Ireland’s Rural Environment:

Research Highlights from 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 ten permanent researchers, eleven contract researchers and 16 technical staff. In addition, between 10 and 15 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. Harvest 2020 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".

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 involved.

Nutrient Efficiency

Developing an On-line tool for nutrient management planning

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Introduction

A nutrient management plan (NMP) consists of an inventory of land, cropping, stocking rate, farm management and soil fertility data for a farm, and the customisation of a fertilizer management strategy based on these parameters. The process of preparing a nutrient management plan requires the calculation of nutrient recommendations for each parcel or field on the farm, and the amalgamation of these recommendations into a summarised nutrient advice plan for the whole farm. This nutrient advice is then cross-checked, and adjusted where necessary, against legislative limits to nutrient inputs for the farm (currently controlled under SI 610 of 2010) based on the aforementioned parameters.

At present, a NMP plan is produced by applying a series of calculations to farm data to estimate fertilizer requirements and ensure Good Agricultural Practice (GAP) compliance. Despite the complexity of the calculations required which involve numerous macros to facilitate lookups, computations, algorithms, etc., it has been developed exclusively in MS Excel. The outputs currently available include a tabular summary of the nutrient management advice for the farmer, at both a whole farm and field by field level. The process can also include recording of fertilizer purchases and nutrient applications as the plan is implemented.

Existing NMP systems

Nutrient management planning (encompassing cross compliance with nitrates and nitrates derogations) has been conducted by Teagasc advisors with the help of a number of sequentially developed versions of NMP tools developed in MS Excel. There have been two types of tools used for a number of years: one for doing NMP for simple non-derogation farm scenarios where only whole-farm fertilizer allowance data was required; and another for giving more detailed field by field fertilizer advice and for preparing derogation fertilizer plans and records. These systems, while functional, are user un-friendly and really only provide fertilizer plans for cross-compliance purposes. The existence of the data in separate Excel files (in a number of different versions) also poses a risk to with respect to data quality control in cross compliance related advice. An online database system which can maintain central control over calculations, and which could also be available as a resource database for research regarding soil fertility trends, fertilizer and lime advice and usage, etc, would be a far superior tool to have in place for NMP activities within Teagasc.

Developing an on-line software

The objective of the new on-line software will be to replace the multi-version and non-centrally controlled MS Excel templates in operation since 2007, and move to a more robust and user friendly platform for producing map and enhanced tabular based outputs. It is envisaged these changes will improve the quality and efficiency of the NMP planning process by providing more user friendly outputs for farmers to interpret and implement NM planning on their farms. Recent work through surveys and research focus groups with advisors and farmers has highlighted the importance of how the system functions for advisors; and the outputs that it produces for farmers. These new components of the system are well beyond the capabilities of current MS Excel technologies, further supporting the requirements for a root and branch assessment of the software Teagasc uses and the functionality that it facilitates.

System benefits

These additional requirements, particularly the mapping functionality, have been identified as being critical to the success of NMP activities in Ireland. The Agricultural Catchments Programme at Teagasc has provided a proof of concept to the implementation of maps and linkages to additional in-house data sources from both an agronomic and technical perspective.

The development of this system will involve the transfer of existing calculations into an online database environment that will incorporate relational database and mapping functionality. Generating linkages to existing data sources of land use, livestock, soil test results and automated reporting of farmer records for cross-compliance are key elements to the development process. Potential for future development of SMART phone applications, additional mapping layers and 'what if' functionality are also being considered in future iterations of the software.

Figure 1 Examples of how nutrient advice (lime application (left) and slurry application (right)) may be displayed in a mapping based output format to assist in nutrient management planning adoption on farms.

Fertiliser Nitrogen Source, Urease and Nitrification Inhibitors: Tools for Increasing Nitrogen Use Efficiency

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Introduction

Optimizing nitrogen (N) availability for crop growth is critical for productive agricultural systems and for minimizing potential negative economic and environmental impacts associated with N loss from agro-ecosystems.

