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Technology

Main results:

The MS Excel based Forest Investment and Valuation Estimator (FIVE) is the most comprehensive forest valuation tool developed for Ireland. Using the FIVE it is shown that forestry is a financially competitive land-use option for many farmers in Ireland. Farmer's willingness to plant and the barriers to planting were investigated using a number of surveys. A number of policy and farm related drivers are identified but a negative attitude towards forestry still exists amongst some farmers. A spatial model of land-conversion to forestry was developed which identifies the most important drivers of land-use change and has the potential to identify where future change will occur. In addition, forest non-market benefits are reviewed and recreation visits are valued employing a travel cost study.

Opportunity/Benefit:

The FIVE offers the best available forest valuation tool in Ireland and is employed by Teagasc forestry advisors and private sector foresters when interacting with farmers. This facilitates the detailed measurement of the financial implications of converting agricultural land to forestry. Future demands for advisory services can be identified with the spatial afforestation model. The results of the project have been outlined in a number of peer-reviewed and published academic papers and working papers.

1. Project background:

Farmers have undertaken 90% of afforestation in the last 20 years and are identified as the primary source of planting in the future. Converting agricultural land to forestry can result in an increase in non-market benefits, in addition to being financially beneficial to land-owners, and is thus viewed as contributing to sustainable rural development. The financial implications of planting depend on a number of factors and although it has been recognised that forestry may be a competitive land-use option for farmers, there has been a lack of detailed research in the area. This study sought to investigate the economic impacts of converting agricultural land to forestry in Ireland, both from farmer and societal perspectives.

2. Questions addressed by the project:

Although previous research has been conducted on the economics of forestry in Ireland, a question still existed as to which farmers would benefit from planting land and by how much. This is of particular importance to advisors who must describe the implications of planting. In addition, although forests are well recognised as being providers of non-market benefits, there has been limited research into valuing such benefits in Ireland. Thus the project sought to answer:

- Why do farmers plant or not plant forests?
- What are the financial implications of planting?
- How should we measure this?
- What type of farmers plant and who would benefit most?
- What are the broader implications of planting for farmers and the state?
- What are the physical and policy factors driving afforestation?
- How do we value the non-market benefits of forests?

3. The experimental studies:

National Farm Survey data were employed to analyse farmer characteristics that influence planting and a supplementary survey was conducted to investigate farmers' plans to plant and the barriers to planting.

The FIVE was developed by building on a simple 'Visual Basic for Applications' in MS Excel. Timber predictions are based on UK Forestry Commission Yield models (Edwards and Christie, 1981) and a range of timber pricing options are available.

A regional survey of farmers was conducted that sought to examine farmers views on planting forestry in more detail. The survey included farmers with and without forests.

A national household survey of public attitudes towards the non-market benefit of forests was conducted which included a representative sample of the general population.

Existing spatial data were combined to generate a panel dataset of afforestation at the Electoral Division (ED) level. These data were analysed using spatial econometric techniques.

Forest recreation travel cost data were collected in face-to-face interviews in Renville forest park in Co. Galway and a range of analysis techniques were employed to identify the consumer surplus of a recreational trip.

4. Main results:

Forestry is recognised as a land-use that can deliver many of the goals of sustainable rural development by diversifying farm outputs and the local economy. Accounting for the opportunity cost of land conversion from a range of agricultural enterprises (spring barley, winter wheat, lowland sheep and store to finish beef) the net present value (NPV) of Sitka spruce, ash or mixed plantations were found to be positive in all situations except where ash replaces winter wheat or lowland sheep. From a financial perspective, the greatest gains can be made by replacing a store to finish beef enterprise with Sitka spruce, which results in an NPV of €6,156.

General farmer motivation can affect the probability of a farmer planting or not. Farmers who possess a strong productivist farming motivation were found to be less likely to establish forests. Of the main reasons given by farmers for not planting, the most common response was "need my land for agriculture". Concern was also expressed about the permanent nature of forestry and the potential to lower the value of land. Farmers involved in livestock production and those with a lower stocking rate were found to be more likely to have land in forestry. In addition, this research would suggest that the presence of children and perhaps successors on a farm influenced the probability of planting. The number of farmers with plans to plant forestry are generally low (3% in 2006 and 3.5% in 2008).

Forests also provide important non-market benefits, including enhancing carbon sequestration and recreation and the public identify forests as an important part of the landscape. Being closer to forests, having children and having a third level education were found to increase the likelihood of visiting forests. This study identifies the consumer surplus of a recreation trip to Renville forest park as €1.48, and an estimation of 89,974 visitors per annum.

Soil and other physical land characteristics play an important role in land-use change to forestry. Results from the spatial afforestation model suggest that land-availability will be an important factor in determining whether afforestation targets will be met, particularly if extensive farming enterprises become more profitable or environmental restrictions are increased.

5. Opportunity/Benefit:

The FIVE is the most useful forest valuation tool available for Irish conditions making it of interest to any individual or institution interested in forest investment. The results of the financial study offer greater confidence to land-owners and both Teagasc and private sector advisers that forestry is a competitive land-use. This study highlights the type of farmer likely to benefit financially from converting some land to forestry as well as assessing the characteristics of farmers most likely to plant. In addition, the results of this study highlight the non-market benefits of forests in Ireland.

6. Dissemination:

Dissemination took the form of a number of conference presentations and publications in peer-reviewed journals and the popular press. In addition, a forest economics workshop was organised in 2008, which included the project participants, researchers and policy-makers. The FIVE is used by forestry advisers in financial clinics to assess the financial returns from different planting and thinning scenarios for prospective and existing farm forest owners.

Conference Presentations:

Breen, J and Ryan, M. (2008) 'Situation and Outlook for Forestry 2008/09'. Presented at the annual Teagasc Situation and Outlook in Agriculture Conference in Tullamore, Dec 9, 2008.

Breen, J., Ryan, M., Donnellan, T. and Hanrahan, K. (2009) 'Measuring the Impact of Policy on Farm Afforestation Rates: An Irish Case Study' presented at the British Agricultural Economics Society Annual Conference, Dublin, March 31 – April 1 2009

Breen, J., Clancy, D., Ryan, M., Wallace, M. (2010) 'Evaluating the Irish Farm Afforestation Decision: A Discounted Cash Flow Analysis'. Paper presented at the 84th Annual Conference of the Agricultural Economics Society Edinburgh, Scotland 29th March to 31st March 2010.

Cullinan, J., Hynes, S. and O'Donoghue, C. (2008). 'Using Spatial Microsimulation to Estimate Aggregate Consumer Surplus Values in Travel Cost Modelling'. Presented at the 16th Annual meeting of the European Association of Environmental and Natural Resource Economists in Gothenburg, Sweden (June 25th to 28th).

Howley, P., Hynes S., Ryan, M. and Farrelly, N. (2010). 'Afforestation in Ireland: An examination of farm structural factors affecting participation in farm forestry'. Paper presented at Agricultural Economics Society of Ireland.

Ryan, M. (2011) 'Situation and Outlook for Forestry 2010/2011'. Paper presented at the annual Teagasc Situation and Outlook in Agriculture Conference in Portlaoise, Jan 2011.

Upton, V., O' Donoghue, C., Ryan, M. (2012) 'A spatial model of afforestation in Ireland'. Presented at the Agricultural Economics Society of Ireland Annual Conference, 18th October 2012.

Main publications:

Cullinan, J., Hynes, S. and O' Donoghue, C. (2008) 'Estimating Catchment Area Population Indicators for Outdoor Recreation Sites in Ireland' *Irish Geography* 41 (3): 279 – 294.

Breen, J., Clancy, D., Ryan, M., Wallace, M. (2010). 'Irish land use change and the decision to afforest: an economic analysis' *Irish Forestry* 67, Nos. 1&2

Breen, J., Ryan, M., Donnellan, T. and Hanrahan, K. (2008) 'Projecting Future Irish Farm Afforestation' 'Figures for Forests' Workshop Published conference proceedings – Nov 2008, Freiburg Germany.

Howley, P., Hynes, S., O' Donoghue, C., Ryan, M. and Farrelly, N. (2012) Farm and farmer characteristics affecting the decision to plant in Ireland. Irish Forestry volume 69, Nos. 1&2 : 33–43

Howley, P., Ryan, M. and O Donoghue, C. (2011) 'Forestry in Ireland: An examination of individuals' attitudes and preferences towards the non-market benefits of forests'. *Irish Geography* 44 (2):291 – 302

Popular publications:

COFORD Connects 2010: Modelling the economics of forestry in Ireland – the returns to farm forestry.

'Positive findings in Farm Survey'. Irish Farmers Journal in February 2009

'Sharp Rise in Felling Licences Reflects Increased Private Thinnings'. Irish Timber and Forestry in March/April 2009.

'Planting trees – good for farmers, good for rural Ireland!' Irish Timber and Forestry. No. 4, 2009.

'Demand for forestry planting grants exceeds supply' Irish Farmers Journal, February 10, 2010.

'Dramatic surge in farmer demand for planting' Irish Timber and Forestry. No.1, 2010.

'Outlook for forestry – 2011' Irish Farmers Journal. February 2011

Analysis of the competitiveness of Irish dairy farming

Project number:
6131
Date:
March, 2012
Funding source:
Allied Irish Bank
Project dates:
Nov 2010 – Jun 2011

Key external stakeholders:

Dairy farmers, milk processors, policy makers.

Practical implications for stakeholders:

This study examines the competitiveness of the Irish milk sector at farm level compared to that of a number of EU and non-EU countries.

Main results:

This study has found that the competitive position of the Irish dairy sector at farm level remains favourable in cash costs terms. However, when full economic costs are considered, the competitive position of the current average size Irish dairy farm is likely to become an increasing cause for concern.

Opportunity/Benefit:

This study will be of benefit to farmers, dairy processors and policy makers interested in planning for milk production in Ireland in the era after milk quota removal.

1. Project background:

World trade in dairy products remains a small share of global production. Global dairy trade continues to grow, but the EU's share of that trade is in decline.

The gap between world and EU dairy prices has been closing over time due to changes in EU policy and rising world prices. As a result, world (New Zealand) milk prices are converging on EU and US milk prices. Several EU member states have a growing gap between their milk production and their milk quota. The elimination of milk quotas is unlikely to bring about a sizeable increase in EU milk production.

Collaborating Institutions:
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External collaborators:
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The researchers would like to acknowledge the advisory committee which was involved in the study

Compiled by:
Trevor Donnellan

Technology

The increase in average US and NZ farm size is much greater than in Ireland. Ireland still has few herds of over 100 cows. In NZ, the proportion of herds of less than 200 cows has declined considerably, as the proportion of larger herds increases. In the US, the proportion of herds of over 2,000 cows has increased considerably. Milk prices and input prices have exhibited considerable volatility in recent years with fertiliser prices exhibiting greater volatility than feed.

In this context the assessment of the international competitiveness of the Irish dairy sector at farm level is warranted.

2. Questions addressed by the project:

The study asked:

- What is the current international competitive position of the Irish dairy sector at farm level in both an EU and global context?
- What would be the implications for future competitiveness of the Irish dairy sector under scenarios involving changes in milk and input prices?

3. The experimental studies:

Costs were measured on a total cash costs and total economic cost basis.

For the dairy sector in countries of the EU the Farm Accountancy Data Network (FADN) was the primary source of data used in this analysis. Derived from national surveys, the FADN is the only source of micro-economic data that is harmonised, i.e. the bookkeeping principles are the same in all the countries.

For the dairy sector in countries outside the EU data was obtained from the International Farm Comparison Network (IFCN). The IFCN network is a world-wide partnership that links agricultural researchers, advisors and farmers to create a better understanding of the costs and returns of agricultural production worldwide. The cost calculations within the IFCN network are based on individual representative farms, rather than on the results from stratified random samples of the population as is the case with FADN data. Nonetheless, IFCN provides a data source which can be used to examine the relative competitiveness of 'representative' Irish milk producers in a global context. IFCN data is assembled and analysed using a common methodological framework. Like the methods outlined previously for FADN data, IFCN data also presents costs as total 'cash' costs, which consists of expenses from the profit and loss account and total 'economic' costs with opportunity costs calculated for farm-owned factors of production (family labour, own land, own capital).

4. Main results:

The results of this study indicate that the competitive position of the Irish dairy sector in an EU15 context has been relatively unchanged over the last five years. On a cash cost basis the sector compares favourably with its main competitors in the EU. However, consideration of imputed costs allow for an evaluation of competitiveness based on total economic costs. In this context the Irish dairy sector would appear to be at about the average among the competitor EU15 Member States dairy sectors examined.

While the Irish dairy sector has low cash costs of production, it is also characterised by relatively low productivity in terms of labour, milk yields and constituents. Land costs, as measured by land rental values are high in Ireland and are a key reason why the competitive position of the Irish dairy sector is less favourable on a total economic cost basis.

Taking Eastern Europe and countries outside the EU into consideration, the position in relation to cash costs is similar to that identified within the EU15, with Ireland appearing as a relatively competitive dairy producer. On a total economic cost basis, the average size Irish dairy farm in contrast had costs well in excess of some of the major dairy exporting regions of the world. However, the relative competitiveness of the larger size Irish dairy farm was more positive on a total economic cost basis. While the larger size Irish dairy farm may not have the lowest economic costs in the world, a considerable proportion of the typical farms examined internationally had economic costs well in excess of the Irish farms examined.

In conclusion, as Irish dairy farming transforms to larger scale production in a no quota situation, the competitive position of Irish dairy farms will be strengthened and better able to cope with a cost/price squeeze in the future.

5. Opportunity/Benefit:

Stakeholders who would benefit from examining this study include dairy farmers, dairy processors and policy makers interested in planning for milk production in Ireland in the era after milk quota removal.

6. Dissemination:

The results of the study were presented to stakeholders at a launch which took place at AIB Bank Centre, Dublin on 23rd July 2011.

