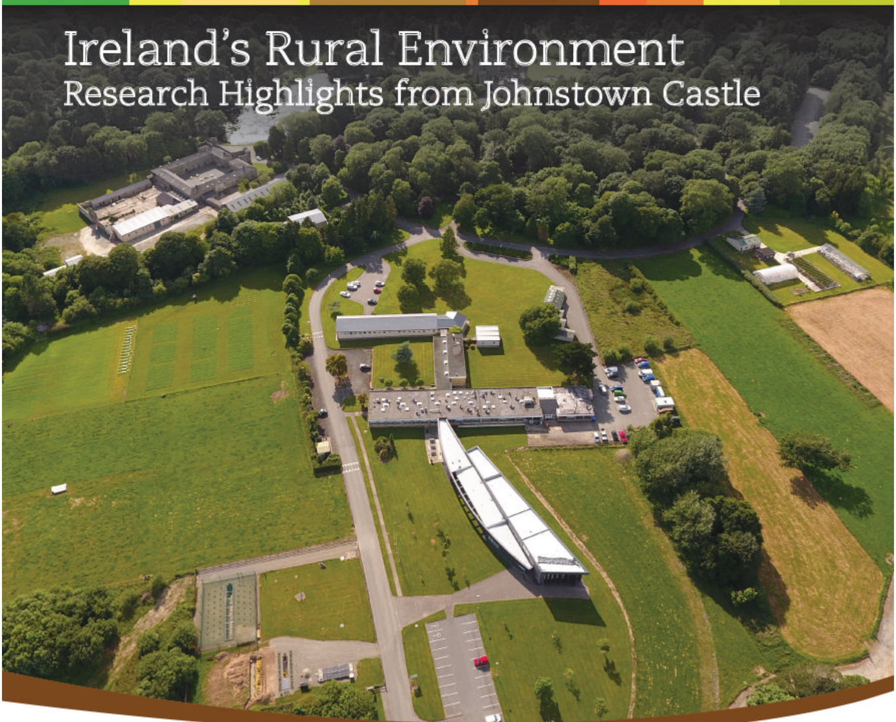
Crops,
Environment
& Land Use
Programme
Johnstown Castle

Ireland's Rural Environment
Research Highlights from Johnstown Castle



Teagasc

Agriculture and Food Development Authority

Ireland's Rural Environment:

Research Highlights from Johnstown Castle

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Agriculture and Food Development Authority

www.teagasc.ie/environment/johnstown

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Welcome to Johnstown Castle

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Welcome

We are pleased to welcome you to Johnstown Castle, Ireland's leading research centre for soils and the rural environment. Johnstown Castle is one of six research centres in Teagasc, the Irish Agriculture and Food Development Authority, which conducts agricultural research, education and advice in the Republic of Ireland. Johnstown Castle is responsible for research on nutrient efficiency, gaseous emissions, agro-ecology, soils and water quality.

Facilities

The Johnstown Castle estate covers approximately 400 hectares, of which 190 is farmland, with the balance being forestry, parkland, and lakes. Our centre consists of three research farms on the estate: a dairy farm and two drystock farms. These enterprises facilitate field experiments and component research on solutions for sustainable farming.

Johnstown Castle boasts state-of-the-art laboratories to support the research programme with water, air, soil, plant, microbiology and ecology facilities. The research programme includes 12 permanent researchers, 8 contract researchers and 15 technical staff. In addition, between 20 and 30 post graduate students from Irish and international universities avail of Teagasc Walsh Fellowships at our centre at any one time, and their studies are an integral part of our programme.

Our mission

The aim of the Teagasc Crops, Environment and Land Use Programme is to develop and transfer cost-effective sustainable agricultural production systems along with evidence based knowledge to support and underpin the development of a profitable, competitive and environmentally sustainable agri-food sector.

Given the current and future challenges to our food supply and to the environment, sustainable intensification of agricultural production is emerging as a national and international priority. Sustainable intensification is defined as producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services.

The Teagasc Crops, Environment and Land Use Programme is at the heart of the sustainable intensification of the Irish agri-food sector. Land use in Ireland is facing a complex array of challenges. Food Wise 2025 sets out challenging production targets, whilst there is ever increasingly stringent environmental legislation coupled with consumer demands for sustainably produced agricultural goods. The main challenge is to reconcile the imperative of economic sustainability with the demands of minimising impacts of agriculture on the wider environment. Our mission at Teagasc, Johnstown Castle is to develop technologies and management strategies that facilitate farmers to combine economic sustainability with environmental sustainability.

Environmental Research

The key to combined economic and environmental sustainability is to develop technologies and strategies that reduce losses to the environment and save farmers money. To achieve this, Johnstown Castle operates 5 agri-environmental research programmes:

1. Nutrient Efficiency: aims to maximise the utilisation of nutrients in soil, organic manures and inorganic fertiliser. Its primary output is the National Nutrient Advice “Green Book” and the further development of Nutrient Management Planning online.

2 Gaseous Emissions: aims to understand and mitigate losses of greenhouse gases and ammonia. Our focus is on mitigation of nitrous oxide emissions and carbon sequestration; our results feed directly into national inventories.

3. Agro-ecology: aims to develop synergies between ecology and agriculture by identifying management practices to enhance biodiversity in both high nature value farmland and intensively managed systems. Understanding the positive interactions between ecology and productivity is important for sustainable production.

4. Soil Quality and Classification: aims to develop soil management strategies tailored to maximize soil functions (e.g. food & fibre production, C-sequestration, water purification), and to avert threats to soil quality. This is underpinned by the recently developed Irish Soil Information System.

5. Water Quality: aims to understand the hydrological and biogeochemical processes that govern the transport of pollutants to water. This understanding underpins the development of new technologies to reduce losses.

Research Infrastructure

Continuing investment in our research facilities ensures that we are nationally and internationally recognised as a centre of excellence for sustainable agricultural production. Our facilities include highly instrumented agricultural research catchments, environmental control laboratories, soil monolith lysimeters, and advanced environmental research laboratories. We are highly pro-active in collaborating with universities and research institutes in Ireland, the EU and around the world. This is facilitated through joint projects and Teagasc’s Walsh Fellowship Scheme (www.teagasc.ie).

Our programme is funded by, among others, the Department of Agriculture, Food and Marine, the National Development Plan, EPA, EU and Global Research Alliance.

Finally

The primary focus of our research is to provide a strong research programme that facilitates sustainable farming. This booklet will give you a flavour of the current research in our centre and introduce you to the staff and students involved.

Lab Support at Johnstown Castle

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Laboratory Manager, Johnstown Castle
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Introduction

The environmental research laboratory at Johnstown Castle takes an integrated approach to providing technical support to the research programme. The laboratory is comprised of an experienced technical team who work in combination with the research team to deliver project goals. The scientific output of the laboratories is directed by the research programme under the leadership of Dr. Karl Richards, Head of ESLU Department; Johnstown Castle. Details of these staff members and their laboratory focus area are outlined below:

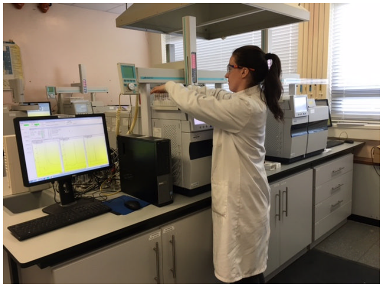
Laboratory Staff:

A. Fenelon, PhD, Spectroscopy.
L. Moloney Finn, MSc, ICP and QC.
B. Healy, PhD, Soil technologist.
C. Somers, MSc, Soil physics.
C. O' Connor, MSc, Elemental analysis.
L. Roche, PhD, Gas analysis.
D. Brennan, MSc, Water analysis.
M. Radford, MSc, Water analysis.
S. Colfer, Soil and plant.
M. McGuire, Lab support.

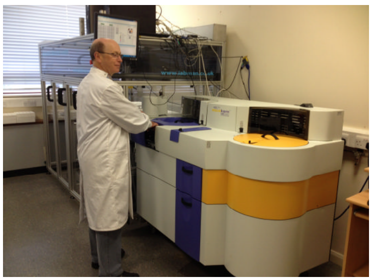
Laboratory facilities:

Outlined below are the analytical capabilities of the laboratories according to their lab function:

Gas lab*:* Analysis of greenhouse gases such as N_2O, CH_4 ,CO_2 and SF_6. The lab is resourced with 4 GC's equipped with TCD, ECD and FID detectors. All GC's are supported with combiPal autosamplers for high throughput headspace analysis.



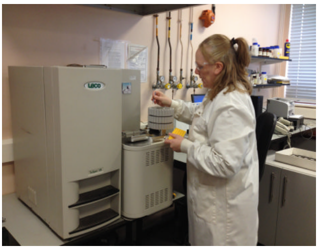
Water Lab: Nutrient, organic and isotopic analysis of ground and surface water samples. Mineral N analysis of soil extracts. The water lab is equipped with automated instrumentation including AquaKem 600, IC, HPLC, Gamimede-N, Ganimede-P, Automated BOD, TOC/TN, MIMS.



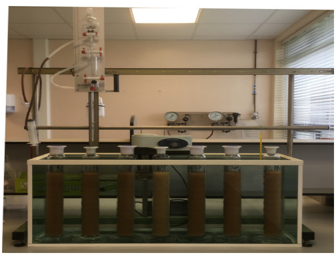
Soil Lab: Determination of chemical and nutrient parameters in soil using traditional wet chemistry techniques. The lab is equipped with AA, Flame photometer, UV Vis spectrometer, automated pH and diluter systems. The current focus of the soil lab is method development of traditional soil chemical tests.

ICP lab: Analysis of Major nutrients and trace elements in soil, water and plant samples. The ICP lab is equipped with an Agilent 720 ICP-OES and Perkin Elmer Elan ICP MS

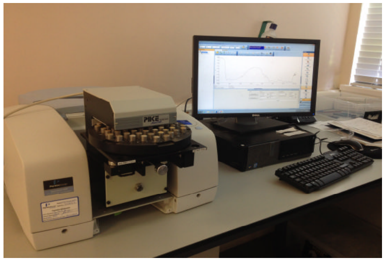
Elemental analysis lab: Analysis of C, N and S in soil and herbage samples. Elemental analysis is executed on a LECO Truspec and Elementar Macro Cube instruments.



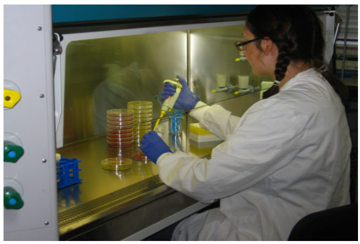
Soil physics Lab: The soil physics lab is equipped for determination of soil physical properties and processes. Hyprop, pressure plates and Kaolin sand box are used for generating soil water retention curves. Classification of soils is achieved using laser diffraction and particle size pipette methods.



Spectroscopy lab: Development of non- destructive spectroscopic methods for the analysis of soil and herbage samples. The lab is equipped with a *Spectrum* 400 NIR/MIR spectrometer, Handheld Agilent MIR spectrometer, Rigaku NEX CG XRF



Micro/Molecular Lab: Analysis of pathogen survival and community structure in soil, slurry and bio solids. The micro/ molecular suite is comprised of a class 2 micro lab and a molecular lab equipped for DNA/RNA extraction and genetic fingerprinting.



Ecology Lab: Species classification and taxonomic identification using a variety of confocal and compound microscopes.

Summary:

The Environmental Research Lab at Johnstown Castle is a high throughput state of the art laboratory. The goal of the lab is to provide high quality data which underpins the scientific output of the research programme in line with international best practice.

Nutrient Efficiency

Long-term test facility for testing of conventional and enhanced efficiency nitrogen fertilisers

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Background

Fertiliser nitrogen (N) is a cornerstone input in many intensive agricultural systems including those prevalent in Irish temperate grassland. In the accounting period October 1st 2015 to September 30th 2016 sales of fertiliser N were 339,104 tonnes N nationally (DAFM, 2017). This nutrient addition plays a critical role in yield enhancement but is also susceptible to environmental loss through leaching, denitrification and volatilisation loss pathways. Different N fertiliser have different loss susceptibilities and the arrival of enhanced efficiency fertilisers has provided new opportunities for sustaining yields, enhancing fertiliser efficiency and reducing environmental losses.

Figure 1. A selection of conventional and enhanced efficiency N fertilsiers

Recent research has shown that nitrogen fertiliser selection affects nitrous oxide emissions (Harty *et al*., 2016), ammonia emissions (Forrestal *et al*., 2016), yield and N fertiliser efficiency (Forrestal *et al*., 2017; Harty *et al*., 2017) in Irish grassland. Development of additives to enhance the efficiency of N fertiliser is continuing apace. Testing of these new options in Irish conditions is an area of critical importance for Irish agriculture as enhanced efficiency N fertilisers provide opportunity to sustain the N inputs which underpin production while reducing environmental loss; potentially helping Irish agriculture to realise the goals of sustainable growth outlined in the Food Wise 2025 strategy

Figure 2. Ariel view of long-term N fertiliser N testing facility at Johnstown Castle

Objectives of establishing a long-term N fertiliser testing facility

- Assessment of the impact of conventional and enhanced efficiency N fertilisers on long-term agronomic performance along with environmental, soil chemical and microbiological factors and function

- Provision of a facility capable of testing of new N fertilisers for agronomic and environmental parameters

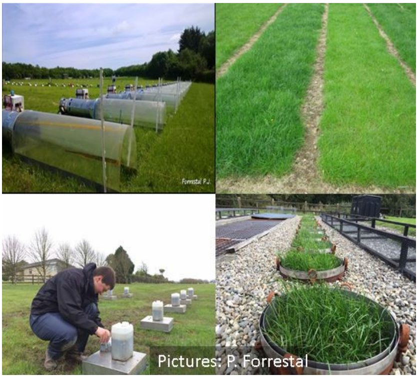

Figure 3. Ammonia, yield, N efficiency, nitrous oxide and leaching test capacity at long-term facility

- Capitalising on test facility capacity to test sensing and low-power communication technologies

Figure 4. CONNECT Pervasive Nation IoT Low power wide area network platform deployment (top), optical, smart phone and plate meter sensing/measurement (bottom)

Acknowledgements

We acknowledge the core support from Teagasc to support the establishment and maintenance of this long term-facility.

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Identifying and correcting site-specific sulphur deficiency

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Background

Sulphur (S) is an essential nutrient for plant growth occurring in the major amino acids, cysteine and methionine and playing a critical role in protein synthesis and photosynthesis. Higher yielding crops require greater levels of S nutrition to maintain optimum yield, protein content and high nitrogen use efficiency. Plants mainly take up the divalent anion sulphate (SO_4) through roots. However, more than 95% of soil S occurs in non-plant available, largely organic, forms. Studies in the 1970's and 1980's found grassland yield responses to S at 71 of 139 Irish sites.

Since the 1970's and 1980's,

- Atmospheric S deposition has reduced due to emission controls

- Crop yields have increased through genetic gain and better management leading to increased S demand

These factors highlight the risk that S limitation in Ireland may now be more widespread than it was in the 70's and 80's. In the context of sustainable intensification of Irish agriculture, which depends on efficiently increasing yields, optimization of S nutrition is more important than ever. Yet this nutrient has received little attention compared to nitrogen and phosphorous.

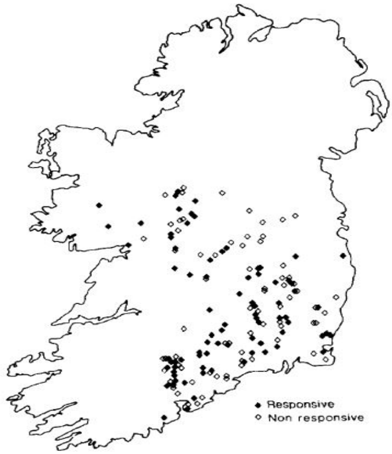

Figure 1. S responsive and non-responsive sites in work conducted in the 1970's and 1980's (Murphy and Boggan, 1988)

Objectives of current work

- Detail the changes in S deposition in Ireland since the 1980's

- Evaluation of grass yield, protein quality and nitrogen use efficiency response to S on a range of contrasting soils managed at high intensity.

- Development of soil and plant based tools for identifying S deficiency risk and site-specific S deficiency

Figure 2. Optical sensing and hand held x-ray fluorescence testing

- Linking soil based parameters with national mapping efforts by the Soil Information System and Tellus to develop deficiency risk maps

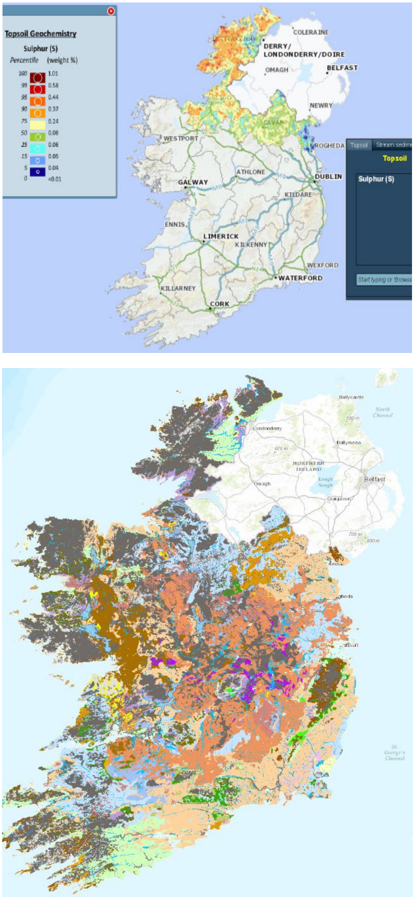

Figure 3. Developing and existing soil parameter mapping: Tellus soil S (top), Irish Soil Information System (bottom)

- Evaluation of a range of existing and novel S fertilization strategies in Irish grassland.

Figure 4. Selection of sulphur sources for agriculture

Expected benefits

This project will provide much needed knowledge on the relationship between soil characteristics, geo-chemical parameters and agronomic response to S for Irish soils. This knowledge could be increasingly useful in conjunction with new ongoing national mapping of soils. Diagnosis of S deficiency can be challenging. This project will contribute to the development of soil specific S nutrition advice and, additionally, site-specific diagnosis of yield reductions due to S deficiency using plant based measurements. The results of this work are expected to contribute updates to national S fertilization advice.

Acknowledgements

We acknowledge financial support from the Walsh fellowship programme for funding the Ph.D student to be taken on in this project.

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Phosphorus management in organic soils for sustainable agriculture

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Introduction

There is an increasing pressure on organic soils (peats, bogs and associated soils) as a consequence of the growing demand to bring more land into pasture and hence increase the milk and meat production. However, these soils have been identified as vulnerable to phosphorus (P) loss due to their poor P retention capacities when fertilizer P is applied: significant differences in the P sorption mechanisms in soils take place depending on the content of organic matter as there are competitive sorption reactions matter for the soil sorption sites between P and the organic acids (humic and fulvic acids, low molecular weight acids) derived from the decomposition of this organic. Hence, soil organic matter content plays an important role regarding P dynamics with regard to agricultural and environmental management. These findings have implications for sustainable use of fertilizer P on peaty soils. Nutrient application to these soils requires a different management strategy compared to mineral soils due to the high potential for P transfer to water. The aim of this research work is to optimize phosphorus use on soils with a high content of organic matter through the execution of a series of agronomic and environmental experiments in lab conditions that will help us to describe P assimilation and transport in these soils.

Material and Methods

A growth chamber experiment (Figure 1) was conducted on six different soils ranging in organic matter content to determine the agronomic optimum fertilizer P application for ryegrass production. The soils were placed in pots (30 cm diameter x 30 cm depth) and 14 different P rates ranging from 0 to 145 kg P ha^{-1} were applied to each soil type. Soils were kept at controlled conditions of 14° C (± 2° C) day time and 8° C (± 2° C) dark period, 70 % relative humidity at day period and 90 % relative humidity dark period, a day length cycle of 16 hours and 8 h darkness.

Figure 1. Growth chamber trial with the pots containing the different soils under controlled conditions of temperature and relative humidity.

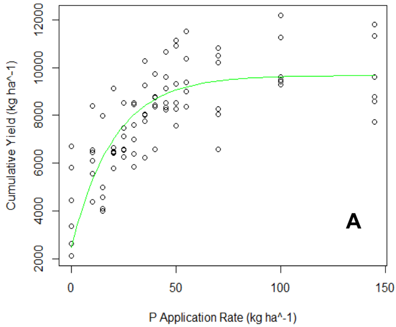
Dry matter yield and herbage content were measure during a period of nine months. The original Mitscherlich equation ($Y = A(1 - e^{-cx})$) was used to fit the yield response to the different P treatments.

From an environmental point of view, a leaching experiment is currently being conducted to ascertain the amount of P lost from two contrasting soils (one organic, one mineral). Soils were packed in 0.3m-deep and 0.104 m-diameter PVC columns. P applications of 15, 30 and 55 kg P ha^{-1} as a single superphosphate fertilizer were applied in either one or two application times. One hundred and eighty ml of distilled water is applied weekly on the surface of the columns to recreate real rainfall conditions in Ireland. The leaching water is collected in individual containers and analysed weekly for Dissolved Reactive P (DRP), Total P (TP) and Total Dissolved P (TDP), along with other nutrients (total nitrogen and carbon)

Results and Discussion

Cumulative yield response curves to the different fertiliser P application rates from the growth chamber experiment are shown in Figure 2. Soils were grouped in organic (A) and mineral (B) based on the percentage of organic matter (OM) content (organic soils have OM > 20 %, minerals have OM < 20 %).

Under P deficient scenarios, organic soils (Figure 2 A) showed a quicker response to the P applications than mineral soils. Mineral soils exhibited slower response, possibly due to build-up required before P is made plant available. This can be due to the ability of mineral soils to absorb and bind phosphate ions into the clay minerals when they are deficient in P. In contrast, the quick response on organic soils suggests that the P applied was not bound but immediately available for grass uptake. The model for the organic soils explained a 56.2 % of the total variation whereas is was lower for mineral soils, only 24.5 %, due to build-up requirement of these soils.



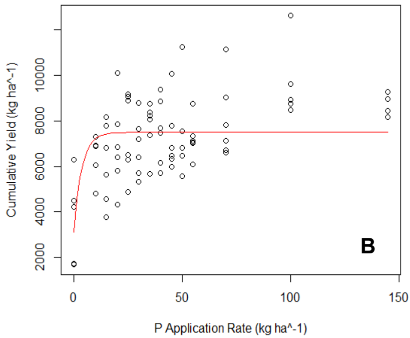


Figure 2. Response of the cumulative yield to fertilizer P for combined organic soils (A) and mineral soils (B)

Conclusions

Fertiliser P requirements for pasture production are higher for organic than for mineral soils. However, further work on leaching and runoff experiments is required in order to understand if these requirements pose a risk of P loss to the environment.

Acknowledgements

This work is funded by the Department of Agriculture, Food and the Marine Research Stimulus Fund 2007-2013.

A rapid and multi-element method for the analysis of major and trace elements in grass using energy-dispersive X-ray fluorescence spectroscopy.

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Introduction

Conventional methods of crop analysis typically involve strong acid or alkaline digestion followed by analysis of the filtrate by either colorimetric analysis, atomic absorption or inductively coupled plasma (ICP) analysis. In routine analytical laboratories delays are common due to high sample throughput, which can hold up the transfer of important results back to the farmer. Extending the grazing season in pasture-based agricultural systems requires rapid and reliable grass analysis to ensure grass quality throughout the growing season, so that grazing animals can met their dietary needs at all times. Energy dispersive XRF can provide higher sample throughput with reliable results than our current methods allow.

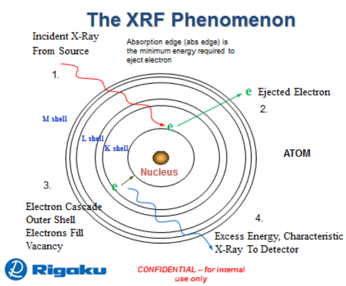

Figure 1. X-ray fluorescence theory.

This technique allows simultaneous analysis of all elements from (^{11}Na to ^{92}U) non-destructively in minutes, eliminating the time spent using different digestive reagents for different elements. Samples presented for XRF measurement are treated with an X-ray radiation source to excite inner orbital electrons within the sample, to an excited state. When electrons relax to ground state, fluorescent energy is emitted and the process results in measurable intensities and spectral lines, specific to each element. (Figure 1). This technique has been more widely used in mining and geochemistry to determine the elemental composition of rocks and minerals (and for ensuring quality control in the production of cement and other industrial materials. For environmental samples such as soils and plants, with large elemental compositions, the presence and predominance of other elements can interfere with values determined for elements of interest. These are known as matrix effects and are often overcome by calibrating using simple matrices or synthetic material spiked with a range of element concentrations.

Materials and Methods

This study used an archive of 600

grass samples with known % P, K and Mg determined using digestive methods with ICP analysis. 21 samples were selected as empirical standards and a further 50 were selected for validation and analysed by XRF to determine P, K and Mg. Three approaches to calibration in XRF were examined, namely; an empirical calibration using grass samples as standards (EMP); a theoretical or Fundamental Parameters (FP) approach using the instrument settings and finaly, an FP method with a matching library of grass samples attached (FPML).

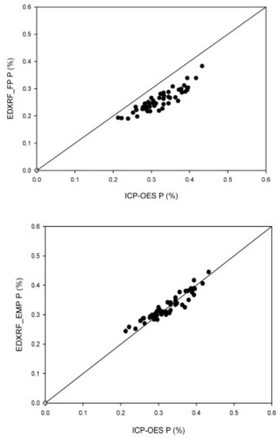

Figure 2. An example of bias observed in % P determination using FP method (top) which was corrected with empirical calibration (bottom).

Results and Discussion

Excellent agreement between XRF and ICP determined values for all elements was found, however, the level of agreement depended on the calibration approach used. For K, best agreement was found using the FP calibration. For Mg, agreement was good but improved with the addition of a matching library. For P, some bias was observed using the FP methods but excellent agreement with empirical calibration using grass standards (Figure 2).

Conclusions

Best agreement was found when grass samples were used as either empirical standards or matching library. XRF is a comparable alternative to conventional methods for grass analysis when samples of similar matrix type are used as empirical standards or matching library.

Acknowledgements

The authors would like to thank Ms. Linda Moloney-Finn for ICP analysis, Mr. Conor Nolan for technical support and Dr. Wall and Mr. Philip Murphy for access to sample archives.