Applying N in synchrony with crop demand is a basic strategy for attaining high N use efficiency. However, at a practical level this can present challenges as multiple applications during a growth cycle can be unattractive or impractical for producers.

In agricultural systems plants primarily uptake nitrate-N (NO_3-N) because normally ammonium-N (NH_4-N) is rapidly converted to NO_3-N, a process mediated by the action of aerobic nitrifying bacteria.

Calcium ammonium nitrate (CAN) is the most widely used straight N source in Ireland and provides rapidly available NO_3-N for plant uptake. However, NO_3-N is vulnerable to leaching and de-nitrification loss pathways under the cool humid conditions of Ireland.

An alternative N source is urea-N which is less expensive than CAN per unit N. Before Urea-N reaches NO_3-N it under goes the processes of being hydrolyzed, which can be delayed using urease inhibitors such as N-(n-butyl) thiophosphoric triamide (NBPT), and nitrification, which can be delayed by nitrification inhibitors such as dicyandiamide (DCD). Therefore fertiliser N source, N source blending, and the use of inhibitors present a potential opportunity to better synchronize NO_3-N availability with plant N demand, contributing to increased grassland N use efficiency. By reducing soil NO_3-N occurrence there is potential to reduce N losses through leaching and de-nitrification.

Materials and Methods

This research is being conducted at three grassland sites, a loam soil at Johnstown Castle, Co. Wexford; a sandy loam soil at Moorepark, Co. Cork; and a clay loam at Hillsborough in Northern Ireland. The experimental design is a randomised block, with five replicates. The fertiliser N sources being investigated are CAN-N, Urea-N, and a CAN-N + Urea-N blend. The N inhibitor treatments being investigated are NBPT, DCD, and NBPT + DCD in combination with Urea-N. The total annual N rates examined are 0, 100, 200, 300, 400, and 500 kg ha $^{-1}$ applied in five equal splits following five grass harvests in a simulated grazing rotation.

Figure 1. Visual Response to N (May 2013).

Dry matter yield, grass yield and N uptake for each treatment will be measured by mowing to 5 cm to simulate grazing at five times annually. Nitrogen use efficiency will be assessed for N source, rate, and inhibitor treatments.

Figure 2. Grassland plots.

Expected Results

Utilization of N source and N inhibitor combinations are expected to reduce N costs for agriculture whilst improving N use efficiency, reducing potential environmental loss of N from agro-ecosystems and sustaining or increasing productivity. This research will play an important role in meeting the agricultural productivity goals set forth in Food Harvest 2020 whilst protecting the environment and meeting future greenhouse gas and air quality targets.

Acknowledgements

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Using a novel geo-computational system to facilitate better Nutrient Management Planning

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Introduction

Food Harvest 2020's ambitious targets for agricultural production will demand superlative nutrient management on Irish farms as the requirement for nutrient inputs intensifies.

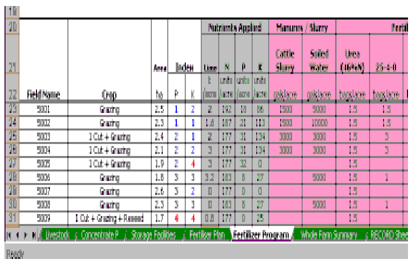
Soil fertility and nutrient management underpins all successful farming enterprises. Getting the "balance right" and responding to agronomic, environmental, legislative and financial constraints is a real challenge.

Data management has the opportunity to play a pivotal role in facilitating the generation of a legally sound and agronomically workable nutrient management plan for farms by removing some of the cumbersome administrative tasks from the farm manager or advisor.

The Agricultural Catchments Programme (ACP) (Fealy et al., 2010), has developed a novel geo-computational information management system based around geographical information systems (GIS) for coordinating nutrient management planning on farms. The ACP has implemented this innovative technology across their six catchments, each involving approx. 35-80 farms (Wall et al., 2011).