Main publications:

Donnellan T., Hennessy, T., Keane, M. and Thorne, F.S. (2012) *Competitiveness of the dairy sector at farm level in the EU.* Grassland Science in Europe 17: 679–692

Donnellan T., Hennessy, T., Keane, M. and Thorne, F.S. (2011) 'Study of the International Competitiveness of the Irish Dairy Sector at Farm Level'. *Rural Economy Research Centre Teagasc.*

Popular publications:

Keeping an Eye on the Competition, Agri Matters. Allied Irish Banks, August, 2011 http://www.aib.ie/business/business-banking/agri/agri-matters/agri-matters-spring-2011-welcome [accessed 5th March 2012]

Rural Economy & Development Programme

Project number:
5626
Date:
December, 2010
Funding source:
Teagasc
Project dates:
Jan 2007 – Dec 2009

An economic analysis of the financial performance of dairy and cereal farms in Ireland

Collaborating Institutions:
Trinity College Dublin (TCD)
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Dr. James Breen, UCD
Mr. Larry Harte UCD

Industrial collaborators:
Advisory specialist staff
DAFF officials
Industry representatives

Compiled by:
Fiona Thorne

Key external stakeholders:

Dairy and tillage farmers, dairy and tillage industry, farm bodies, national government, policy makers.

Practical implications for stakeholders:

- The evolution of costs, returns and margins on dairy and tillage farms were examined.
- New methods, both public and private risk management tools, will be needed in the future on dairy and tillage farms in an effort to manage risk at the farm level.
- Production cost variation is affected by many things other than farm size.
- The importance of the scale of operations proved to be of particular interest on tillage farms, with larger and more specialised farms being more efficient.

Main results:

- The evolution of costs, returns and margins, on dairy and tillage farms were examined.
- Substantial price volatility was experienced by dairy and crop farms between 2007 and 2009. New methods, both public and private risk management tools, will need to be considered in an effort to manage this volatility in the future.
- Based on NFS data for 2006, only 9 percent of the variation in production costs on dairy farms was accounted for by farm size, so it can be concluded that it is not the most important driver of cost efficiency on dairy farms.
- The importance of the scale of operations proved to be of particular interest on tillage farms. The analysis showed that increasing returns to scale are present in the tillage sector. This result shows that larger farms are more efficient. The degree of specialisation will also be an important issue for the competitive future of Irish cereal farming. Higher levels of specialisation lead to higher efficiency levels in the tillage sector.

Technology

Opportunity/Benefit:

The results from this research provide the economic data necessary to make informed decisions by key stakeholders. The specific benefits of the micro data analyses are measures of the effect of a proposed policy or market development on the following factors:

- the viability and economic sustainability of farm households.
- farm production plans.
- farm incomes.
- changes in the farming population, in terms of the effect on entry to and exit from the farming sector.

1. Project background:

When output prices are declining and input prices increasing efficiency gains are the key to survival. The European policy agreements of the last number of years have resulted in a downward trend in output prices for the main commodities. Simultaneously, market based factors and policy developments have had a strong impact on volatility of input and output prices. The aforementioned factors have resulted in significant pressure on farmers to reduce costs and/or become more productive if they are to remain profitable.

Research has been on-going in Teagasc for many years on the cost efficiency of farmers based on NFS data. This project provides an understanding of the main determinants of the profitability of farms so as to better prepare farmers and other agricultural stakeholders for future policy and market developments. The core objective of this project was to provide farmers and farm advisors with more information so as to plan more effectively for the future and thus to ensure the long-term viability of agriculture in Ireland, a key Teagasc and national priority.

2. Questions addressed by the project:

Use of National Farm Survey data to examine the financial performance of dairy and crop farms in Ireland.

3. The experimental studies:

The research project was broken into five principal phases:

- Each year on publication of the NFS results the costs of production on dairy and cereal farms were reviewed and key technical performance indicators were developed.
- Based on NFS data an appraisal of the financial performance of the farms in both sectors was conducted, i.e., number of viable farms and so forth.
- Short-term estimates of the outlook for dairy and cereal production were produced.
- The cost and revenue structure of different enterprises were studied in order to establish the major determinants of enterprise profitability with a view to identifying ways of increasing profitability.
- The results of the enterprise analysis were disseminated to Teagasc advisory representatives and other research centres so that the performance of individual farms and experiment farms could be compared to national averages.

4. Main results:

- Costs of production and financial performance indicators for dairy and crop farms for 2007, 2008 and 2009 were reviewed. Dairy farms continue to have the highest net margin per hectare across all farm types.
- The importance of volatility in agricultural markets was highlighted by the results of the annual situation and outlook for dairy and crops from 2007 to 2009. Substantial price volatility was experienced by dairy and crop farms between 2007 and 2009. This volatility can be expected to be a major characteristic of commodity markets in the future due to the fundamental behaviour of buyers coupled with production uncertainty. Recent policy changes, in relation to price support, export refunds and import quotas, have resulted in European farmers being more exposed to movements in world prices. The incorporation of stochastic forecasts for price in the annual outlook for crops was an important methodological development

of this project.

- In terms of understanding the factors affecting performance on dairy farms, the research has shown that a statistically significant negative relationship exists between production costs and farm size but that this relationship is non-linear. This means that as farm size increases production costs decline but at a declining rate. Based on NFS data for 2006 only 9 percent of the variation in production costs was accounted for by farm size, so it can be concluded that it is not the only important driver of cost efficiency.
- In terms of understanding the factors affecting productivity on crop farms, the results from the analysis have shown that technical efficiency was positively correlated with extension use, soil quality, the overall size of the farm, and the level of specialisation. The importance of the scale of operations is of particular interest. The analysis showed that increasing returns to scale are present in the tillage sector. This result shows that larger farms are more efficient. The degree of specialisation will also be an important issue for the competitive future of Irish cereal farming. Higher levels of specialisation lead to higher efficiency levels in the tillage sector.

5. Opportunity/Benefit:

The expected benefits of this project are as follows:

1. Facilitation of informed decision making at farm level. The analysis of the annual situation and outlook for Irish farming using a representative farm approach which reflects the levels of technical efficiency at farm level provides information that facilitates economically rational production decisions.
2. Understanding of the key determinants of farm profitability.
3. Facilitate informed decision making by policy makers and stakeholders.
4. To facilitate other Teagasc staff in the dissemination of timely reporting on the situation and outlook for Irish crop and dairy farms.

6. Dissemination:

Main publications:

Hennessy, T., Donnellan, T. and Smyth, P. (2007). The Situation and Outlook for the Dairy Sector. In: Teagasc Situation and Outlook Conference, Tullamore.

Hennessy, T., Donnellan, T. and Smyth, P. (2008). The Situation and Outlook for the Dairy Sector. In: Teagasc Situation and Outlook Conference, Tullamore.

Donnellan, T. and Smyth, P. (2009). The Situation and Outlook for the Dairy Sector. In: Teagasc Situation and Outlook Conference, Portlaoise.

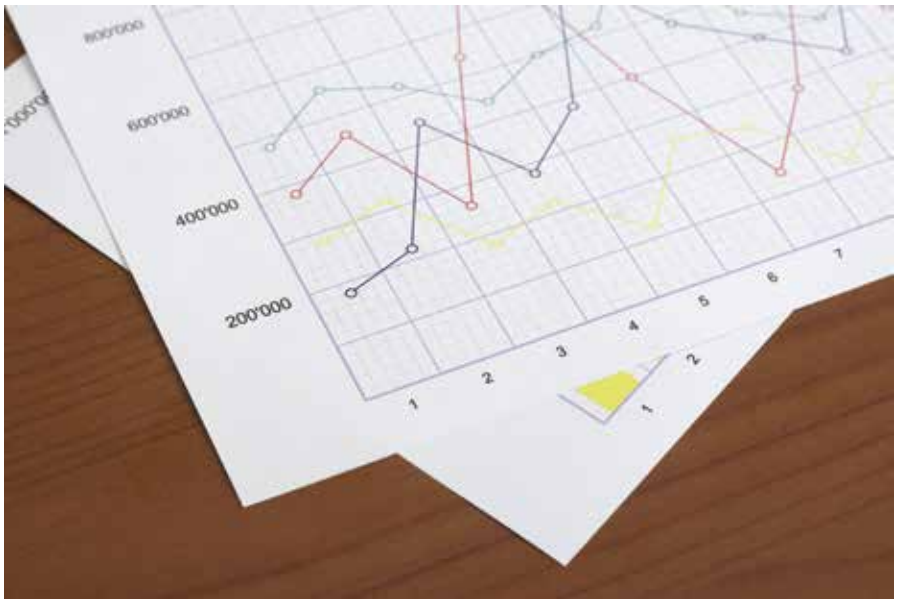
Breen, J., and Thorne, F. (2007) The Situation and Outlook for Crops. In: Teagasc Situation and Outlook Conference, Tullamore.

Thorne, F. (2008) The Situation and Outlook for Crops. In: Teagasc Situation and Outlook Conference, Tullamore.

Breen, J., Clancy, D., and Thorne, F. (2009) The Situation and Outlook for Crops, In: Teagasc Situation and Outlook Conference, Portlaoise.

Smyth, P. and Hennessy, T. (2009). Explaining the variability in the economic performance of Irish dairy farms 1998–2006. Journal of International Farm Management 1–18 ISSN 0967–0785 18397

FAPRI policy modelling



Project number:
5525
Date:
December, 2010
Funding Source:
Teagasc
Project dates:
Jan 2006 – Dec 2008

Key external stakeholders:

Policy makers, farm and food industry representative organisations.

Practical implications for stakeholders:

This project examined the impact of a number of policy issues that are of critical interest to the agri-food sector, including milk quota elimination and reform to international trade policy (World Trade Organisation through a conclusion of the WTO Doha Round negotiations).

Main results:

- This study used an economic model of Irish Agriculture to assess major policy issues of concern to the sector namely, international trade liberalisation and the elimination of the EU milk quota regime.
- With respect to milk quota liberalisation, the study found that the removal of milk quotas would lead to an increase in milk production and an agricultural income in Ireland.
- With respect to international trade liberalisation, the study quantified the impact which a significant reduction in import tariffs would have on Irish and EU agriculture. It was found that the beef sector in particular was vulnerable to a major liberalisation in trade via import tariff reductions.

Collaborating Institutions:
FAPRI at the University of Missouri

Teagasc project team:
Mr. Trevor Donnellan (PI)
Dr. Kevin Hanrahan

External collaborators:
Julian Binfield and Professor Patrick Westhoff (FAPRI – University of Missouri)

Compiled by:
Trevor Donnellan

Technology

Opportunity/Benefit:

The results of this study assist policy makers and other stakeholders in the sector in adopting policy positions which are of benefit to Ireland and the EU.

1. Project background:

This project used the FAPRI-Ireland Model to examine the impact that possible changes in policy could have on agricultural incomes over a ten year time horizon.

2. Questions addressed by the project:

The project specifically looked at two policy reform scenarios: the elimination of milk quotas and a WTO trade reform agreement as proposed in the so-called Falconer text.

3. The experimental studies:

The study used the FAPRI-Ireland model to examine the research questions detailed above. This model is a partial equilibrium, dynamic, multi-commodity model capable of producing supply and use balance estimates including output, trade, domestic use stock and prices and which can also provide projections of the Economic Accounts for Ireland including agricultural income. These projections are produced over a ten year time horizon.

4. Main results:

The milk quota elimination study found that Irish milk production would increase in the absence of milk quotas and that relative to the baseline that this reform of the Common Agricultural Policy (CAP) would add 6 percent to the overall value of agricultural sector income.

Under the WTO reform scenario the results indicate that a 70% reduction in import tariffs and the elimination of EU export subsidies would reduce agricultural sector income in Ireland by €320 million per annum, with the main impact falling on the beef sector. The reforms of trade distorting domestic support is not found to have a major impact on Irish or EU agriculture given that most direct income support payments under the CAP are decoupled from production.

5. Dissemination:

The primary stakeholders for this research are the policy making community and research peers.

The results of the project have been presented at a seminar in Dublin and the wider academic and policy making community.

Main publications:

Two main publications which arose from the project were in the form of National Reports which were published in conjunction with the FAPRI-Ireland Baseline in 2007 and in 2008.

Binfield, J., Donnellan, T., Hanrahan, K. Westhoff, P. 2008. 'FAPRI-Ireland 2008 WTO Reform Analysis: Potential Impact on EU and Irish Agriculture' in Outlook 2008: Medium Term Analysis for the Agri-Food Sector, Teagasc, Ireland. August 2008.

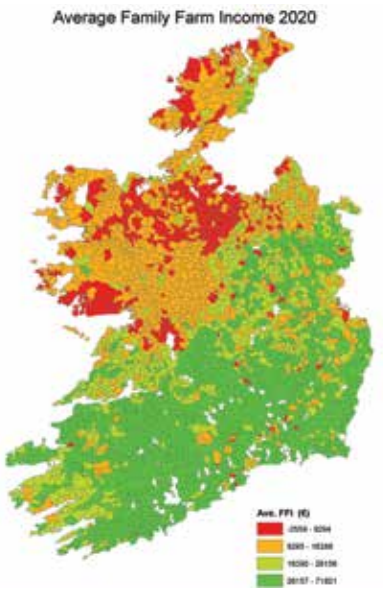
These studies are available from the publications section of the FAPRI-Ireland website www.tnet.teagasc.ie/fapri.

Binfield, J., Donnellan, T., Hanrahan, K. Westhoff, P. 2006. 'World Trade Reform: Possible Impact of the Doha Round on EU and Irish Agriculture', in *World Agricultural Trade Reform and the WTO Trade Round: Analysis of the Impact on EU and Irish Agriculture*. March 2006. Teagasc, Ireland.

In addition a paper on milk quota elimination was presented at the EAEE Seminar in Seville in 2008 and was subsequently selected for publication.

Binfield, J., Donnellan, T., Hanrahan, K. 2008. 'An Examination of Milk Quota expansion at EU member State Level with specific emphasis on Ireland.' Published in *Modelling Agricultural and Rural Development Policies – Selected Papers from the 107th Seminar of the European Association of Agricultural Economists*, edited by Lubica Bartova, Robert M'barek and Tomas Ratinger. Luxembourg: Office for Official Publications of the European Communities. ISBN: 978–92–79–08068–5.