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Understanding the effect of legume-based mixtures on the soil microbiome for improving resource use efficiency and yield stability

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Introduction

Projected global demand for food and fibre will drive intensification of agricultural systems in both Ireland and New Zealand. Production must be supported alongside optimisation of resource utilisation, and reducing greenhouse gas (GHG) emissions. Nitrous oxide (N_2O) is of particular concern (12% of Irish and 11% of New Zealand's total national GHG emissions). There is also a need to develop climate resilient pasture-based systems. Multi-species grasslands have been shown to enhance yield in comparison to monocultures and to maintain yields resilience under changing climatic conditions. There is considerable evidence that rhizosphere microbiome influence plant morphology, growth, nutrient uptake, and confer resilience to drought. Biogeochemical cycling of N and other major elements are mediated by the soil microbiome. The role of soil fungi in both N_2O and N_2 production may be considerably more important than previously recognised.

This project will focus on quantifying how multispecies pastures reconfigure the structure and function of soil microbial communities, and therein enhance resistance and resilience to climatic perturbation. This will greatly increase our understanding of the underlying microbial processes underpinning N cycling in soils under diverse forages. It will help to optimise N use efficiency, improve resilience to climate change, and refine GHG mitigation options.

Objectives

1. Quantify the effect of legume-based grassland mixtures on the soil microbial community structure and function

2. Quantify the role of the soil microbiome in terms of climate resilience related to legume based grassland mixtures

3. Investigate the effect of multi species pastures on the partitioning between fungal and bacterial N_2O and N_2 emissions.

Figure 1: Multispecies plots

Materials and Methods

The overarching hypothesis is that the soil microbiome is under strong influence of pasture species composition, and this can be directly managed to increase productivity and resilience of the pasture. It is also anticipated that this will affect nutrient use efficiency, associated N_2O and total denitrification from soils.

The microbial community composition of soils from current multispecies pasture trials will be characterized to assess how changing pasture composition influences soil microbial communities. Thereafter the impact of drought on the same pastures will be assessed, by quantification of functional genes involved in N cycling and characterising the impact on soil microbial community structure. The soil microbial community response to urine and N fertiliser addition will be investigated over time within mixed grassland treatments to determine the impact of pasture management.

Figure 2: Drought shelters

A sub-set of samples will be selected to determine how alteration of community composition and/or dominance by fungi alters the fate of N added to the soils. After addition of N, the presence and expression of genes associated with bacterial nitrogen reduction will be quantified. Using a 15N isotope, the fate and form of N in the soil will also be determined.

Fungal dominated systems will be identified from New Zealand field-plots to identify soil fungi characteristic of the dominant taxa groups. Isolations of these from soils will be targeted using selective culture techniques. N_2O production of the fungi will be determined under in vitro conditions supporting denitrification and N_2O emissions.

Expected Benefits

By maintaining grassland yields, planned adaptation will promote the development of sustainable management practices. Plant diversity is recognised as a key element for adaptation of grasslands to more variable environments. Increasing attention is being paid to mixtures of species and to their potential for stabilising yields and reducing losses caused by biotic and abiotic stresses.

This project will help to identify benefits of pasture diversity for the soil microbiome and soil functioning particularly in terms of N cycling and identify key organisms involved. Further understanding of the soil microbiome on controlling gaseous N losses and N use efficiency will facilitate the identification of new novel measures to reduce GHG emissions, improve nutrient use efficiency and agricultural sustainability.

This PhD is part of a research cluster involving Teagasc, AgResearch New Zealand, Lincoln University and Rothamsted.

Acknowledgements

This project is funded jointly by Teagasc, through the Walsh Fellowship scheme, AgResearch and Lincoln University.

Dairy Platform Technology Centre (DPTC) – Dairy Processing Waste

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Introduction

Wastewater created during the production of butter, cheese, milk powders, cream, and whey powders at milk processing facilities must be treated. This results in the generation of "dairy processing organic residues (DPOR)", which needs management e.g. approximately 128,636 tonnes were generated in Ireland in 2015. Due to the abolition of European milk quotas in 2015, milk production of the Irish dairy sector is expected to increase by 50% by 2020. This will subsequently create an added challenge of tackling more DPOR generation. Recycling of DPOR to land provides for a circular economy and should also provide farmers with an organic fertilizer. However, there is no systematic study to outline the recycling of DPOR to cover the Irish perspective in terms of nutrient recovery, agronomic benefit and associated environmental impacts.

Objectives

Present research in this area within Teagasc Environment Research Centre focuses on the recovery and recycling of agri-nutrients (N,P,K) from DPOR. In particular, this project aims to investigate and develop comprehensive physicochemical characteristics of DPOR involving major Irish dairy processing industry and subsequently, to identify fertilizer (N/P/K) replacement value and associated agri-environmental impacts from recycling of DPOR through controlled laboratory, micro-plot rainfall simulation and field-scale agronomic trials.

Research & Results

Seasonal DPOR samples (n=16) (predominantly two types: mixed sludge after bio-chemical treatment process and lime treated sludge after dissolved air floatation (DAF) process) were collected from 5 dairy processing plants across Ireland. Samples were analysed for physicochemical parameters (e.g. solid and organic matter, nutrients, heavy metals and other elemental composition) following standard sample preparation (homogenization, freeze drying and grinding in mixer mill). The analytical methods used were ICP-OES, spectrophotometric measurements by Aquakem 600 Discrete Analyser, and LECO TruSpec CN analyser.

Preliminary results of the analysis of DPOR samples showed that the values of dry matter (DM, in %wt.) and total content of nutrients (kg/tonne DM) were in the range of DM=9.4–19.7, N=37–65, P=18–61, K=3.5–13.6 for mixed DPOR (n=11) and DM=19–30, N=9.1–48.7, P=15–82, K=1.2–6.1 for DAF DPOR (n=5), respectively. The levels of N, P and K in DPOR are generally higher than those typically observed with other commonly used organic fertiliser (e.g. cattle slurry, biosolids), while DPOR also showing lower heavy metal levels comparing same (Wall and Plunkett, 2016).

Heavy metals levels in DPOR are significantly lower than those regulated by the European Union in agricultural land due to sludge recycling (EC, 2001). An estimated evaluation reflected a higher financial value of DPOR (€13−22 tonne-1) than cattle slurry (~€5.4 tonne-1) considering total content of nutrient levels. But, it is important to evaluate the realistic fertiliser replacement value (FRV) through agronomic investigation in order to realize actual commercial value of DPOR. Overall, the results indicate that DPOR are enriched in nutrients. The variation in major nutrient contents and other physicochemical composition are highly contrasting across different milk processing plants and DPOR types. There are also some indication of seasonal variability in nutrient contents and other compositions, which will be statistically analysed when the seasonal sampling will complete.

Future work will elucidate the fertilizer (N/P/K) replacement value of DPOR and assess potential agri-environmental impacts through runoff losses, and uptake in soil and grass from the recycling of DPOR to grassland. These experiments have begun in Johnstown Castle with the creation of a new field site (Figure 1 and 2).

Figure 1: Agronomic grassland plots for assessing nitrogen and phosphorus fertilizer replacement value of dairy processing organic residues through land application.

Figure 2: Micro-plot rainfall simulation study site – (top) Amsterdam drip-type rainfall simulator, (middle) Series of isolated grassland micro-plots and (bottom) Individual plot isolated by steel frame of dimension 0.9 m in length and 0.4 m in width with runoff collection channel.

Acknowledgements

This work has been supported by Enterprise Ireland under Dairy Processing Technology Centre (DPTC) programme. Grant Agreement Number TC2014 0016.

Pathogen survival during farm-based anaerobic digestion and subsequent landspreading of digestate compared with unprocessed manure

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Manure and slurry from pig, beef, dairy, and poultry enterprises are considered valuable organic fertilisers, but typically contain a broad range of bacterial, viral and parasitic pathogens. These pathogens can be transferred as bioaerosols during landspreading, ingested directly from grass or vegetables, or be washed off into surrounding watercourses, posing a significant threat to human and animal health. Some benefits of farm-based anaerobic digestion (AD) include; localised renewable energy production, odour control, organic waste management, and noxious and greenhouse gas mitigation. Farm-based AD could also potentially reduce pathogen loads in the environment and their associated public health risks. AD of slurry can reduce pathogen numbers, but Irish farm-based AD surveys by partners in this project highlighted survival of a number of important pathogens. Pathogen survival may be significantly impacted by factors such as: initial pathogen load, addition of co-digestion substrates such as food production waste, and operating conditions of AD plants.

Objectives

The specific objectives of this project are to:

- Characterise operational parameters currently utilised in agriculture based AD plants in Ireland, including feedstocks used, loading rates, retention times, temperature, number of phases and pasteurisation conditions
- Establish a laboratory based AD platform that mimics conditions identified in the characterisation
- Examine the survival of important enteric pathogen indicators during anaerobic digestion of manure under various operational and pasteurisation conditions
- Carry out controlled field trials using rainfall simulator to compare human and animal health risks associated with survival of pathogens in the environment resulting from landspreading of digestate versus manure and slurry
- Develop a predictive modelling and qualitative risk analysis tool with project partners based on the various operational parameters tested in the laboratory scale AD platform and the simulated rainfall conditions to inform future Irish AD policy and practice

Research

The laboratory scale AD platform (10 L, n=3) has been established.

Figure 1: Operating three laboratory scale reactors

Results from batch-fed trials indicate a significant (2-5 $\log_{10}$) reduction in enteric indicator pathogen numbers in slurry processed in mesophilic (37 °C) AD over 28 days, dropping below the required 1000 cfu g^{-1} digestate standard.

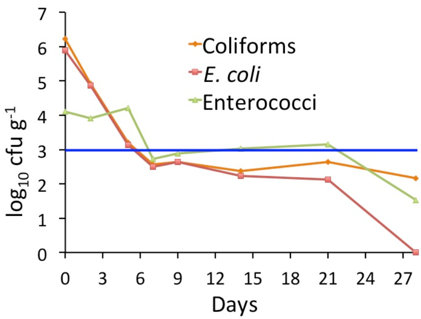

Figure 2: Enteric pathogen indicator dieoff in batch fed, mesophilic AD of slurry co-digested with organic waste

Johnstown Castle and NUIG are leading Task 3: Comparative survival of bacteria, viruses and parasites when applied in digestate, manure and slurry on land. These trials will use digestate produced in the laboratory scale platform for controlled land application using a rainfall simulator to examine survival and leaching of indicator pathogens from digestate, compared with unprocessed slurry. The impact of soil type, application method and rainfall conditions, as well as initial pathogen load, will be considered. The results of this research will contribute significantly to Irish AD policy.

Figure 3: Rainfall simulator

Acknowledgements

This work is being carried out as part of the FIRM Project, 14 F847, *The comparative public health risks associated with spreading anaerobic digestate, animal manure and slurry on land: Science, policy and practice*, funded by the Irish Department of Agriculture, Food and Marine. Project partners include D. Bolton P.I. (Teagasc Ashtown); P. White, B. Markey, A. Zintl, E. Cummins, A. Auer, T. DeWaal, N. Vande Burgt (UCD).

Strategies for controlling cadmium contamination in Irish food production

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Introduction

Recent mandatory testing has shown a proportion of Irish horticultural produce and bovine kidneys to be above European maximum levels (MLs) for cadmium (Cd). Cadmium is a heavy metal and environmental contaminant which is found naturally in soils and at high levels in north Leinster where much of the horticultural industry is based. Proposals by the European Commission to reduce MLs in potatoes and vegetables (from 0.1 to 0.075 mg/kg), and in bovine kidneys, creates an urgent need for research.

Significant gaps in understanding the processes involved will be addressed by fundamental work on how soil chemistry influences Cd uptake in plants and animals and the feasibility of using organic amendments to immobilize Cd in soil. The genetics and physiology of Cd accumulation in plants will be investigated in tandem with identifying suitable low Cd accumulating crop varieties. Focused field surveys of animals and plants in the affected regions of the country will quantify the problem and highlight causal soil factors. As part of an overall strategy to support the industry, it will be necessary to provide guidance on Cd reduction strategies and on selection of land for planting and grazing. The quantitative outcomes from the research above will be used to build a risk assessment model and decision tree, based on soil tests that will allow farmers to assess and avoid risk of Cd accumulation.

Project Objectives

The objectives of this research are to:

- Provide research based advice to ensure food placed on the market in Ireland is safe.
- Develop national expertise, knowledge, and research capacity in the area of heavy metal contamination of food.
- Determine the extent of Cd contamination of Irish food from the impact area.
- Characterise soil parameters which control Cd availability for plant uptake.
- Develop and validate risk indexes and management strategies to guide farmers to minimise Cd levels in produce.
- Rank current and future potato and vegetables varieties for Cd accumulation characteristics.

Experimental Methods

This project will be broken down into the following work packages;

1. Identifying and managing soil parameters which control Cd availability in Irish soil types

- Review of the literature pertaining to soil Cd and its availability for plant uptake
- Studies to understand Cd dynamics in Irish soil types (Fig 1.)
- Evaluating the role of organic amendments for reducing Cd availability
- Evaluation of results in the field.

Figure 1. Pot studies to assess cadmium uptake in potatoes

2. Crop variety study on Cd accumulation

- Potato variety Cd uptake screening study
- Fresh vegetables variety Cd uptake screening study

3. Field survey of soils, crops and herbage in the impact area

- Paired potato and vegetable plant and soil survey
- Paired grass herbage and soil survey.

4. Integration of results and development of a risk assessment to aid commercial decisions on where crops and grazing of animals are produced

5. Dissemination of results and decision support tools to framers and others working in the agricultural industry.

Beneficial Outcomes

Recent decisions to review MLs of Cd in foodstuffs could have a detrimental effect on primary producers of potatoes, vegetables and beef in areas with elevated soil Cd levels. Currently Ireland has no specific expertise in Cd and heavy metal reduction technologies for crop and animal production. It is likely that other heavy metal contaminants like lead will be on the agenda in the future.

This project will ensure that

▪ A competent research capacity exists to advise farmers to reduce and avoid Cd contamination of food and influence policy makers at the highest levels.

▪ Irish produce meets the highest safety standards and maintains its excellent international reputation.

The project aims to

▪ deliver a suite of soil tests and a risk index that can predict Cd uptake from soils in both horticultural produce and grazing animals.

▪ screen suitable vegetable varieties with reduced Cd uptake.

▪ support the potato, vegetable and beef product sectors and ultimately generate knowledge significant for the public good.

Acknowledgements

This project is funded by the Department of Agriculture, Food and the Marine, Research Stimulus Fund.

Increasing the efficiency of phosphorus fertilizer use in grassland

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Introduction

Irish grassland swards have the potential to yield in excess of 15 t DM ha-1 yr-1. To sustain this growth, fertilizer inputs are needed to match the nutrient requirements of grass crops and to sustain soil fertility levels. However, declining levels of phosphorus (P) fertilizer use in Ireland and a recent increase in soils with a low soil test P (STP) value (Index 1 and 2) may be having a negative effect on grassland productivity. Lower STP values will potentially lead to lower herbage yield and lower herbage P content. As reserves of phosphate rock are finite, it is important that farmers make best use of this dwindling and increasingly expensive resource. Improved understanding of P adsorption characteristics, its interactions with lime, and the role of organic P in crop nutrition, is necessary if the efficiency of P use at farm level is to be improved.

The overall aim of this study is to examine results from existing and new experiments in order to find ways of increasing P use efficiency and of making P fertilizer recommendations more soil specific and sustainable.

Materials and Methods

Long term P field trial

A phosphorus field trial was set up in Johnstown Castle in 1995 to investigate the effects of three rates of P fertilizer (triple super phosphate) application on herbage yield and mineral content on two contrasting soils types: heavy and light. Phosphorus fertilizer was applied at rates of 0, 15, 30 and 45 kg P ha^{-1} yr^{-1} in the spring of each year, and plots where harvested on average 6-8 times a year. A split plot effect was introduced in 2016 where a slurry treatment was applied to half of the main plots and the grass yield harvested separately from then on.

Phosphorus and Lime interactions

A field trial was established in 2011 to look at the interactive effects of P and lime on herbage yield and mineral content at two sites with contrasting STP and soil pH levels. Fertilizer N (CAN) was applied after each harvest to give annual cumulative rate of 300 kg N ha^{-1} yr^{-1}. Phosphorus at rates of 0, 20, 40, 60 kg P ha^{-1} yr^{-1} (triple super phosphate) where applied at the start of the trial and in the spring of subsequent years. Lime (ground limestone) at rates of 0 and 5 t ha^{-1} was applied at the start of the trial and also in 2014. Plots where cut approximately 8 times each year.

Soil test P response to chemical and organic (slurry) phosphorus sources and lime
An experiment was set up to examine the fate of P and lime additions to 22 different un-vegetated soils in a controlled environment facility. The treatments consisted of 100 kg P ha^{-1} (applied as super single phosphate and as slurry P), 5 t lime ha^{-1} (ground limestone), P and lime together (same rates) and a control. The treatments where mixed with the soil in pots and placed in a controlled environment facility which was maintained at a constant humidity (80%) and temperature (15°C) and in darkness. The soils were sampled after 3 months and 12 months incubation.

Results and discussion

Long term P field trial
Results from the long term *field* trial showed that maximum yield for both sites was obtained at a P rate of 15 kg $ha^{=1}$ yr^{-1}. The P concentration in herbage was significantly affected by P fertilizer, with the response being highest in spring.

Phosphorus and Lime interactions
Nitrogen fertilizer rate had the largest effect of herbage yield at both sites, with responses to P also being observed. Further work is being conducted to analysis the results of this experiment, which will continue for a number of years.

Figure 1. Nitrogen, P and lime interactions are being studied in field plots.

Soil test P response to chemical and organic phosphorus sources and lime
Results from this experiment have shown that large variation exists in the response to P fertilizer. Soils that have low initial STP levels had the lowest rise in STP which suggests that these soils have a high capacity to fix P. In general the application of lime increased soil P availability and where both P and lime were applied soil P availability was higher

Conclusion

While some of the results discussed here are preliminary, they show that there is large variability in inorganic and organic P forms in Irish soils, and that there is a potential to increase P fertilizer efficiency by developing soil-specific P fertilizer recommendations.

Acknowledgements

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Teagasc Green Book of Nutrient Advice – the national nutrient management reference for agricultural crops

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Introduction

A major responsibility of the research staff at Johnstown Castle has been the publication of leaflets, booklets and manuals giving nutrient and trace element advice for grassland and crops. This began in the 1940s and was the scientific basis for soil analysis (Coulter 2000), since then, further updates were published by Coulter in 2004 (2nd edition) and by Coulter and Lalor in 2008 (3rd edition). This version has now been enhanced and expanded to produce the present volume (4th edition) published by Wall and Plunkett in 2016. New sections soil types and nutrient cycling, fertilizer ingredients, adaptive nutrient management planning and nutrients for energy crops have been added. Additionally new information and updates based on the latest scientific findings have been made to soil acidity and liming, organic manures, grassland, and crops sections. Many of the chapters have been reorganised to make them easier to consult and the advice and tables have been redesigned to be compliant with the latest European and Irish legislation.

Objectives

A major objective in this revision was to ensure that it was comprehensive and that it contained sufficient information to allow agricultural and farm advisors and consultants to recommend optimum levels of major and micro nutrients for the most important agricultural and field horticultural crops. The manual sets out to minimise conflicts between the need to ensure an economic return from grassland and tillage farming on the one hand, and growing concerns about losses of nutrients to water or gaseous emissions to the atmosphere on the other.

Many of the changes in this fourth edition were made necessary by legally binding requirements of the EU Nitrates Directive - National Action Programme (NAP) regulations, statutory instrument (SI) 31 of 2014 – the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2014. These NAP regulations have major implication for use of N and P in farming, both for the farmer and for organisations and advisers recommending levels of nutrient use for agriculture. Before the NAP regulations were enacted, Teagasc nutrient advice involving N and P was determined by the level of these nutrients that gave the economic optimum yield of the crop or grazing livestock in question, having regard to other factors such as the risk and consequences of losses to the environment and/or the needs of subsequent crops in the rotation. It has been the intention of Teagasc that fertilizer advice, if followed carefully, should have the desirable effect of optimising yield, protecting the environment, as well as saving money for the farmer. In revising this document, this policy has been continued, within the constraints of the NAP, particularly when dealing with the environmental consequences of N and P use.

New Developments

Soil Types and Nutrient Cycling: Information on the major soil types in Ireland and their influence on nutrient cycling and management

Fertiliser Ingredients: Definitions and information on the main fertiliser ingredients available in Ireland

Soil Acidity and Liming: Improved information on soil pH and new information on lime and lime products has been included

Nutrients in Organic Manures: Updated fertiliser replacement values for slurries and new information on organic manure and biosolid types.

Grassland: New N advice for beef and sheep systems and suggested application timings for fertilisers.

Information on soil test P response to fertiliser P inputs as influenced by varying soil parameters

Nutrients for Energy Crops: New information and nutrient recommendations for energy crop production

Adaptive Nutrient Management Planning; NMP–online: Information on the new nutrient management system “NMP-online” and how it can be used to facilitate better nutrient management planning and sustainable outcomes for farmers into the future

Acknowledgements

We would like to acknowledge the many contributors to the review of the Teagasc, Green Book - National Nutrient Advice and the funders of the research drawn upon.

The Kildalton Open Source Sustainable Demonstration Farm

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Introduction

Food Wise 2025 was launched in 2015 and sets out a sustainable growth vision for the Irish agri-food sector. As Ireland's farmers manage the majority of the country's natural resources, it places them in a unique position of delivering many public goods and social benefits, which contribute to the wellbeing of the country. In doing so, Irish producers are playing, and must continue to play, a vital and positive role in the protection and the potential further enhancement of Ireland's landscapes, waterways, biodiversity and air quality. This position is particularly important given the increased global demand for food

Figure 2. Low emission spreading of slurry using a trailing shoe spreader reduces ammonia emissions from Kildalton

Glanbia Ingredients Ireland (GII) is a key partner in the Kildalton Open Source Sustainable Demonstration Farm, providing financial support and technical expertise. GII is a founding member of Origin Green and in preparing its milk suppliers for auditing and, further developing its sustainable approach, Glanbia has developed the Glanbia Open Source Sustainability and Quality Assurance code.

Objectives

The Kildalton Open Source Sustainable Demonstration Farm builds on the large body of research and knowledge-transfer experience in Teagasc and draws on international knowledge to showcase solutions to the economic and environmental sustainability challenges facing the Irish agri-food industry. Collaborating with GII, work at Kildalton to transform it into a showcase of sustainable dairy production

While there is universal agreement on the desirability of the concept of sustainable agriculture, there are differences on how it is interpreted. There is general agreement that sustainability should be considered under three pillars: economic, environmental and social. Echoing the 1987 Brundtland Report, Teagasc has succinctly defined sustainable agriculture as an approach that we can sustain into the foreseeable future. This project focuses on seven dimensions of sustainability: resource use efficiency; water quality; biodiversity; economic sustainability; gaseous emissions; animal welfare; and health and safety. These sustainability variables are not independent and links can exist between them, e.g., spreading slurry using low-emission technologies can reduce greenhouse-gas emissions but may also reduce impacts on water quality

Figure 2. The seven elements of sustainable farming being measured at Kildalton.

Implementing the plan

Improving the sustainability of the farm will be delivered over four distinct phases, although these phases will overlap with each other to some degree.

- Phase 1: Benchmarking the sustainability performance of the farm to provide a baseline against which future changes can be measured.
- Phase 2: Implementation of proven technologies and best practices.
- Phase 3: Redesign and improvement of the farm infrastructure (including ecological infrastructure).
- Phase 4: Step-by-step implementation of emerging technologies.

Progress on Implementation

As per Phase 1, a baseline is being established with the installation of electricity and water metering, soil sampling of the entire farm, establishment of nutrient-use efficiencies, completion of annual carbon navigators, participation in the National Farm Survey, mapping biodiversity resources, development of animal welfare metrics and installation of sampling points for ground and surface waters. Further work is needed in developing a baseline and surveys are currently undergoing of biodiversity elements, e.g., birds, bats, hedgerows, woodlands and aquatic habitats condition. There has been a strong effort to communicate this work through media reports, open days etc. Work in 2017 will carry on the baseline assessments but will also progress to a greater adoption of proven technologies and best practices, including a field trial of protected urea and greater establishment of clover through overseeding with white clover and correcting soil pH and nutrient status.

Recent research from Johnstown Castle shows that urea protected with the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) reduces greenhouse gas emissions compared to calcium ammonium nitrate (CAN). Protected urea also consistently yields as well as CAN and has higher fertilizer efficiency than urea and the Kildalton Sustainable farm will integrate protected urea into its fertilizer plan.

Figure 3. Soil testing and grass monitoring are key elements ensuring we get best value from nutrient inputs.

Acknowledgements

This work is funded by Teagasc grant-in-aid and GII

Gaseous Emissions

A review of nitrogen flow models and their suitability for pasture-based systems

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Introduction

Pasture-based systems have a high requirement of nitrogen (N) inputs as feed and fertilizers to sustain production. However, only small percentages (15-35%) of farm N inputs are converted into useful agricultural products (milk and meat). The remaining N (surplus N) is mostly lost from the farm as emissions such as nitrous oxide (N_2O), ammonia (NH_3) to the atmosphere and nitrate (NO_3) to groundwater which are environmentally harmful and environmentally benign dinitrogen gas

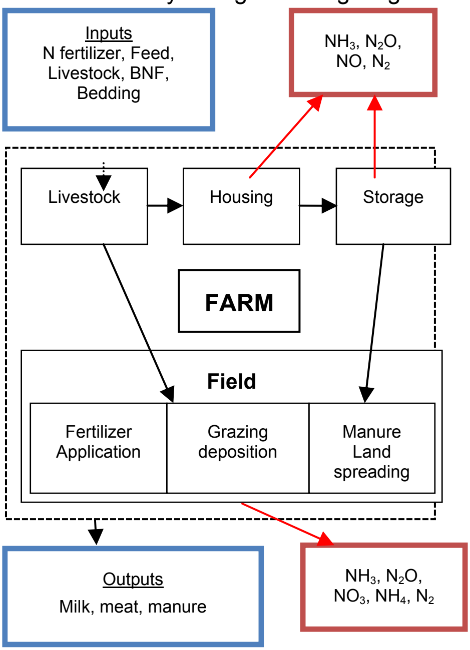

Figure.1- Typical N flows (black arrows) and losses (red arrows) on a pasture-based livestock farm

These losses represent an economic loss of N to the farmers. Although it is possible to carry out measurement studies of farm N flows and losses, they are difficult and expensive due to the complex nature of N flows within farms (figure.1). Modeling can be used to estimate N flows and losses in livestock systems which can help to improve the management of N at the farm, regional and national level and can help in evaluation of mitigation strategies. There are a number of models available which estimate N cycling at these scales; however, there is no review of these models to assess their individual strengths and limitations. This study reviewed available N flow models and their suitability for temperate pasture-based systems.

Materials and Methods

The work comprised of a literature review of 27 available models for estimating N flows and losses at different scales. The review provides an overview of the type of models available and the farm components (Housing, storage, fertilizer application, grazing deposition, manure land spreading) and the N losses that each model includes along with highlighting their suitability for temperate pasture-based systems.