Traditional NMP Development

To date, developing a nutrient management plan (NMP) has involved piecing together data including farm attributes, livestock type & numbers, soil nutrient status, organic manure production etc from a number of disparate sources. Good Agricultural Practice (GAP) compliance is ensured by applying a series of calculations to these data to estimate fertilizer requirements. An in-house MS Excel Tool (Lalor, S., 2007) has been developed and is used extensively to assist with these complex calculations. However the outputs as well as the inputs are hugely restricted to the confines of MS Excel functionality (Fig. 1) and limit flexibility to display tabular summaries of the nutrient management advice for the farmer, at both a whole farm and field by field level.



Field Name	Crop	Area (ha)	Index P	Index K	Lime (t/acre)	N (units/acre)	P (units/acre)	K (units/acre)	Cattle Slurry (gals/acre)	Soiled Water (gals/acre)	Urea (46%N) (bags/acre)	25-4-0 (bags/acre)
5001	Grazing	2.5	1	2	2	192	18	86	1500	5000	1.5	1.5
5002	Grazing	2.3	1	1	1.8	187	21	113	1500	10000	1.5	1.5
5003	1 Cut + Grazing	2.4	2	1	2	177	31	134	3000	3000	1.5	3
5004	1 Cut + Grazing	2.1	2	2	3	177	31	134	3000	3000	1.5	3
5005	1 Cut + Grazing	1.9	2	4	3	177	32	0			1.5	
5006	Grazing	1.8	3	3	3.2	183	8	27		5000	1.5	1
5007	Grazing	2.6	3	2	0	177	0	0			1.5	
5008	Grazing	2.3	3	3	0	183	8	27		5000	1.5	1
5009	1 Cut + Grazing + Reseed	1.7	4	4	0.8	177	0	25			1.5	

Livestock / Concentrate P / Storage Facilities / Fertilizer Plan / Fertilizer Program / Whole Farm Summary / RECORD Shee

Ready

Figure 1. Tabular one-page output from an existing NMP; including soil test P and K indices, organic & chemical fertilizer advice on a per field basis.

ACP GIS approach

The ACP has developed a more automated system that not only offers a farmer a NMP but also the facility to create maps representing the numerical data outputted from these plans.

The fields and land management units within each farm were digitized using ArcGIS 9 ArcInfo version 9.3. Fields were coded spatially to identify soil test sample areas (~2 ha) and related geodatabases were developed. The soil analysis results were retrieved using a laboratory information management system (LIMS) and linked with the geodatabase and existing nutrient management planning software (MS Excel) to develop nutrient management plans.

The ACP also developed a facility to capture day-to-day management events (e.g. fertilizer applications) on every farm within the catchments using a Nutrient Management Recorder. All the data collected are stored centrally using a Document Management System (DMS – MS SharePoint). This provides a secure data warehouse and facilitates the development of a relational database.

Results and Discussion

Maps can facilitate spatial representations of soil test (e.g. Morgan's P) results and application rates for individual fields on a whole-farm basis in accordance with a soil census reports simultaneously (Fig. 2).

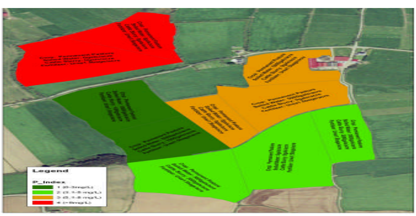


Figure 2. Colour coded spatial representation of crop & soil test specific P indices including chemical and organic application advice.

With such systems in place, ACP farmers are better equipped to plan their nutrient management strategies for the future, and also to track their progress and make informed changes to their plans when needed.

Providing solutions do not always require lengthy development downtime. Examining existing technologies and joined up thinking can arrive at workable solutions.

Conclusions

The development of this geo-computational information management system has enabled ACP farmers, advisors and researchers to maximize the usage of available datasets.