The rural development model: SMILE 2



Project number:
5572
Date:
November, 2013
Funding source:
(NDP), BMW
Project dates:
Jan 2007 – May 2013

Key external stakeholders:

Government policy-makers, LEADER companies, regional assemblies, county and city councils, EPA.

Practical implications for stakeholders:

This project, which developed a Spatial Microsimulation of the Irish Local Economy (SMILE) model, allows Teagasc researchers to examine a variety of policy questions, relevant to rural and regional development and environmental issues. The SMILE model is focused on the creation of a representative micro-level dataset that may be used to examine quality of life, health, poverty and the impact of agri-environmental schemes across Ireland.

- The SMILE model allows Teagasc researchers to apply a simulation methodology to a range of policy relevant areas of interest to the current and future policy agenda.
- The SMILE model will result in an increased capacity to examine the impact of rural and regional development policies ex-ante and ex-post on local communities. Thus, allowing scarce resources and policies to be targeted at the groups most likely to benefit from new policy intervention.

Main results:

- The first spatial microsimulation model that examines the Irish rural and regional economy was developed.
- A new calibration and validation technique for static spatial microsmulation was developed.
- A range of rural and regional policy areas that were previously under-researched in Ireland, due namely to data non-availability were examined.

Collaborating Institutions:
University of Leeds
NUI Galway

Teagasc project team:
Dr. Karyn Morrissey (PI)
Prof. Cathal O'Donoghue
Dr. Stephen Hynes

External collaborators:
Graham Clarke (University of Leeds)
Dimitris Ballas (University of Sheffield)

Compiled by:
Karyn Morrissey
John Cullinan
Cathal O'Donoghue
Stephen Hynes
John Lennon.

Technology

Opportunity/Benefit:

This project was a developmental strategic project that developed modeling capacity that has subsequently been used as part of the inputs into Teagasc's involvement in spatial related policy reform such as the Commission for the Economic Development of Rural Areas and the Less Favoured Areas Value for Money Review.

1. Project background:

The context of this project was to develop a policy impact assessment model for economic, social and policy issues that incorporate a spatial dimension. These include rural development and environmental issues. Currently available data and policy simulation models in Ireland do not allow for this. The model is thus a methodological improvement for use to analyse specific policy issues of relevance to Rural Ireland. The model builds upon a previous RMIS project that developed a farm level spatial microsimulation model that did not have the capacity to analyse the wider rural economy issues.

The objective of this project is to develop a spatial microsimulation model developing current methods of matching different micro-datasets. Using these statistical techniques one can develop an attribute-rich spatial micro-dataset, thus allowing the development of various quality-of-life indicators at the spatial scale. The demographic structure produced by SMILE at the small area level (electoral division, ED) matches the CSO's Small Area Population Survey (SAPS) perfectly and incomes are consistent with CSO County Incomes and ESRI County Poverty Rates. Its' agricultural model replicates the spatial distribution of the Census of Agriculture and is consistent with the Teagasc National Farm Survey. It is thus an attribute-rich model that can be used for a variety of policy analyses.

SMILE is unique amongst spatial microsimulation models with the detail of its agricultural sector, combined with the Rural Economy sector, allowing the model to be used for agricultural and rural policy analysis. For example, the model has been used to assess the differential impact of the economic downturn on urban, rural and agricultural areas.

A new technique – static alignment – was developed and implemented to improve the data quality of SMILE. This technique was principally employed to the labour force and income level data produced by SMILE. Implementing this technique essentially means that SMILE now contains representative labour force and primary level income data at the ED level for the whole of Ireland. This means that SMILE may be used to produce quality-of-life measures for each individual in Ireland given their individual characteristics and spatial location.

A further extension to SMILE was a health component. Similar to the labour and income component, the health component has been validated to produce a realistic representation of the health status, both physical and mental of the Irish population. Thus, allowing policy-makers to examine the health profile or the Irish population across space. A further extension to SMILE has also been the use of spatial microsimulation to estimate aggregate consumer surplus values in environmental valuation studies. This allows analysis of rural and regional recreation and its' impact on the local economy.

2. Questions addressed by the project:

The project also had two analytical goals. The first was to develop the SMILE microsimulation framework. This involved developing an algorithm-based model that created representative population data for the whole of Ireland. A number of innovations were used in the development of the model, namely the static alignment technique used to validate the simulated data. The project thus had a large methodological component, so that the model would have a valid database on which to base policy analysis.

The second objective was to use the data created to examine a number of policy issues relevant to the sub-national level area (including districts within the BMW area, funded by the NDP), particularly in policy areas that were poorly represented before, due to data limitations. The SMILE model, once developed and validated, creates an attribute-rich spatial micro-dataset, thus allowing the development of various quality-of-life indicators at the sub-national scale. Work to date using data from the SMILE model has focused on poverty, inequality, agri-environmental impacts and health service provision and needs in rural areas.

3. The experimental studies:

The objective of this research project was to develop a model capable of generating socio-economic data at the local area in Ireland.

Initial work involved choosing the correct algorithm and methodologies to create such a dataset. International cooperation from the University of Leeds was an important part of this initial work.

The second part of the project was to ensure that the data was validated and representative of the Irish population. A methodology new to the static spatial microsimulation model was developed. This allowed researchers to validate and calibrate the data of interest to ensure that the model outputs were representative of the Irish population. This essentially means that SMILE now contains representative labour force and primary level income data at the ED level for the whole of Ireland.

4. Main results:

The main outcome of the project was a modeling system. A range of analyses were undertaken to test the effectiveness of the model. The principle outputs from the calibrated and validated SMILE model have been used to:

- Produce quality of life measures for each individual in Ireland given their individual characteristics and spatial location.
- Labour market and poverty analysis at the small area level in rural Ireland.
- Rural Health Service Demand and Provision.
- The impact of forestry recreation at the small area level.
- The impact of carbon taxes on family farm income.
- The willingness to pay for habitat conservation among Irish farmers.
- The spatial distribution of family farm income in rural Ireland.

5. Opportunity/Benefit:

The primary stakeholder for this research is rural and regional policy-makers, the broad range of policy areas that one may examine, for example rural poverty, regional tourism, health service provision, means that the benefits of the project will be conferred to public stakeholders via the exploitation of these results through further research programmes and interaction with public stakeholders.

An indication of its' impact is that stakeholders (Bord Bia and LEADER) have financed follow-on projects to use the model for Strategic Rural Development policy analysis and to help develop local sustainability indicators for the Irish beef sector.

6. Dissemination:

The model has been used actively in policy research to produce submissions for government policy. A book and peer reviewed journal publications have been developed to disseminate to academics. A follow on project is transferring the methodology to partner institutions in the EU.

Main publications:

2 PhD thesis have used the SMILE Model

7 journal publications using the results of the SMILE Model

2 book chapters using the data from the SMILE Model

14 International & National Conferences attended/ presented at using Data from SMILE

Morrissey, Karyn, Clarke, Graham, Ballas, Dimitris, Hynes, S.P. and O'Donoghue, C. (2012). SMILE – An Applied Spatial Microsimulation Model for Ireland, (eds.) Stimson, R and Haynes, K. *Geography and Geographers at Work*, Springer. A3

Morrissey, K., O'Donoghue C., (2011). The Spatial Distribution of Labour Force Participation and Market Earnings at the Sub-National Level in Ireland, *Review of Economic Analysis*, forthcoming A1

Morrissey, Karyn, Hynes, Stephen, Clarke, Graham and O'Donoghue, Cathal (2010). 'Examining the factors associated with depression at the small area level in Ireland using spatial microsimulation techniques', Irish Geography, 43: 1, 1 — 22 A1

Morrissey, Karyn, Clarke, Graham, Ballas, Dimitris, Hynes, S.P. and O'Donoghue, C. (2008). Examining access to GP services in rural Ireland using microsimulation analysis. Area Vol. 40, No. 3, Pages 354–364 ISSN 0004–0894 17223 A1

Morrissey K., G. Clarke and C. O'Donoghue, Accessibility Modelling: A Rural Health Care Application (2009), Christophe Mager and Francois Bavaud (EDs.), Handbook of Theoretical and Quantitative Geography A3

Cullinan, J., Hynes, S.P. and O'Donoghue, C. (2008). Estimating catchment area population indicators using network analysis: an application to two small-scale forests in Co. Galway. Irish Geography Vol 41: pp 279–294 ISSN 0075–0778 17557 A1

Hynes, S., Morrissey, K., O'Donoghue, C. and Clarke, G. (2009). Building a Static Farm Level Spatial Microsimulation Model for Rural Development and Agricultural Policy Analysis in Ireland. *International Journal of Agricultural Resources, Governance and Ecology, 8 (3): 282–299.*

Hynes, S., Morrissey, K., O'Donoghue, C. and Clarke, G.. (2009). A Spatial Microsimulation Analysis of Methane Emissions from Irish Agriculture. *Journal of Ecological Complexity* 6: 135– 146.

Hynes, S., Farrelly, N., Murphy, E. and O'Donoghue, C. (2008). Modelling habitat conservation and participation in agri-environmental schemes: A spatial microsimulation approach. *Ecological Economics*, vol. 66, issue 2–3, pages 258–269

Morrissey K., (2008) Access to Health Care Services in Rural Ireland, Unpublished PhD Thesis

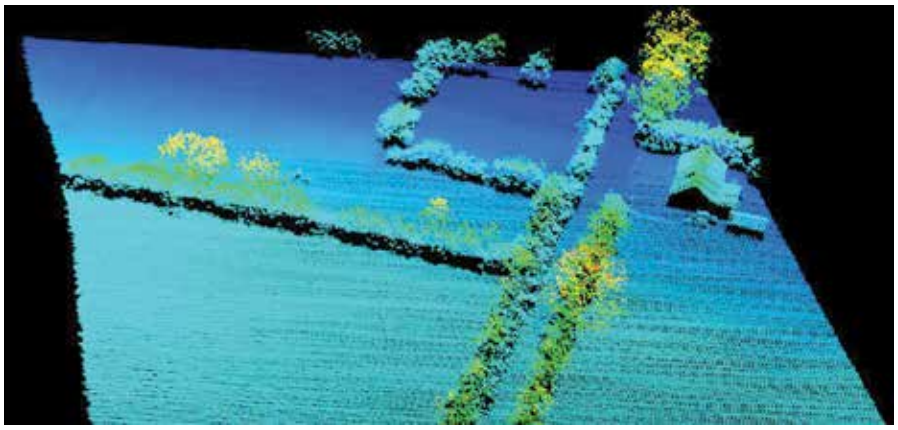
Cullinane, J. (2009) Recreational Modelling, Unpublished PhD Thesis

Cullinan, J., Hynes, S.P. and O'Donoghue, C. (2008). Using spatial microsimulation to estimate aggregate consumer surplus values in travel cost modelling. In: 16th Annual meeting of the European association of environmental and natural resource economists, Gothenburg, Sweden, 25-Jun-2008, *** 17572

Morrissey, K, Clarke, G.P., and O'Donoghue, C., 2008 'The Spatial Pattern of Ill-Health and Health Service Utilisation in Ireland, European Regional Science Association, Liverpool, England, 27th – 31st of August, 2008

Morrissey, K, Clarke, G.P., Hynes, S., Ballas, D., and O'Donoghue, C., 2007 'Access to GP Services in Rural Ireland', ECTQG, Montreux, Switzerland, 7th – 13th of September, 2007

Using laser scanning to estimate carbon locked in hedgerows



Project number:
6155
Date:
November, 2012
Funding source:
EPA
Project dates:
Nov 2011 – Nov 2012

Key external stakeholders:

Farmers, Department of Environment, community and local government, Department of Agriculture, Food and Marine, Environmental Protection Agency, local authorities.

Practical implications for stakeholders:

This desk-based study indicates the potential of hedgerows to improve the carbon balance accounting of Irish agriculture: any future carbon foot-printing of Irish agricultural products can now take into account the beneficial sequestration function of any farm hedgerows and scrub.

Main results:

- Airborne LIDAR (Light Detection And Ranging) surveys can accurately measure the physical characteristics of hedgerows.
- These physical characteristics can be converted to carbon holdings for hedgerows.

Opportunity/Benefit:

- These hedgerow carbon sinks are potentially worth millions of Euros in European Trading Scheme (ETS) credits. The biomass held in hedgerows can now accurately be measured. Further field experiments are needed to convert biomass precisely to carbon equivalents. The exact value depends on the current price of Carbon in ETS.
- A national ongoing inventory methodology for hedgerow and non-forest woody biomass utilising laser sensing has been shown to be cost effective.

Collaborating Institutions:
FERS Ltd, Dublin
Treemetrics Ltd, Cork

Teagasc project team:
Mr. Stuart Green (PI)
Dr. Niall Farrelly

External collaborators:
Kevin Black, FERS Ltd
Alex Poveda, Treemetrics

Compiled by:
Stuart Green

Technology

1. Project background:

Hedgerows and woodland habitats are an important feature of the Irish landscape due in part to their roles in biodiversity, agricultural management and potential carbon sequestration. Greenhouse gas (GHG) emission reductions in the land use, land use change and forestry sector (LULUCF) are largely associated with forestry sinks. However, it is suggested that there could be possible GHG mitigation potential (sink potential) in grazing land or cropland following the introduction of the REPS scheme, which promoted the planting of indigenous trees and development of hedgerows.

Under the EU burden sharing agreement, Ireland will be committed to reduce its GHG emissions by 20% below the 2005 value by 2020 (5th National Communication, DoE). Additional measures or accountable sinks are required for the 20% target to be met for the non-emission trading sectors. Emissions and removals (Kyoto removal unit , RMUs) associated with the LULUCF sector can be used as a mitigation option under the Kyoto protocol mechanism. Article 3.4 of the protocol allows for the accounting of emission removals (sinks) associated with management or croplands, grazing land and forest management. Selection of these activities for the current commitment period of the protocol is voluntary, but likely to become mandatory post 2012. Ireland did not elect cropland and grassland land management for the first commitment period due to uncertainty in the magnitude of emissions or sinks in this land use activity and a lack of methodology to report these activities on a national basis.