Results and Discussion

The 27 reviewed models were static inventory based (n=6), empirical (n=11), mechanistic (n=6) and dynamic (n=4) in nature. Some of the models (n=10) were greenhouse gas models with a built-in N flow model. As seen in table.1, eight of these models- BEEFGEM, Netherlands- GHG, Dairy wise, Farmscoper, Farm AC, Fasset, $Sims_{Dairy}$ and IFSM included all farm N flows and losses.

Table.1- A few available (n=19) N flow models in literature

Model name	Model Type	Farm Components	N losses modeled
NARSES	Static inventory	All	NH_3
BEEFGEM	Static inventory	All	NH_3, N_2O, NO_3
NEMA	Static inventory	All	NH_3
Dan Am	Static inventory	Housing, storage, land spreading & grazing	NH_3
Netherlands-GHG	Static inventory	All	NH_3, N_2O, NO_3
ALFAM	Statistical analysis	Land spreading	NH_3
N-Cycle	Empirical	Grazing & Fertilizer application	NO_3, NH_3
Dairy wise	Empirical	All	NH_3, N_2O, NO_3
Manner	Empirical	Land spreading	NH_3
Farm AC	Empirical	Housing, storage, land spreading & Fertilizer application	NH_3, N_2O, NO_3
Neap-N	Empirical	Grazing & Fertilizer application	NO_3
CH-Farm	Dynamic	Grazing & Fertilizer application	NH_3, N_2O, NO_3
$Sims_{Dairy}$	Dynamic	All	NH_3, N_2O, NO_3
NH_3 volatilization model	Dynamic	Housing, storage, land spreading & grazing	NH_3
Fasset	Dynamic	All	NH_3, N_2O, NO_3
GAG	Mechanistic	Grazing	NH_3
VoltAir	Mechanistic	Fertilizer application	NH_3
Manure-DNDC	Mechanistic	Housing, storage, Land spreading	NH_3, N_2O, NO_3
IFSM	Mechanistic	All	NH_3, N_2O, NO_3

Of these only $Sims_{Dairy}$ and Fasset accounted for climate, soil and farm management conditions. Therefore these were the more appropriate available N flow models for pasture-based systems. The remaining models (n=19) did not include all farm N flows and losses, instead they focused on one or two N losses from one or more farm components. For example as seen in Table 1, statistical, ALFAM [1] is a field level model which estimates NH_3 volatilization from land spreading of manure on field plots whereas NARSES [2] is a national scale, static inventory based model which estimates annual NH_3 losses from all farm components- livestock housing, storage, land spreading, grazing and fertilizer application.

Conclusions

This study found only 8 models that included all farm N flows and losses, two of which was dynamic in nature thus highlighting the need to either modify existing models or develop a new whole farm N flow model for pasture-based systems.

Acknowledgements

The research was funded by the Irish Department of Agriculture, Food and the Marine (Project no. 13/S/430).

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LowAmmo: Measurement and abatement of ammonia emissions from agriculture

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Introduction

Ammonia (NH_3) volatilization from N fertilizer and the manure management chain (housing, storage & landspreading) reduces N use efficiency and represents a substantial economic loss of N on Irish farms. NH_3 volatilization also contributes to eutrophication and acidification of natural ecosystems and indirect nitrous oxide emissions. Ireland has committed to reducing NH_3 emissions by 5% by 2030 compared to 2005 levels under the revised National Emission Ceilings Directive. Meeting these reduction targets presents a challenge for Irish agriculture, which accounts for 98% of national NH_3 emissions.

The 'LowAmmo' project was established in 2013 and aims to close some of the gaps in knowledge related to NH_3 emissions from Irish agriculture. The objectives are: (1) quantify NH_3 emissions associated with cattle housing, cattle excreta deposition on pasture & yards and slurry storage, (2) quantify the abatement potential of NH_3 mitigation strategies for yards and slurry storage & (3) develop models to estimate NH_3 emissions from Irish farms.

Materials and Methods

Housing

Ammonia emissions were measured from four livestock houses in the south of Ireland over three winters (2014 to 2017) using passive flux samplers (Ferm tubes) (Fig. 1a).

Yards

Three experiments were conducted on a beef handling yard in August 2016. Experiment 1 consisted of 1kg dung applied with either (i) 0.67 ltr urine, (ii) 1 ltr urine and (iii) 2 ltr urine. In experiment 2 and 3 the treatments were (i) non cleaned control, (ii) cleaned after 1hr and (iii) cleaned after 3hr. The cleaning method in experiment 2 and 3 was pressure washing and scraping, respectively. Ammonia emissions were measured using wind-tunnels for 72hr (Fig 1b).

Excreta deposition on pasture

Excreta treatments applied to pasture in 2014 included (i) dung, (ii) urine and (ii) urine spiked with the nitrification inhibitor dicyandiamide (DCD: 30 kg ha^{-1}). Treatments in 2015 included (i) urine, (ii) urea, (iii) urine + urea, (iv) urine + urea coated with N-(butyl) thiophosphoric triamide (NBPT), (v) urine + urea coated with DCD and (vi) urine + urea coated with both NBPT and DCD. Ammonia emissions were measured using wind-tunnels for 14 days.

The slurry storage and modelling elements of the 'LowAmmo' project are reported in accompanying articles in this booklet.

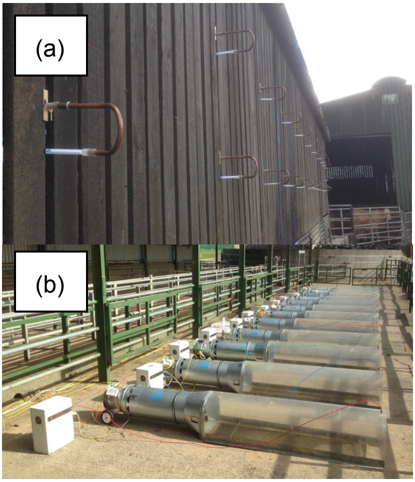

Fig 1. Ferm tubes for measuring NH_3 emission from housing (a) and wind-tunnels used for measuring NH_3 emissions from yards (b).

Results and Discussion

Housing

The overall mean NH_3 emission factor (EF) from the four houses was 15.6g NH_3-N lu^{-1} d^{-1} or 12.5% of TAN excreted. This was somewhat lower than the current EF of 31% of TAN excreted used in Irelands national NH_3 inventory.

Yards

Ammonia emissions increased linearly with increasing urine N rate in Experiment 1 with EF ranging from 46% to 50% of urine urea-N applied. In experiment 2 and 3 the greatest reduction in cumulative NH_3 emissions was obtained from pressure washing at 1h which reduced emissions compared to the non-cleaned control by 91% (Fig. 2). Pressure washing at 3 hr reduced emissions by 80% while scraping after 1hr and 3hrs reduced emissions by 78% and 54%, respectively.

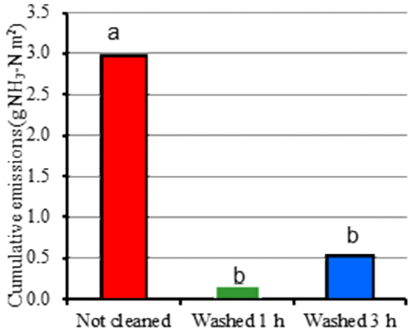

Figure 2. Cumulative emissions of ammonia from yards depending on pressure washing timing.

Excreta deposition on pasture

Dung had a significantly lower EF (3.8% total N applied) compared to both urine treatments (12%) which were not different from each other. The N stabilizer amended urea applied to urine patches had no significant effect on NH_3 emissions from urine patches in the 2015 experiment.

Conclusions

The data collected on the LowAmmo project will feed directly into the refinement of Irelands' national NH_3 inventory. The mitigation options investigated in this project will also provide valuable data for the future development of the NH_3 marginal abatement cost curve (MACC) for Irish agriculture.

Acknowledgements

This research was funded by the Irish Department of Agriculture, Food and the Marine (Project no. 13/S/430).

Characterisation of the kinetics of N_2 and N_2O emissions and N_2O reduction in urine patches.

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Introduction

During recent decades, increases in global livestock have been reported and numbers are projected to continue rising due to increasing global population. Much of the associated animal excreta is deposited on grassland soils and agricultural areas around the world. Excreta is deposited directly on the pasture by grazing animals, or the manure is collected and used as a fertilizer. Due to a greater focus on agricultural greenhouse gases, alterations in farming methods and enhanced knowledge of the nutrient cycles of excretal decomposition processes have become a focal point of interest.

Production of N_2O is largely driven by microbial pathways in soil. Denitrification (and codenitrification) in pasture soil transforms the nitrogen and N_2O of animal waste to environmentally benign dinitrogen (N_2). While classical denitrification is a relatively well understood process, it was recently discovered that microbes also produce hybrid N_2O on a large scale via codenitrification. This process requires a second nitrogen source coming from the soil. Gaining further knowledge about the reasons for incomplete denitrification which leads to losses of N_2O, is essential. A more detailed knowledge, especially about codenitrification, could help facilitate mitigation of N_2O by allowing the design of mitigation strategies that facilitate complete reduction of excreta nitrogen to N_2.

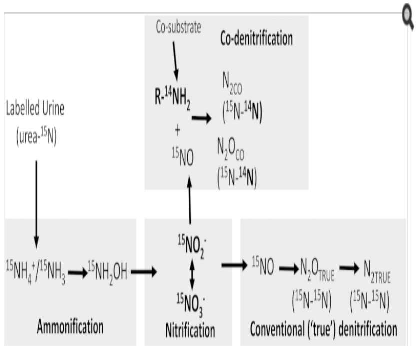

Figure 1. Conceptual model of codenitrification under urine patches in grassland soils, commencing with urea, the dominant N substrate found in ruminant urine (Selbie et al., 2015).

Materials and Methods

A series of laboratory studies is planned to identify the key drivers of codenitrification. Using soil mesocosms for inhibitory experiments, along with a ^{15}N-tracing approach, will reveal more information about the fate of the applied nitrogen as well as the nitrogen components in the soil. Furthermore, it is planned to use this data for an N-trace model (Mùller et al., 2007). In addition, the usage of inhibitors will allow insights in the role of soil microorganisms at different points in time.

The first two studies were performed in Lincoln University (New Zealand. The experiment included treatments for inhibition of fungi and/or bacteria as well as a positive and negative control. After the application of ^{15}N labelled urea, N_2O emissions as well as the mineral N concentration in the soil over time were measured, as well as the ^{15}N content of each N-compound, the surface pH and the CO_2 emissions (as indicator of microbial activity).

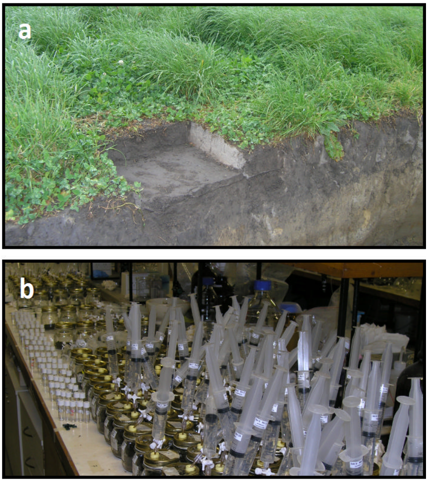

Figure 2. First experiment a) sampling side of top 10 cm of soil, based in Lincoln, b) soil mesocosms during gas sampling for N_2O concentration and ^{15}N content of N_2O and N_2.

Two more experiments are in progress; one focuses on determining soil N contributing during formation of hybrid N_2O. Another experiment will compare codenitrification rates across several soil types.

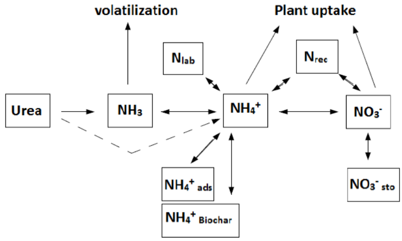

Figure 3. Concept of the extended N-trace model considered N-fluxes and pools in soil

Results and Discussion

First results confirm codenitrification as a wide spread process in pasture soil contributing significantly to N_2O emissions (Clough et al., 2017). Furthermore, it is revealed that soil N_2O emissions are mainly caused by fungal activities.

Acknowledgements

This work is funded by the Irish Teagasc Walsh Fellowship Scheme, the New Zealand Fund for Global Partnerships in Livestock Emissions Research to support the objectives of the Livestock Research Group of the Global Research Alliance on Agricultural Greenhouse Gases (Agreement number: 16084).

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Assessing the impact of urease inhibitors on agronomic and environmental parameters in grassland and spring barley

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Introduction

The EU 2020 Climate Change and Energy Package poses considerable challenges for Irish agriculture, particularly in the context of ambitious production targets envisaged by Food Wise 2025. Increasing nitrogen use efficiency (NUE) is an important factor for achieving these targets whilst simultaneously ensuring both financial and environmental sustainability.

Nitrogen (N) fertiliser is the largest variable cost on Irish farms. Fertilisation can also lead to losses to the environment in the form of nitrous oxide (N_2O), ammonia (NH_3), and nitrate (NO_3^-) leaching. Nitrous oxide is a potent greenhouse gas which accounts for one third of total Irish agricultural emissions. NH_3 is an air pollutant contributing to indirect N_2O emissions, deterioration of regional air quality, and eutrophication and acidification of natural ecosystems, while nitrate leaching is a water pollutant responsible for water quality degradation and eutrophication of water bodies. These emissions also represent a financial loss to a farmer.

Novel fertiliser formulations that abate environmental losses and enhance yields are currently under development. This project seeks to test these new products (Figure 1), together with the commonly used formulations, and their feasibility in terms of reconciling Irish environmental and agricultural targets by providing a win-win solution to improve NUE and lower N_2O and NH_3 emissions and nitrate leaching.

Figure 1. N fertiliser formulations tested in trials on grassland and arable sites.

Materials and Methods

Trials are currently conducted on a permanent grassland site in Johnstown Castle and long-term spring barley sites in Johnstown Castle and Marshalstown, all located in Co. Wexford. Fertiliser formulations applied to experimental plots are: (1) calcium ammonium nitrate (CAN), (2) urea, (3) urea with one N stabiliser from the urease inhibition class, N-(n-butyl) thiophosphoric triamide (NBPT), and (4) urea with two N stabilisers from the urease inhibition class, NBPT and N-(n-propyl) thiophosphoric triamide (NPPT), Limus® (Figure 1). A range of agronomic and environmental parameters specific to each crop is monitored. The experiments focus on the main N loss pathways, i.e. N_2O and

NH_3 in grassland, and nitrate leaching and NH_3 in arable.

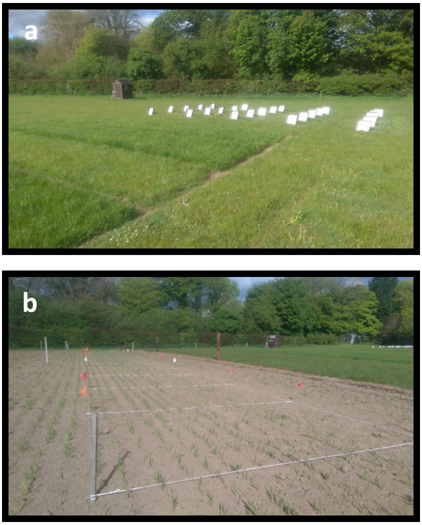

Figure 2.Experimental plots based in Johnstown Castle, a) grassland agronomic and N_2O monitoring plots, b) spring barley NH_3 monitoring windtunnel plots.

Grassland plots (Figure 2 a) receive a standard agronomic rate of 200 kg N/ha/yr in six split applications and grass dry matter yield and N content is measured at the end of each fertilisation split. Nitrous oxide is monitored for a full year using the static chamber method (Figure 3 a), while NH_3 emissions are measured for two weeks post-fertilisation using a combination of shuttles (integrated horizontal flux, or IHF), and windtunnel methods (Figure 3 c, d). Spring barley plots (Figure 2 b) receive a standard agronomic rate of 150 kg N/ha/ye in two split applications and barley dry matter yield and grain N and protein content is measured at harvest. Nitrate leaching is monitored for a full year using existing lysimeters installed on-site below the ploughing depth (Marshalstown) (Figure 3 b), while NH_3 emissions are measured for two weeks post-fertilisation using a combination of IHF and windtunnel methods (Johnstown Castle) (Figure 3 c, d).

Figure 3. Overview of experimental methodology used; a) N_2O sampling with the static chamber method, b) nitrate leaching sampling with lysimeters, c) NH_3 sampling with shuttle method (IHF), d) NH_3 sampling with windtunnels.

Results and Discussion

Outputs from the above experiments will have a dual purpose serving both the farmers and policymakers. On one hand, new fertiliser advice will be formulated, leading to a better NUE, while on the other hand improved estimates of N losses will guide policymakers through the process of mitigating agricultural N2O and NH_3 emissions and nitrate leaching and allow reductions to be accounted for at the national level.

Acknowledgements

This work is funded by the Irish Research Council through the Enterprise Partnership Scheme Postdoctoral Fellowship (grant number EPSPD/2016/54), where the Enterprise Partner is BASF PLC and BASF SE and the Enterprise Mentor is Mr. Ben Miles.

Exploring microbial denitrifers and potential for mitigation of N2O emissions in agricultural soils

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Introduction

Nitrous oxide (N_2O) is a potent greenhouse gas with global warming potential 310 times that of carbon dioxide. N_2O emissions comprise over one-third of all agricultural emissions and decreases of N_2O emissions are critical in reaching nationally and globally agreed targets. Reductions of emissions, within the context of a growing human population and sectoral expansion, represent a major challenge for agriculture. Nitrogen (N) losses from agricultural soils also represent an economic loss to the agricultural sector. Thus, managing N resources in soil is critical for environmental and agronomic sustainability, and underpins efforts to meet global challenges of increasing food production and climate change mitigation.

Microorganisms drive the majority of biogeochemical processes in soil and are responsible for much of the gaseous losses. By understanding how these organisms function there is great potential to predict when deleterious environmental N losses are likely to occur and to manage soils in such a way as to reduce losses.

Objectives

1. To determine the occurrence, diversity and activity of microbial denitrifiers in Irish soils
2. To determine the impact of management, environmental and edaphic factors on microbial production of N_2O
3. To identify and quantify the contribution of different nitrogen transformation pathways on nitrogen budgets in soils, and their resulting impacts on N_2O emissions
4. To identify regulators of each pathway, particularly those regulating co-denitrification and denitrification to N_2
5. To devise strategies, based on those key regulators, to divert N_2O to N_2 arising from urine and fertiliser N application

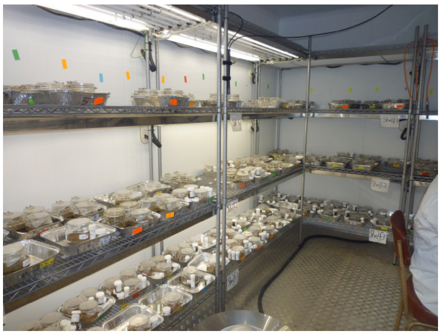

Figure 1. Labelled N studies assessing gaseous N losses

Materials and Methods

The study is part of a larger project funded by the Irish Department of

Agriculture, Food and the Marine, which is entitled MINE (Manipulation and Integration of Nitrogen Emissions). The overall objectives of MINE are to divert gaseous N losses from N_2O to N_2 and integrate N_2O emissions on a spatial and temporal scale. This project will use a mixture of molecular and high throughput sequencing methods in conjunction with biochemical and isotopic approaches.

This work will assess the potential denitrification activity of a wide range of representative Irish soils with varying management history (e.g. liming, long term high and low phosphorus, long term high and low application rates of cow and pig slurry and inorganic N etc). This will be used to determine the range of denitrification potential within Irish soils, and particularly to identify soils with high and low denitrification capacity. The physicochemical properties of soils with high and low N_2/N_2O emissions will be determined in association with characterisation of soil biological properties by quantitative PCR and sequencing of phylogenetic and functional gene targets. The impact of agricultural management factors and mitigation measures, designed to reduce emissions, on the soil denitrifying communities and gaseous N emissions will be assessed.

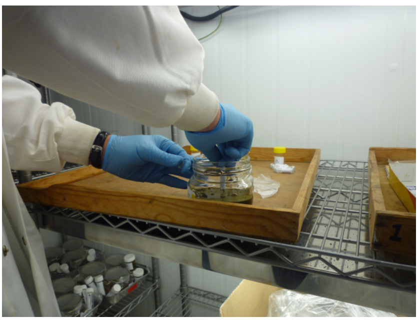

Figure 2. Investigating microbial community structure and function in soil

Expected Benefits

This work will underpin efforts to accurately quantify, and mitigate, greenhouse gas emissions of N_2O, and thus facilitate sustainable expansion of the agricultural sector. By understanding the processes and the organisms producing N_2O, and their response to management, environmental and edaphic factors there is great potential to manage soils in such a way as to divert gaseous losses away from environmentally damaging N_2O to environmentally benign N_2. By examining a wide range of representative Irish soils with varying management history this project will provide valuable data on which soils are inherently at higher and lower risk of generating N_2O emissions and the impact of management factors on this risk.

Figure 3. In-plot measurements of N_2O emissions under different fertiliser regimes

Acknowledgements

This project is funded by the Irish Department of Agriculture, Food and Marine

A Marginal Abatement Cost Curve (MACC) for Ammonia Emissions

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Introduction

Agriculture contributes virtually all (98%) of Ireland's national ammonia emissions (Duffy et al., 2015). In 2015, dairy and non-dairy bovines comprised 76.9% of agricultural ammonia, with these emissions arising principally from animal housing and storage (41.4%) and the landspreading of manures (28.6%). Manure emissions from pig and poultry systems comprise the bulk of the remaining emissions, followed by fertiliser-based emissions.

The Food Wise 2025 Strategy envisages substantial increases in agricultural production. Concurrently, EU Clean Air targets require a reduction in ammonia emissions, relative to 2005, of 0.5% to 2030 and 5% from 2030 onwards.

In order to assess the maximum abatement potential and associated costs, marginal abatement cost curves were generated. Individual strategies were inputted into an ammonia emissions model in order to assess antagonisms and synergies between housing/storage and landspreading strategies.

Impact of Food Wise 2025 on Ammonia Emissions

The increase in agricultural production under the Food Wise 2025 results in total NH_3 emissions of 113.8 kT by 2030 (see Figure 1). This represents an 8.9 kT NH_3 increase relative to 1990 and a 6.6 kT NH_3 increase relative to 2005. This increase is principally due to a 16.8 kT NH_3 increase in dairy emissions and 0.7 kT NH_3 increase in pig-sourced emissions by 2030 relative to 2005. In contrast, non-dairy bovine and sheep emissions are projected to decrease by 11.5 and 0.9 kT NH_3 respectively by 2030.

Ammonia Abatement Potential

The cumulative maximum ammonia abatement potential was calculated to be 12.05 kT NH_3 by 2030 (Figure 1). This maximum abatement assumed a 50% adoption of trailing shoe and represents a 5.1% reduction relative to 005.

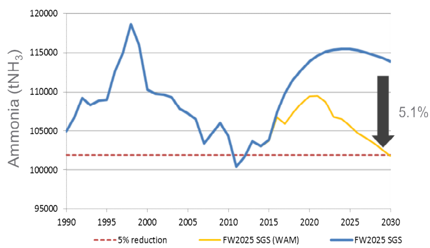

Figure 1: Estimated ammonia emissions under Food Wise 2025 Sustainable Growth Scenario without (blue line) and with (gold

line) ammonia abatement measures (WAM).**

The most cost-effective measures were from timing of application, replacement of straight urea with urea amended with urease inhibitors, the use of trailing hose for bovine slurries, reducing poultry pH with alum amendment and the reduction of crude protein in pig diets. It should also be noted that the costs associated with crude protein supplementation could be cost-neutral depending on the relative costs of soy bean meal and supplemental amino acids. These measures accounted for 60% of the mitigation for less than 40% of the total cost.

The cumulative abatement and costs are shown in Figure 2. Two abatement scenarios are shown: the first (red line) where 50% of pig and bovine slurry is band-spread and the second where 50% is applied by trailing shoe. A maximum abatement potential of 10.6 and 12.0 kT NH_3 is possible under the bandspreading and trailing shoe projections respectively, at a total cost of €24.9 million (bandspread) and €35.6 million per annum (trailing shoe).

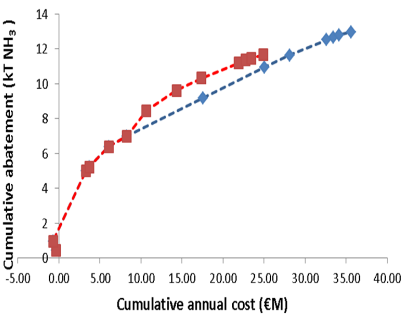

Figure 2: Cumulative costs and abatement for the Food Wise 2025 Sustainable Growth Scenario. The blue line indicates abatement with trailing shoe included, whilst the red line includes bandspreading as a landspreading abatement option.

Conclusion

By 2030 the maximum technical potential to abate ammonia is between 10.6 and 12 kT NH3 at a cost of between €24.9 and €35.6 million for the Food Wise 2025 Sustainable Growth Scenario. This represents the maximum achievable potential, with 8 – 9.2 kT NH_3 abatement more likely in terms of cost effectiveness. Altered slurry spreading, crude protein diets in pigs, urea substitution, chemical amendment, and trailing hose/trailing shoe offer the most cost-effective strategies, while Housing and storage abatement, particularly in the pig sector were the least cost-beneficial. When adopting strategies, particularly in terms of fertiliser and landspreading techniques, there is a risk that higher N_2O emissions may result from ammonia abatement. The combined impact of measures of total reactive N losses should subsequently be assessed.

Acknowledgements

This research was funded by the Irish Department of Agriculture, Food and the Marine (Project no. 13/S/430).

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Micrometeorological Assessment of Ecosystem Carbon Balance

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Introduction

Agricultural ecosystems in temperate climates are generally net carbon sinks; however, management, fertiliser input and climatic variability can have a significant impact on ecosystem carbon dynamics (Soussana et al., 2004). The aim of this programme of research was to investigate the potential for carbon sequestration in multiple ecosystems and to gain an understanding of the main drivers of carbon cycling.

Materials and Methods

The research was conducted on two dairy farms with contrasting soil types and grazing intensity. The Solohead Research Farm in Co. Tipperary is characterized by low permeability soils and is dominated by poorly-drained gleys (90%) and grey brown podzolics (10%). The grass-clover swards were rotationally grazed at a stocking rate of 2.4 cows ha^{-1}. The second site at Johnstown Castle has sandy loam textured soil and moderate to good drainage. The annual stocking rate is 3.2 cows ha^{-1} and the herd is managed under an intensive rotational grazing system. Both sites were instrumented with open-path eddy covariance systems which enabled spatially integrated measurement of CO_2, water and energy fluxes over an area of one to several paddocks (depending on atmospheric turbulence) (Figure 1).