It facilitates integration for geospatial analysis and other research against a wide variety of other datasets whilst maximizing the integrity of the data

This technology can be used to overlay many years of data, enabling researchers and advisors to track temporal changes in soil fertility and nutrient management.

It delivers a workable ICT solution that is cost effective.

Acknowledgements

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

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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 have 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 nitrogen (N) and 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 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.

Nitrogen, P and Lime interactions

A new field trial was set up in early summer 2011 to look at the interactive effects of N, 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 rates of application of 0, 150 and 300 kg N ha^{-1} yr^{-1} (half these rates were applied in 2011 as the experiment began in June). 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 but not in subsequent years. Plots where cut four times in 2011 and 8 times in 2012.

Soil organic P speciation

Organic P is a significant component of total P in soils, and is present in various forms including microbial biomass P. NMR (Nuclear magnetic resonance) spectroscopy was used to identify and quantify different organic P species, and microbial biomass P was assessed using the fumigation method. Using these techniques differences in the organic P composition of different soils were investigated.

(Both of these methods where carried out with the assistance of Dr Martin Blackwell at Rothamsted Research, North Wyke, Devon, UK)

Soil test P response to phosphorus and lime
An experiment was set up to examine the fate of P and lime additions to 16 different un-vegetated soils in a controlled environment facility. The treatments consisted of 100 kg P ha^{-1} (super single phosphate), 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.

Nitrogen, P 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 analyse 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 organic P identification
Results from P NMR analysis highlight the large variation exists in the amount of organic P that is found in Irish soils. Phosphate mono-esters are the dominant group in the soil, with phosphonates and DNA also being present in significant quantities. Work is being conducted to relate the abundance of the different organic P forms to soil fertility and grass growth.

Soil test P response to phosphorus and lime
Results from the 3 month sampling period 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.

Conclusion

While these results 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

This work is funded by the Teagasc Walsh Fellowship Scheme.

Developing soil based nitrogen tests for grassland soils

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Introduction

Current nitrogen (N) advice is based on a "one size fits" all system. Varying levels of soil N supply from different soil types through the process of N mineralisation (N_o) is not taken into account. This increases the risk of under- or over-supply of N fertilizers to many fields, resulting in poor economic returns for the farmer and unnecessary losses of N to the environment. The aim of this project is to develop a practical soil N test to predict soil N supply across a range of Irish soils types. This soil N test could then be used as a basis for developing soil specific N advice on farms in the future helping to increase N fertilizer use efficiency (N_fUE).

Materials and Methods

Series of experiments were established:

1. Laboratory study: (to identify suitable soil N tests) 35 soils were sampled (10cm) across Ireland. Soil samples were analyzed for potential N_o using a standard biological 7 day anaerobic incubation test (AI-7) and also 7 rapid chemical tests, including the Illinois soil N test (ISNT). The best rapid soil N test for estimating N_o was then identified by exploring the relationships between the standard AI-7 and rapid tests.

2. Microcosm study: (to validate lab findings) 30 soils from across Ireland were potted and seeded with ryegrass (*Lolium perenne L).* The microcosms were laid out in a randomised complete block design (RCBD) in a controlled environment research facility (Figure 1) at 15^{o}C, 80% relative humidity, 16 h daylight and soil moisture at 65% field capacity. The soils received zero N fertilizer over the duration of the experiment. Soil samples were collected at the beginning of 3 successive 5 week growth periods and analysed for soil mineral N, N_o (using ISNT) and total C & N. Grass was harvested at the end of each growth period and analysed for dry matter (DM) yield and N uptake. The soil N supply and recovery by the grass was investigated using regression analysis.

Figure 1. Controlled environment pot experiment

3. Field study: (to assess the temporal variability of soil N pools) Nitrogen fertilizer response experiments were set up in a RCBD with 4 reps and 6 treatments (0, 150 and 300 kg N ha^{-1} yr^{-1}, 33m^3 and 66m^3 slurry ha^{-1} yr^{-1}, and a lime treatment) on a well drained loam (Well-D) and a moderately drained clay loam (Mod-D) soil type. Soils were sampled every 3 weeks (10 cm) from Oct 2011 to Nov 2012 and analyzed for mineral N, N_o (ISNT) and total C & N. Climatic data was recorded between each soil sampling point. Grass was harvested between Feb to Oct and analyzed for DM yield and N uptake. The temporal trends in soil N supply and grass yield uptake were then examined.