LiDAR (Light Detection And Ranging) remote sensing technology and ground truthing techniques could offer an ideal opportunity to utilise existing land use policies and incentives (e.g. agri-environment schemes) to realise the potential return of investment without any added cost except for the implementation and testing of a compliance monitoring, reporting and verification (MRV) programme at a relatively low cost.

2. Questions addressed by the project:

- Is it possible to measure hedgerows using LIDAR to a sufficient accuracy that this could be used instead of a manual survey?
- Is it possible to convert physical measurement of hedgerows into an accurate estimate of their biomass and thus carbon holdings/sequestering potential?
- Can a cost effective national inventory be designed?

3. The experimental studies:

1) Literature review of existing hedgerow accounting in Ireland (e.g. County Surveys) and on the use of LIDAR in non-forest biomass estimation. The review found limited literature on LIDAR scanning of hedgerow and woodlands. Internationally there are published guidelines on field surveys and some estimates of hedgerow density and length for different countries. Data on hedgerows in Ireland is contained in separate county surveys (though not all are covered). The nearest to a national estimate of occurrence of hedgerows in Ireland is to be found in the European LUCAS survey (2009, conducted by the EEA). Analysis of the report based on this survey shows Ireland has double the occurrence of hedgerow than our nearest neighbour, Great Britain.
2) Re-analysis of an existing LIDAR survey: A pilot study was conducted using existing LIDAR data from Frenchpark, Co Roscommon, to develop a hedgerow classification and sampling system to assess biomass and carbon (C) sequestration by adopting a range of geo-processing techniques and empirical models. Direct modeling of LIDAR metrics, such as intensity and percentiles of 1st and 2nd laser returns, were used to accurately (RMSE ±7.3 to 19 tC ha^{-1}) estimate hedgerow and non-forest woodland biomass.
3) Applying conventional forest plot approaches to estimating biomass and carbon budget from physical measurements. Above-ground biomass measurements were derived using an algorithm developed from harvested broadleaves as described in the CARBWARE forest model. The algorithm was refined to provide above-ground biomass based on tree height (H) derived from the segmentation of tree crowns or randomly sampled tree heights. A second approach to derive biomass directly from laser metric data based on regression analysis against biomass estimates was also investigated.
4) A cost benefit analysis looking at estimated costs of a national LIDAR survey for hedgerows (based on known costs of LIDAR surveys) against conventional methods and value of the carbon inventory in the Kyoto accounting mechanism.

4. Main results:

This desk study was initiated to demonstrate the use of Light Detection And Ranging (LIDAR) remote sensing technology and terrestrial laser scanning (TLS) for assessing hedgerow biomass with the aim of developing a cost effective and efficient national hedgerow carbon inventory.

A pilot study was conducted using existing LIDAR data from Frenchpark, Co Roscommon, to develop a hedgerow classification and sampling system. In order to assess biomass and carbon (C) sequestration by hedgerows a range of geo-processing techniques and empirical models were adopted. Direct modeling of LIDAR metrics, such as intensity and percentiles of 1st and 2nd laser returns, were used to accurately (RMSE ±7.3 to 19 tC ha^{-1}) estimate hedgerow and non-forest woodland biomass. Optimisation of LIDAR sampling techniques suggest that the minimum laser return sample density for detecting hedgerow biomass could be set at 5 returns per m^2 without influencing the performance of model estimates, thereby reducing survey costs.

Following optimisation of sampling and processing requirements, guidelines and costs for developing a national LIDAR based inventory were established. It is estimated that the total annual cost of a national hedgerow inventory could be between €80,000 and €100,000, ameliorated over a six-year reporting cycle. However the financial impact could be substantially reduced if the acquisition and processing cost for LIDAR data is shared by governmental bodies interested in the use of LIDAR for other applications.

Preliminary estimates suggest that hedgerow and non-forest woodlands could sequester 0.66 to 3.3 tCO_2 ha^{-1} yr^{-1}. These estimates exclude potential emissions associated with hedgerow management or disturbance. However, the reported estimates are within the range reported by other hedgerow studies. If these estimates are representative of national hedgerows and non-forest woodlands, this could potentially result in a net removal of 0.27 to 1.4 M tCO_2 per year, which would increase the total land use change and forestry (LULUCF) sink estimate by ca. 8 to 28%. However, under the current accounting framework for Article 3.4 of the Kyoto Agreement, claimed emission reductions are calculated using a net-net approach. This is done by comparison of the net removal in a given year with the net removal or emission in a reference year. For the cost benefit analysis, the year 2000 was selected as the base year using available statistics on increases in hedgerow area to derive a net-net removal estimate of 3,000 to 17,000 t CO_2 per year. Based on the estimated cost of a hedgerow inventory and the expected accountable removals, it is estimated that a national inventory would be cost neutral at a CO_2 market price of €6 per t CO_2. Under the 2012 market conditions and Kyoto accounting mechanism, a national hedgerow inventory would offer no cost benefit. However, it is plausible that the market demand for CO_2 and the value of Kyoto RMUs would increase when new emission reduction and burden sharing targets come into effect post 2020.

5. Opportunity/Benefit:

In conclusion, a national, LIDAR-based inventory of hedgerows is feasible and cost effective (pending future internationally agreed accounting modalities). It is recommended that additional research and inventory capacity is required to include hedgerows into a fully compliant LULUCF inventory. For example, extensive validation and ground-truthing of LIDAR and TLS biomass estimates are required to ensure estimates are robust and defensible in the international review process. In addition, national institutions and government departments should develop cohesive LIDAR survey, dissemination, and inventory policies, compatible with the INSPIRE directive, so that the costs of acquiring and processing LIDAR data for multiple users can be reduced.

6. Dissemination:

Work presented at the 5th and 6th symposia on Irish Earth Observation Research

Stakeholder workshop held in Ashtown, November 2012. Hosted by Teagasc with EPA and national and international stakeholders.

Main publications:

Black K., Green S., Mullooley G. and Poveda A., 2012, Towards a national hedgerow biomass inventory for the LULUCF sector using lidar remote sensing, Final Report. EPA Climate Change Research Programme, EPA, Ireland. http://erc.epa.ie/safer/reports2

Project number:
5956
Date:
December, 2012
Funding source:
DAFM
Project dates:
Feb 2009 – Oct 2012

Consumer and industry acceptance of novel food technologies

Collaborating Institutions:
Univeristy College Cork (UCC)
Dublin Institute of Technology (DIT)

Teagasc project team:
Dr. Maeve Henchion
Dr. Sinéad McCarthy
Dr. Emma Dillon
Ms. Gráinne Kavanagh

External collaborators:
Mary McCarthy, UCC
Gwilym Williams, DIT
Gráinne Greehy, UCC

Compiled by:
Maeve Henchion
Sinéad McCarthy
Emma Dillon
Mary McCarthy
Gráinne Greehy
Gráinne Kavanagh
Gwilym Williams

Key external stakeholders:

Food companies, researchers, research funders, industry support agencies, consumer representative bodies.

Practical implications for stakeholders:

New Food Technologies (NFTs) are required to help food companies address challenges such as increased competitive pressures, globalisation, and dynamic and diverse consumer demands. They are also required to enable global food systems change and adapt to become more efficient and resilient. However, developing NFTs is a costly and risky business for academia and industry. Furthermore, converting investments in this area into financial reward requires overcoming at least two hurdles, i.e. industry uptake and consumer acceptance. The research highlights the need to consider these hurdles, and have a clear understanding of the key factors influencing them, at an early stage in the development pathway of NFTs.

Main results:

- Factors determining acceptance of NFTs at industry and consumer levels are complex as (a) all technologies are not the same; (b) all companies are not the same, (c) all consumers are not the same.
- Consumer attitudes towards various technologies range from concern and fear to apathetic and blasé.
- Different segments exist in the population in terms of how accepting they are of new food technologies; the number and size of these segments varies by technology application.
- Irish food companies can be divided into three (approximately equal) capability levels ranging from those that possess the required profile to commercialise advanced technologies to those with virtually no ability to assimilate knowledge and commercialise outputs from a typical FIRM-funded project.

Technology

Opportunity/Benefit:

Overall this research shows that consumer acceptance and industry uptake cannot be assumed for NFTs. It illustrates clear challenges for technology developers seeking widespread adoption. Deeper understanding of the reactions of stakeholders to the development and application of new and emerging technologies, as well as the factors influencing adoption and acceptance, are provided. Such knowledge is crucial to any organisation aiming to develop innovation efficiently, effectively and democratically. From a practical perspective, it demonstrates the value of segmenting consumers, as they are not uniformly anti-technology. Whilst the research reports that segmenting consumers based on demographic variables is of limited use in attempting to develop targeted strategies to influence acceptance, an alternative method of segmenting consumers based on general attitudes to nature, the environment and science and technology is proposed. On the industry side, it highlights technological complexity, and associated industry capacity, as a barrier to uptake. To help address this, it identifies a method of classifying companies based on their capacity to adopt NFTs; this could be useful for support agencies seeking to provide targeted supports to companies to promote higher levels of innovation in the industry.

The main recommendation arising from this research is: *The development trajectory of new technologies needs to be considered well in advance of market launch with specific strategies required for different stages of the development trajectory. Openness and transparency should be fostered by all stakeholders during this process.*

1. Project background:

Despite significant investment in novel technology research, these technologies will not yield desired returns unless adopted by industry and accepted by consumers. It is therefore important to determine:

- how consumers evaluate NFTs.
- the factors supporting and impeding industry uptake of novel food technologies (NFTs).

This research helps inform and guide industry strategies and government policies to support a knowledge based bio-economy. It provides relevant information to support greater industry uptake of NFTs and highlights the need to take account of sources of public concerns.

2. Questions addressed by the project:

The project sought to gain understanding from both the consumer and industry perspective on likely acceptance/adoption of NTFs. From the consumer perspective, it aimed to:

- understand how individuals construct meaning around and interpret information about NFTs.
- consider the trade-offs made by individuals when a product offering benefits is produced using a NFT.

From the industry perspective, it aimed to:

- examine drivers/barriers influencing technology investment decisions by industry.
- measure the receptivity of industry to new technology innovation.

3. The experimental studies:

The study employed a mixed methods approach. The consumer research used an innovative qualitative research approach to address eight NFTs ranging from extremely far from market technologies (e.g. *in vitro* meat) to those already on the market (e.g. functional foods). This was complimented by a nationally representative survey of 1,000 Irish consumers that focused on two applications of nanotechnology; its application to a food product ("nano-inside") and its application to food packaging ("nano-outside"). The industry focused research used executive interviews in the exploratory and confirmatory stages to compliment a national postal survey of 445 Irish food companies (response rate 30%). It is noteworthy that the qualitative research approach was essential when engaging in data collection with both industry stakeholders and consumers to deliver deeper insights into the motivations and drivers influencing technology adoption/acceptance.

4. Main results:

Consumer acceptance varies across technologies, moreover the particular application of a technology can influence acceptance for some consumers. The types and forms of information provided to consumers to aid their evaluation of NFTs influences the process by which they form, and change, attitudes to such technologies. However the extent to which consumers will actively seek and process information depends on characteristics of the technology as well as the consumer. The majority of people, although interested in obtaining information, do not appear to spend too much time

or effort trying to form a knowledge-based attitude in their evaluation of NFTs. Given general low levels of awareness of NFTs, consumers frequently rely on intuition, rules of thumb and associative evaluations in assessing technologies.

This research shows the influence of low levels of awareness, and associated high levels of uncertainty, on acceptance of nanotechnology. The role of regulatory authorities, and bodies such as government agencies and GPs, as trusted sources of information in such an environment is highlighted. Whilst different segments can be identified in terms of acceptance of various technologies, demographic variables are of limited value in targeting such segments. Attitudinal variables, such as attitudes to nature, the environment and science and technology provide a better basis for differentiation.

Irish food companies vary in their ability to exploit NFTs. They also vary in terms of their acknowledgement of the need to invest in such technologies. Characteristics of the technology, particularly in terms of complexity, and also in terms of compatibility with existing products and systems, influence acceptance.

5. Opportunity/Benefit:

Overall, this research shows that consumer acceptance and industry uptake cannot be assumed for novel food technologies. It illustrates clear challenges for technology developers seeking widespread acceptance/adoption of novel food technologies at consumer and industry level. Deeper understanding of the reaction of these stakeholders to the development and application of new and emerging technologies, as well as the factors influencing acceptance, is provided. Such knowledge is crucial to any organisation aiming to develop innovation efficiently, effectively and democratically.

From a practical perspective, it demonstrates the value of segmenting consumers, as they are not uniformly anti-technology. Whilst the research reports that segmenting consumers based on demographic variables is of limited use in attempting to developed targeted strategies to influence acceptance (e.g. in terms of communications strategy) an alternative method of segmenting consumers based on attitudes to constructs such as nature, the environment and science and technologies is proposed. On the industry side, it highlights technological complexity, and associated industry capacity, as a barrier to uptake. To help address this, it identifies a method of classifying companies based on their capacity to adopt new food technologies which could be useful for support agencies seeking to provide targeted supports to individual companies to promote higher levels of innovation in the industry.

The main recommendation arising from this research is as follows:

The development trajectory of new technologies needs to be considered well in advance of market launch with specific strategies required for different stages of the development trajectory. Openness and transparency should be fostered by all stakeholders during this process.

6. Dissemination:

Main publications:

Kavanagh, G., Henchion, M., McCarthy, M., McCarthy, S. and G. Williams (2012). Technological Innovation – A Route Towards Sustainability, *International Journal on Food System Dynamics*, Vol 3, No 1.

Greehy, G., McCarthy, M., Henchion, M., Dillon, E., and S. McCarthy (2012). 'Food for Thought: How Citizens Frame and Process Information about Novel Food Technologies' *International Conference on Science Communication*, Nancy, France, 04–07/09/12.