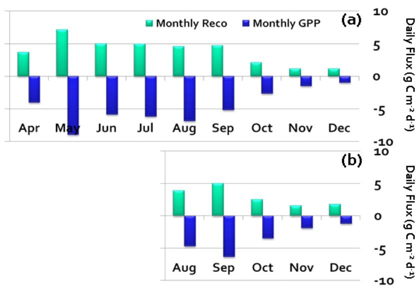

Figure 1. Basic components of the eddy covariance systems consisting of a 3-D sonic anemometer and fast response CO_2 infra-red gas analyser.

The raw 10Hz data was averaged over 30-minute intervals and daily and long-term cumulative values were determined following quality analysis and gap-filling procedures. Footprint analysis, based on the analytical model of Kormann & Meixner (2001), was employed to eliminate contributions from areas outside of the investigated paddocks. Plant biomass yields were determined prior to grazing and sward height was measured on a weekly basis.

Results and Discussion

Daily patterns for net ecosystem exchange (NEE) of carbon at Solohead site are shown in Figure 2, in addition to cumulative values for gross primary productivity (GPP), total ecosystem respiration (Reco) and NEE. Assimilation of carbon by the grassland ecosystem exceeded total respiratory losses for the 9-month interval from April to December leading to a net uptake (negative cumulative NEE) of -247 g C m^{-2} over this period. Intensive grazing led to a decrease in leaf area and, in turn, a clear reduction in GPP, the magnitude of which was dependent on the intensity and duration of grazing.

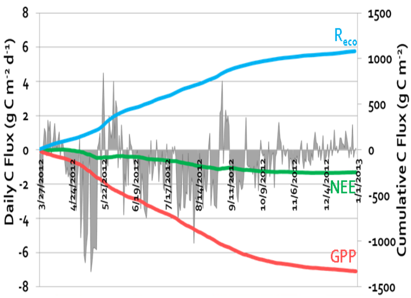

Figure 2. Daily totals of net ecosystem exchange (NEE) (grey trace) and cumulative sums of gross primary productivity (GPP), total ecosystem respiration (Reco) and NEE for the Solohead site.

Comparing net C uptake from Solohead with that from Johnstown Castle grassland showed that net exchange for Solohead ranged from -218 to -285 g C m^{-2} y^{-1}, whilst that from Johnstown Castle ranged from -221 to -386 g C m^{-2} y^{-1}. The higher values associated with Johnstown were principally associated with higher levels of silage offtake in Solohead (Figure 3)

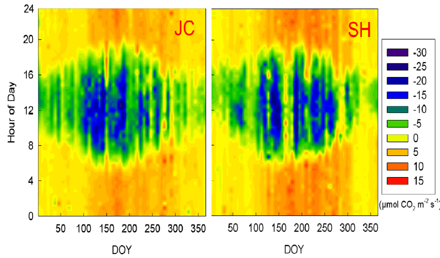

Figure 3. Monthly-averaged daily fluxes of R$_{eco}$ and GPP at (a) Solohead and (b) Johnstown Castle.

Conclusions

Net ecosystem uptake of carbon was observed at both grassland sites, with net C assimilation occurring even in the less productive winter months and at comparable rates. Grazing and cutting influenced the rate and direction of carbon flux, highlighting the importance of management effects on the overall carbon balance. Measurements continue to assess the annual carbon balance of grazed grasslands and to elucidate further the drivers of C dynamics in these systems.

Acknowledgements

This work was undertaken as part of the EU-FP7 AnimalChange project (Grant Agreement 266018) and AGRI-I (RSF10 RD/SC/ 716).

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The Role of Aggregation in Soil Carbon Sequestration

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Introduction

Soil organic carbon (SOC) sinks play a key role in the global carbon (C) cycle The Intergovernmental Panel on Climate Change (IPCC) provides good practice guidance on the methodology to account for the impact of land use management and land use change on organic carbon stocks in soils. Generally for Tier 1 (default) or Tier 2 (national-specific) approaches, a stock change is calculated by assessing the reference soil organic carbon (SOC) level down to 30 cm and measuring again after a period of at least 3 to 5 years (Torres-Sallan et al., 2017). However, this approach neither accounts for different turnover rates of different fractions of SOC, nor recognises that substantial pools of recalcitrant SOC exist below 30 cm, which may be affected by land management. There have been attempts to directly relate these modelled pools to the different aggregate fractions such as macroaggregates, microaggregates and silt/clay. The turnover time of SOC contained in macroaggregates is reported as 1 to 10 years, while SOC associated with microaggregates is considered stable up to 100 years in soil. Silt plus clay associated SOC is stable in excess of 100 years. Therefore, encapsulation of SOC within microaggregates or silt plus clay particles is considered long-term C storage.

Our research aimed to elucidate the patterns of SOC distribution in typical temperate grasslands and answer the following:

1) Does the topsoil and subsoil have similar physical protection against mineralisation?

2) How does this vary across soil types, specifically between freely draining soils and those subject to clay illuviation over depth?

Materials and Methods

Thirty one grassland sites were sampled, representing six different soil types. These soil types represent a range of SOC and drainage characteristics typical of grassland soils occurring in Ireland. At each site (a profile pit was dug to 1 m and 1 kg sample was taken from the centre of each horizon. An adaptation of the wet sieving method was followed to separate each sample into four aggregate sizes: large macroaggregates (2-8 mm), small macroaggregates(250μm-2mm), microaggregates (53-250 μm) and silt plus clay (<53μm) (Figure 1). SOC of each fraction was analysed with a LECO Truspec CN analyser following the ISO 10694:1195, and expressed on a sand-free basis.

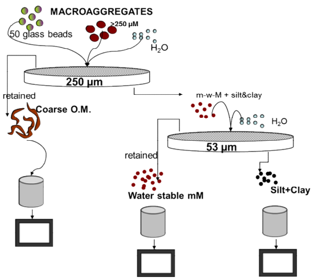

Figure 1: Schematic of aggregate fractionation

Results

The distribution of SOC across the four different aggregate size classes in all six soil types (Figure 2) reveals three patterns:

1. The total amount of SOC declines with depth in all soils;

2. The proportion of SOC associated with large and small macroaggregates declines with depth in all soils;

3. A larger proportion of the SOC is associated with microaggregates and silt plus clay fractions in soils affected by clay illuviation (namely: Typical Luvisols (TLu), Stagnic Luvisols (SLu) and Typical Surface-water Gleys (TSWG)) than in Brown Earths (Humic Brown Earths (HBE), Typical Brown Earths (TBE) and Stagnic Brown Earths (SBE).

As a result, most (68.9% ± 11.5) of the SOC was found within the top 30 cm of the soil profiles, and a significant proportion (84% ± 9.5) of this topsoil SOC was located within large and small macroaggregates, as indicated by the predominance of the 'large bubbles' in quadrant B.

A small proportion (16.1 ± 9.1%) of the SOC in the top 30 cm was associated with the microaggregates and silt plus clay, as indicated by the 'empty' quadrant A. In contrast, SOC associated with these smaller fractions equates to 42.2 ± 19.5% of the subsoil (30 cm to 1 m depth) SOC stock.

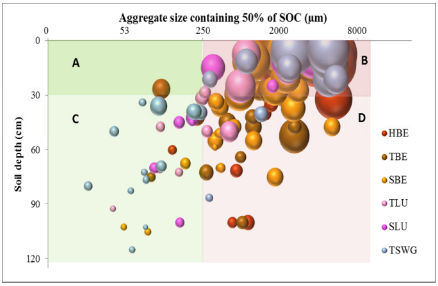

Figure 2: Relative distribution of SOC within aggregates by depth. The figure plots the obtained m values (natural logarithm of aggregate size containing 50% of SOC).

Conclusion

The results indicate that it is important to consider soil depth and SOC distribution within aggregates when measuring and/or modelling the SOC sequestration potential of soils in grassland systems. At lower depths in the soil profile, SOC is increasingly associated with smaller aggregate sizes which are more recalcitrant. In particular, high levels of protected C at depth were found in Stagnic Luvisols.

Acknowledgements

This research was funded by the Irish Department of Agriculture, Food and the Marine (Project no. 10/RD/SC/716).

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Assessment of the impact of management factors on soil denitrifying communities and N emissions

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Introduction

Nitrogen fertiliser is one of the largest costs on farms and thus losses from agricultural soils represents an important economic loss to the agricultural sector. Agriculture accounts for over 30% of Irish greenhouse gas emissions with methane, carbon dioxide and nitrous oxide being the main greenhouse gases. Globally, agriculture is expanding to meet food demands of the growing global population. Nitrous oxide (N_2O) is a potent greenhouse gas which originates from nitrogen transformations in soil. N_2O is emitted when nitrogen is deposited to soil in the form of fertiliser, manure or urine through denitrification and nitrification processes. These processes are influenced by a range of physical, chemical and biological soil properties which influence the amount of N_2O that is reduced to the environmentally benign dinitrogen gas.

Internationally there is very limited data on N2 emissions from soils due to methodological constraints. Recent research in Johnstown Castle has highlighted that over 50% of applied N was emitted as N_2 from simulated urine patches as a result of codenitrification, which is a seldom investigated process where N_2 is formed via inorganic and organic N in soil (Selbie et al. 2015). The management drivers that alter the rate of N_2 and N_2O relative to each other and those factors driving co-denitrification are unclear with the latter process, in particular, having been poorly studied. Previous studies indicate that factors such as soil pH, the proportion of fungi, copper (Cu) availability, C: N ratio, soil moisture and fertility can all influence (co) denitrification processes.

A key challenge is the coupling of increasing agricultural product while reducing costs with improving environmental performance. The challenge for all sectors of the economy to reduce greenhouse gas emissions is a global one. Improved understanding of the factors influencing N_2 and N_2O emissions in Irish soils will enable practices to be developed that balance agricultural production with environmental targets. Thus, managing N resources in soil is critical for environmental and agronomic sustainability, and underpins efforts to meet global challenges of increasing food production and climate change mitigation.

Objectives

- To identify and quantify the impact of agricultural management on

N_2 emissions across a range of grassland soils with different denitrification potential

- To investigate the impact of soil factors such as pH control through liming on the N2O: N2 ratio in Irish soils

Materials and Methods

The study is part of a larger project funded by the Irish Department of Agriculture, Food and the Marine, which is entitled MINE (Manipulation and Integration of Nitrogen Emissions). The overall objectives of MINE are to divert gaseous N losses from N_2O to N_2 and integrate N_2O emissions on a spatial and temporal scale.

Using ^{15}N isotope techniques the project will quantify N_2 and N_2O fluxes from denitrification and co-denitrification across a wide range of soils from long term experiments. The soil nitrogen transformation rates will then be modelled using an isotope tracing model (Figure 1).

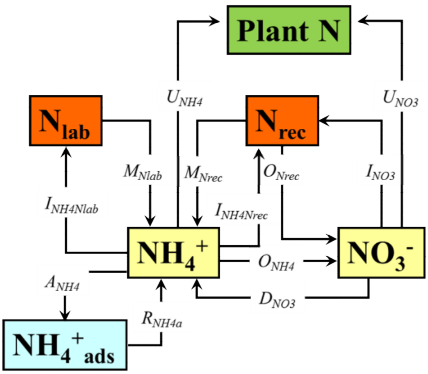

Figure 3. Using soil nitrogen modelling to investigate the influence of soil properties on transformations (Müller et al. 2007).

This work will assess the potential denitrification activity of a wide range of representative Irish soils with varying management history (e.g. liming, long term high and low phosphorus, long term high and low application rates of cow and pig slurry and inorganic N etc). A field based ^{15}N tracing study will quantify N_2 and N_2O emissions (Figure 2). The soil biological properties will also be quantified using quantitative PCR and sequencing of phylogenetic and functional gene targets.

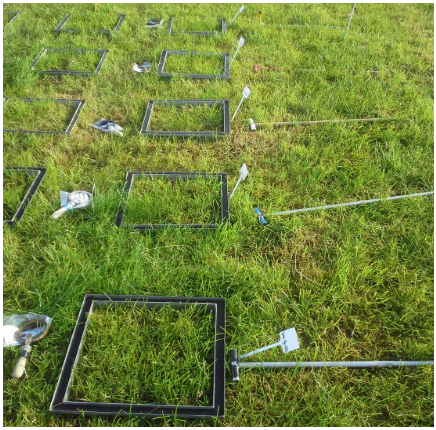

Figure 2. Field investigation of N_2 and N_2O emissions within long term agronomic trials.

Expected Benefits

This work will identify soil factors that can be manipulated to reduce greenhouse gas emissions by reducing N_2O emissions and improve nitrogen use efficiency by reducing N_2 emissions.

Acknowledgements

This project is funded by the Irish Department of Agriculture, Food and Marine under the Research Stimulus Fund grant number RSF11S655.

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Mitigation of ammonia and greenhouse gas emissions from stored cattle slurry using acidifiers and chemical amendments

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Introduction

Cattle account for 80% of Ireland's agricultural ammonia (NH_3) emissions, of which slurry storage contributes 15% (EPA, 2015). These emissions can have a detrimental effect on natural ecosystems, causing eutrophication as well as acidification of waterways and lakes. Cattle slurry also produces other harmful gases such as methane (CH_4) and carbon dioxide (CO_2), which are greenhouse gases (GHG). Slurry pH influences these emissions, and acidification of cattle slurry using sulphuric acid has been well documented to reduce NH_3 emissions, with up to 70% reductions reported (Stevens et al., 1989).

The use of ferric chloride ($FeCl_3$) and alum in previous studies has resulted in retention of P as well as some reduction of N_2O emissions (O'Flynn et al., 2013). However, NH_3 and GHG emissions from stored cattle slurry have not been well documented using these amendments.

The objective of this study was to investigate the impact of the addition of sulphuric acid, acetic acid, alum and ferric chloride on NH_3, CO_2 and CH_4 emissions from stored cattle slurry of two different dry matter (DM) contents. These represent slurries typical to dairy and beef production systems.

Materials and Methods

Cattle slurry with two different dry DM contents of 4% and 7%, were amended with sulphuric acid, acetic acid, alum, and ferric chloride until a target pH of 5.5 was attained. A control, with no amendment, was also included.

The study was conducted using 1.6 L-capacity containers, which were stored in a temperature controlled environment at 8.6^{o}C with 60% humidity, representing typical Irish winter conditions (Figure 1). Airflow was also regulated by placing modified caps on the containers to replicate storage conditions under a slatted tank. Ammonia emissions were measured using a photoacoustic field gas-monitor. CO_2 and CH_4 emissions were monitered using a closed static chamber technique. The pH was measured using a JENWAY 1510 pH meter. The study duration was 83 days.

Results and discussion

The amendments reduced NH_3 emissions by 84% - 98% and by 86%-

Figure 1: Slurry containers simulating winter storage and emissions measurements

97% relative to the controls in the 4% DM and 7% DM slurries, respectively. Alum and $FeCl_3$ produced the highest reductions. However, $FeCl_3$ had significantly lower NH_3 emissions than both sulphuric acid and acetic acid in both DM slurries as seen in Figure 2. Methane emissions were reduced by 80%-95% in the 4% DM slurry and by 94%-98% in the 7% DM slurry relative to the controls, with $FeCl_3$ attaining the highest reductions.

The pH of all treatments gradually rose during the study, and attained values of between 6.8 to 7.2 in the 4% DM slurry and 6.5 and 6.9 in the 7% DM slurry by day 83, while the control remained at 7.4 ± 0.1 during the study. For the majority of the amendments, the rise in pH during the study correlated with a rise in emissions to a point; however, this was not the case for $FeCl_3$, which appeared to act independently of pH towards the end of the trial period. This suggests that $FeCl_3$ not only acidifies the slurry but that it has a secondary mode of action that is retarding emissions also. Carbon dioxide emissions were similar across all treatments in the 7% DM slurry. However, acetic acid increased CO_2 production in the 4% DM slurry by 62% compared to the control.

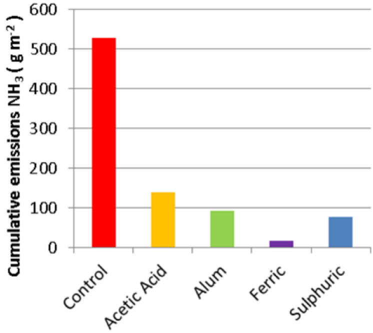

Figure 4: Ammonia emissions from stored slurry with and without amendments.

Conclusion

All the amendments examined significantly reduced NH_3 and CH_4 emissions. To the authors' knowledge, this is the first study to show that the addition of alum and $FeCl_3$ to cattle slurry under winter storage conditions significantly reduces NH_3 and CH_4 emissions without increasing CO_2 production. In the case of $FeCl_3$ an unexpected result showing the reduction in emissions regardless of an increase in pH towards the end of the study warrants further investigation.

Acknowledgements

This work was funded by the Irish Department of Agriculture, Food and the Marine (Grant number RSF 13/S/430).

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Agricultural Ecology

Farming and natural resource: measures for ecological sustainability. FARM-ECOS

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Introduction

Conservation of natural resources and halting the degradation of ecosystem services are key environmental objectives of the European Union. Significant resources are allocated to these objectives in the Common Agricultural Policy (e.g. 'Greening'; Agri-environment schemes). However, deficiencies in relation to the design, targeting, monitoring, evaluation and flexibility of measures and schemes have resulted in their effectiveness being questioned. Challenges lie in developing measures with a strong evidence base to support their environmental effectiveness and cost-efficiency.

This project, in close consultation with key stakeholders, will identify and outline the evidence base for novel, cost-effective measures to protect and enhance farmland biodiversity. These measures will increase habitat quantity, enhance habitat quality and improve ecological connectivity, from farm to landscape scale. Measures will thus help halt biodiversity loss and enhance the provision of above and below ground ecosystem services, thus supporting agriculture and local communities.

Objectives

1. Identify cost-effective novel measures to protect and enhance biodiversity, improve landscape connectivity and enhance ecosystem services.
2. Evaluate habitat quality and develop an ecosystem 'health assessment scoring card' for farm habitats.
3. Determine how habitat quantity and quality influences soil quality and nutrient composition, and delivery of selected ecosystem services
4. Develop predictive models to simulate introduction of novel measures into agricultural landscapes.
5. Assess the spatial extent to which high quality habitats can influence species abundance and the extent of benefits and delivery of ecosystem services

Figure 1: Fragmented landscape where wildlife habitats are isolated by large areas of intensively

managed land and urban settlements.

Research approach

The study will build on existing research to identify novel agri-environment measures appropriate to Irish conditions. We will work at various scales from field and farm to landscape scale to identify measures to increase habitat quantity and quality and improve ecological connectivity.

Stakeholder engagement, coupled with cost-benefit analysis of selected measures (Task 1 & 2) will identify those most suitable for inclusion in future agri-environment schemes. Field and farm scale (Task 4-5) and farm and landscape scale (Task 6-7) research will address gaps in knowledge in relation to the importance of habitat quality and ecological connectivity in halting biodiversity loss and degradation of ecosystem services. Addressing these gaps in knowledge will facilitate the identification of measures and practices required to enhance habitat quality, connectivity and the provision of ecosystem services.

The research approach will be a combination of desk studies, stakeholder workshops, expert-group evaluation, attitudinal survey and field and landscape analysis.

- Cost-benefit analysis of novel measures to protect and enhance biodiversity on farmland (Task 1-2; Task 6- 7).

- Ecological surveys and soil analyses (using existing and novel bioindicators) to assess the quantity (Task 3) and quality (Task 4-7) of habitats along with selected ecosystem services on a gradient of farming intensities and enterprises.

- Landscape surveys to assess the importance of context and connectivity in enhancing biodiversity and delivery of ecosystem services on a gradient of farming intensities and enterprises (Task 6-7).

- Disseminate project results via demonstration field sites (Task 8), stakeholder engagement (workshops/conferences) (Tasks 1-2), popular articles, research publications and an end-of-project conference (Task 9).

Figure 2: Establishment of new habitats such as ponds can play an important role in halting the decline of farmland biodiversity.

Expected Benefits

The project will provide stakeholders with the necessary evidence base for novel measures and practices to effectively protect and enhance biodiversity and associated ecosystem services. Addressing these challenges will help the agri-food sector achieve its objectives in relation to the development of economically and environmentally sustainable food production systems.

Acknowledgements

This project is funded by the Department of Agriculture, Food and the Marine under its Research Stimulus Fund (grant number – 15 S 619).

Payments for ecosystem services: conservation of freshwater habitats through agri-environment schemes

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Introduction

Biodiversity contributes to human well-being through the delivery of ecosystem services. In addition to the 'provisioning services' (e.g. food and fuel), ecosystem services include 'regulatory services' (e.g. flood mitigation, water purification), 'supporting services' (e.g. soil formation, nutrient cycling) and cultural services (e.g. aesthetic, recreational). Many of these non-provisioning ecosystem services have no market price to indicate their economic value to society, therefore payment for ecosystem services (PES) has been proposed as an effective tool for the delivery of Agri-Environment Schemes (AES).The majority of EU protected freshwater habitats and species in Ireland are considered to be of poor or bad conservation status. Changes in farming practices, to increase the supply of agricultural produce have impacted on the landscapes, water quality and quantity and soil process such as nutrient cycling.

An ecosystem service approach to Agri-Environmental Schemes would provide farmers with payments based on the value to society of cultural, regulatory and supporting ecosystem services as opposed to the current approach which bases payments on the cost and loss of income due to the implementation of AE measures.

The aim of this project is to develop a framework for targeting payments for ecosystem services to address the favourable conservation status of key freshwater aquatic habitats and species.

Objectives

1. Identify the main regulatory and supporting ecosystem services and functions underpinning the maintenance of freshwater biodiversity in selected catchments.

2. Through expert focus groups, determine the management required to maintain or provide favourable conditions for priority aquatic habitats and species in a sub-sample of catchments.

3. Determine the spatial relationship between ecosystem services and hydrological connectivity in a sub-sample of representative catchments.

Figure 1. Freshwater aquatic habitats play an important role in providing ecosystem services.

Materials and Methods

The research approach to be used in this study is based initially on the detailed characterization of catchments with priority freshwater aquatic habitats or species, through gathering and mining of existing national datasets on land-use, hydrology and economic parameters.

A Geographical Information System (GIS) multi-criteria decision analysis will then be used to select a number of representative catchments for more detailed case studies of how best to target payments for ecosystem services in AES designed for the conservation of key freshwater aquatic habitats and species.

An expert focus group approach will be utilised to identify measures and management strategies required for the conservation of the freshwater ecosystems within the representative catchments.

Using high resolution digital terrain model data, this study will investigate how to spatially target payments for ecosystem services based on their hydrological connection to freshwater ecosystems within selected catchments.

The outputs of valuation analysis of key ecosystems services will be integrated with the hydrological connectivity analysis within a GIS framework to develop a risk-based approach for the targeting of payments for ecosystem services through AES.

Expected benefits

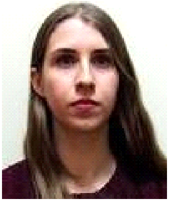
To date, the focus on farm-scale implementation and the voluntary nature of Agri-Environment Schemes has limited their potential effectiveness in maintaining the health of freshwater ecosystems as this is predominantly a function of processes occurring at the landscape scale. Therefore, to increase the environmental benefits and cost effectiveness of AES, there is a need to target payments at areas within catchments where landscape processes control the response of waterbodies to land-use practices. A key question is how can payment for ecosystem services be effectively targeted so as to maximise the economic benefits and cost effectiveness of AES?

Arising from the outputs of this research, recommendations on institutional structures, mechanisms for implementation and a list of policy measures will be proposed.

Acknowledgements

This work is funded by the Environmental Protection Agency.

Figure 2. The focus on farm-scale implementation and the voluntary nature of Agri-Environment Schemes has limited their potential effectiveness in maintaining the health of freshwater ecosystems



The establishment and management of ecological focus areas to enhance ecosystem services and integrated pest management.

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Introduction

Under the Common Agricultural policy of the EU, in order to qualify for the greening portion of their basic payment scheme farms with over 15 hectares of arable land need to designate 5% of that land as Ecological Focus Areas (EFA). This may increase to 7% from 2017 onwards. EFAs are intended to increase biodiversity and include existing landscape features (e.g. hedgerows or ditches), or newly established habitats (e.g. sown arable margins).

Each member state select which EFAs are eligible for their country and which landscape features count towards the 5% requirement. It is believed that arable margins will be eligible as EFAs in Ireland from 2017. Additionally, EFAs can be supported through national agri-environmental schemes. The current agri-environment scheme in Ireland is the Green Low-Carbon Agri-Environment Scheme (GLAS), which facilitates the inclusion of arable margins.

Appropriate design and management of EFAs could ensure that they not only play an important role as a refugia for biodiversity, but also a role in the delivery of additional ecosystem services. For example, EFAs are important for biocontrol, where they are

a source of beneficial insects for integrated pest management. If communities of natural enemies are sustained within EFAs then there may also be indirect effects on crop production e.g. disease suppression through the reduction of disease vectors; yield improvement through the limiting of pest damage. This is particularly important for arable farmers considering the reduction in the number of available pesticides and the growing challenge of pesticide resistance.

Figure 1: Experimental Margin at Teagasc OakPark, Carlow.

Objectives

- To determine best practice and methods for the establishment of desirable plant and insect species in arable margins
- To determine the best practice to manage and maintain these margins in subsequent years.
- To determine which plant species and community structure within the arable margin supports natural enemies at a beneficial level to the adjoining crops.
- To recommend appropriate changes where necessary in practical management and policy governing Ecological Focus Areas in order to best support biodiversity and the provision of ecosystem services.

Methods

Using experimental plots of different grass and wildflower mixes along with natural regeneration to assess the establishment of an optimal mix.

Using observational margins to assess what is already in practise within the GLAS scheme as well as voluntary efforts to aid biodiversity in arable margins.

Assessing the difference between what was sown in previous years and how many of those species established and persisted in following years.

Sampling the insect populations of the margins and crops in order to determine what is living in which area, what advantages/dis-advantages these insects provide and the effect of distance from the margin on their abundance.

Assessing the adjacent crop's health and productivity through virus sampling and yield measurements to determine any advantages/disadvantages.

Figure 2: Arable margin in full flower at Kildalton College, Teagasc.

Expected benefits

The identification, evaluation and dissemination of effective management to enhance ecosystem services (including essential pest management services) is an essential element of the vision for sustainable agricultural systems.

Incorporation of such management can provide important and much needed evidence that Irish and Scottish farmers, and retailers deliver on their 'clean, green' image, within their respective national strategies for agriculture.