Results and Discussion

1. The soil N supply potential ranged from 93 - 403 mg N kg^{-1} (measured by AI-7 test). The ISNT was the best rapid chemical soil N test for predicting N_o ,as it displayed the best relationship with AI-7, (R^2=0.68, p<0.0001).

2. Large differences in the production potential of grass were observed across the 30 soil types (511 - 3288 kg grass DM ha^{-1} and 11.8 - 131.1 kg N ha^{-1}). When soil ISNT (N_o) was combined with soil mineral N (accounting for residual levels of N) and C/N ratio (regulating N_o) grass DM yield and N uptake could be predicted (model of R^2=0.58 & 0.78, p<0.0001, respectively).

3. The Mod-D soil had higher N_o throughout the growing season (mean: 393 mg N kg^{-1}) compared to the Well-D soil (mean: 378 mg N kg^{-1}). Both soils received similar total cumulative rainfall over the season, however, high rainfall between June and July 2012 (Figure 2) caused soil saturation and high N losses through denitrification on the Mod-D soil. This is reflected in the lower N_fUE levels achieved (N_fUE 65%) on this soil type compared to the Well-D soil (N_fUE 124%) for the 300kg N ha^{-1} yr^{-1} treatment.

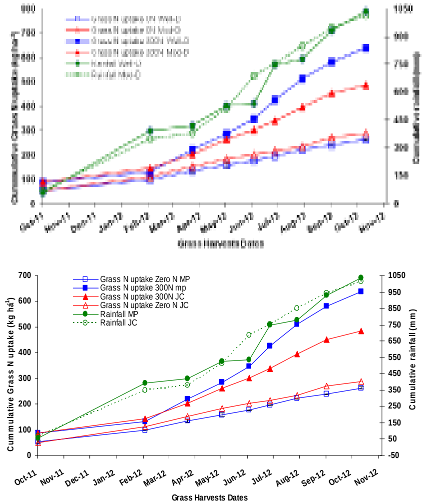


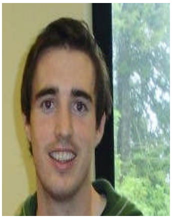
Figure 2. Cumulative grass N uptake and rainfall for the well drained and moderately drained soils over a growing season

Conclusions

This study emphasises the need to account for soil N supply when making N fertilizer advice in order to increase N_fUE on farms. Variability in soil N supply and grass N recovery exists between different grassland soils. Weather conditions may have a large influence on soil N supply and needs to be considered when quantifying net N supply for grass uptake. The ISNT was the most suitable rapid test to predict N_o in grassland soils, and shows potential to aid farmers when making N fertilizer application decisions.

Acknowledgements

Funding provided by the Department of Agriculture Food and the Marine through the ACP.



The importance of plant-soil interactions for N mineralisation in different soil types

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Introduction

An increase in global food demand coupled with the need for sustainable farming has increased the need to understand the mechanisms and drivers involved in soil organic matter (SOM) turnover and N mineralisation. Priming effects (PE) can be defined as the increase/decrease in SOM turnover due to substrate addition. PE couple the growth of plants with SOM and nutrient dynamics via the microbial biomass.

The mechanisms, that control how the PE affect N availability and gross N mineralisation is not well understood. The aim of this project is to build new knowledge on the impact of root exudates on turnover of C and N in soil, as mediated by the microbial community.

Project Objectives

To assess if the addition of labile C to soil increases SOM turnover and gross N mineralisation – (PE).

To investigate if plant growth stimulates N mineralisation and if this plant mediated priming is soil-specific.