Dillon, E. J., Greehy, G., Henchion, M., McCarthy, M. and S. McCarthy (2011). 'Functional foods into the future – examining Irish consumer acceptance', *European Association of Agricultural Economists (EAAE) Congress*, Zurich, Switzerland, 30.08.11–02.09.11

Kavanagh, G. Henchion, M., McCarthy, M, and G. Williams (2011) 'Technological innovation –A route towards sustainability in the Irish food industry". 5th *International European Forum on System Dynamics and Innovation in Food Networks*, Igs, Austria, 4.02.11–18.02.11).

Greehy, G. McCarthy, M. Henchion, M. Dillon, E and S. McCarthy (2011). 'An Exploration of Irish Consumer Acceptance of Nanotechnology Applications in Food'. 5th *International European Forum on System Dynamics and Innovation in Food Networks*, Igs, Austria, 4.02.11–18.02.11).

Popular publications:

Dillon, E. Henchion, M., Greehy, G., McCarthy M., McCarthy, S. and Williams G (2012) Could 'lab grown' meat really be on the menu? *TResearch* Vol. 7: No. 4 Winter 2012 pp 26–27, ISSN 1649–8917

Kavanagh G, Henchion, M., McCarthy M and Williams G (2011). Measuring up for innovation. *TResearch* Vol.6: No. 3 Autumn 2011 pp 30–31, ISSN 1649–8917

Rural Economy & Development Programme

Project number:
5877

Date:
September, 2012

Funding source:
Teagasc

Project dates:
Jun 2008 – Dec 2012

The future of farm partnerships in Ireland

Key external stakeholders:

Dairy farmers, Department of Agriculture, Food and the Marine (DAFM), dairy cooperatives; farmers interest groups such as Macra na Feirme, agricultural advisors and consultants.

Practical implications for stakeholders:

Farm Partnerships have the capacity to deliver significant economic, social and cultural benefits to farmers, and to enhance the sustainability and productivity of Irish agriculture. However, a strategic advisory approach to facilitating farmers' establishment of Farm Partnerships is required to optimise the range of achievable benefits and to avoid common pitfalls. This research has developed a methodology for advisors' use in facilitating farmers' learning of key benefits as well as challenges associated with Farm Partnerships. The methodology also incorporates the key information required by farmers in preparation for formulating customised Farm Partnership agreements.

Main results:

- The research found that the types of Farm Partnerships operating in Ireland are diverse, involving private individual neighbouring farmers and different combinations of family members. Farmers with different needs, family situations, work preferences and aspirations have established Farm Partnerships in Ireland. Farmers can be motivated differently, thus, to establish Farm Partnerships. This research found that Farm Partnerships have the capacity to respond to farmers' diverse motivations through customised partnership agreements.
- Irish farmers experienced a wide range of economic, social and cultural benefits as a result of entering Farm Partnerships.
- Reflecting the diversity of circumstances that Farm Partnerships can accommodate, a viable partnership requires a detailed and comprehensive formalised agreement as well as an ongoing process of review.
- With appropriate extension and policy support, there is significant potential for Farm Partnerships in Ireland to reach the level of uptake in countries such as Norway, where over 20% of dairy farmers are involved in partnerships.

Collaborating Institutions:
NUI, Galway
Centre for Rural Research (CRR), Norway

Teagasc project team:
Dr. Áine Macken-Walsh (PI)
Mr. Ben Roche

External collaborators:
Dr. Anne Byrne (NUI, Galway)
Prof. Reidar Almas (CRO, Norway)
Dr. Bjorn Egil Flo (CRO, Norway)

Compiled by:
Áine Macken-Walsh

Technology

Opportunity/Benefit:

An extension template has been developed through a collaborative effort between research and specialist advisory personnel at Teagasc (Macken-Walsh and Roche, 2012). The extension template highlights the challenges as well as benefits experienced by Irish farmers operating partnerships and sets out an extension methodology for advisors' direct use in promoting and facilitating farmers' establishment of Farm Partnerships.

1. Project background:

In the context of joint farming ventures having a crucial role in the development of Irish agriculture, a research project was initiated by Teagasc (2008–2012) to explore Irish farmers' experiences of Farm Partnerships. The core objective was to reach an in-depth and comprehensive understanding of the factors influencing Irish farmers' establishment of Farm Partnerships.

2. Questions addressed by the project:

The project sought to identify from farmers' perspectives the incentives and disincentives to establishing partnerships and the advantages and disadvantages associated with partnerships.

3. The experimental studies:

Eleven qualitative case-studies using the Biographic Narrative Interpretive Method (BNIM) were undertaken to explore the experiences of farmers who were operating a Milk Production Partnership (MPP); and farmers who actively considered but, for various reasons, did not establish a MPP. The case-studies represented a diversity of Irish farmers who are involved in or who have actively considered MPPs.

4. Main results:

Influential factors corresponded to diverse types of Farm Partnerships, including partnerships involving various combinations of family members operating the same farm and partnerships involving individual farmers:

- Farmers with diverse needs, family situations, work preferences, and aspirations have established Farm Partnerships in Ireland.
- Numerous benefits of Farm Partnerships were identified. Farm Partnerships:
  - Developed larger farm enterprises/ increased scale by managing two previously independent enterprises together.
  - Provided access to milk quota.
  - Increased efficiency by consolidating land and facilities and by developing new management strategies and business plans.
  - Assisted farmers to share their work-loads to cope with the extra work involved in up-scaling and applying new technologies on the farm.
  - Introduced new skills, specialisations and occupational preferences to enhance the operation of the farm.
  - Fostered new diversification activities on the farm by bringing in new expertise and business interests.
  - Facilitated off-farm work.
  - Shared decision-making power between members of farm families (e.g. spouses, heirs).
  - Reduced isolation in farmers' working lives and improved farm safety.
  - Accommodated family circumstances and needs where, for example, farmers had childcare responsibilities.
  - Allowed farmers time-off to pursue other interests and take holidays, improving their quality of life.
- Partnerships have the capacity to be versatile and flexible, but require a detailed planning process and a comprehensive partnership agreement in order to provide customised benefits to farmers.
- Extension activities promoting and facilitating the establishment of farm partnerships are challenged with:
  - Facilitating farmers' learning of technical information relevant to Farm Partnerships (legal, taxation, procedural, financial).
  - Facilitating farmers' learning of benefits associated with Farm Partnerships and practical 'Know-how'.
  - Encouraging farmers' discussion of and mediation through key issues (relationship issues, for example) that arise in Farm Partnerships.

5. Opportunity/Benefit:

Teagasc has published the extension template to promote and facilitate farmers' establishment of Farm Partnerships. This template is available to Teagasc and private advisors/facilitators of discussion groups. DAFM utilised information generated by the research in the development of its *Farm Partnerships Reference Paper* (DAFM, 2011). A new project has been funded by DAFM's Research Stimulus Fund (RSF) (2013–2015) to expand the approach of the research to other examples of joint farming ventures.

6. Dissemination:

Main publications:

Macken-Walsh, A. and Roche, B. (2012) Facilitating Farmers' Establishment of Farm Partnerships: a Participatory Template, Teagasc, Carlow, Ireland ISBN: 10–1–84170–585–3

Byrne, A., Duvvury, N., Macken-Walsh, A., Watson, T. (forthcoming, 2014) Women on Farms in Ireland: Understanding ownership, work and contemporary family life through the lens of intersectionality, in (eds) Barbara Pini, Berit Brandth, Jo Little, Feminisms and Ruralities, Lexington, *accepted*

Macken-Walsh, A. (2011) Farm Partnerships in Ireland: socio-cultural factors influencing participation and implications for extension, presentation to the Irish Rural Studies Symposium, Irish Royal Academy, 6th Dec., 2011

Macken-Walsh, A. (2010) The Future of Farm Partnerships in Ireland: Project Update, presentation to Milk Policy Division of DAFM, Kildare St., 28th Sept., 2010.

Input to:

DAFM (2011) Farm Partnerships Position Paper www.agriculture.gov.ie/.../FarmPartnershipsReferencePaperNov2011.doc

Popular publications:

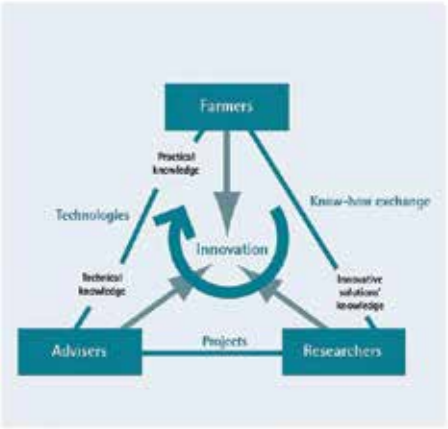
Macken-Walsh, A. and Roche, B. (2012) Farm Partnerships in Ireland, T-Research. Vol. 7 No. 3, Pages 32–33 ISSN 1649–8917 25845

Macken-Walsh, A. (2009) The Social Benefits of Working Together: Farm Partnerships, presentation to advisors and farmers at Teagasc, Mullinavat, 8th February 2009.

Macken-Walsh, A. (2009) The Social Benefits of Working Together: Farm Partnerships and share farming, in conference proceedings of 'A New Way of Farming: Farm Partnerships and Share Farming' Teagasc/Irish Farmers Journal. Teagasc RERC Working Paper Series 10-WPRE-02

Hennessy, T., Kinsella, A., O'Donoghue, C., Thorne, F., Roche, B. (2009) The Economic Benefits of Working Together: Farm Partnerships and Share Farming, in conference proceedings of 'A New Way of Farming: Farm Partnerships and Share Farming' Teagasc/Irish Farmers Journal.

Understanding farmer behaviour



Adapted from: http://www.tasfob.eu/framework.htm

Project number:
5917
Date:
September, 2013
Funding source:
Teagasc
Project dates:
Jun 2008 – Dec 2012

Key external stakeholders:

Beef farmers; the BETTER Farm Beef Programme, Department of Agriculture, Food and the Marine (DAFM), agricultural advisors and consultants.

Practical implications for stakeholders:

There is a need for targeted research to understand the wide range of complex factors influencing beef farmers' adoption of attitudes and practices that are conducive to enhancing productivity. This project undertook in-depth examination of case-study beef farmers, identifying the factors that were implicated in the farmers taking particular paths in terms of their agricultural production and farm development decisions. The main practical learning arising from this research is 1) the need for extension approaches to leverage the social relationships (including peer-to-peer and professional relationships) that are instrumental for farmers' learning processes and 2) to take a comprehensive approach in encouraging a farm development 'package', responding to social and cultural needs of the farm family as well as economic considerations.

Main results:

- Two overarching themes emerged in the data that explained farmers' farm production and development decisions: *farmer characteristics* (farmers' circumstances, needs, experiences, mindsets); and *knowledge and social enablers* (the experiences, events and/or structures that have assisted farmers' technological and efficiency successes).
- While farmers had many different characteristics, they also shared among them broadly common characteristics. In the context of these broadly common characteristics, the research identified 'transformative' experiences that led BETTER Farm Beef Programme farmers to take decisions and actions that led to enhanced farm performance. These transformative experiences (e.g. farmers' exposure to particular information/events; socially triggered realisation of new ways of thinking or prioritising) contain insights to the factors that ultimately cause change to occur among farmers and thus provide important learning arising for extension.

Collaborating Institutions:
NUI, Galway
Open University, UK,
University of Grönningen, Netherlands

Teagasc project team:
Dr. Áine Macken-Walsh (PI)
Dr. Paul Crosson
Mr. Aidan Murray

External collaborators:
Dr. Anne Byrne (NUI, Galway)
Prof. Frank Vanclay (University of Grönningen)
Dr. Chris High (Open University, UK)

Compiled by:
Áine Macken-Walsh

Technology

- The transformative experiences identified in the analysis related to the following themes: family farming; cultural capital and emotional attachment to farming; the role of pioneering farmers in farming communities; and engendering an appetite for achievement. The social settings of both participating and non-participating farmers in the BETTER Farm Programme related to these themes, allowing for the analysis to identify factors leading to particular farm development paths. Farmers' transformative experiences under these themes (for instance the experiences of a younger farmer inheriting a farm and gaining indepdendence very early on in life, or a farmer who became involved in agricultural competitions early on in life) were found to be directly influential on the direction of future development and production decisions on farms.
- Through a collaborative Teagasc research/specialist advisory effort, we highlight lessons arising from the research for extension models such as the BETTER Farm Programme and the Beef Technology Adoption Programme (BTAP).

Opportunity/Benefit:

A report highlighting key learning arising from the research for stakeholders has been developed through a collaborative research/specialist advisory effort.

1. Project background:

Farmers are not necessarily maximisers of profit (economic capital) over all other forms of capital (social and cultural) and a collaborative qualitative research project was initiated to gain insights to farmers' decision-making in the context of the BETTER Farm Beef Programme. A research project entitled 'Qualitative Analysis of Farmer Behaviour' (2009-2012) undertook detailed case studies to explore beef farmers' production decisions and activities. The project was implemented by a sociologist and the empirical focus was decided in consultation with a production scientist, extension professionals, and the management team of a joint industry programme, the Teagasc/Irish Farmers Journal BETTER Farm Beef Programme.

2. Questions addressed by the project:

The research examined the life experiences and 'mindsets' of the farmers involved in ten farms with a view to identifying the factors that were implicated in the farmers' approaches to agricultural production and farm development.

3. The experimental studies:

The case-studies involved ten farms: five farms participating in the BETTER Farm Beef Programme and five counterpart non-participating beef farms on which, by comparison, few or no new technologies were in use.