This project will:

- Test and evaluate methodologies for the establishment and management of Ecological Focus Areas
- To inform policy regarding Ecological Focus Areas in Ireland and Scotland
- To raise awareness of the benefits of promoting natural habitat to support natural enemies of economically significant pests

Acknowledgements

This study is a collaboration between Teagasc, SRUC and the University of Edinburgh and is funded by the Teagasc Walsh Fellowship Scheme.

Ecological Focus Areas on Intensive Farms in Ireland

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Introduction

The reform of the Common Agricultural Policy has seen the introduction of three "Greening" measures aimed at increasing agricultural sustainability. These measures are crop diversification, the maintenance of permanent grassland and the establishment of Ecological Focus Areas (EFAs). Currently, the EFA measure requires farmers with over 15 hectares of arable land declare 5% of this land as "Ecological Focus Areas"; however, it is likely that the percentage EFA required will increase to 7% in future Greening reforms. Additionally grassland farms, currently exempt from the EFA measure, may be included for participation.

Ecological Focus Areas are landscape features and practices that are ecologically beneficial and will have a positive effect on biodiversity and the environment. In Ireland, current eligible EFAs include hedgerows (Figure 1), drains, and riparian buffer strips. These, and other semi-natural habitats, are vitally important for maintaining and enhancing biodiversity. It is hoped the establishment of EFAs (coupled with the associated ecosystem services they provide such as food, fresh water, pollination, flood protection, clean air etc.) will help halt the loss of farmland biodiversity and contribute to sustainability and environmental targets (e.g. Biodiversity Strategy 2020, Water Framework Directive, Climate Change Strategy).

Figure 1: An example of a hedgerow on an arable farm which classifies as an EFA under Irish prescriptions.

Materials and Methods

It is unclear what percentage of Irish farmland currently qualifies as EFA; this study undertook a farm habitat survey on intensively managed tillage, beef and dairy farms in Ireland to determine the proportion of farm area currently under semi-natural habitat cover. The survey included quantification of habitats that are eligible as EFA under Irish prescriptions (Irish eligible EFA), habitats that are allowed under EU legislation which Ireland chose not to implement (EU eligible EFA) and habitats not currently eligible under EU specifications (non-eligible EFA).

A subset of hedgerows on each farm was also surveyed in relation to their quality, according to methodology outlined in The Hedgerow Appraisal System.

Results and Discussion

Thirty-eight tillage farms, 38 beef farms and 43 dairy farms throughout Ireland were surveyed. Preliminary results indicate that all surveyed farms exceed the current 5% EFA requirement. Our analysis suggests that approximately 13% of tillage farms, 10% of dairy farms and 3% of beef farms may experience difficulties in meeting a revised 7% requirement, if assessed under current eligibility prescriptions.

This study indicates that hedgerows account for approximately 64% of Irish eligible EFA, occurring on 100% of farms surveyed and are often the only semi-natural habitats present. This highlights the importance of appropriate hedgerow management prescriptions if quality habitats are to be achieved. Other common Irish eligible EFAs surveyed include drains and buffer strips. Of the nine EFAs allowed under Irish prescriptions two habitats (catch crops and short rotation coppice) were not surveyed on any farm visited.

EU eligible EFAs and/or non-eligible EFAs were surveyed on the majority of farms visited. Field margins were the most abundant EU eligible EFA surveyed across the three farm types, occurring on 82% of farms; while woodlands were the most abundant non-eligible EFA surveyed, occurring on 56% of farms surveyed. Hedgerow Appraisal was split into two different categories;

1) Hedgerow significance which looks at a hedgerow under historical, ecological and landscape parameters

2) Hedgerow condition which is divided into structural variables, continuity and negative indicators.

Forty-six percent of beef hedgerows and 51% of tillage hedgerows were found to be significant under Category 1; while 10% of beef hedgerows and 4% of tillage hedgerows were found to be in favourable condition under Category 2.

Figure 2: A hedgerow overrun with *Galium aparine,* an indicator of nutrient enrichment which leads to an unfavourable condition score in the Hedgerow Appraisal System.

Conclusion

All farms surveyed across the three different farming enterprises exceed the required 5% EFA target. This fact could potentially provide a very important and much overlooked marketing opportunity to Irish farmers and retailers in terms of capitalising on Irelands ‘clean, green’ image, which is one of the key priorities within the current national strategy for agriculture i.e. Food Harvest 2020 (DAFF, 2010) ‘Origin Green’ (Bord Bia).

However, while Irish farms are meeting targets with regards the quantity of habitats present, results suggest that on occasion the quality of these habitats is lacking.

Additionally, other habitats present that are not currently eligible under existing legislation are at risk of being lost as there is no incentive for farmers to continue to preserve them.

Acknowledgements

This work is funded by the Teagasc Walsh Fellowship Scheme.

The sustainable management of the priority terrestrial Habitats Directive Annex 1 habitats of the Aran Islands

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Introduction

The Aran Islands have long been recognized for their significant natural heritage. The traditional agricultural landscape of Aran Islands is largely a mosaic of rare European habitat types - Limestone pavement, Orchid-rich calcareous grasslands and Machair; 75% of the total land area is designated for protection under the Habitats Directive (Annex 1). A spring-calving suckler beef production system is the main farm enterprise type. Typical farm holdings are relatively small-scale, have a low herd size, below average stocking rates, and are highly fragmented.

It is widely recognized that past and present traditional farming practices are greatly responsible for creating and maintaining the high nature value of these semi-natural farmland habitats. However, traditional farming practices are being lost due to the low financial returns and high labour inputs associated with small-scale and spatially fragmented farming systems that are composed of relatively low productivity semi-natural grasslands. As a result, undergrazing and changes to traditional farming practices are leading to a decline in the quality of these habitats.

AranLIFE (2014-2018), an EU LIFE Nature demonstration project is working with 68 Island farmers to develop and demonstrate best management practices designed to achieve specific biodiversity gains in Natura 2000 habitat.

Objectives

This study has three main objectives:

1. To develop a grazing management model that incorporates optimal grazing regimes to maintain plant biodiversity, as well as elucidating nutritional deficits in forage resource.

2. To assess the relationship between management practices and habitat quality at field level in order to provide an evidence base for optimal conservation management strategies.

3. To profile the socio-economic environment using stakeholder surveys in order to understand the social, institutional and economic context within which farms operate.

Figure 1. Orchid-rich calcareous grassland on Inis Oirr

Materials and Methods

The grazing potential i.e. forage quality, mineral content and aboveground net primary production, will be profiled across the three Aran Islands through the collection and analysis of forage samples.

A variety of scrub removal and retreatment methods employed by farmers across a variety of scrub types will be monitored in order to identify the most effective scrub control strategies. In addition, general habitat condition assessments will be undertaken and related to site management practices.

A socio-economic study will outline information on farmer families, their demographics, educational level, changes to farming practices and farmer use of time on and off the farm. We will outline the costs of farming today and the income it generates.

Farmer attitude plays an important role in influencing past and future conservation management behaviours. This study will undertake stakeholder surveys to assess farmer attitudes towards nature conservation, awareness and acceptance of the benefits of the Natura 2000 network and awareness of effects of agriculture on the biodiversity resource

Figure 2. Small fields on Aran Islands

Expected Benefits

A detailed examination of forage production and utilization will enable the development of a model for optimal grazing on a range of vegetation types identified within farmland habitats on the Aran Islands. The research will facilitate the development of a targeted grazing management plan, ensuring the effective utilization of the forage resource, thereby minimizing unnecessary supplementary feed costs and supporting biodiversity.

This research will highlight dietary and grazing factors which limit animal performance. This will support the development of a supplementary feedstuff that may be integrated into an optimal grazing management model that promotes biodiversity and livestock production outputs from semi-natural grasslands.

This research will provide an evidence base for optimal management strategies for the conservation of priority habitats on the Aran Islands.

Understanding the context within which farms on the Aran Islands operate, will help improve our understanding of the motives behind changes to traditional farming practices, and the challenges facing landowner on the Aran Islands.

Figure 3. Scrub encroachment as a result of land abandonment on Aran Islands.

Acknowledgements

AranLIFE, EU LIFE+, DAHG, Teagasc, DAFM, Failte Ireland, The Heritage Council and Galway County Council

How to include farmland habitats in sustainability assessments?

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Introduction

How can farmers with wildlife habitats on their farm get sufficient credit for this in sustainability assessments? Many sustainability assessments struggle to include and implement assessments of farmland biodiversity. This is despite farmland habitats (e.g. hedgerows, ponds, woodlands and species-rich grasslands) being quite common on Irish farmland (Sheridan et al., 2011, Sullivan et al. 2011), and biodiversity being an important pillar of environmental sustainability. In addition, many Irish agri-food companies are seeking environmental accreditation through benchmarking against internationally recognized benchmarks and standards e.g. Sustainability Assessment Initiative (SAI) Platform.

A common requirement of environmental accreditation standards that include biodiversity is the provision of a farm habitat map.

Traditionally, habitat surveys involve visits to individual farms, which is expensive and time-consuming. Teagasc has been working closely with Bord Bia on a pilot project to develop cost-effective and scalable methods to map farm habitats.

Materials and Methods

Farmers were invited to participate in the project and there was a total of 187 dairy, beef and arable farms. Those that accepted agreed to an ecological survey of their farmland. Three separate methods of habitats identification were conducted and compared: 1. the use of orthophotography, 2. the use of orthophotography coupled with farm-level photos, and 3. an on-the-ground habitat survey.

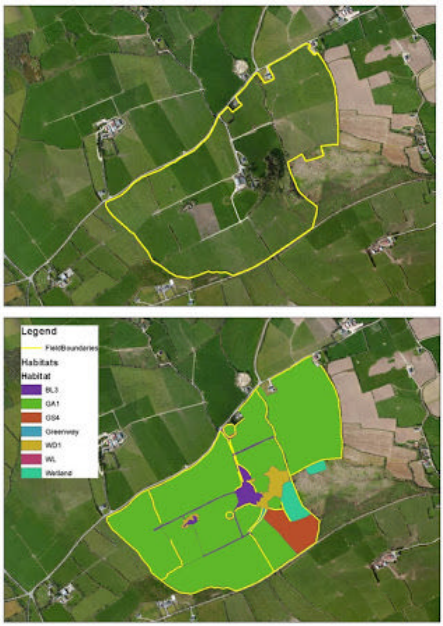

Figure 1. (a) Aerial photography is an excellent starting point for identifying semi-natural wildlife habitats. (b) A habitat map was produced that is the starting point for a farm plan for biodiversity.

Results and Discussion

The use of orthophotography by an ecologist is a reliable method to distinguish between semi-natural habitats and improved agricultural land for the purposes of accreditation for a sustainability assurance scheme. It is sufficiently reliable to develop farm habitat plans without requiring a farm visit.

Once a habitat map (Fig. 1b) is generated, we can develop a short customised farm habitat plan that can satisfy the requirements of sustainability assessment criteria e.g. Sustainability Assessment Initiative (SAI) Platform. The farm habitat plan contains:

- a habitat map for a farm

- the area of habitats on the farm

- general information on the wildlife benefits and important management practices of the habitats that occur on an individual farm

- photos of the habitats that occur on the farm.

Conclusions

File-sharing technology to share habitat photos with an ecologist could be used, and without the costs normally associated with ecological surveys of individual farms. These photos could be taken by a farmer.

Many sustainability schemes place a strong focus on environmental themes that typically include nutrient management, reduction of greenhouse gas emissions, water quality, and soil management. The agri-food industry is being challenged to include biodiversity in farm-scale sustainability assessments – this pilot project guides us on how to meet this challenge.

Acknowledgements

This work was funded by Teagasc, and also supported by Bord Bia.

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Yield of temperate forage grassland species: either largely resistant or resilient to experimental summer drought

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Background

Recent studies have shown that there is potential to increase agricultural grassland productivity using modest increases in plant diversity in grassland swards (Finn *et al.* 2013).

This study builds on previous work which showed that higher plant diversity in semi-natural ecosystems could lead to increased biomass production and increased production stability. Due to climate change, an increasing frequency and severity of drought events are expected to impair grassland productivity, particularly of intensively managed temperate grasslands.

Figure 1. Field trial at Johnstown Castle with use of rain-out shelters to create experimental drought.

Materials and Methods

To assess drought impacts, a common field experiment to manipulate precipitation was set up at three sites (two Swiss and one Irish) using monocultures and mixtures with two and four key forage species (see Hofer et al., 2016 for details). Species differed in their functional traits: a shallow-rooted non-legume (*Lolium perenne* L.), a deep-rooted non-legume (*Cichorium intybus* L.), a shallow-rooted legume (*Trifolium repens* L.) and a deep-rooted legume (*Trifolium pratense* L.). A nine-week summer drought was simulated (Fig. 1)

Results

There was severe drought at the two sites, and extreme drought at the Wexford site.

Different species demonstrated different responses to the drought. Looking at the second harvest under drought conditions (when the effect was greatest), there was substantial differences in yield (Fig. 2); however, the multi-species mixtures under drought could exceed the average of monoculture yields under rainfed control conditions (at least under conditions of severe drought). There was rapid recovery of yields when soil moisture was restored (Hofer et al., 2016).

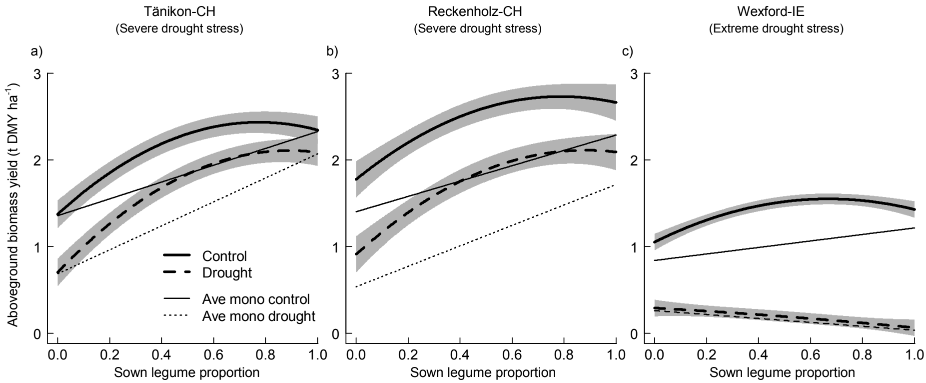

Figure 2. Multi-species mixtures under drought could exceed the average of monoculture yields under rainfed control conditions. Predicted aboveground biomass yield of the second regrowth during the drought period for increasing legume proportions under rainfed control and drought conditions at Tänikon-CH (a), Reckenholz-CH (b) and Wexford-IE (c). Predicted lines (±1 SE, grey shaded) are based on regression analysis (Table 1 and Table S4) and are displayed for mixtures that are equally composed of the two non-legumes and legumes, meaning that the left and right endpoints of lines represent binary mixtures and the prediction at 50% legume proportion represents the equi-proportional mixture (see Table S1 for the design of mixtures). Thin lines represent aboveground biomass yield that could be expected from the weighted average of the respective monocultures (Ave mono) in the absence of any diversity effect. DMY: dry matter yield.

Conclusions

Yields of selected species of intensively managed temperate grasslands are either resistant to a single severe drought or are highly resilient as soon as soil moisture levels recover after the drought event. However, these forage species seem unable to cope with an extreme drought event. Combining species in mixtures can compensate for yield reductions caused by severe drought, and offers a practical management tool to adapt forage production to climate change.

Acknowledgements

We acknowledge financial support by the AnimalChange project from the European Union's Seventh Framework Programme (FP7/2007-2013; grant 266018) and the Teagasc Walsh Fellowship Scheme.

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Estimating the distribution of High Nature Value farmland in Ireland

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Introduction

The European Community's Rural Development Measure includes HNV farming and forestry systems as one of the seven headline Environment indicators, and Member States are required to:

- identify areas with HNV farming practices in each Member State (by 2006);

- support and maintain HNV farming through Rural Development Programmes (by 2008), and;

- monitor changes to the HNV farmland area over time.

Due to the absence of complete and up-to-date national habitat maps in Ireland, there is relatively poor knowledge of the spatial distribution of HNV farmland. Thus, a major effort is needed to fill the data gaps on the distribution and character of HNV farmland areas. This was addressed by the IDEAL-HNV project. For further details, see www.high-nature-value-farmland.ie.

Materials and Methods

Within a Geographical Information System, values were calculated for each tetrad in the country (2 km × 2 km grid) for all five indicators: semi-natural habitat cover, stocking density, hedgerow density, river and stream density, and soil diversity. Each tetrad was assigned the mean value of the input feature, except for the length of river and stream layer, for which the total sum of the line feature was assigned to the tetrad.

Figure 1. High Nature Value farmland occurs where agriculture is the major land use and where agriculture sustains or is associated with either a high species and habitat diversity, or the presence of species of European conservation concern, or both. Maintaining both the nature value of this farmland and the livelihoods of farmers in these areas is a key policy challenge.

To maintain all the input layers in one format and range, all the input values were rescaled to between 0 and 1. For the additive overlay analysis, the weighted sum model (WSM) was used, which uses distinct weights to the input layers and combines multiple inputs to create an integrated output at the desired scale and only in farmland areas. Finally, the modelled output was masked with the 1 km^2 pixel farmland data of Ireland to display farmed areas only. Here we present the output rescaled to Electoral Divisions. The map was validated against extensive field work that involved habitat mapping in various farmland areas across the country, along with other data on farming systems and habitats.

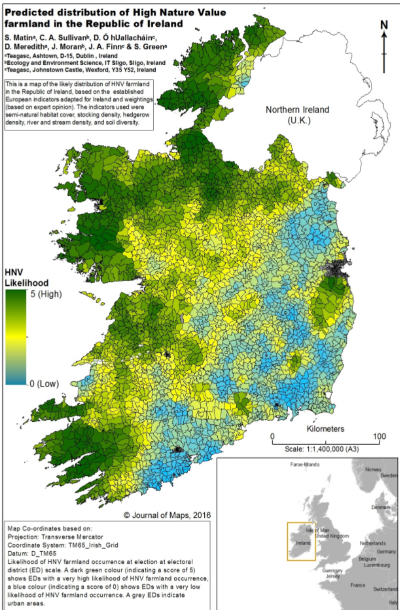

Figure 2. Likelihood of HNV farmland occurrence at electoral district (ED) scale. A dark green colour (indicating a score of 5) shows EDs with a very high likelihood of HNV farmland, a blue colour (indicating a score of 0) shows EDs with a very low likelihood of HNV farmland. A grey colour indicates urban areas. From Matin et al. (2016, Supplement available as Open Access).

Results and Discussion

We developed methods to improve knowledge of the distribution of High Nature Value farmland. We mapped the distribution of the likelihood of HNV farmland in the Republic of Ireland based on five indicators: semi-natural habitat cover, stocking density, hedgerow density, river and stream density, and soil diversity (Fig. 2).

We also developed a web-based tool to better assess the HNV status of individual farms, and this is available online at www.high-nature-value-farmland.ie.

Conclusions

The IDEAL-HNV project produced the first national-scale map that used key HNV farmland indicators to estimate the distribution of all HNV farmland in the Republic of Ireland.

Improved knowledge of the distribution of HNV farmland will allow better evaluation of the extent to which it is being targeted for support, and being maintained or improved.

These data can be used to incorporate estimates of farmland nature value into national-scale models of the impacts on farmland biodiversity through, for example, land use change, climate change, or alternative scenarios for the agricultural sector.

Acknowledgements

This work was funded by an award from the Research Stimulus Fund (11/S/108) by the Department of Agriculture, Food and the Marine (DAFM) under the National Development Plan 2007 -2013.

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A national typology for High Nature Value farmland in Ireland

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Introduction

The European Community's Rural Development Measure includes HNV farming and forestry systems as one of the seven headline environmental indicators. High Nature Value farmland (HNVf) plays an important role in delivering biodiversity and has the capacity to deliver many important environmental public goods such as clean air, clean water, climate regulation and aesthetic landscapes. A lack of information on what exactly characterises a HNV farm is a major impediment to the application of more targeted policy supports. For the first time, we describe the diversity of HNV farms in Ireland and the characteristics that distinguish the different types from one another. This work was conducted as part of the IDEAL-HNV project (www.high-nature-value-farmland.ie).This study aimed to:

- develop a national typology to describe the diversity of HNVf from different geographical areas in Ireland with known high HNVf potential

- describe the characteristics that distinguish the main types of HNVf, using farm-scale land cover and management data

- examine the extent to which the Irish typology corresponds with the existing broad-scale EU descriptions.

Materials and Methods

We collected habitat and management data from 102 farms across ten sites with a high likelihood of occurrence of HNV farming systems. Principal Components Analysis (PCA), followed by cluster analysis was used to group farms based on their inter-farm homogeneity.

Results and Discussion

We found that PC1 in the PCA reflected management intensity as indicated by the following variables: proportion of improved agricultural grassland, proportion of semi-natural habitat, proportion of peatland habitats, stocking density, field boundary density and nature value score. PC2 reflected farm complexity through habitat diversity, habitat evenness and dominant habitat percentage. PC3 was related to elevation, farm size and field boundary density. The cluster analysis indicated six clusters, as follows:

1. Whole-farm HNV, no common land.

2. Whole-farm HNV, small farms.

3. Whole-farm HNV, large farms (upland areas).

4. Whole-farm HNV, with common land, and with intensively farmed land.

5. Partial HNV (~55% cover of semi-natural habitat).

6. Aggregate HNV (see Fig. 1).

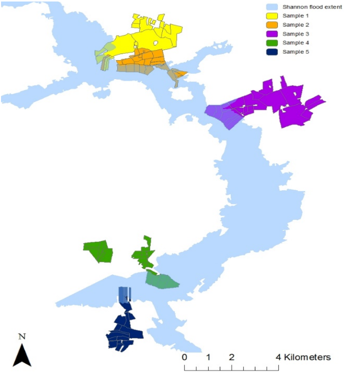

Figure 1. Examples of Aggregate HNVf show that while each individual farm may have a small proportion of semi-natural habitats, they aggregate to form the much larger and nationally important Shannon floodplains (for example).

We also examined how these clusters relate to existing broad HNV farmland classifications (Fig. 2).

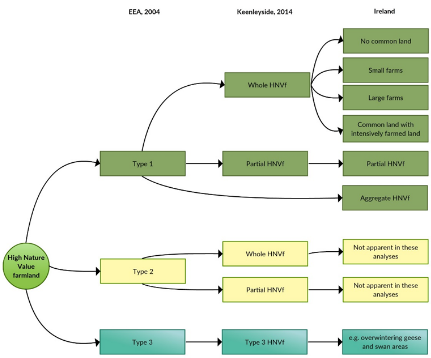

Figure 2. Types of HNV farmland that occur in Ireland and their relation to previously described European types.

The more detailed Irish HNVf typology can easily be combined to reflect broader EU classifications thereby providing the detail required nationally to target these areas and allowing reporting to the EU on a broader scale (Fig. 2).

Conclusions

There is a clear diversity of HNV farmland in Ireland and this can be captured and described in a broad typology that includes selected farm structural characteristics, management variables and basic habitat attributes.

A high proportion of the farms in some clusters (e.g. 1, 3 and 4) were designated as Natura 2000 sites; however, not all HNV farmland occurred in areas with Natura 2000 designations, as was the case for clusters 2, 5 or 6. Therefore, policies that only target designated lands would overlook supporting large areas of HNV farmland.

Similar farm types occurred across geographically disparate parts of Ireland, indicating the need for policy supports that target each of the HNV farmland types rather than address specific geographic locations.

This typology can facilitate better understanding of HNV farmland at farm-scale for policymakers and farm advisors and thereby aid the development of national policies and measures that better target, support and conserve HNV farmland.

Acknowledgements

This work was funded by an award from the Research Stimulus Fund (11/S/108) by the Department of Agriculture, Food and the Marine (DAFM) under the National Development Plan 2007 -2013.

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Soils

Unravelling the soil microbiome: Insights into degradation and mineralisation of soil organic matter

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Introduction

Managing nitrogen (N) and carbon (C) resources in soil is critical for environmental and agronomic sustainability, and underpins efforts to meet global challenges of increasing food production and climate change mitigation. Microorganisms drive the majority of biogeochemical processes in soil, and are essential for providing plants with key nutrients. By understanding how these organisms function there is great potential to manage soils in such a way as to link the cycling of nutrients to plant growth, thereby decreasing economic costs associated with fertiliser application, while reducing deleterious environmental losses of N and C. Soil organic matter (SOM) is the principal store of nutrients required by plants, However, currently there is limited knowledge on how plants and microbes interact to mobilise nutrients from SOM. This lack of knowledge of soil N mineralization processes limits our ability to predict the nutrient-supply capacity of soils, and to determine when and in what form these nutrients will be made available.

Application of stable isotope approaches has shown that plant-derived C-flow to soil can alter rates of SOM mineralization. Further, it is has been found that root exudation results in a directed response of the microbial community to mobilise N-rich components of SOM. Potentially, this represents a key mechanism by which plant productivity can be coupled with soil nutrient cycling. This work aims to understand the organisms and pathways involved in SOM mineralisation to inform best management of soils

Figure 1. Understanding soil microbial functioning will enhance our capacity to predict nutrient cycling in soils

Objectives

1. To quantify N mineralisation from soil organic matter related to plant-derived C-flow (i.e. priming) in Irish grassland soils

2. To determine the quantitative significance of N mineralised through priming to productivity of ryegrass swards

3. As a function of soil type and grassland management, determine the

variability of priming and supply of N from soil organic matter

4. To determine the microbial communities and processes involved in primed N mineralisation

Figure 2. Quantifying the contribution N mineralisation to the productivity of grassland systems

Materials and Methods

This project will use established stable isotope approaches to quantify biogeochemical process rates in soil, as a function of plant-derived inputs, and concurrently apply metatranscriptomic, metaproteomic, and metagenomic approaches to identify the mechanisms and microorganisms responsible for mineralisation. Initially, the approach will be to constrain system complexity under controlled environmental conditions, where perennial ryegrass will be grown on a range of soil types in a 13C-CO_2 enriched atmosphere. This will allow quantification of plant-derived inputs to soil, tracing of these inputs through soil and microbial pools and to quantify associated impacts on soil organic matter mineralisation. Throughout the experiment, the rate of SOM mineralisation will be determined by quantification of soil CO_2 efflux, and isotopic partitioning of this flux into plant- and SOM-derived components. Therefore, for each soil, plant-mediated SOM turnover will be quantified.

The impact of soil type and agronomic management on the interaction will be explored. The extent of priming will be assessed in a representative range of soils with widely differing intrinsic N supply rates as part of the national SQUARE project (which is assessing soil quality and the provision of ecosystem services across nationally representative grassland soils in Ireland).