To determine if N availability affects SOM mineralisation and if the presence of available N reduces plant uptake of SOM derived N.

To investigate if these effects are soil specific, independent of N-availability.

Experimental Methods

Experiment 1

Soils of different N mineralization capacity were investigated using incubated soil microcosms.

Labelled ^{13}C (glucose) and ammonium-nitrate tracer ($^{15}NH_4$ $^{14}N0_3$) were added to the microcosms.

Soil CO_2 efflux was measured and ^{13}C isotope partitioning was applied to quantify the added C and SOM-derived components (Fig 1).

Gross N mineralization from soil organic matter (SOM) was quantified by ^{15}N isotopic analysis of the 14-d incubation period.

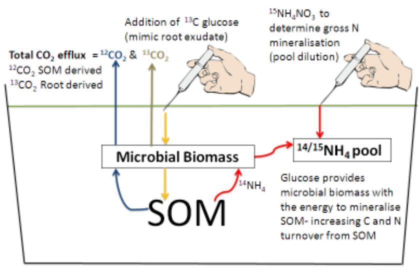

Figure 1. Representation of the C and N fluxes investigated in experiment 1.

Experiment 2:

These soils were further incubated in microcosms over a 10 week period. Perennial ryegrass was planted in half of the microcosms and N fertilizer was added to half of the planted and half of the unplanted.

Following an initial 2 week incubation period the N fertilizer was added twice a week and CO_2 measurements were taken once a week thereafter.

Total N in plant biomass was separated into SOM derived and fertilizer derived N.

Root and SOM derived C was determined as per Expt. 1.

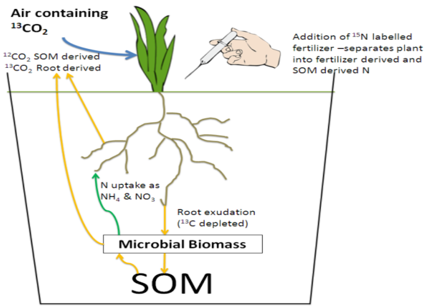

Figure 2. Representation of the C and N fluxes investigated in experiment 2.

Experiment 1 Results

- Addition of labile C increases the turnover of SOM (positive PE).
- The high-nutrient soil (HNS) mineralised more N than the low nutrient soil (LNS). Gross N mineralisation for glucose amended soils was higher in the HNS compared to the N tracer treatment; this was not observed in the LNS (Fig. 3)

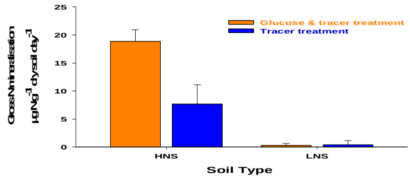

Figure 3. Gross N mineralization for the glucose + N tracer and N tracer treatments for the high and low nutrient soil types.

- The microbial biomass also increases.

Experiment 2 Results

- Plant growth decreased SOM turnover
- The LNS supported lower SOM turnover and N uptake relative to HNS.
- Addition of N fertilizer decreased SOM turnover.

Beneficial Outcomes

- The addition of C (representing root exudates) increased SOM turnover and gross N mineralisation in the HNS. The labile C provides energy to microorganisms to mineralise SOM. In the LNS, N is limiting gross N mineralisation.
- Plant growth stimulates N-mineralisation; and the degree of plant-mediated priming is soil-specific. Addition of N fertilizer results in negative priming of SOM but overall, the plant takes up more organic-N.
- This work will increase our knowledge of N dynamics in the rhizosphere and how to manage N fertiliser and C inputs for increased N use efficiency.

Acknowledgements

Funding provided for this project from Teagasc Walsh Fellowship Scheme.