4. Main results:

- There is a need to foster and promote the independence of main farm operators in leading farm related decision-making while also accommodating family farm dynamics. In other words, family farming is the dominant farming model Europe-wide and while there are advantages of family farming such as labour supply and social supports, there can also be disadvantages relating to the 'independence lag' of farm heirs. Various joint farming ventures (e.g. farm partnerships) have potential in this regard.
- Farmer 'role models' had high credibility among farmer peers in demonstrating the use and adaptation of technologies.
- The cultural and emotional aspects of farming was strongly influential on all farmers studied and such aspects can be addressed through extension practice.
- Opportunities to enhance lifestyle was a strong motivating factor in farmers' decisions to change their farm production systems, particularly in the context of fulfilling the needs of family farm members.
- Expertise channelled through extension services, particularly when provided in the form of a comprehensive and customised package, was a powerful knowledge enabler.
- Social supports provided through discussion groups, for example, were critical pre-requisites for farmers' strategies to implement change at farm-level.
- Experiences of farming competitions (organised by Teagasc/industry) were among the most transformative experiences: they could engender a sense of achievement and appetite for experimentation and 'progression' from an early stage in farmers' careers.

5. Opportunity/Benefit:

Understanding the critical social and cultural 'triggers' that influence farmers' behaviour is important for fostering change at farm level through extension practice and also for gauging farmers' reactions to policy instruments/ programmes. Highlighting the key issues arising from the research for policy and extension design, a collaborative research/specialist advisory effort led to the development of a short summary report of specific interest to those involved in BTAP. The report highlights how extension and policy approaches can be attuned to the needs of the family oriented farm, by supporting joint farming ventures, for example, and to the cultural and social priorities of farmers, where farmers may not necessarily prioritise profit-making. Increased attunedness to the family-oriented, social and cultural aspects of farming may lead to policy and extension programmes having greater credibility and popularity among farmers as well as greater impact in instigating change.

6. Dissemination:

Main publications:

Macken-Walsh, A. (2013) Tales of Transformation: a study of BETTER Beef Farmers in Ireland, Teagasc REDP Working Paper Series.

Macken-Walsh, A. and Byrne, A. (2012) Relational Sustainability: examples of the Human and Animal interface in Irish rural society, Teagasc REDP Working Paper Series.

Buckley, C. Mechan, S., Macken-Walsh, A., Heanue, K. (2013) Stakeholder Co-development

of farm level nutrient management software, EGU General Assembly 2013, Geophysical Research Abstracts, Vol. 15, EGU2013-9175, 2013.

Macken-Walsh, A. (2012) Multi-Actor Research and Extension Processes in Agriculture, Congress of the International Rural Sociological Association, Lisbon, 31st July 2012.

High, C. Nemes, G., Macken Walsh, A., O'Dwyer, T. (2012) The Use of Participatory Evaluation Methods in Agricultural Extension, presentation to Teagasc, Best Practice in Extension Services: Supporting Farmer Innovation, Aviva Stadium, Dublin, November 1st, 2012.

Seale, C., High, C. Lane, A., Reynolds, M. (2012) Forty Shades of Green: Implications for Knowledge Transfer under a Changed CAP, presentation to Teagasc, Best Practice in Extension Services: Supporting Farmer Innovation, Aviva Stadium, Dublin, November 1st, 2012.

McDonald, R., Pierce, K., Horan, B., Heanue, K., Macken-Walsh, A. (2012) New Dairy 2020: A Multi-disciplinary Study of Technology Adoption among New Entrants to the Irish dairy industry, presentation to Teagasc Best Practice in Extension Services: Supporting Farmer Innovation, Aviva Stadium, Dublin, November 1st, 2012.

Heanue, K. and Macken-Walsh, A. (2010) Indigenous wisdom and the alternative logics for Irish farming, Invited Paper to the Campo Adentro Conference: Art, Agricultures & Countryside, Madrid, 21-23rd October 2010.

Popular publications:

Macken-Walsh, A., Crosson, P., Murray, A. (2012) A Qualitative Study of Irish Beef Farmers' Production Decisions: Summary and Implications for Extension, Teagasc, Oak Park, Carlow, November 2012. Presented to the Management Group of the BETTER Farm Beef Programme, 4th Oct., 2012.

Heanue, K., Macken-Walsh, A., Maher, P. (2012) (*eds*) Teagasc Best Practice in Extension Services: Supporting Farmer Innovation, edited book of conference proceedings, Aviva Staium, Dublin, November 1st, 2012, Teagasc, Oak Park, Carlow, Ireland ISBN: 1-84170-593-4, pp. 1-61.

Macken-Walsh, A., McHugh, S., Byrne, A., Woods, A., Crosson, P. and Murray, A. (2010). Understanding and Facilitating Farmers' Adoption of Technologies. TResearch Vol. 5 2010 34-36.

Économusée

Project number:
6088
Date:
November, 2011
Funding source:
Northern Periphery Programme (NPP)
Project dates:
Jun 2010 – Mar 2011

Teagasc project team:
Maria Heneghan (PI)
Dr. Kevin Heanue

External collaborators:
Terje Inderhaug,
Hordaland County Council
Bergen, Norway
Réjean Tardif
Économusée Society
Network, Eastern Canada
Tinna Arnadottir
Innovation Centre
Iceland
Olga BiskopstØ
Centre for Local and
Regional Development
The Faeroe Islands
Sarah Irwin
Causeway Coast and
Glens Heritage Trust
Northern Ireland
Mads Skifte
Tourism and Economic
Council of Greenland
Greenland
Ingela Fredell
Jämtland County
Council, Institute of Rural
Development
Sweden
Claude Dubé
Laval University,
Quebec, Canada

LEADER companies:
FORUM Connemara Ltd
Westmeath Community
Development Ltd

Compiled by:
Kevin Heanue

Technology

Key external stakeholders:

Rural artisan businesses, LEADER companies, Bord Bia, Fáilte Ireland.

Practical implications for stakeholders

This development project demonstrates an innovative model of rural artisan enterprise support.

- An Économusée is a rural artisan business that is supported to develop a tourism aspect to their operations, therefore, diversifying into the cultural tourism market and increasing their viability.
- The proven customised business support model promoted in this project could be mainstreamed to help a larger number of rural artisan companies.
- The project's targeted specialist business advice, mentoring and support can help rural artisan businesses harness the capabilities to diversify into the cultural tourism market.
- Transnational networking helps build rural enterprise competencies and opens up additional tourism related opportunities.

Main results:

Two Économusées one in County Galway, one in County Westmeath established:

- The Économusée in County Westmeath launched by the Canadian Ambassador to Ireland in March 2011. County Galway Économusée to be launched early 2012.
- Partnerships were established with LEADER companies to support Économusées established in each county.
- At the invitation of the BMW Regional Assembly, Dr. Kevin Heanue of the Teagasc team was the sole Irish NPP project member to present on the theme of Stimulating Rural Business Innovation at the NPP Annual Conference 2010.

Opportunity/Benefit:

A follow-on two and a half year project called Craft International started in July 2011 and ensures that the learning, materials, networking and expertise from this project remains available to the participating enterprises and stakeholders. More opportunities for dissemination will arise in the follow-on project and it also opens up the possibility of going one step closer to mainstreaming the Économusée idea.

1. Project background:

Between October 2008 and March 2009, Teagasc RERC was Lead Partner in an EC Northern Periphery Programme (NPP) Preparatory Project. As a result of that involvement, Teagasc was invited to be a partner in a main project together with eight other partners. This main project was called Economuseum Northern Europe (ENE).

The Northern Periphery Programme (NPP), which is part of the European Commission's Territorial Cooperation Objective, is one of thirteen INTERREG programmes aimed at encouraging and supporting transnational co-operation between the regions of Europe (for more details on the NPP see www.northernperiphery.net). The NPP 2007–2013 aims to help peripheral and remote communities on the northern margins of Europe to develop their economic, social and environmental potential. To do this, the NPP provides funding towards development projects that create innovative products and services.

Against that background, the ENE project sought to introduce the successful Canadian Économusée concept, quality assurance and business model to the NPP project area, including the Atlantic counties of Ireland. An Économusée is a rural artisan business that is supported to develop a tourism aspect to their operations, therefore, it diversifies into the cultural tourism market. The expectation was that at the end of the project (March 2011), 16 Économusées would be operational as a result of the project, two of which would be in Ireland.

2. Questions addressed by the project:

- Could the successful Canadian concept of Économusée be brought to Europe and put into use?
- Did the concept need to be altered for European rural enterprises and if so, how?
- Will European artisan businesses see value in the Économusée concept?

3. The experimental studies:

- A feasibility study, investigating the suitability of the artisan product and the commitment of the business owner to be badged as an Économusée, was commissioned from external consultants for each enterprise. This study also reviewed the physical suitability of the premises and alterations necessary to fulfill the six necessary components of an Économusée.
- Intensive business support was provided to each candidate Économusée pre and post the feasibility study.
- Customised promotional and interpretive material was developed for each Économusée.
- Linkages were facilitated between the candidate Économusée and the local LEADER companies.

4. Main results:

The Économusée concept needed remarkably little alteration for the European context:

- Two Irish artisan producers with international reputations validated the concept by being badged as Économusée.
- The follow-on project will seek to add value to the Économusée created in the first project.

5. Opportunity/Benefit:

- The Économusée concept, as an innovative rural enterprise support model, has been validated for Europe.
- A follow on two and a half year project called Craft International started in July 2011 and ensures that the learning, materials, networking and expertise from this project remains available to the participating enterprises and stakeholders.

6. Dissemination:

The knowledge developed in this project will be utilised in the follow-on Craft International Project, which seeks to create two additional Économusée (artisan food) in Ireland, and then focus on working with the two Économusée developed in the ENE project and the two new Économusée to optimize their internet sales, maximize (drawing on the Canadian experience) their point of sales techniques, and embed the Économusée network in Ireland in the strategic plans of key stakeholder organizations such as Fáilte Ireland and Bord Bia.

There are several project related websites with information on both the European and Canadian individual Économusée and the associated networks.

Économusée Northern Europe www.economusee.no Canadian Économ usée www.economusees.com/iensen.cfm

Main publications:

Heanue, K. (2010) Stimulating Rural Business Innovation, *Northern Periphery Programme Annual Conference,* September 9th , Bunratty Castle, Co. Clare. (Invited presentation)

Popular publications:

Heanue, K., McIntyre, B. and Heneghan, M. (2012) Supporting Rural Enterprise Innovation, *TResearch,* Vol. 7, No. 3. Autumn, pp 34–35

Deciphering the gap between good intentions and healthy eating behaviour

Project number:
5744
Date:
October, 2012
Funding source:
Teagasc
Project dates:
Oct 2008 – Dec 2011

Collaborating Institutions:
University College Cork (UCC)

Teagasc project team:
Dr. Sinead McCarthy (PI)
Mr. Paul Naughton

External collaborators:
Dr. Mary McCarthy, UCC

Compiled by:
Paul Naughton
Sinead McCarthy

Key external stakeholders:

Public Health Policy, consumer associations, food manufacturers

Practical implications for stakeholders:

The food choices of many Irish people do not correspond with healthy dietary guidelines and, therefore, we observe a rising prevalence of overweight and obesity in Ireland. Research shows that people are motivated to make healthy food choices, however, translating healthy intentions into healthy eating behaviour is challenging in the current food environment. The present study focused on dietary change with the objective of identifying the factors that impede and facilitate people to successfully translate their healthy eating intentions into behaviour.

- Unhealthy eating behaviour is often a result of automatic/ unconscious eating. This is also termed passive consumption and must be tackled in order to achieve a healthy and balanced diet.
- Having a dietary related goal is one of the key factors in successfully translating good intentions into good behaviour. However, the goal alone is not enough and must be supported by dietary self-control.
- Dietary planning and dietary self-monitoring are two activities that can help people to overcome passive consumption.

Technology

Main results:

- Food choice and eating behaviour is often driven by eating habits or passive consumption.
- People can counteract the factors that impede healthy eating behaviour by bringing order and structure to their diet. This can be achieved through advanced food planning and self-monitoring their dietary behaviour.
- People are likely to be successful in making a healthy dietary change if they set specific behavioural change goals and if they take control of their food consumption patterns.

Opportunity/Benefit:

In order to improve compliance with dietary guidelines, public health agencies should promote the idea of setting dietary related goals that are reasonable to achieve. The importance of setting sub-goals that are related to behaviour (e.g. eat less high calorie foods) rather than a physiological target (e.g. to feel healthier) should be highlighted. From an industry perspective, new/reformulated food products and associated marketing strategies that facilitate dietary self-control are likely to be received favourably by consumers. For example, manufacturers could incorporate easy-to-understand food labels as a value added brand feature. Food packaging is a product feature that can be developed to aid consumer self-monitoring. For example, markings on a packet may indicate how many calories are in the quantity of food consumed and this may also help people to maintain control over portion sizes. Augmented product features could include internet and phone application dietary planners that can help people to track calories consumed.

1. Project background:

In health behaviour research it has been found that healthy eating intentions often do not result in healthy eating behaviour. This is termed the intention-behaviour gap. Healthy eating is regarded as 'self-directed' behaviour, given that individuals can contribute to their own health and well-being through adopting particular health-enhancing behaviours and avoiding health-compromising behaviours. Therefore, it is useful to identify what are the factors associated with successfully bridging the gap between intention and behaviour in terms of healthy dietary choices?

2. Questions addressed by the project:

- What are the barriers to eating and maintaining a healthy diet?
- What factors may facilitate people to implement their healthy eating intentions?

3. The experimental studies:

Qualitative in-depth interviews were conducted with 80 Irish adults who participated in the National Adult Nutrition Survey (NANS). In these interviews, participants provided accounts of their food choices and eating behaviours over their life course. Twelve of these interviews were analysed in depth in order to identify all discourse related to food choice strategies/goals and successful/failed attempts to make dietary changes. Analysis of the interviews indicated that three important issues mediate the intention-behaviour relationship; unconscious patterns of behaviour, dietary self-control and dietary engagement. These issues were further examined in a questionnaire administered to a representative sample of 500 adults. The questionnaire investigated in detail sugar/confectionery consumption intentions and behaviour. The amount of sugar consumed by individuals is a public health concern in Ireland (Department of Health, 2012) and it may underlie the recent industry trend of reducing the amount of sugar in products (Leatherhead, 2011).