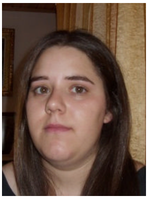
Expected Benefits

This research will give scientists, agronomists and farmers' new insight and understanding of soil nutrient supply in grassland systems. Insights into functioning of microbial communities involved in mineralisation will provide a basis for improved predictions of N, P and C cycling in soils. These can then be incorporated into fertiliser recommendations. Soil specific fertiliser advice will align N fertiliser application rates to crop requirements, thereby reducing nutrient surpluses and environmental losses. This work also has the potential to identify a soil biological indicator for predicting soil N mineralization potential

Figure 3. Harvesting of perennial ryegrass swards for determination of the impact of agronomic management

Acknowledgements

This work is funded by Teagasc, the Irish Research Council and the College of Science, NUI Galway.



Phosphorus fractions in grasslands and interaction with soil properties

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[1] Teagasc Environmental Research Centre, Johnstown Castle, Ireland; [2] University of Limerick, Department of Biological Sciences, Ireland; [3] Wageningen University and Research, Soil Biology and Biological Soil Quality, Wageningen

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Introduction

Worldwide food demand has intensified over the past century and future perspectives for sustainable agricultural systems point toward the reuse of soil P reserves and an efficient use of P fertilizer. Therefore it is crucial to understand P reactivity and bonds in soil. Chemical P fractionation involves a series of sequential soil extractions with selected reagents that dissolved P based on the nature and strength between P bonds in soil minerals (figure 1). The objectives of the present study were (i) characterize soil P fractions in temperate grassland soils, (ii) investigate the relationship between P fractions and ancillary soil properties and (iii) and to assess the impact of soil properties and P fractions on agronomic soil P tests.

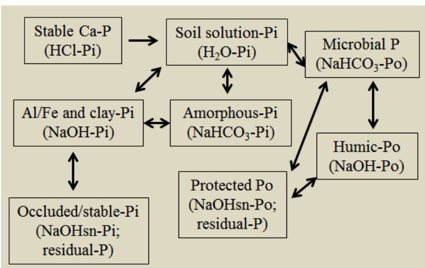

Figure 1 Conceptual diagram of soil P transformations and measurable fractions

Material and Methods

Twenty nine grassland soils were collected representing the main mineral soil groups. Composite samples (0-10 cm depth) were divided into a) field moist samples, sieved (2 mm) and submitted to P fractionation and b) dried samples (40°C, 2 mm) and soil chemical properties (pH, % OM, Mehlich3 extractable P (M3-P), Al (M3-Al), Fe (M3-Fe) and C (Me-Ca), Morgan's P were measured. Sequential P fractionation was used to determine fractions present in figure 1. Phosphorus concentrations are presented as the proportion (%) of total soil P

Results and Discussion

On average, 77 % of the total P was found to be held in inaccessible residual P fraction (38 %) and in less available P fractions associated with Al/Fe oxides and humic substances (39 %). Labile P fractions (H_2O-P and $NaHCO_3$-P) and P associated with Ca-P (HCl-P) comprised 8.9 % and 9.2% proportions of soil total P, respectively (figure 2). Labile inorganic (Pi) fractions were both correlated with plant available-P (Morgan-P and M3-P). Extractable Ca (M3-Ca) and soil pH were inter-related and both strongly correlated with HCl-Pi fraction and to a less extent with organic P (Po) HCl-Po fraction, indicating that increases in soil Ca concentrations, potential associated with pH correctives such lime, increases soil Ca-P forms. Daly et al., (2015) reported that Morgan-P could be overestimating soil plant available P. The present study supports this finding since Morgan-P correlated with HCl-Pi fraction and M3-Ca. This suggests that this relationship in enhanced with increases in soil Ca concentrations in non-calcareous (data not shown).

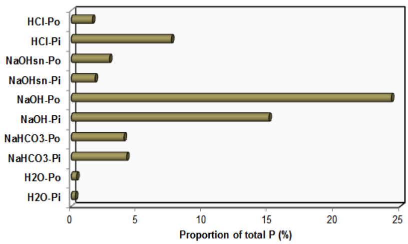

Figure 2 Proportion (% of total P) of soil P fractions.

Soil Fe and Al concentrations were associated to distinct soil P fractions, being M3-Fe closely related with $NaHCO_3$ (Pi and Po) and NaOH-Po fractions. NaOH-Pi and sonicated fractions seem to fix Pi forms bounded to Al. These results showed that Al hydroxides were more important for fixing Pi and suggest that majority of Po forms could be associated with organo Fe-P, relatively more labile than Al-P forms. Despite 40 % of total P was found in the residual-P fraction the lack of correlation with agronomic P tests (Morgan-P and M3-P) indicates that this fraction does not contribute for plant-available P in grassland soils

Conclusions

Most of the P in grassland soils is locked up in the soil and a substantial portion in the residual-P fraction. Its characterization is the primary step to understand its importance and dynamics in grassland soils. Soil Fe was identified as a main driver for the second most abundant soil P fraction (NaOH-Po). Indication that some Po associated with organo-metallic Fe forms and microbial P could be important in sustain soil fertility. Further research needs to be conducted to target mineralization of organo-metallic Fe. Increases in soil Ca concentrations drives formation non-available Ca-P forms. Soil P test, Morgan's P, is overestimating plant-available P, due to its affinity for Ca, and ability to extract non-labile Ca forms of P. Investigating the inclusion of P retention measures in agronomic recommendations and the use of different lime formulation products could overcome the increasing inefficiency of Morgan`s P.

Acknowledgements

This work is part of the Soil Quality Assessment Research Project (SQUARE), funded by the Department of Agriculture, Food and Marine and the Teagasc Walsh Fellowship Scheme.

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Infrared spectroscopy for analysis of phosphorus sorption in agricultural soils

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Introduction

Foodwise 2025 set challenging targets to increase agrifood exports and the value of primary production in the coming decade. While progressing towards these targets, issues such as sustainability and environmental impact must be carefully considered. Tests for soil fertility and quality are essential for sustainability. Testing for parameters such as, Morgan's phosphorus (P), pH, percentage organic matter (% OM), Al and Fe, monitors soil fertility. However, there are disadvantages associated with traditional soil testing methods.

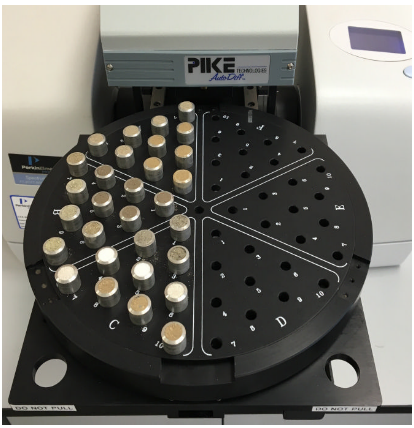

Figure 1. Benchtop PerkinElmer dual range (NIR, MIR) spectrometer, with PIKE diffuse reflectance accessory

Traditional soil testing methods can be time consuming, costly and produce a lot of chemical waste. This project explores the application of infrared diffuse reflectance (DRIFT) spectroscopy (Figure 1), in combination with chemometrics, to predict indicators of soil fertility, specifically, P buffering and P sorption capacities. Both of these parameters are good indicators of soil's ability to take up P. The application of DRIFT has the potential to predict various soil properties using just one soil sample. This new technique will be less time consuming, inexpensive and it will hopefully act as a surrogate for extractive and digestive techniques traditionally used in soil analysis.

Materials and Methods

Archived Irish Soil Information System (SIS) samples are used for calibration of the infrared spectrometer in this project. Two hundred and twenty five, first horizon, soil samples have been subsampled from an archive of 888 SIS samples at Johnstown Castle, Wexford. The Irish SIS project also provides a substantial amount of reference data for multivariate analysis to this project, for example, parameters such as: cation exchange capacity (CEC), total N, pH in water, oxalate extractable Fe, oxalate extractable Al, Mehlich-3 P, Al/P, Sand, Silt and Clay.

The method for this research is to, (1) build reference laboratory data using conventional methods, (2) carry out spectral analysis of soil samples (in both near- and mid- infrared regions of the spectrum), relating the results back to the reference data and (3) predict soil properties from unknown samples using modeled data. The software package, R Studio, and the method of partial least squares regression (PLSR), are the tools most used for multivariate analysis and calibration in this project.

Results and Discussion

To date, preliminary results have been obtained using first horizon Irish SIS samples for the mid-infrared (MIR) calibration of percentage organic matter (Figure 2) and pH (Figure 3). These properties are known to affect P buffering capacity and P binding energy in soil.

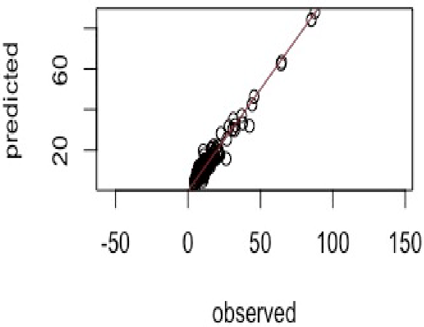

Figure 2. 'Goodness of fit' plot for the mid-infrared calibration of percentage organic matter using partial least squares regression.

It is clear from the 'goodness of fit' plot in Figure 2, that the partial least squares model fits the prediction of percentage organic matter in the MIR region of the spectrum well. However, in this instance, a lot of points are concentrated near the base of the prediction line, indicating the need for further optimisation of this model.

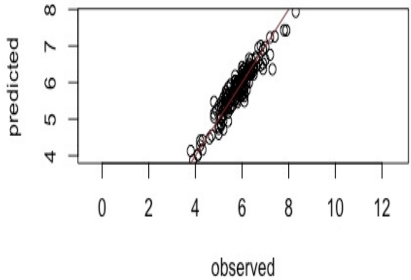

Figure 3. 'Goodness of fit' plot for the mid-infrared calibration of pH in water using partial least squares regression.

It is clear from the 'goodness of fit' plot in Figure 3 that the partial least squares model also fits the prediction of pH (water) in the MIR region very well.

Conclusions

With optimisation, such as, spectral data preprocessing, these models and related ones (e.g. oxalate extractable Al and oxalate extractable Fe) will be improved even further. The expected outputs of this research are novel, rapid and cost effective infrared spectroscopic models that predict soil fertility properties, specifically P buffering and sorption capacities.

Acknowledgements

This work is funded by the Teagasc Walsh Fellowship Scheme.

The application of soil spectroscopy to predict soil physical quality in arable systems.

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Introduction

Soil compaction as one factor of soil degradation has come to the attention of research as a serious problem in tillage fields. Caused mainly by intensive field traffic of heavy machinery, it is responsible for considerable yield losses and degradation of the soil structural quality. To measure soil physical quality and soil compaction parameters, soil spectroscopy in near- (NIR) and mid- (MIR) infrared is a promising tool, as it is possible to obtain information about various soil parameters from the spectrum in one single scan. This study aims to develop a calibration model for soil physical quality and soil compaction from infrared spectra and to detect the spatial distribution of soil compaction within tillage fields in Ireland.

Materials and Methods

The main mechanism of IR spectroscopy is based on the absorption of light at a given wavelength by constituents of the sample. Opposed to homogenous samples where only certain peaks at defined wavelengths are examined, in soil spectroscopy the whole spectrum is evaluated with chemometric techniques. Common means to calibrate the traditional soil parameters to the spectra are multivariate regression techniques and machine learning algorithms.

For the calibration database 21 tillage fields (Cereals, recently harvested) in eastern Ireland were sampled. In each sample point disturbed and undisturbed (ca. 100 cm³ cylinders) samples were taken in a pattern according to Fig. 1. In addition a visual evaluation of soil structure (VESS) was conducted throughout the whole depth of the pit.

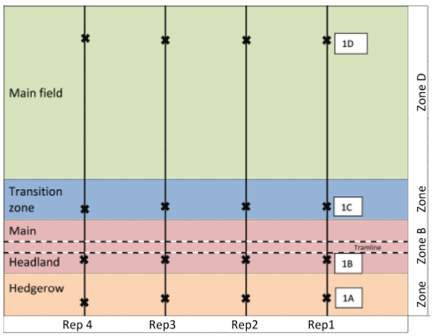

Figure 1 Position of the sampling points in the field

The undisturbed samples were analyzed for bulk density, stone free bulk density, and water holding capacity in the laboratory of Teagasc in Oak Park. The disturbed samples were dried at 40°C and sieved to 2 mm on a mechanical sieve. They are being analyzed for particle size distribution, pH, lime requirement, organic matter (as loss on ignition, LOI) and nutrient status.

Figure 2 Field with the sampling pits

As soil quality and soil compaction are dependent on numerous soil properties it is challenging to describe soil quality with one single parameter, thus various indices were developed in the last decades. Some promising indices to be tested include the soil physical quality parameter S (Dexter, 2004), the degree of compactness (Håkansson, 1990) and the physical state sub indicator of the "general indicator of soil quality" (Velasquez et al., 2007). These indicators consist of parameters with promising attributes to be detected with NIR and MIR spectroscopy (e.g. clay content, organic matter).

Figure 3 sampling pit

Results and Discussion

The SPM testing for the composite samples has been finished. The texture classes range from sandy loam to clay loam and represent the expected range in tillage fields in eastern Ireland.

The next steps are to calibrate the LDM with the SPM samples, obtain the missing soil parameters in the laboratory, test the power of the soil quality and soil compaction indicators against the VESS readings of the plots, scan the samples in NIR and MIR and develop a calibration model for suitable indicators. Once a robust model is developed, selected fields will be tested in a higher spatial resolution to get information about the spatial variability in soil compaction.

Conclusions

Finding a calibration model for soil compaction and IR spectroscopy involves a big amount of data. Once a model is developed it facilitates the acquisition of soil quality data and their infield variation. This will lead to a more efficient procedure in detecting (and then limiting) zones of high soil compaction.

Acknowledgements

We acknowledge the CTF-Optimove project of EU ICT AGRI ERA-NET and Teagasc Walsh Fellowship.

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Soils of Ireland

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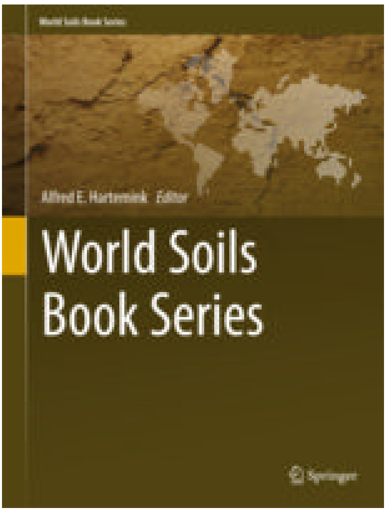
Introduction

The Springer World Soils Book Series publishes books containing details on soils of a particular country. These books include sections on soil research history, climate, geology, major soil types, soil maps, soil properties, soil classification, soil fertility, land use and vegetation, soil management, soils and humans and more. The work synthesizes the country specific knowledge in a reader-friendly way.



Our soil is an irreplaceable natural resource that has a critical role in food and feed production, as well as in services such as water purification, the provision of a home for biodiversity and as a major store of carbon. However, our soils are threatened by: soil degradation from agriculture and forestry; sealing from urban sprawl and contamination from industrial activities. As pressure to intensify soil use continues, the variety of demands on our soils must be balanced and managed in a sustainable manner. This relies, in the first instance, on a comprehensive knowledge of soil and its properties.

'The Soils of Ireland' represents the Irish contribution to this world book series. The scope of this book is extensive, with topics ranging from the history of soil research, to soil development in Ireland, through to more contemporary soil topics including the role of soils in the delivery soil-based ecosystem services. The book combines, collates and updates existing knowledge on the soils of Ireland. The historical contribution of previous researchers is integrated with the latest advancements in soil research in Ireland. Ireland has a history of soil mapping and the soil survey by An Foras Talúntais mapped 44% of the country. This book builds upon and completes that his historic data by including the Irish Soil Information

System, funded by the EPA Research Programme and co-funded by Teagasc.

Materials and Methods

The work contained in this volume includes extensive literature review. The book includes contributions from 37 co-authors, who currently or previously work in soil science or soil related disciplines primarily in Ireland but with some overseas contributions.

The topics addressed in this volume include:

- A history of soil research in Ireland
- Soil classification
- Soil geography, development of the Irish Soil Information System and the 3rd Edition National Soils Map
- Irish landscapes including: mountain, hill, peatlands, limestone lowlands, rolling lowlands, drumlins and urban soils.
- Soil functions including: primary production, nutrient cycling and fertility, water quality, carbon cycling and storage, soil biodiversity, archaeology, platform for construction.
- Soil policy and the future.

Conclusions

The Soils of Ireland will be published in 2017.

This book will help us understand how this natural and national resource can be managed sustainably, how it is impacted by our decisions and how we can respond collectively to the most significant challenges of or time. It is intended that this book will be a rich resource for students, educators and researchers.

Acknowledgements

The Soils of Ireland book project was co-funded by the Irish Environmental Protection Agency and Teagasc.

SoilCare for profitable and sustainable crop production in Europe

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Introduction

European crop production is facing the challenge to remain competitive, while at the same time reducing negative environmental impacts. In many instances, along with technology, production levels are maintained through increased use of nutrients and pesticides. As a result, production losses associated with changes in soil quality may be masked. Excess nutrient inputs may promote plant growth but applications of inputs such as nutrients and pesticides in excess of plant requirements can result in negative environmental externalities, such as eutrophication. Also, the increased use of inputs in excess of production requirements, as well as negatively impacting the environment may also reduce profitability due to their costs.

The overall aim of SoilCare is to assess the potential of soil-improving cropping systems to identify and test site-specific soil-improving cropping systems and agronomic techniques that have positive impacts on profitability and sustainability in Europe.

Key objectives

The following are the key objectives of SoilCare:

- To review which cropping systems can be considered soil-improving, to identify current benefits and drawbacks, and to assess current and potential impact on soil quality and environment.
- To select and trial soil-improving cropping systems in 16 sites across Europe.
- To develop and apply an integrated methodology to assess benefits and limitations, and profitability and sustainability of soil-improving cropping systems in study sites.
- To study barriers to adoption and to analyse how farmers can be encouraged through appropriate incentives to adopt suitable soil-improving cropping systems.
- To develop and apply a method to upscale study site results to European level.
- To develop an interactive tool for selecting soil-improving cropping systems throughout Europe.
- To analyse the effect of agricultural and environmental policies on adoption of cropping systems.

Materials and Methods

SoilCare will trial soil-improving cropping systems across Europe with different pedo-climatic zones and socio-economic conditions across 16 study sites (Fig. 1). A transdisciplinary approach will be used to evaluate benefits and drawbacks of a new generation of soil-improving cropping systems, incorporating all relevant biophysical, socio-economic and political aspects. Existing information from literature and long-term experiments will be analysed to develop a comprehensive methodology for assessing performance of cropping systems at multiple levels. A multi-actor approach will be used to select promising soil-improving cropping systems for scientific evaluation in the study sites. Implemented systems will be monitored with stakeholder involvement, and will be assessed jointly with scientists. Specific attention will be paid to adoption of systems and agronomic techniques within and beyond the study sites.

Fig. 1 SoilCare Study Sites and countries involved in the project

Results and Discussion

Results from the study site wills be up-scaled to European level to draw general lessons about the applicability potentials of soil-improving cropping systems and related profitability and sustainability impacts, including assessing barriers for adoption at that scale.

An assessment of current policies and incentives will be conducted to target policy recommendations.

SoilCare will adopt an active dissemination approach to achieve impact from local to European level, addressing multiple audiences, to enhance sustainable, competitive crop production in Europe.

The results are expected to identify scientifically proven soil-improving cropping systems, techniques and machinery across study sites. These results will be scaled to European level and an interactive tool will be developed for end-users to identify and prioritize suitable soil-improving cropping systems anywhere in Europe.

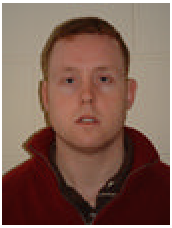
Conclusions

The key outcomes of SoilCare will be:

- The identification of soil-improving cropping systems, techniques, and management across the study sites.
- Insights into how barriers to adopting techniques can be minimized and overcome.
- An assessment of the opportunities for and the effects of upscaling of adoption at European level.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 677407.



LANDMARK: working together to make the most of our land

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Introduction

Global demands on land and soil are increasing. Agriculture is faced with the challenge of increasing primary production to meet the growing global demand for food security. As a majority of the world's soil resources are in poor condition, and one-third of land is degraded, gains in productivity must be achieved in a sustainable way. Previously, research focused on developing land management strategies aimed at preventing threats to soil quality. However, this did not give guidance on how to optimise and sustain the utility of the majority of agricultural land.

The main objective of the LANDMARK PROJECT is to provide guidelines on land management in order to satisfy the multiple demands we place on soil resources. Specifically, LANDMARK focuses on five soil functions: i) food production, ii) the provision of clean water, iii) carbon storage iv) habitat for biodiversity and v) nutrient re-cycling.

LANDMARK will deliver:

1. An agricultural Decision Support Tool (DST) for soil management that optimises soil functions;
2. A monitoring scheme for Soil Functions applicable at regional scale, for a range of soil types, land uses and pedo-climatic zones;
3. A policy framework for 'Functional Land Management' at EU scale that aims to optimize the sustainable use of soil across major land uses.

Materials and Methods

LANDMARK is a consortium that brings together a diverse community of scientists, advisors and policy makers from Europe, Brazil and China.

This 4.5 year project, funded by the European Commission, uses a participatory approach to addressing the research requirements of stakeholders. These include land managers and advisors, policy makers, scientific and educational communities and the private sector. From the start of the project, these partners are jointly formulating the research objectives to be addressed by LANDMARK. This allows a more nuanced approach towards meeting challenges to sustainability, which vary spatially by location.

In 2016, 32 participatory workshops took place in Ireland, France, Austria, Germany and Denmark. These brought together land managers at local level and diverse stakeholders groups at regional, national and European level. The workshops have a two-way flow of information. Existing stakeholder knowledge on the perception of soil quality and land management was harvested, while at the same time our new integrated framework for understanding the functionality of land was being disseminated.

This inclusion of end-users from the start will have multiple benefits:

a) It facilitates a process of co-innovation by combining both scientific and practical knowledge;

b) This will create ownership by end-users of the research outcomes;

c) This will in turn augment the impact of the research in the form of practice change.

Results and Discussion

Every soil differs in the extent to which it can deliver the five soil functions.

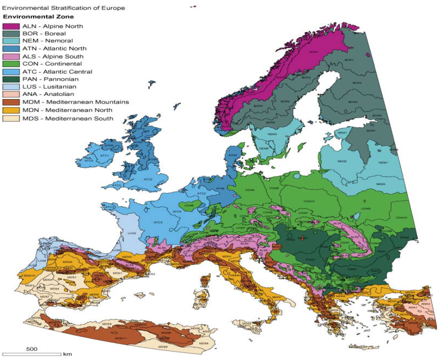

Figure 5. Environmental Zones map (Metzger *et al.* 2005).

Each function depends on the local climate (C) (Figure 1), on soil properties (S), on land use (LU) and on soil management options (M):

$$SF_{i,j} = F\,(S,\ C,\ M)$$

where $SF_{i,j}$ *is soil function i for land use j.*

This quantification of soil functions across a diverse range of farm environments (Table 1) will inform the management of Europe's land with a view to optimising the functionality of its rich heritage of soils.

Table 1. Selected farm types based on EU classification

Farm types definition	
Arable	Including specialist cereals, oilseed and protein crops; General field cropping; Mixed cropping
Permanent crops	Including vineyards, olives, fruit and permanent crops combined
Dairy	
Beef	
Mixed livestock	Mainly grazing livestock and granivores
Mixed farms	

These data underpin the agricultural DSM tool that is currently being developed using a combination of DEXi qualitative modelling in tandem with quantitative data mining methodologies for Pillar 1.

To quality the supply and demand for soil functions, large scale indicators of soil functions are being quantified using a combination of maps and databases. Proxy-indicators based on agri-environmental policies will be developed to quantify demand. Building on this, scenario analysis using Beysian Belief Network with GIS techniques will identify pathways to manage soil functions. Other options to support optimised governance of the resource and related soil functions within the Functional Land Management framework are also being explored through co-innovation and shared learning with partners.

Acknowledgements

LANDMARK has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 635201.

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SQUARE – soil quality assessment and research

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Introduction

SQUARE is the Soil Quality Assessment Research Project for Ireland. Soil is a vital non-renewable resource that delivers multiple functions simultaneously including food and fibre production, nutrient retention and cycling and filtration of water. The ability of the soil to deliver multiple soil functions simultaneously is referred to as functional soil capacity.

Within Ireland, Harvest 2020 objectives to intensify agriculture are coupled with a demand to meet greening objectives of the Common Agricultural Policy. Thus, any intensification of agriculture must be achieved in a sustainable manner. SQUARE centralises functional soil capacity to promote the delivery of many soil functions whether productivity or environmental.

SQUARE is an Irish research project, led by Teagasc Agriculture and Food Development Authority. Partners include the Department of Agriculture, Food and the Marine, University College Dublin, University of Limerick, IT Sligo. Funding is provided by the Irish Government under the National Development Plan 2007-2013. SQUARE also relies on many farmers across the country who are central to effective research for sustainable soil management.

Objectives

Any impairment of soil quality affects the delivery of soil functions. Thus, SQUARE seeks to support the delivery of co-benefits achievable from the same soil resource. However, knowledge gaps exist in relation to both the threats and benefits of soil quality. In particular, soil structural quality is one major threat within Ireland. These knowledge gaps form the basis of the SQUARE research agenda.

The specific project objectives are as follows:

- Evaluate the status of soil structural quality in Ireland
- Assess impact of soil structural degradation on functional capacity of soil
- Develop a toolbox for farmers to assess structural quality
- Enhance understanding of functional soil capacity

Methods

Field campaign – 160 grassland and tillage sites surveyed over three years

Farmer surveys to assess ranges in soil management practices.

Outputs

A Visual Soil Assessment method designed for Irish soils and toolkit for farmers

Impacts of management practices and scope for improved practices

Better understanding of functional capacity of soil

Acknowledgements

We would like to acknowledge the funding for this project from DAFM Research Stimulus Fund.

Water Quality

Investigating Microbial Risks in Water Used in Food Production and Preparation

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Introduction

Water is increasingly being identified as a source of foodborne infectious disease outbreaks, either through direct consumption or as a dissemination route onto vulnerable food products such as salad leaves and shellfish which can often be consumed raw. However, there is a currently a paucity of integrated data relating to the presence and source of enteric pathogens in Irish water sources used in food production. This project will address this by utilizing novel molecular tools (available through the EU project AQUAVALENS) to build up a dataset on the presence of strains of *E. coli*, *Salmonella* as well as *Cryptosporidium*, Norovirus and Hepatitis A virus, in water used in water intensive food industries and in private wells. The project will provide validated data sets regarding the presence of a broad range of human pathogens in water supplies utilized in Irish food production, and which may act as a source of contamination. This will allow for appropriate intervention strategies to be put in place, underpinning the safety of our food production systems, something that is vital to maintaining the sustainability of the agriculture and food sectors and safeguarding public health. Factors affecting the native microbiome of wells will be investigated, as will the impact of native microbial communities on pathogen persistence potential. Such factors may play a key role in the selection of suitable and effective treatments if required.