Fate and transport of fertilizer nitrogen under spring barley cultivation on contrasting soils

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Introduction

Spring barley is the most extensively grown arable crop in Ireland, accounting for approximately 50% of the arable area. The marketability of barley grain for malting purposes depends on its quality; grain protein concentration being one of the main criteria. Since 2007 grain protein levels have fluctuated widely in Ireland and concern has grown amongst farmers and the malting industry as to the best methods to produce consistently high barley yields with optimal protein concentrations. Nitrogen fertilization is one of the main factors affecting grain protein levels. However, the management of N fertilizer inputs for spring barley crops must balance the varying crop N needs over the growing season with the potential for N loss to the air and water over the year. Maximum fertilizer N inputs to spring barley in Ireland are set out in the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2009. If changes to the quantities of N fertilizer required for spring barley are identified then we must ensure that the changes are economically and environmentally sustainable.

Project Objectives

The objectives of this research are:

- Improve our understanding of nitrogen dynamics in spring barley systems.
- Quantify nitrate leaching and nitrous oxide emissions from varying rates of fertilizer N.
- To increase N use efficiency of spring barley production systems and support the development of new N fertilizer recommendations.
- Investigate options for mitigating nitrogen loss to the environment in spring tillage systems i.e. using N inhibitor technologies.

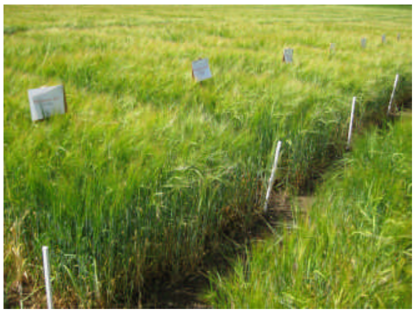

Figure 1. Spring barley trials

Experimental Methods

Two experimental field sites, with contrasting soil types and drainage characteristics, are being used to conduct N fertilizer rate response experiments on spring barley (Figure 1). These sites are located at Johnstown Castle (poorly-drained clay loam), and Castledockerell (free-draining loam) in Co. Wexford.

The experiments are being conducted over three field seasons to capture a range in climatic variability. The N response studies are laid out in a randomized complete block design, with various replicated N fertilizer treatments encompassing multiple combinations of N fertilizer formulations at different rates. The N fertilizer treatments are designed investigate the potential of nitrification inhibitor technology dicyandiamide (DCD) and the urease inhibitor technology nBTPT to reduce N losses.

Agronomic measurements are collected at harvest each year and crop N fertilizer use efficiency and grain protein levels being determined. Nitrogen emissions from each of the experimental treatments are also being measured. Static chambers are deployed to measure N_2O emissions (Figure 3) and continuous flow chambers are being used to measure NH_3 emissions from the different N fertilizer formulations. Nitrogen leaching (mainly as NO_3) from the root zone (0-90cm) is being monitored using passive capillary fluxmeters which were installed at both sites (Figure 2).

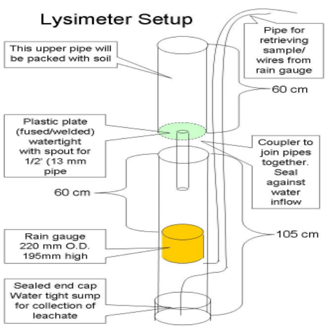

Figure 2. Fluxmeter setup for measuring nitrate leaching

Figure 3. Static chamber used to measure nitrous oxide emissions

Beneficial Outcomes

Scientific impact:

- New understanding of soil N transformations and dynamics for spring tillage systems.
- New nitrate leaching and nitrous oxide emission data that can be used for future scenario analysis and will contribute to future GHG inventory calculations.

Impact on industry:

- New N advice will help farmers to produce target spring barley grain yields and grain quality.
- We anticipate that "fine-tuning" the current recommended N rates used by farmers will result in increased N fertilizer use efficiency and savings on farms.

Impact on environment:

- New N fertilizer application strategies to mitigate against N loss processes/pathways that prevail in different fields/soils.
- Reduced risks of N loss to water (NO_3) and air (N_2O and NH_3).