4. Main results:

People's food choices and eating behaviours are often the result of well established habits. In the study, confectionery habit explained 26% of the variance in sugar consumption. Furthermore, people often make instinctive rather than considered decisions to eat foods that contain high amounts of sugar. Attaining dietary self-control is essential in order to break unhealthy patterns of behaviour as indicated by the significant negative relationship between self-control and confectionery habit ($b = -0.26$, $p = < 0.01$). In addition to dietary self-control, the findings indicate that people who plan and monitor their dietary behaviour are less likely to have confectionery consumption habits ($b = -0.24$, $p = < 0.01$). Furthermore, individuals who target specific behavioural change goals are likely to be more successful in making a healthy dietary change compared with individuals who have vague or no goals. The analysis indicates that individuals who are motivated to reduce their sugar consumption are eight times more likely to successfully make a change if they set a dietary goal.

Finally, in order to assist people to eat a healthy diet, it is necessary to identify healthy eating segments in the market. The findings from this study indicate that identifying people's willingness to make and maintain healthy dietary change is an effective way to divide the market and target health orientated individuals. In relation to confectionery food consumption, four segments were identified;

- People who tried to maintain their level of sugar consumption over the previous six months and are adhering to recommended sugar consumption guidelines (14%)
- People who tried and succeeded in reducing their sugar consumption in the previous six months and are adhering to recommended sugar consumption guidelines (41%)
- People who tried but failed to reduce their sugar consumption in the previous six months and are not adhering to recommended sugar consumption guidelines (23%)
- People who made no effort to change sugar consumption in the previous six months and are not adhering to recommended sugar consumption guidelines (22%)

5. Opportunity/Benefit:

Health promoting messages should be designed with the objective of helping people to better attain control over their diets. Based on the findings from this study, people should be encouraged to set dietary related lifestyle goals that are reasonable to achieve. This should entail communications that emphasise the positive implications of switching to a healthy diet. People's expectations need to be grounded by providing information on the likely outcomes associated with a specific dietary change. Therefore, the importance of setting sub-goals that are related to behaviour rather than a physiological target should be highlighted. For example a long term abstract goal 'to feel healthier' influences a medium term goal to lose weight which influences a shorter term goal or behavioural intention to eat less high calorie foods. People need to be encouraged and facilitated to self-monitor dietary behaviour related to short and medium term goals, which are easier to evaluate. Food packaging is a product feature that can be developed to aid consumer self-monitoring. For example, markings on a packet may indicate how many calories are in the quantity of food consumed and this may also help people to maintain control over portion sizes. Augmented product features could include internet and phone application dietary planners that can help people to track their food intake and calories consumed.

Planning meals in advance is another means towards dietary self-control. Food labelling that is easy to understand will help people to plan and monitor their diets. There may be an opportunity for food manufacturers to incorporate easy-to-understand food labels as a value added brand feature; this will require food manufacturers to go beyond basic regulatory guidelines. New product developments and reformulations of existing products will facilitate dietary self-control. For example, popular food/snack products should be reformulated to offer low/fat/salt/sugar variations. From a public policy perspective, information campaigns should be based on identifying common barriers to healthy eating, such as time constraints and stress, and suggestions of how to overcome these constraints e.g. through planning and preparing daily meals in advance. However, dietary self-control alone may not be enough to counteract the affects of unconscious eating behaviour and, therefore, it may be necessary to alter the food environments that people are regularly exposed to.

6. Dissemination:

Presented at the Agricultural Economic Society of Ireland (AESI) annual conference 2010 and the AESI student seminar 2011

Presented at the Nutrition Society's 2010 Postgraduate Research Meeting

Presented at the Walsh Fellowship Seminar 2010 and 2011

Presented at the Food, Health, Choice and Change Conference 2012

Popular publications:

Naughton, P. McCarthy, S., McCarthy, M. (2010) 'Mind the gap; deciphering the gap between good intentions and healthy eating behaviour' *T-research* 5: 18–20.

Deciphering the gap between good intentions and healthy eating behaviour, The Teagasc Food Innovator, issue 11, Autumn 2011.

Project number:
5734
Date:
May, 2012
Funding source:
Teagasc
Project dates:
Jan 2008 – Dec 2011

Farm fatalities in Ireland

Collaborating Institutions:
Health and Safety Authority (HSA)

Teagasc project team:
Dr. David Meredith (PI)
Dr. Jim Grant
Mr. John G. McNamara

Compiled by:
David Meredith

Key external stakeholders:

Health and Safety Authority of Ireland, Teagasc, farmers.

Practical implications for stakeholders:

The outcome of this research includes:

- The need to target the farm safety message at particular groups within the farm population at specific times of the year.
- Demonstrating that the farm accident fatality rate has increased.

Main results:

- The age profile of those involved in a fatal farm accident changed substantially from the early 1990s.
- During this period fatalities became increasingly characterised by an increasingly elderly age profile of those involved in fatal accidents.
- The fatality rate increased from 15 to 22 per 100,000 workers.
- The primary causes of farm fatalities are vehicle related followed by animal related.
- Fatalities are most prevalent during the winter and summer months.

Opportunity/Benefit:

- The increasing number of fatalities amongst older farmers suggests that Ireland's Farm Safety Partnership needs to place greater emphasis of raising awareness amongst older farmers of fatality risks.
- There is a concern that the farm safety message may become overly focused on elderly farmers. Specific programmes need to be developed to change the behavior of younger farmers to ensure that their approach to farming does not result in fatal accidents as they get older.

Technology

1. Project background:

It is widely recognised that farming constitutes a dangerous occupation resulting in high levels of work-related injuries and fatalities. A review of literature concerned with occupational health of farm workers and farm fatalities finds that there is a growing body of research covering the incidence and cause of injury and death amongst farm populations. Relatively little direct consideration has, however, been given to the demography of fatalities. It was also established during the literature review that little empirical research has been published concerning farm fatalities in Ireland. This is particularly surprising given that farm fatalities are an ongoing issue of serious concern to policy makers, industry representatives and farm households.

The primary aim of this research was to address this knowledge gap and, in doing so, develop a better understanding of farm fatalities in terms of the age profile of victims, the spatial distribution of incidents, causes and timing.

2. Questions addressed by the project:

- What is the age profile of farm fatalities in Ireland and how has this changed over time?
- What is the geographic distribution of farm fatalities in Ireland?
- Are there geographic concentrations in farm fatalities?
- What are the primary causes of farm fatalities?
- Are the primary causes similar for all cohorts of farmers?
- When do most fatalities occur?

3. The experimental studies:

Main components of this methodology are:

(a) A spatial dataset containing the details of every fatal farm accident during the 1992–2010 period, including location, victim characteristics and information concerning the incident, was developed.

(b) A comparative assessment of changes in farm fatalities was undertaken using descriptive statistics.

(c) Statistical analysis was undertaken to establish if the age profile of farm fatalities changed during the period 1993–2010.

(d) Spatial analysis was undertaken to establish whether there are spatio-temporal clusters of farm fatalities in Ireland.

4. Main results:

- The results of the research point to the impact changes in farming and farm households are having on farm safety. Declining numbers of children in farm households, reduced numbers of farmers and the increasingly elderly profile of the farm population underpin changes in the profile of farm fatalities in Ireland.
- The average number of annual farm fatalities in Ireland declined from roughly 18 to 16 per year between 1993–1997 and 2003–2007 respectively.
- The age profile of farm fatalities in Ireland changed over the period 1993–2010. Fewer deaths amongst those under 55 years of age were recorded. Unfortunately, greater numbers of fatalities were recorded amongst farmers over 55 years of age.
- The fatality rate has, however, increased from 15 to 22 per 100,000 workers. This is an important finding; it indicates that whilst the number of fatalities is declining they are not falling as fast as the number of people working in agriculture.
- The primary causes of farm fatalities are, in descending order, tractor and other vehicles, machinery, animals, trips and falls, drowning, collapse of working platforms, wood/forestry related, electrocution and other.
- Whilst tractor and machinery related incidents are the most common form of fatality to farmers, animal related fatalities are largely concentrated amongst those over 45 years of age.
- Whilst fatalities can occur at any time of the year, they are most prevalent during the winter and summer months. Fatalities amongst younger people (less than 29 years of age) are concentrated in the summer period.
- Geographically, farm fatalities became increasingly concentrated in the South-West and West between 1999 and 2004. This spatial pattern has since changed with a greater dispersion throughout the country.

5. Benefit:

1. The study established the profile of farm fatalities in Ireland and developed a better understanding of the changing age distribution, timing, causes and spatial distribution of fatal incidents.
2. The results informed the activities of the Farm Safety Partnership and the Health and Safety Authority in terms of the dynamics of farm fatalities in Ireland. The results were used to target publicity campaigns regarding farm safety towards elderly farmers and the timing of these campaigns, i.e. during Winter and Autumn.

6. Dissemination:

A series of seminars that drew on the research findings were held in locations throughout the country in 2009. These seminars targeted Teagasc clients and farm households. The seminars were well attended by roughly 800 persons.

The results of the research were presented at a number of national and international (Canada and Denmark) conferences concerned with health and safety of farmers and farm workers.

Main publications:

Meredith, D. (2010) Farm Fatalities in Ireland. *TResearch,* 5, 42.

Meredith, D. & J. McNamara (2008) Farm Fatalities in the Republic of Ireland *TResearch,* 3, 44 – 45.

Osborne, A., C. Blake, D. Meredith, J. Phelan, J. McNamara & C. Cunningham (2012) Work-related musculoskeletal disorders among Irish farm operators. *American Journal of Industrial Medicine*.

Osborne, A., C. Blake, B. Fullen, D. Meredith, J. Phelan, J. McNamara & C. Cunningham (2012) Risk factors for musculoskeletal disorders among farm owners and farm workers: A systematic review. *American Journal of Industrial Medicine*. DOI: 10.1002/ajim.22001

Osborne, A., C. Blake, B. Fullen, D. Meredith, J. Phelan, J. McNamara & C. Cunningham (2011) Prevalence of musculoskeletal disorders among farmers: A systematic review. *American Journal of Industrial Medicine,* 55, 143–158.

Osborne, A., C. Blake, J. McNamara, D. Meredith, J. Phelan & C. Cunningham (2010) Musculoskeletal disorders among Irish farmers. *Occupational Medicine,* 60, 598–603.

Popular publications:

The issue of farm safety and farm fatalities in particular has received significant media attention in both the farming and mainstream media. This led to the research results being used in a large number of newspaper articles and presented on national, regional and local radio.

Rural Economy & Development Programme

Economic evaluation of public access provision to Irish farmland

Project number
5655
Date:
January, 2011
Funding source:
DAFF
Project dates:
Nov 2006 – Sept 2010

Key external stakeholders:

Department of Agriculture, Fisheries and Food, Department of Environment and Local Governmen, Department of Transport, Tourism and Sport, the Irish Sports Council, local authorities, farm organisations, walking/hiking groups', representative bodies, community groups.

Practical implications for stakeholders:

Results from this research will assist policy development in the area of walking-based recreational tourism across the Republic of Ireland.

Main results:

- Twenty one per cent of landowners were willing to participate in a proposed public access recreational walking-based scheme (under certain conditions) on a free of charge basis while 28 per cent indicated that they would be willing to participate if given financial compensation. A total of 51 per cent of farmers indicated they would not participate in such a scheme.
- The mean willingness to accept payment for those farmers seeking compensation was 46 cent per linear metre. When combined with farmers willing to provide access for free, the average willingness to access for willing farmers was 27 cent per linear metre.
- The general public generally preferred shorter walks (1-2hrs) and generally would be willingness to pay for the provision of trail facilities such as a gravel path, car parking facilities, fencing and signage.

Collaborating Institutions:
National University of Ireland, Galway.

Teagasc project team:
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Dr. Peter Howley

External collaborators:
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Stephen Hynes, National University of Ireland Galway, Galway
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Compiled by:
Peter Howley

Technology

Opportunity/Benefit:

The analysis conducted and published in this project can help inform policy formulation in the Republic Ireland in the area of public access provision for recreational walking. The research examines both the demand and supply sides of the policy issue.

1. Project background:

Despite the potential benefits accruing from recreational use of the rural landscape, public access to private farm land is a contentious issue with public access generally at the discretion of the landowner. This is not a situation unique to the Republic of Ireland as issues relating to public access to land for outdoor recreation are a contemporary preoccupation amongst governments worldwide. Rural based recreational activities provided through amenities such as well maintained and developed walking routes have the potential to deliver significant economic benefits to rural areas through tourism based revenue and as such can be an important tool for rural and regional development. For instance, in 2007, a total of 517,000 overseas visitors to the Republic of Ireland undertook some form of walking activity which was estimated to be worth €340 million to the Irish economy and there is potential to grow this market. The present situation where public access is limited and dependent on the goodwill of landowners is a serious constraint on tourism development. Through original survey research the aim of this project was to examine the issue of public access from the perspective of the general public (demand side) as well as the farmer landowner (supply side).

2. Questions addressed by the project:

Given the divisive nature of this issue in the Republic of Ireland the research was undertaken to examine both individuals' demand for access to the rural landscape and farmers' willingness to allow individuals to access their land for recreational activities. With this aim in mind, two nationally representative surveys, one of the farming population and one of the national population, were carried out to examine this issue. More specifically, this project used non-market valuation techniques to examine farmers willingness to accept estimates (WTA) for public access provision and individuals' willingness to pay (WTP) for the provision of walking trails. Given that public access to the countryside can be classed as a public good, obtaining an economic value for provision aids policy decisions in this area.