Project objectives

The main objectives associated with this research project are the following:

1. To investigate the suitability of molecular tools developed by the EU project AQUAVALENS to assess irrigation water quality

2. To investigate the presence of a panel of microbial pathogens of human health importance in water used in food production and preparation (including salad leaves, sprouting seeds and soft fruits)

3. To investigate the potential contamination dynamics of lettuce irrigated with artificially contaminated irrigation water

4. To characterize the microbiome of two vulnerable wells over time to determine factors which impact on the microbiome and on pathogen persistence

Methodology

1. Assessment of performance of developed technologies in assessing irrigation water quality. Irrigation water will be spiked with surrogate strains of key pathogens (*E. coli* and *Salmonella*).

2. Implementation of developed technologies in the ready to eat food industry. Samples of irrigation water and post-harvest processing water (either on farms or processing facilities, focusing on leafy green vegetables, sprouted plants, soft fruits and bottled water) will be collected at representative sites across Ireland and new technologies will be compared against conventional methods.

3. Assessment of lettuce contamination by overhead spray irrigation with water contaminated with surrogate strains of key pathogens (*E. coli* and *L. innocua)*. Survival of the pathogens in water will also be assessed.

4. Characterization of microbiome of two vulnerable water sources by next generation sequencing in order to determine the predominant microbial communities present in the microbiome. The microbiomes will be compared temporally and the impact of physiochemical properties will also be investigated. Biofilm formation of *Salmonella*, *E. coli* and *Campylobacte*r in the presence and absence of water associated microbiota will be evaluated.

Expected results

The research output will be invaluable for public health and consumers as it will provide scientifically validated data to base risk reduction strategies on, with the overall aim of reducing the risk posed by waterborne dissemination of human enteric pathogens into the food chain. The project will provide validated data sets regarding the presence of a broad range of human pathogens in water supplies, which, when consumed directly or utilised in Irish food production would act as a source of contamination, allowing for appropriate intervention strategies to be put in place. This will underpin the safety of our food production systems, something that is vital to maintaining the sustainability of the agriculture and food sectors and safeguarding public health.

Acknowledgments

This work is funded EU project AQUAVALENS and by the Walsh Fellowship Scheme.

Cattle exclusion from watercourses: environmental and socio-economic implications. COSAINT

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Introduction

Loss of nutrients from grassland systems to waterbodies is a significant threat to water quality and represents one of the main environmental problems facing agri-ecosystems in Ireland. The EU Water Framework Directive requires Member States to achieve or maintain at least 'good' ecological and chemical status in all waters by 2021.

Studies suggest that unrestricted cattle access to watercourses can result in deteriorating water quality and therefore the Green Low carbon Agri-environment Scheme (GLAS) has included measures preventing bovine access to watercourses to improve water quality. However, conflicting studies indicate that cattle do not have a significant effect on stream water quality, and thus cattle exclusion measures may not be cost-effective mitigation.

The COSAINT project is assessing the environmental, ecological and socio-economic impact of cattle exclusion measures on freshwater ecosystems. The project will generate temporal and spatial data on the environmental impact of cattle exclusion measures. The cost-effectiveness of proposed and potential mitigation measures is being assessed through research and expert opinion, along with attitudinal responses of land-owners to the implementation of proposed and potential measures.

Objectives

The aim of this project is to assess the environmental, ecological and socio-economic impact of existing and potential measures that prevent cattle access to watercourses. The project is:

- Assessing the impact of cattle access and cattle in-stream activity on freshwater geochemical, sediment and ecological parameters.
- Determining the extent of ecosystem impact and recovery at a spatial-scale downstream of cattle access points.
- Evaluating impact of proposed cattle exclusion measures (under GLAS) on freshwater geochemical, biological and ecological (in-stream and hyporheic) parameters.
- Evaluating the cost-effectiveness of existing and novel water provision mechanisms.
- Determining the proportion of farms that have flowing or still water on or adjacent to their land parcel, thus potentially impacted by cattle exclusion measures.

- Assessing 'willingness to adopt' cattle exclusion measures and determine level of incentives required to ensure adequate participation in voluntary cattle exclusion measures.

Research approach

The research approach being used in this project is a combination of meta-analysis of existing datasets, and collection of new field and experimentation datasets (temporal and spatial). These data will help determine the impact of cattle access to (and exclusion from) watercourses on freshwater ecosystems.

Datasets will be coupled with analysis of existing and newly collected data in relation to farmer attitudes to the environment, their perception of estimated costs associated with cattle exclusion measures and their likelihood of adopting specific existing and potential measures to prevent cattle access, or novel water provision mechanisms.

This approach will facilitate the evaluation of the cost-effectiveness of existing and potential cattle exclusion measures. Recommendations in relation to existing and potential mitigation measures will be made based on the research findings, and widely disseminated to land-owners, policy-makers and the scientific community.

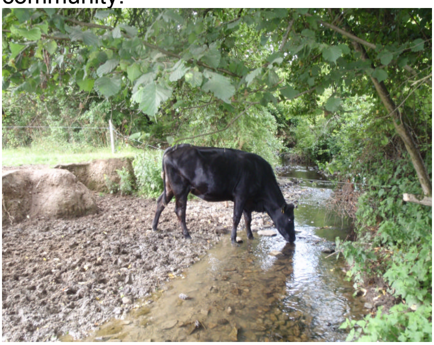

Figure 1. Cattle access to watercourses can have an impact on freshwater ecosystems through the introduction of excess nutrients and sediment.

Figure 2. Increased turbidity due to fine sediment at a cattle access point can have an impact on aquatic ecology.

Expected Benefits

The project will provide important information for policymakers in relation to the Nitrates and Water Framework Directives. It will also help guide agri-environmental policy and facilitate sustainable intensification objectives under Food Harvest 2020 and FoodWise 2025.

Acknowledgements

This project is funded by the Environmental Protection Agency (EPA) (Research Programme 2014-2020).

Sustainable land use management for the conservation of the Freshwater Pearl Mussel: sediment flux and provenance

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Introduction

The Freshwater Pearl Mussel (FPM) is a long-lived aquatic invertebrate listed as Critically Endangered (IUCN) and protected under the Habitats Directive (Annex II and Annex V). In Ireland, the FPM has experienced a 96% decline in recruiting populations over the last century, due in part to sediment losses from agricultural land and forestry. Sediment losses are thought to affect the FPM at the post-parasitic stage in their life cycle, by clogging interstitial gravels which juveniles inhabit, leading to oxygen starvation and death.

One of the key improvements needed for the restoration of juvenile habitat is the mitigation of excessive sediment inputs. Therefore, this project will employ sediment provenance and flux methods within representative sub-catchments to further the understanding of the effect of land use on sediment dynamics extensive Irish catchments.

Objectives

1. Assess the annual sediment yields and load flux of three rural sub-catchments with FPM. This will develop understanding of the effect of land management on sediment pollution

2. Identify the critical source areas (CSAs) of sediment in study catchments through in-depth soil analysis and sediment fingerprinting

3. Investigate historical trends in sediment yields in catchments dominated by extensive agriculture and forestry

Figure 1. An adult Freshwater Pearl Mussel in the Caragh catchment

Materials and Methods

The study is part of an EU LIFE funded project, KerryLIFE, and is being conducted in three sub-catchments within the Kerry Blackwater and Caragh SACs i.e. the Kealduff (having evidence of juvenile recruitment); the Owenroe (having relatively lower levels of FPM); and the Bridia (Upper Caragh) (supporting just a small number of adult mussels).

Catchment sediment yields are being estimated using a continuous turbidity monitoring programme; the results of which will be calibrated to instream sediment concentrations using a combination of low-flow manual water samples and auto-sampling in flood events. River discharge is being ascertained through continuous level readings and acoustic Doppler profiling. Continuous sediment concentration and river discharge records will be compiled to produce high-resolution sediment trends and yields for the catchments.

Time-integrated samples of suspended and deposited sediment are being collected using time-integrated suspended samplers (TISS) and bed sediment samplers respectively. The natural tracer signatures of time-integrated sediment samples will be compared with those of soil samples from a range of land uses and actively eroding areas, identified during catchment walkovers (poached field entrances, eroding channel banks, forestry tracks etc.). Analyzed tracers will include magnetics, radionuclides and inorganic/organic trace metals. Uncertainty-inclusive un-mixing models will be used to assess the optimal combination of tracers as well as to determine the relative contribution of each source.

Figure 2. Inlet of a TISS (left); bed sediment samplers

FPM populations are thought to have declined particularly severely over the last century. Local lake core analysis, as well as the study of land-use records (ortho-photography etc.) will be used to elucidate historical sediment yields in the study region.

Expected Benefits

An understanding of the quantity and timing of sediment delivery to these sensitive habitats should inform future sediment mitigation strategies. We will assess the role sediment fingerprinting can play in determining the relative impact of different land uses on sediment load. If effective, this should help to optimise the efficiency and effectiveness of mitigation strategies in extensive Irish catchments. Increased knowledge of the effect of modern intensification of land use on sediment dynamics may provide valuable insight into the future of biodiversity conservation in endangered fluvial ecosystems.

The delivery of efficient management plans for catchment-scale pollution is essential to the conservation of the Freshwater Pearl Mussel, and can contribute to sustainable land management on a broader scale.

Figure 3. Eroding channel bank and poaching damage in FPM catchment

Acknowledgements

This project is funded by the Teagasc Walsh Fellowship Programme.

We acknowledge support from KerryLIFE LIFE13 NAT/IE/000144.

Assessing the impact of cattle access to watercourses on stream sediment faecal contamination

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Introduction

In Ireland, most drinking water is extracted from rivers and lakes, with many potable water sources in rural areas experiencing various degrees of faecal contamination (Doris *et al.,* 2015). Faecal contamination can be associated with livestock farming, including direct defecation in waters (Collins *et al.,* 2007). Direct deposition of fresh faeces is particularly important because animal faeces contain bacteria levels as high as 10^9 g^{-1} cells (Murphy *et al.,* 2015). This pathway is of particular concern in cattle farming areas because cattle are characteristically attracted to water and tend to defecate more frequently when in the proximity of water (Collins *et al.,* 2007). Faecal contamination is indicated by the presence of *Escherichia coli* (*E. coli*), which is generally commensal but includes pathogenic strains. Stream sediments have been shown to act as reservoirs for *E. coli*, including in Ireland (Bragina *et al*., 2017). In sediments, bacteria can survive for prolonged periods due to stable conditions and protection from predators and UV radiation (Pachepsky and Shelton, 2011). These reservoirs can recontaminate overlying waters after sediment disturbance, and therefore can play an important role in stream faecal contamination and affect water quality monitoring. This study is assessing the impact of cattle access to streams on sediment faecal contamination.

Methods

The levels of *E. coli* in bed sediment were investigated in five catchments. Two catchments (Co. Laois; Co. Cork) were considered higher status/low impact (Lo) with low cattle stocking density, while the remaining three catchments (Co. Monaghan; Co. Louth; and, Co. Wexford) were moderate status with higher stocking density/higher impact (Hi).

Sampling was performed in June 2016 and November / December 2016 after cattle had been housed for the winter. Three sediment samples were collected at each of three active cattle access points and upstream of these sites (10 – 30 m; no cattle access) in each catchment. Mean values were calculated for each site (n = 3). In the moderate status catchments these sites were situated along a downstream gradient, while in the high status catchments they were located in different streams. The samples were analysed for levels of *E. coli* and Other Coliforms by adapting a technique described by Boehm *et al*. (2010) for sediment extraction and using a membrane filtration technique (BS EN ISO 9308-1:2000) with Harlequin *E. coli* / Coliform medium (LabM™, Lancashire, UK). The results were analysed using a Generalised Linear Model (two way ANOVA).

Results and Discussion

In general, across all five catchments and both sampling times, levels of *E. coli* in bed sediments at cattle access points were higher than those immediately upstream of these sites; this was more pronounced for the moderate status sites (Fig.1). The highest levels were observed in the Co Louth Catchment (2.49×10^6 CFU g^{-1} DW) and the Co. Wexford catchment (1.85×10^6 CFU g^{-1} DW) in June. There was also no evidence of a downstream cumulative effect in moderate status catchments.

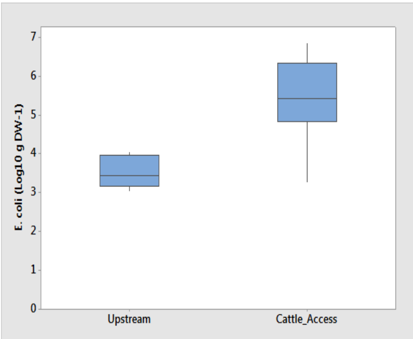

Figure 1 - Sediment *E. coli* levels upstream (US) and at cattle access sites (CAP) (log10 values) in the high impact catchments in summer (n=9).

When data for sites with low upstream agricultural pressures were compared (upper sites on moderate status/higher impact streams (Hi) and all sites for the high status/lower impact streams (Lo)), there was no significant difference between the 'upstream' sites (Fig. 2) although the levels at the access points were significantly higher for Hi sites.

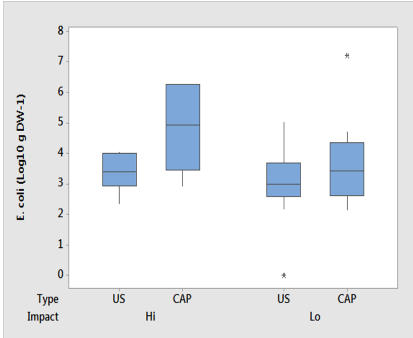

Figure 2 - *E. coli* levels upstream (US) and at the access sites (CAP) (log 10 values)(both times) at high (Hi n=6) and moderate status (Lo n=12) catchments.

Conclusions

The results indicate that sediment at access points can act as a source of faecal contamination in streams especially where stocking density is higher, although *E. coli* levels measured at upstream sites indicate that diffuse routes of contamination also play an important role. Future work will assess links to management and water quality.

Acknowledgements

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The impact of acute and chroic hydrochemical disturbances on stream ecology

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Introduction

River regulation, alteration of stream habitats and degradation of water quality have had significant impacts on aquatic ecosystems worldwide. In Ireland, the two main threats to water quality are municipal (point source) and agriculture (diffuse sources). The Water Framework Directive was established as an overarching approach to protect waterbodies in Europe. It requires Member States to achieve or maintain at least 'Good' ecological and chemical status in all waters by 2021.

The Teagasc Agricultural Catchments Programme is identifying links between land managed according to the National Action Programme (Good Agricultural Practice, GAP) measures and water chemical and ecological quality. However, the degree to which stream ecological status will improve in response to implementation of the GAP measures requires further investigation. Hypotheses emerging from the ACP are that a high frequency of storm events that cause overland flow (acute disturbance) increases the likelihood of poor in-stream ecological status.

The study will identify how stream ecological communities respond to agricultural and non-agricultural acute and chronic stressors throughout the year. Identifying the impact of these stressors will help inform how agriculture can be sustainable with regard to water quality in agricultural catchments.

Objectives

- Investigate the impact of acute versus chronic inputs (sediment and nutrients) on stream ecology (abundance, diversity and functioning) across a range of land uses and intensities.
- Assess how the timing of storm events (i.e. at periods of high ecological activity and low base flow) affects different taxa in riverine habitats.
- Through controlled mesocosm experiments, examine how nutrients and sediment interact to effect stream communities.
- Inform policy expectations regarding the potential for Good Agricultural Practice and other measures to enable stream waters in Ireland to reach Good Ecological Status as per WFD requirements.

Figure 1. Freshwater aquatic habitats play an important role in providing ecosystem services.

Materials and Methods

The study is examining the ecological response to acute and chronic stress to streams. Furthermore, the temporal impact of stress (including at periods of high ecosystem activity) on stream ecological community structure and the implications for the WFD is being examined.

The study is a combination of literature review, catchment scale field studies and controlled environment experiments. We are analysing existing high temporal resolution hydrochemical monitoring infrastructure and seasonal stream biology and habitat data (Figure 1) from the ACP. New, higher temporal resolution stream ecological datasets have also been generated.

The study is also examining how nutrients and sediment interact and influence stream communities through the use of an ex-stream mesocosm (Figure 2).

Expected benefits

This research will provide information to policy-makers in relation to the impact of agricultural and non-agricultural nutrient stresses on the ecological status of watercourses. By having this knowledge, mitigation measures and schemes can be better targeted such that Ireland fulfils its obligation in relation to the Water Framework Directive.

The proposed study addresses some of the priorities under the Strategy for science, Technology and Innovation which aims to provide a scientific foundation and support for a sustainable, competitive, market-oriented and innovative agriculture, food and forestry sector.

Furthermore, the study will help policy-makers target suitable and cost-effective mitigation measures which will help alleviate some of the pressures associated with nutrient and sediment input to watercourses and help Ireland attain its targets under the Water Framework Directive and the Habitats Directive.

This project will directly address one of the goals of Pillar 3 (Agri-environmental Products and Services) of the Teagasc Foresight 2030 Report to provide evidence-based knowledge to support policymakers in designing, implementing and evaluating programmes for agri-environment products and services.

Figure 2. Ex-stream mesocosm system in Johnstown Castle.

A greater understanding of the major stressors and processes of stress that impact aquatic ecosystems will help address some of the key objectives of Food Harvest 2020 and FoodWise 2025 i.e. protect water resources and protect biodiversity. Furthermore if agriculture is to achieve its production targets in a sustainable manner, greater knowledge in relation to the impact of episodic and sustained events on the ecological status of aquatic systems is required.

Acknowledgements

This work is funded by the Teagasc Walsh Fellowship Scheme.

Emerging Organic Contaminants Arising in Rural Environments: Investigations in Karst and Fractured Bedrock Aquifers

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Introduction

Emerging organic contaminants (EOC's) are becoming more and more of a growing international concern with respect to their occurrence in and contamination of groundwater bodies. In Ireland, due to increased intensification of the food production in response to Food Wise 2025, agro-chemicals such as veterinary drugs and crop protection agents have become a critical component of agriculture. The administration and application of such substances can potentially lead to their occurrence in groundwater. As a result, loss of agro-chemicals to water is not only a matter of international scientific interest, but potentially a health risk to humans and the environment.

There is limited information available on the occurrence and associated levels of these agro-chemicals in the environment with information on the occurrence of metabolite and transformation products (TPs) even more scarce. This project is part of the Irish Centre of Research in Applied Geosciences (iCRAG). It will fill the void in current research and provide data on EOC occurrence in Irish groundwater.

Project aim and objectives

The project aim is to investigate the occurrence of EOCs arising from rural activities in Irish karst and fractured bedrock aquifers. The primary focus will be on the loss to groundwater of three main groups of anti-parasitic agents (anthelmintics, anti-coccidials and pyrethroid insecticides) which represent some of the most widely used veterinary compounds in Irish agriculture production. Project objectives include:

1. Investigate the occurrence of EOCs and its relationship to the chemical characteristics of the compounds, to include both parent compounds and transformation products (TPs) where appropriate.

2. Determination the source of EOC detections.

3. Determine the transport pathway factors involved in EOC occurrence

Methodology

1. Comprehensive literature review to establish the method performance capability required. To include review of legislative requirements, expected levels in the environment and best analytical techniques available.

2. Development and optimisation of three comprehensive multi-analyte solid phase extraction (SPE) (Fig. 1) techniques for the determination of anthelmintics, anti-coccidials and pyrethroids respectively in water with ultra-high performance liquid chromatography tandem mass spectrometry (UHPLC-MS/MS) instrumental determination (Fig. 2).

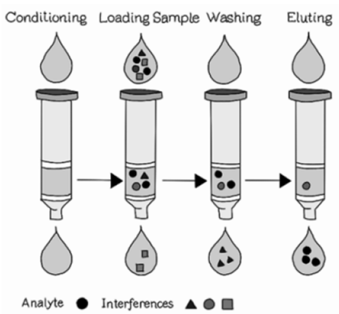

Figure 1: Solid Phase Extraction

3. Application of the developed method to environmental samples with an initial pilot sampling programmes targeting high risk sites to allow for refinement of the analytical parameters and to inform future sampling programmes.

4. Investigation of the spatial occurrence of EOCs in Irish groundwater

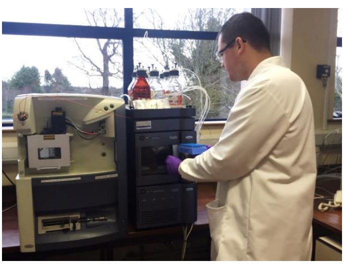

Figure 2: instrumental analysis by UHPLC-MS/MS

5. Assessment of temporal occurrence of groundwater EOCs to examine seasonal aspects in terms of timing of application and groundwater recharge activity.

Expected outcomes

The work carried out as part of this overall project will help to assess whether or not anti-parasitic agro-chemicals are an issue in Irish groundwater. In addition, this work will contribute to evaluating environmental effects of agricultural expansion under Food Wise 2025 in terms of investigating such potential rural groundwater concerns, which may not previously have been considered adequately in an Irish context. Not only will the project help assess Irish groundwater quality; it will also contribute to international research by providing more comprehensive multi-analyte analytical methods for determination of both parent compounds, and more importantly TPs. These methods will allow us to obtain better understanding of the occurrence and fate (i.e. mobility) of TPs in the environment, which lacks understanding at present.

Acknowledgments

This is a joint project between Trinity College Dublin and Teagasc funded through the Walsh Fellowship scheme and it forms part of the Groundwater spoke of iCRAG. This presentation has emanated from research supported in part by a research grant from Science Foundation Ireland under Grant Number 13/RC/2092 and is co-funded under the European Regional Development Fund and by iCRAG industry partners.

Assessing the risk of phosphorus transfer in high ecological status rivers.

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Introduction

Diffuse, non-point pollution remains a major threat to surface waters due to eutrophication caused by nitrogen (N) and phosphorus (P) transfers originating, in part, from agricultural land. In Ireland, phosphorus (P) transfer from agricultural land has been asserted as the primary cause of degradation in 53 % of the river water bodies that failed to achieve 'good' ecological status under the WFD. However, it is difficult to make the same assertion about rivers that are at risk of failing to maintain 'high' ecological status due to the uncertainty around the causes of degradation and also due to natural variations in high status conditions. Nevertheless, P transfer from agriculture does warrant consideration given its wider importance for the ecological quality of rivers. The objectives of this research were to characterize the geochemical and hydrological setting for agriculture in high status catchments in Ireland, and assess current nutrient management at field scale and the relative risk of P loss under different biogeochemical and hydrological condition.

Materials and Methods

Three case study catchments were selected from an existing database of 508 high status catchments. Catchment selection used a simple multi-criteria decision approach to represent agriculture on the dominant soils across the wider high status catchment population. The catchments selected were the River Allow in County Cork, the River Black in County Galway/Mayo and the River Urrin in County Wexford (Figure 1). The upstream catchment of the River Allow is dominated by poorly drained surface water gleys underlain by siliceous drift and shale bedrock with blanket peat in the upland areas toward the river's source. The catchment of the River Black is dominated by well drained brown earth mineral soils underlain by calcareous drift and limestone geology but interspersed with large areas of lowland raised bog peat. Situated in the south east, the River Urrin catchment is dominated by well drained acid brown earth, mineral soils underlain by siliceous drift and shale and slate geology, blanket peat exist in the upland areas near to the source of the river.

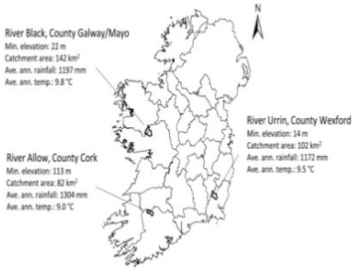

Figure 1. Location of case-study catchments

Results and Discussion

In total 10, 13 and 16 farm surveys were completed in the Allow, Black and Urrin catchments, respectively, to gather soil samples and information on farm and field nutrient management practices. These farms were selected to represent the range of farming systems present. Across the 39 farms surveyed, a total of 520 fields (195 in the Allow, 112 in the Black, and 213 in the Urrin catchments), were sampled and records of P management were assessed.

At farm scale, P surpluses were common on extensive farm enterprises despite a lower P requirement and level of intensity. At field scale, data from 520 fields showed that Histic topsoils with elevated organic matter contents had low P reserves due to poor sorption capacities, and received applications of P in excess of recommended rates. On this soil type 67 % of fields recorded a field P surplus of between 1 and 31 kg ha^{-1}, accounting for 46 % of fields surveyed across 10 farms in a pressured high status catchment. A P risk assessment combined nutrient management, soil biogeochemical and hydrological data at field scale, across 3 catchments and the relative risks of P transfer were highest when fertilizer quantities that exceeded current recommendations on soils with a high risk of mobilization and high risk of transport as indicated by topographic wetness index values. This situation occurred on 21 % of fields surveyed in the least intensively managed catchment with no on-farm nutrient management planning and soil testing. In contrast, the two intensively managed catchments presented a risk of P transfer in only 3 % and 1 % of fields surveyed across 29 farms (Figure 2).

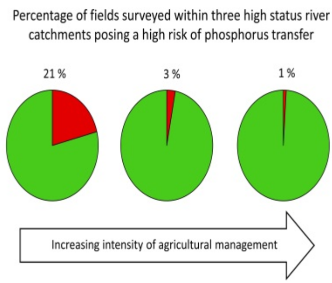

Figure 6. Percentage of fields surveyed within three high status river catchments posing a high risk of phosphorus transfer.

Conclusions

Future agri-environmental schemes under the EU Common Agricultural Policy and Rural Development Programme could consider providing % OM surveys on a field-by-field basis to farms in high status catchments. Farmers in these areas need greater access to advisory services.

Acknowledgements

This work was funded by the Department of Agriculture Food and the Marine, Research Stimulus Fund.

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Nutrient mobilisation and transfer pathways

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Introduction

Understanding nutrient mobilisation and transfer pathways is useful for finding solutions for best management practice and for interpreting the effectiveness of mitigation measures aimed at reducing nutrient losses from diffuse agricultural sources to water bodies. The objective of this work is to link nutrient sources with the movement of water in order to determine the contributions of water and nutrients that reach the stream via the various pathways (surface and subsurface). Another objective is to understand how nutrient transfer pathways may vary over time and space and in their connection to nutrient sources and the potential effects of temporal changes in weather and land management. The challenges are the complexities of scale involved that arise from the spatial variability of soil physical properties and the geology that determine the pathway and residence time, as well as the temporal variability of rainfall, land management and the nutrient transformations that occur in the soil.