3. The experimental studies:

Data collection – Farmers willingness to accept:

The data source used to examine landowners WTA for improved public access to their land for recreational was the Teagasc National Farm Survey (NFS) in 2007. The NFS is collected annually as part of the Farm Accountancy Data Network (FADN) requirements of the European Union. A supplementary questionnaire eliciting landowner attitudes on the provision of public access for walking was conducted in conjunction with the regular NFS data collection. In carrying out the survey (n=975) each interviewee was asked to indicate their level of participation in a five year walking scheme under certain conditions. The scheme conditions described identified a specific route, and specified that walkers would be expected to follow a countryside code, no permanent right of way would be established, full public liability insurance indemnification would be provided and maintenance costs for the walkway would be covered. Landowners were then given three choices indicating that they would either; not participate in such a scheme, participate on a free-of-charge basis or participate only if given financial compensation. Those respondents who indicated that their participation was dependant on financial compensation were then presented with a contingent valuation WTA scenario to establish the minimum amount a landowner would be prepared to accept (€ / per annum) per metre of walkway crossing their land to ensure participation. Farmers have become accustomed through participation in agri-environment schemes to making trade-off between production and provision of environmental public goods and this was the template adopted in this instance.

Data collection: Individuals' WTP for walking trails

The data source utilised to determine individuals' demand for walking trails was a nationally representative survey (n=601) of the general population based on age, gender, socio-economic and geographical stratification of respondents. A labelled choice experiment was used to determine individuals' preferences for four different types of farmland walking trails; these were a.hill walk, riverside walk, field walk and bog walk. These were the walking trail types most commonly identified by respondents in focus groups that were conducted to inform the questionnaire design as being particularly important. Two focus groups were also held following the survey to help provide a deeper understanding of issues raised in the survey.

4. Main results:

Farmers willingness to accept for public access provision

Twenty one per cent of landowners were willing to participate in the proposed public access scheme on a free of charge basis (providing there were no personal costs to them) while 28 per cent indicated that they would be willing to participate in a walking scheme if given financial compensation. The remainder of the sample (51%) reported that they would not participate in this scheme even if given financial compensation. The conditions under which farmers were willing to grant access included no permanent right of way being established, full public liability insurance indemnification and finally the maintenance costs for the walkway being covered. This has significant implications for the public provision of walking trails as it suggests that there is a significant opportunity to provide a large number of walking trails at relatively low cost. For the cohort (29 per cent of farmers) who sought financial compensation for access provision, the mean WTA was estimated at 46 cent per metre of walkway per annum. This would suggest an average cost of €460 per kilometre of walkway per annum for these landowners to cooperate with providing walking trails.

As described above, there were approximately an equal proportion of farmers willing to participate in the proposed walking scheme (21% for free and 28% with compensation) and those not willing to participate (51%). Farmers who were not willing to engage with improved public access provision cited reasons such as nuisance impacts (interference with agricultural activities), public liability concerns and potential invasion of privacy as the main reasons why they would be unwilling to allow public access to their farm land for walking activities. Econometric analysis was employed to better understand the major factors influencing farmers' willingness to participate in the walking scheme described above and the results are summarised below.

Previous experience of walkers accessing their land for recreation had a positive effect on the probability of landowners' participation in the proposed public access scheme. This indicates that what often may be unfounded negative perceptions surrounding walking activity by landowners with low exposure to walkers may be a factor influencing non-participation rates. Potential public liability was also found to be a significant factor; landowners with relatively large insurance premiums were much less likely to participate in this scheme.

Household demographics also strongly influenced the probability of farmers' willingness to participate in the walking scheme. More specifically, landowners willing to engage for free and for compensation had significantly less household members in the 65 years and over age bracket. Landowners of elderly years are traditionally associated with a more conservative approach on issues relating to land and property rights, particularly in the Republic of Ireland. It should also be noted that landowners willing to participate for free tended not to have young children (less than 5 years of age).

Location also appeared to be an important variable influencing participation. Farmers in the Midlands and Eastern part of the country are much more likely to be unwilling to participate in the hypothetical walking scenario than farmers along the Western seaboard. The Midlands and Eastern part of the country has a higher proportion of larger, more intensive farm holdings and less of a tradition of walking based recreational activity. As such, farmers in this region would be expected to be more concerned with the potential negative impacts on their production activity arising from members of the general public using their land. On the other hand, farms along the Western seaboard are, for the most part, extensive in nature and operate on relatively marginal soils. These farmers generally have lower incomes and lower opportunity costs to agriculture and as such have fewer concerns surrounding potential negative effects on production activity.

Individuals' demand and views towards the provision of walking trails

This project examined individuals' preferences towards four different types of walking trails, namely a 'river walk', 'field walk', 'hill walk' and a 'bog walk'. Respondents had a strong willingness to pay for all the walking trail types. The 'river walk' was found to be the most highly valued by respondents. This is consistent with many landscape preference studies in which a water related feature is often reported as the most desirable landscape feature for individuals. The next most important trail type was the field walk which was closely followed by the hill walk. The bog walk was the least attractive trail type for respondents. In relation to trail facilities, respondents generally had a positive willingness to pay for the provision of trail facilities such as a gravel path, car parking facilities, fencing and signage. Respondents also favoured shorter walks (1-2 hours). In particular, individuals who are relatively older, female and/

or have children are much more likely to rate the provision of various trail facilities as important. It could be hypothesised that the provision of trail facilities to improve safety and ease of use is relatively more important for these individuals.

Focus group participants stressed the importance of addressing the present uncertainty surrounding public access to farmland for recreational activities. This, in turn, will, as one participant described "*help tourism which will be a big help for the local community*". Participants reported that with the current situation they often felt nervous about using informal walking trails as they were unsure whether landowners wanted them accessing their land. As one respondent commentated in describing the potential advantages of formalised access: *"I have felt quite nervous before coming across people in places which is quite stressful and I would rather have a relaxed walk knowing I have the right to be there".*

5. Opportunity/Benefit:

This research can aid policy development in the area of public access provision for recreational walking across the Republic of Ireland. The primary stakeholders for this research project are national policymakers such as the Department of Agriculture, Fisheries and Food, Department of Transport, Tourism and Sport, Department of Environment and Local Government, Local Authorities, the Irish Sports Council, farm organisations, walking groups, community groups, the policy making community in general.

6. Dissemination:

The results of the project have been presented at a variety of both national and international conferences as well as academic seminars and policy workshops. These included the Agricultural Economics Society, the Teagasc Rural Development conference, the Irish Economic Association conference and a Public Access Stakeholders workshop.

A number of academic journal articles have been published on the back of this research.

Main publications:

Buckley, C., Hynes, S.P. and Van Rensburg, T. (2008) Public access for walking in the Irish Countryside - can supply be improved. *Tearmann*, pp. 1-14.

Buckley, C., Van Rensburg, T, Hynes, S and Doherty, E. (2009). Walking in the Irish Countryside: Landowner preferences and attitudes to improved public access provision. *Journal of Environmental Planning and Management*, pp.1053-1070.

Howley, P., Doherty, E., Buckley, C., Hynes, S.P. Van Rensburg, T. and Green S. (2012). Exploring preferences towards the provision of farmland walking trails: A supply and demand perspective. *Land Use Policy*, 29, 111-118.

Howley, P., Buckley, C., Hynes, S. and Van Rensburg, T. (2010). Understanding individuals' preferences for coastal walking trails: an Irish case study, *SEMRU Working Paper.*

Popular publications:

Hynes, S., Buckley, C. (2007) Putting a value on access to farmland. *Tresearch*, 2(3), 16-19.

Buckley, C., Hynes, S., Heneghan, M., van Rensburg, T, 2008. Walking and Rural Tourism in Ireland. Paper presented at the Teagasc Rural Development Conference 2008.

Welfare Quality

Key external stakeholders:

Farmers, farmer associations, animal breeding organisations, retailers, consumers, veterinarians, European and national politicians, policymakers.

Practical implications for stakeholders:

Animal welfare is of considerable importance to European consumers. Nowadays food quality is not only determined by the overall nature and safety of the end product but also by the perceived welfare status of the animals from which the food is produced. Improving the animal's welfare can positively affect pathology and disease resistance and also has a direct bearing on food quality and safety. This research project was designed to develop European standards for on-farm welfare assessment and product information systems as well practical strategies for improving animal welfare.

Standards for on-farm welfare assessment and information systems should be based upon consumer demands, the marketing requirements of retailers and stringent scientific validation. Teagasc research provided information on consumer demands. The wider project provided results that were translated into reliable on-farm systems for monitoring the welfare status of cattle, pigs and poultry and developed practical improvement strategies that provide producers with the opportunity to enhance the welfare status of their stock. Information from the broader project is available from www.welfarequality.net/everyone.

Project number:
4854
Date:
June, 2009
Funding source:
EU Framework 6
Project dates:
May 2004 – Apr 2009

Collaborating Institutions:
National Institute for Consumer Research Norway
University of Cardiff, Wales
University of Pisa, Italy
Wageningen University and Research Centre, The Netherlands
University of Stockholm, Sweden
University of Toulouse, France
University of Reading, UK
Teagasc, Ireland

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Dr. Jean-Pierre Poulain, University of Toulouse
Dr. Richard Bennett, University of Reading

Compiled by:
Bridin McIntyre

Technology

Main results:

Teagasc was part of a group of social scientists which examined existing knowledge on consumer beliefs, concerns, expectations, and use of information on animal friendliness, with particular emphasis on product labeling across six European countries (Great Britain, Italy, Hungary, Norway, Sweden and The Netherlands). This work was based on 48 focus group discussions that were undertaken by the research teams. It highlighted that consumers were generally concerned about, and knowledgeable of, the connection between animal welfare and food quality; that they make distinctions between "factory farms" (low animal welfare) and alternative systems such as organic, traditional, free-range, small scale (high animal welfare); and that they require a clear, standardized logo verified by a competent independent authority to communicate animal welfare standards. Price, lack of trust in the claim made on labels; convenience and limited availability of welfare-friendly goods were barriers to purchase of animal welfare friendly foods.

Opportunity/Benefit:

The project provides standardised welfare measures that can be converted into accessible and understandable information to allow clear marketing and profiling of products.

1. Project background:

This study is part of the Welfare Quality® research project which has been co- financed by the European Commission, within the 6th Framework Programme, contract No. FOOD-CT-2004–506508. Welfare Quality is about integration of animal welfare in the food quality chain: from public concern to improved welfare and transparent quality. This project aims to accommodate societal concerns and market demands, to develop reliable on-farm monitoring systems, product information systems, and practical species-specific strategies to improve animal welfare. Forty institutes and universities (representing thirteen European countries) with specialist expertise participated in this project.

2. Questions addressed by the project:

- What are consumer concerns about food animal welfare?
- What type of information is demanded by consumers?
- Develop effective communication and information strategies.
- How can consumer barriers to purchasing welfare friendly products be overcome?
- Improve the understanding of consumers' expectations concerning information on animal welfare in various countries and on food distribution systems.

3. The experimental studies:

A qualitative research approach was used. Forty-eight focus groups were conducted using an experienced moderator. 349 different participants from seven European study countries: France, Hungary, Italy, the Netherlands, Norway, Sweden and the UK were recruited. The criteria used to select participants across countries included; urban mothers, rural women; married or living with a partners but no children living at home (empty nesters); seniors; young singles; 'politically active'/ vegetarian.

Individual research teams were also able to select a seventh country-specific group that consisted of consumer-citizens who were of particular interest within their study country (UK-'Young singles north', Netherlands-no extra group, France-'Ethnic minorities', Sweden-'Politically active fathers', Norway- 'Hunters', Italy-'Gourmets', Hungary-'Health conscious').

In order to ensure best practice and to standardise approaches across the different study countries a detailed focus group protocol was produced, which provided national research teams with a range of practical information and suggestions about how to undertake the focus group research. The protocol included details regarding focus group techniques, the roles of the facilitators, how the focus groups should be transcribed, etc. The focus groups were recorded and transcribed. The transcriptions were imported into N'Vivo and analysed.

4. Main results:

- Consumers were concerned about the welfare of farm animals and were knowledgeable about the connection between animal welfare and food quality. However, consumers were less knowledgeable about more technical welfare issues such as animal diseases and animal behaviour and some of the complexities that might influence the link between high animal welfare and high food quality.
- Consumers made distinctions between 'factory farms', which they perceived as having low levels of animal welfare, and alternative systems (such as organic, free-range, traditional, small scale) which were perceived to offer higher levels of welfare.

Consumers expressed a number of preferences regarding form and content of product information and labeling about farm animal welfare. They required a logo that would be clearly legible and any unfamiliar terms should be clearly explained using in-store information, leaflets and websites. The label should be trustworthy and certified, monitored and enforced by a reliable body. Labeling should be standardised across different retail formats. Consumers expressed a desire to receive specific information regarding; the origin and traceability of the product; the nature of the feed given to animals and whether the animal had been given GM feeds or antibiotics; how the animals were treated; whether the animals had access to the outdoors; the distance the live animal had to travel.

- Consumers believed that welfare-friendly products were healthier, were of a higher quality and tasted better than lower welfare products. They also believed that welfare-friendly animals received fewer routine medicines such as antibiotics.
- Consumers identified a range of negative attributes and barriers that might prevent them from purchasing animal welfare friendly foods, these included; price and lack of trust in the claim made on labels; convenience; limited availability of welfare-friendly goods.
- Consumers acknowledged the priority and relevance of addressing issues of animal suffering before addressing issues concerning positive aspects of animals' quality of life (e.g. freedom to move, social contact, sexual reproduction). Consumers, and in particular Dutch consumers, expressed concern that issues of animal suffering still need to be addressed, as they believed that animal suffering should no longer exist in a 'civilised' Europe and that a new standard for animal welfare should deal with the positive aspects of animals' lives.

5. Opportunity/Benefit:

The provision of standardised welfare measures that can be converted into accessible and understandable information allows clear marketing and profiling of products.

Involvement in this project is enabling Teagasc to make a major contribution to the development of consumer based pan-European standards for on-farm welfare assessment and product information systems as well as practical strategies for improving animal welfare. Implementation of such a system will have a major impact on the marketing of beef, milk, poultry and pigmeat throughout the EU.

6. Dissemination:

www.welfarequality.net

Main publications:

McIntyre, B. and Cowan, C. 2005. Welfare quality, consumer concerns: Hungary, focus groups, Report for EU Commission

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