Materials and Methods

Nutrients are monitored in sources, storage and delivery points in six agricultural catchments with different hydrological settings. Mobilisation and transfer pathways can be described using methods facilitated by high frequency monitoring of water quality and discharge in streams, water quality in a network of piezometers, mapping of soil nutrient sources and landscape information from high resolution LiDAR Digital Elevation Models. Detailed pathway studies from focused study sites (Fig. 1) are combined with catchment integrated studies in the stream outlet.

The output from this task contributes to the scientific evaluation of the effectiveness of the measures through an improved understanding of the pathways and will also provide a basis for any modifications to the measures.

Figure 1. Focused study site for nutrient mobilisation and transfer pathways in the Castledockerell catchment, Co. Wexford.

Results and Discussion

Analytical methods such as hydrograph and nutrient loadograph separation, nutrient/discharge hysteresis, end-member mixing analysis, development of a critical source area index, allowed the: i) identification and quantification of nutrient loads and concentrations in pathways, ii) elucidation of mobilisation processes of nutrients, iii) understanding of nutrient retention along pathways, iv) identification of where in the nutrient transfer continuum the response to measures are, v) identification of when and where in the landscape the critical delivery points are, and vi) linking of nutrient mobilisation, transfer and retention at catchment scale to regional/global weather changes.For example, for phosphorus (P) it was found that: i) hydrology overrides source pressure but P flux was larger between years than between catchments (Mellander et al., 2015), ii) the mobilisation mechanisms, explained by soil chemistry, influenced leaching and loss to rivers (Mellander et al., 2016), iii) a revised assessment of retention potential along pathways in a karst reduced the previous vulnerability map and highlighted 2% of the land at high risk for transfer to water (Mellander et al., 2013), iv) despite an increased agricultural productivity a reduction of P transfer to rivers was identified (Murphy et al., 2015), v) temporal and spatial information on delivery points can facilitate targeted mitigation measures (Thomas et al., 2016), and vi) amplified weather patterns may override positive benefits of mitigation measures in some years or indicate greater benefits in other years, and this will be catchment specific due to components such as mobilisation/transfer processes and hydrological connectivity.

Conclusions

A clearer understanding of the relative influence of soils, geology, farm practice, landscape and weather, on the propensity for nutrients to be lost to water, is needed to reshape the thinking on future nutrient management.

Acknowledgements

These studies were funded by the Department of Agriculture, Food and the Marine. We thank farmers, staff at the Environment, Soils and Land Use Department.

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WATERPROTECT: Innovative tools enabling drinking water protection in rural and urban environments (Irish case study)

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Introduction

High-quality, safe, and sufficient drinking water is essential for life: we use it for drinking, food preparation and cleaning. Agriculture is a source of pesticides and nitrate pollution in European fresh waters. The objective of this recently approved European Union's Horizon 2020 funded project is to contribute to effective uptake and realisation of management practices and mitigation measures to protect drinking water resources.

The project consists of seven case studies over Europe involving multiple actors in implementing good practices to ensure safe drinking water supply. The case studies cover different pedo-climatic conditions, different types of farming systems, different legal frameworks, larger and smaller water collection areas across the EU. The project is coordinated by VITO in Belgium and the Irish case study is led by Teagasc with University of Ulster, Wexford County Council and Glanbia Ingredients Ireland Ltd as partners.

In close cooperation with actors in the field in the case studies (farmers associations, local authorities, water producing companies, private water companies, consumer organisations) and other stakeholders (fertilizer and plant protection industry, environment agencies, nature conservation agencies, agricultural administrations) at local and EU level, WATERPROTECT will develop innovative water governance models investigating alternative pathways from focusing on the 'costs of water treatment' to 'rewarding water quality delivering farming systems'. Water governance structures will be built upon cost-efficiency analysis related to mitigation and cost-benefit analysis for society, and will be supported by spatially explicit GIS analyses and predictive models that account for temporal and spatial scaling issues.

Irish case study

The Irish case study will consist of two subprojects aimed at assessing i) the efficacy and ii) the uptake of mitigation methods. Each project is composed by work packages to be carried out within two catchments (ca. 11 km^2) in County Wexford, both of which are extensively monitored within the Agricultural Catchments Programme (ACP). One of the catchments has mostly free draining soils overlaying fissured slate bedrock and is dominated by arable land, while the other has mostly poorly drained soils overlaying volcanic rhyolite and is dominated by grassland for beef and dairy production. The free draining arable land is largely groundwater fed and risky for leaching of nutrients and pesticides to groundwater while the poorly drained grassland has a flashy hydrology and is sensitive to surface runoff and quick shifts in weather. Both catchments have small scale abstraction of groundwater to supply individual farms. Additionally, a small number of households within the catchment have common water supply from groundwater within the catchments. Since 2009 the ACP monitor water discharge and Nitrate-N concentration sub-hourly in the rivers, groundwater flux hourly and nitrate-N concentration (and a suit of chemical parameters) monthly in a network of monitoring wells (2 – 50 m below ground level (bgl)). Onsite weather is monitored sub hourly and information on nutrient management is recorded.

Expected results

The project will create an integrative multi-actor participatory framework including innovative instruments that enable actors to monitor, to finance and to effectively implement management practices and measures for the protection of water sources.

The expected outcome of WATERPROTECT will be improved participatory methods and public policy instruments to protect drinking water resources.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 727450.

Case study lead organizations

Inagrio (Belgium), Teagasc (Ireland), Geus (Denmark), CSIK (Spain), PIC-PIB (Poland), UCSC (Italy) and EcoLogic Association (Romania).

Land Drainage – Nitrogen source fate and transformation across soil drainage classes

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Introduction

Global increase in demand for dairy products has led to increasingly intensive farm production. The challenge is now to create intensive dairy systems that are sustainable (socially, economically and environmentally). In order to cope with higher demand, agriculture has been subjected to both intensification and expansion and farming systems are exploiting soil types less suitable for grazing and crop production (e.g. gley soils) with higher expectation of profitability. Gley soil sand high rainfall often combine to create high saturation contents, which limit may reduce annual yields from 3 to 31%. Artificial land drainage, with soil profile data dictating the type of drainage system needed, reduces waterlogging, enhancing crop production throughout the year and keeping costs low. However, it is well documented that land drainage can enhance environmentally deleterious nitrogen (N) losses.

Objectives

Quantify N losses and speciation at different points across five artificially drained sites along the N-transfer continuum: in the groundwater, at the end of in-field pipes, and within open ditches receiving water from field drainage systems and exiting the farm to discharge in neighbouring water bodies.

Characterise, across five artificially drained sites, the sources of the N losses and the occurring attenuating processes in terms of stable isotopes and dissolved gaseous emissions.

Produce guidelines in terms of water and functional soil management for heavy soils farms characterised by artificially drained gley soils.

Research & Results

Across five sites where gley soils were artificially drained based on site specific conditions, it was shown using multi-faceted data sources that N sources and surpluses were uniform but transformation and therefore fate of nitrogen differed across the farms.

Ammonium was the major pollutant on all sites with three groups forming. Group 1 showed low ammonium-N concentration coupled with a high denitrification potential suggesting that the installation of the drainage is further stimulating soil aeration and promoting the cycling of nitrification and denitrification. Group 2 was characterised again by low ammonium concentration but with a high nitrification potential and a small component of complete denitrification. Group 3 had high ammonium concentration due to low denitrification or the occurrence of parallel processes. In this last group installation of a drainage system had a negative impact on water quality causing a bypassing of the soils natural bioremediation capacities. Results showed that each site within the so called have soils category must be characterised individually.

Future Work

Figures 1 and 2 show the next phase of this study, where we take a closer look at the conversion of nitrate to ammonium on heavy soils. The big take away message from this research is that land drainage in some cases transport naturally remediated water from within landscapes to open ditches but in some other cases land drainage bypasses this natural attenuation capacity. Sustainable drainage into the future must take soil and water characterisation seriously.

Figure 1. Soil cores taken from one of the sites within this study to examine drained versus non-drained conditions

Figure 2. Gas sampling during field and laboratory work.

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Marie Curie ITN - INSPIRATION

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Introduction

Agriculture is vital to Europe's prosperity. However, while agricultural production in Europe has significantly increased food security it has also damaged soil and water resources and ecosystem biodiversity, and contributed to climate change. With the global population predicted to grow to 9.1B by 2050, it is estimated that current food production must increase by 60% to meet this demand. Demand for water is also expected to grow by the same amount by 2025, much of it required to support irrigated agriculture. Further intensification of production to support population growth must be sustainable to minimise future environmental impacts and negative externalities. Sustainable agriculture has been implemented in many developing countries. It integrates technologies, practices and natural processes to manage pests, nutrients, soil and water, with local knowledge, community and stakeholder participation and management methods which adapt to specific conditions. External inputs (e.g. non-renewable energy, fertilisers and pesticides) are replaced by natural processes and resources to minimise environmental impacts and conserve resources. Sustainable intensification of rain fed and irrigated agriculture can improve food production and crop yields while reducing pesticide use, GHG emissions and environmental degradation. A key feature is that production is increased only in ecosystems supporting this. There are many social, economic and environmental benefits, which increase sustainability in different sectors.

Objectives

The specific objectives of INSPIRATION are to:

○ Train a group of highly qualified professionals in state-of-the-art approaches managing soil and groundwater impacts from agriculture for sustainable intensification

○ Develop "smart" monitoring techniques and new multi-suite stable isotope methods needed to investigate and quantitatively assess soil and water quality impacts from agricultural practices for sustainable intensification

○ Using the above methods, determine C, N and organic pollutant flux dynamics between atmosphere-soil-water systems at farm and catchment-scale to devise measures supporting the sustainable intensification of agriculture

○ Develop sustainable low-technology management practices and pollution mitigation concepts at laboratory- scale through to on-farm-scale application, supported by process understanding for design and implementation

○ Develop biosensor biotechnology to design organic amendments to restore degraded soil for agricultural use

○ Develop new quantitative approaches and modelling tools for the performance assessment and engineering design of sustainable management processes, practices and technology concepts at farm and catchment-scale

○ Develop a decision-making framework and assessment tools that integrate agricultural intensification within the sustainable development of soil and water resources, across different scales and considering relevant actors

Research

Johnstown Castle are leading Work Package 4: The creation of low-technology sustainable management concepts for land drainage to conserve resources, manage water pollution, enhance soil quality and mitigate GHG emissions is the focal point of the collaboration in WP4 (Early Stage Researchers 11-13). These projects investigate sustainable treatment technologies using mixed waste media to mitigate agricultural contaminants; evaluate recycling possibilities of media used for mitigation of contaminants in land drainage; and apply isotope techniques for process and performance assessment of nutrient treatment in bioreactor and land drainage systems. Developing novel farm-scale bioreactor and nutrient recycling technologies for resource (N, P) recovery/re-use and mitigating point source and diffuse C, N and P emissions may apply considerable savings in fertiliser usage and therefore costs.

Figure 1 Teagasc and UFZ collaboration on groundwater remediation using local media and isotopic techniques.

Figure 2 Our Logo.

Acknowledgements

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Investigating the genomics of soil-persistent Escherichia coli

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Introduction

E. coli is a common bacteria originally isolated as from the gut in 1886. While the majority of strains are commensal, several lineages of *E. coli* are capable of causing disease in humans (primarily in the gastrointestinal and urinary tract, but occasionally more systemic infections). The primary route of transmission is through ingestion of water or crops exposed to faecal contamination. The WHO estimates that *E. coli* accounts for about 5 million disability adjusted life years lost annually, making it the second most problematic food-borne pathogen in the world (Kirk 2015).

Because of its ubiquity in faecal material and it's perceive inability to survive for extended periods in the environment, *E. coli* is widely used as an indicator of faecal contamination. However, a growing body of work now supports the idea that while *E. coli* is often indicative of faecal contamination, stable populations may persist in the soil for long periods of time. This compromises *E. coli's* effectiveness as an indicator species.

Our aim is to use advances in DNA sequencing technology to study the genomes of these soil-persistent *E. coli*. By looking at the genomic differences exhibited by these bacteria compared to their gut-associated relatives, we hope to discover what allows them to adapt to an alternative lifestyle from the gut, and to assess whether soil-persistent strains pose a threat to human health.

Objectives

1. Determine the basis for the remarkable long-term survival of E. coli in maritime temperate soil

2. Determine if environmentally persistent soil E. coli populations constitute a health risk to human populations

3. Determine if enteric E. coli-specific genomic markers exist

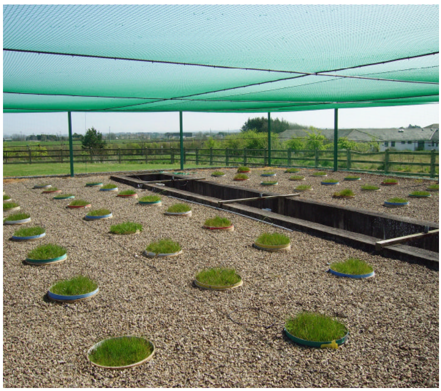

Figure 1: Lysimeter unit, Johnstown Castle

Materials and Methods

To isolate soil-persistent strains, *E. coli* were enriched from leachate from soil lysimeters housed at Teagasc, Johnstown Castle. These soil columns were originally set up by Ryan and Fanning (1996) to study effects of fertiliser on various soil types, and later used by Brennan, et al. (2010) to study the transport of pathogens from slurry through soil columns.

The control columns from the latter experiment were last exposed to slurry in 1998. Thus, at least 9 years passed between the last contamination event and the isolation, and any isolates obtained from these lysimeters represent strains exhibiting soil-persistence for at least 9-13 years. Leachate from these control columns was collected, and *E. coli* was enriched from the liquid. After the resulting colonies were purified, DNA was extracted and sent for Illumina sequencing.

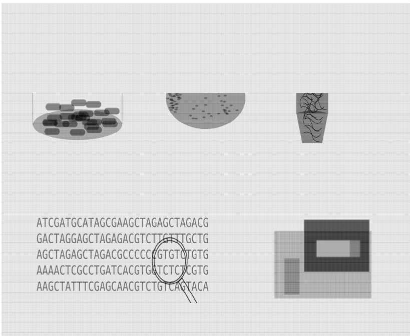

Figure 2: Summary of workflow

Overview of the collection

153 soil-persistent *E. coli* were successfully isolated and sequenced. The isolates exhibited a large degree of phylogenetic diversity, with representative members from each of the phylogroups of *E. coli*.

This suggests that soil-persistent *E. coli* are not a succinct clade, but that a diverse subgroup is capable of becoming naturalised in soils.

Next Steps

This collection offers a unique look into the genomics of soil-persistent *E. coli*. While the genomes of thousands of *E. coli* have been sequenced, these genomes are dominated by clinical isolates and environmentally derived strains are poorly represented. To our knowledge this is the only collection of soil-persistent strains currently in existence, made possible by the long-term curation of the lysimeters. Current work is underway to characterize the virulence and antimicrobial resistance capacities of the strains, to determine metabolic adaptations involved with soil-persistence, and to identify markers that could potentially be used to differentiate between enteric and environmental strains.

Acknowledgements

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Agricultural Catchments Programme

The Agricultural Catchments Programme

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Introduction

The Agricultural Catchments Programme (ACP) is funded by the Department of Agriculture, Food and the Marine and is operated by Teagasc. Its core objective is to measure the effectiveness of the Good Agricultural Practice (GAP) measures implemented under the Nitrates Directive, i.e. the Nitrates Regulations, at catchment scale while also evaluating the efficacy of the nitrates derogation.

The scientific findings from the ACP help fulfil Ireland's monitoring and reporting requirements under the EU Nitrates and Water Framework Directives and support key agri-environmental policies and strategies such as, the Nitrates Regulations, including the derogation the 2nd cycle of River Basin District Planning under the Water Framework Directive, Food Wise 2025 and Origin Green.

The ACP approach, which uses high-resolution economic and environmental data gathered over successive years, is well suited to measuring changes in both these areas. These research outputs are being used to support Ireland's green credentials in the context of policy frameworks such as Food Wise 2025.

The ACP approach

Since it began in 2008 the programme has continuously developed and established itself as a unique asset in meeting Irish farming's sustainable intensification challenge.

Phase 1 (2008-2011) was concerned with project design, development and scientific assertion from the first years of data collection. Phase 2 (2012-2015) was mainly concerned with validation of assertions and policy impact. Phase 3 (2016-2019) continues the approach established in the first two phases while developing the modelling area and expanding the dissemination effort.

Key Strengths

The ACP has three key strengths:

1. *A single, common experimental design is used in all six agricultural catchments*.

The bio-physical element of the design is based on the concept of a continuum from the source of farm nutrient to where that nutrient, if lost, would potentially cause an ecological impact. The implementation of this design entails high resolution monitoring of the main physical parameters such as the N and P concentrations in the surface and groundwater, stream flow, weather data, soil nutrients levels and ecological status.

2. *Integration of a strong socio-economic element with the biophysical component in the experimental design.*

This integration enables the Programme to go beyond sophisticated monitoring and allows for the development of a deeper understanding of catchment processes related to changes in the agri-environment due to policy drivers. It also allows for key pressure and state expectations to be explained beyond just 'positive, negative or no change' over time.

3. *Partnership with over 320 farmers across the six selected agricultural study catchments*.

The participation and goodwill of farmers has been essential in ensuring the success of the programme, in particular the socio-economic research. Four ACP advisers provide an advisory service to the farmers is and collect farm data.

Figure 1. Farmer, David Mitchell with his ACP Agricultural adviser, Tom O'Connell.

Phase 3

Phase 3 of the ACP (2016 – 2019) builds on the data collected and the work done in the previous two phases by continuing with the current approach while developing a greater modelling competence. The modelling work requires an integrated environmental-economic modelling approach to specifically address the challenges inherent in meeting the production and environmental targets set out for Irish agriculture. The primary aim of this work is to develop the capability to identify the risks to expansion and advise on the overall costs and benefits associated with sustainable intensification practices at field, farm and catchment scale. Data collected in all three phases of the programme as well as appropriate external data, will be used. Phase 3 also aims to deliver an enhanced knowledge transfer (KT) and dissemination programme in collaboration with Teagasc colleagues. It focuses primarily on getting key messages from the ACP to farmers mainly via the existing Teagasc KT structures but but also includes dissemination to a wider audience of policy makers, regulators, environmental scientists and the general public. Given the range and diversity of the audience and the resource constraints that exist an approach that uses all feasible channels, including this newsletter, is needed to deliver dissemination programme.

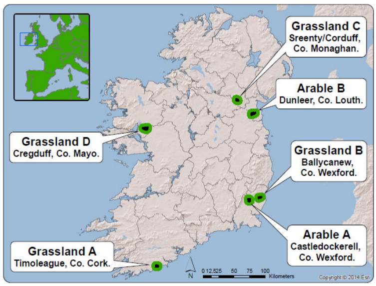

Figure1.Catchment Locations

Acknowledgements

This work is funded by the Department of Agriculture, Food and the Marine.

References

ACP publications, including the Phase 1 and Phase 2 reports and scientific papers can be found at www.teagasc.ie/environment/water-quality/agricultural-catchments

Nutrient Source Trends in the Agricultural Catchments

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Introduction

Ensuring that primary nutrients of nitrogen (N) and phosphorus (P) are utilized for plant growth and animal maintenance requires that environmental losses to the air and water are continued to be minimized. Targeting nutrients towards optimum levels and increasing the efficiency of their utilization can assist in achieving the "Win-Wins" on farms for increased production and reduced risks of harmful nutrients emissions to the environment. As part of the overall ACP objectives to assess the effectiveness of the GAP regulations and the means to meet FoodWise (FW) 2025 targets, the nutrient sources component evaluates the management, magnitude and mobilization potential of N and P sources in each catchment.

Materials and Methods

Soil nutrient census, where soils are sampled at a <2ha resolution, to evaluate soil P status, distribution and trends was carried out fully in 5 of the 6 catchments at the start of the ACP (Baseline), and repeated every 3-4 years (Figure 1).

Nutrient management data in the context of inputs (i.e. fertilizer use, feed and livestock) and exports (crop & animal product) at farm and field scale are recorded annually from a cross section of farm types and intensities. This information is used to calculate N and P farm-gate balances, field balances and efficiencies.

Characterizing catchment soils to understanding the potential mobilization risk of N and P was done using an additional grid-sampling scheme in each catchment (27 to 35 sample points). Samples were analyzed for a range of chemical properties (e.g. aluminum (Al) and pH). Also using Irish soil mapping classification methods, catchment scale soil survey maps were created identifying dominate soil types and their textural characteristics.

Figure 1: Soil Sampling Arable A

Results and Discussion

In five out of the four catchments the trend in excessive soil P (Index 4) levels decreased (between 3 to 8%) over a 4 year period. In the intensive, mostly dairy, Grassland A catchment soil test P (STP) levels positively converged towards the agronomic optimum Index 3 (Figure 2). This was achieved through reduced average farm-gate inorganic P inputs of 5.2 kg/ha/yr, P balances of 2.4kg/ha/yr and increased P use efficiencies of 89%. While concurrently average farm productivity remained high with signs of improving trends in water quality.

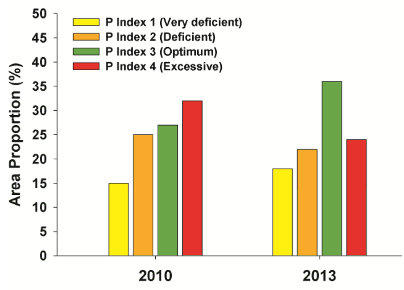

Figure 2. Areal proportion of soils in each soil P Index in the Grassland A

Where soil P trends increased in the Arable B catchment, it is further explained by the increase in field soil P balances from -10.1 to +16.1 kg/ha between the soil sampling years (2010-2014), this is attributed to poor on-farm nutrient distribution of organic sources.

For the remaining 3 catchments, where full soil census were carried out in 2009/2010 and repeated in 2013/2014, the STP levels continued to decline, with an increase (between 7 and 12 %) in the proportional areas of sub-optimal P (i.e. Index 1 and 2 combined).

For some of these catchments the reduced STP levels cannot be directly related to a reduction in farm and field P inputs levels. Specifically, for Arable A, where the average soil P field balances increased by 5kg/ha/yr between 2010 and 2013), indicating that landowners in this catchment were applying P to meet crop and soil P build-up needs. Additional chemical characterization of the soils in the Arable A catchment suggests that due to the high levels of extractable Al found, these soils are capable of binding large amounts of applied P, hence making P less available to the plant and less mobile, i.e. a reduced risk of P loss to water.

Conclusions

Areas with excessive P (risky) levels have fallen in the majority of catchments, which is attributed to reduced farm-gate P levels, increased P use efficiency and soils with limited capacity to mobilize P. Whereas, poor nutrient distribution, especially organic sources, are attributed to catchment soils where STP levels increased. The ACP is continuing to monitor tends in nutrient sources across all catchments to access the impacts of GAP regulations and provide guidance in meeting FW2025 targets, with additional focused studies on improving organic manure management.

Acknowledgements

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Nutrient delivery and impacts in agricultural catchments

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Introduction

The qualitative status of Irish waterbodies in relation to Water Framework Directive (WFD) objectives is assessed according to their chemical and ecological composition. For national reporting purposes, chemical concentrations (including phosphorus (P) and nitrogen (N)) of surface-waters are monitored at a minimum frequency of every 3 months. High temporal resolution monitoring of catchments within the Agricultural Catchments Program is achieved using bankside kiosks, at sub-hourly frequencies.

This monitoring has revealed repeated spikes in reactive phosphorus (RP) concentration during low-flow periods (Figure 1), which could exceed the P threshold set by the WFD (Shore *et al*., 2017). Hypotheses for this include:

a) Lack of dilution during low-flow

b) Persistent point sources

c) Biochemical mobilization of stored P in stream and bank sediment

Lack of dilution does not appear to be the sole factor, based on data from the outlet, as P concentrations in some catchments increase as low-flow conditions are maintained, suggesting a delivery or mobilization component.

The objective of the current research is to determine the cause and mechanisms resulting in elevated P during low-flow conditions.

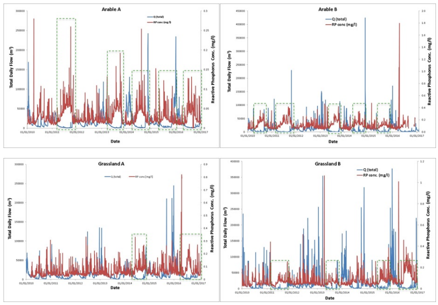

Figure 1. Total daily flow (m^3) and reactive P concentrations (mg/l), measured at the outlet in four catchments (Arable A and B; Grassland A and B).

Materials and Methods

In order to identify catchment areas contributing to P loss during low-flow conditions, synoptic surveys are being conducted throughout 2017. These will be performed during April-May, June-July and September, to correspond with ecological surveys and key periods within the farming calendar. The surveys are targeted for low-flow conditions (Q70 percentile) with no antecedent rainfall in the previous 24 hours (to avoid the influence of flushing from the system). In each of the four catchments c. 60 water samples (500 ml) will be taken at intervals along the main stream, tributaries and selected ditches over the course of <4 hours. This gives a resolution of c. 5-6 samples per km stream length. Essentially, this manner of survey provides a high spatial resolution 'snapshot' of stream nutrient concentrations at a given flow. Additional surveys may be added at a later date, to target other flow conditions.

The physical samples will be analyzed for total P, total dissolved P, reactive P, and Boron. Boron is included in the sampling suite as an indicator of domestic point sources such as septic tanks, as it is a constituent of domestic detergents. Conversely, in catchments with low septic tank density and in which fodder beet is grown or fed (such as Grassland A), boron can be used as a co-indicator of P arising from these sources, as fodder beet typically receives boronated fertilizer. Samples will also be analyzed for total N, oxidized N, nitrate and nitrate, with a view to future research. It is anticipated that these samples will identify any persistent point sources of an agricultural, domestic or industrial nature.

Additional samples will be taken at a subset of sample points in each catchment (7 points), for analysis of faecal indicator organisms E. coli and Enterococci and host-associated bacterial markers of human and ruminant faecal matter. This analysis is conducted in collaboration with National University of Ireland, Galway.

At the time of sampling Aquaread^{tm} handheld probes will be used to measure in-situ pH, temperature, conductivity, dissolved oxygen and turbidity. In the absence of evident point sources, these parameters may be used for biogeochemical modeling to determine whether release of sediment-bound P is occurring during low-flow periods.

Conclusions

This work is ongoing and results should be forthcoming in early 2018.

Acknowledgements

This work is partly funded by the Department of Agriculture, Food and the Marine through the Agricultural Catchments Program.

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