Acknowledgements

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

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. The project will deliver a

Acknowledgements

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Mitigation of N losses with nitrification inhibitor DCD: limitations and alternative method

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Introduction

Reactive nitrogen (N) losses and greenhouse gas emissions from agricultural soils are a source of concern for animal/human health and the environment. To mitigate agriculture's environmental footprint, a commercially available nitrification inhibitor dicyandiamide (DCD) has been used with some success to slow down NO_3^- production and reduce N_2O emissions. However, inhibitors have a limited life-span in soils and repeated applications are required to maintain efficiency. The objective of this research was i) to estimate the impact of DCD degradation on nitrification inhibition across soils with contrasting physical and chemical characteristics, and ii) to test the potential of an alternative application method whereby inhibitor DCD is encapsulated in a protective slow-release matrix of biodegradable polymeric hydrogel.

Materials and Methods

The impact of DCD degradation was studied on twenty-one soil types (Ireland and UK) that received two treatments: 20 kg/ha NH4-N ± DCD (15 kg/ha DCD). Soil units arranged in a randomised block design were incubated in triplicate at 15°C for 6 times (between 2 days and 64 days). Samples were then extracted with 2M KCl and analysed for DCD (HPLC analysis) and NO_3-N content (colorimetry). Based on these measurements, two response variables were calculated: DCD degradation constant (from an exponential decay model) and % nitrification inhibition. Regression analysis was carried out for each incubation time.

Chitosan hydrogel beads (Figure 1) were formed by precipitation of a chitosan gelling solution and covalent crosslinking with glyoxal (O'Carroll et al., 2010). Beads also underwent a washing step aimed to minimize the formation of polyglyoxal inside chitosan. Slow-release of DCD was tested with twenty beads dropped on compacted soil (equivalent to 15 kg DCD/ha). Experimental units (soil + beads) incubated in triplicate at 5°C for 3 times (between 1 and 7 days) were subject to 2 treatments (simulated rainfall, soil moisture) and 3 rates (low, medium, high). In the rainfall treatment, water was added from above after beads addition. In the soil moisture treatment (expressed as % of soil water holding capacity (WHC)), water was added to the soil before the beads were dropped. ANOVA analyses were carried out to estimate the effects of treatment, rate and time.

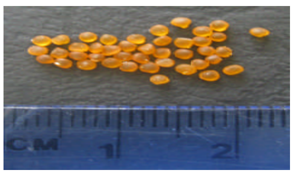

Figure 1. Chitosan beads loaded with DCD

Results and Discussion

Soils used in the first part of the experiment (DCD degradation) contained between 0.89 and 9.4 % organic C. % sand, silt and clay ranged between 21 and 68, 20 and 51, 11 and 30, respectively. Soil pH varied between 4.6 and 7.6. DCD degradation was equally variable. A 24 % DCD loss was observed after 64 days from the soil with the lowest constant k (1.8), whereas a 93 % DCD loss was observed from the soil with the highest k (18.8). For most soils, % nitrification inhibition increased sharply until incubation day 8 or 16 and stabilised or slightly decreased thereafter. There was a significant ($p < 0.05$, day 64 not significant) negative correlation between DCD degradation constant k and % nitrification inhibition (Figure 2). In other words, the higher the degradation rate of DCD, the lower the % nitrification inhibition. These results suggest that soils with faster DCD degradation will require more frequent/higher rates of application. This could be dealt with more conveniently (and possibly more efficiently) if small amounts of DCD were consistently delivered over long periods of time.

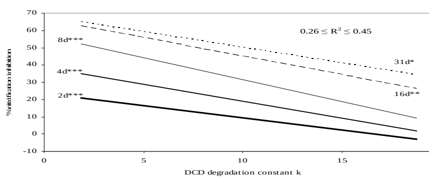

Figure.2. Linear regression lines between DCD degradation constant and % nitrification inhibition after 2, 4, 8, 16 and 31 day-incubations (2d, 4d, 8d, 16d and 31d respectively) (* $p \leq 0.001$, ** $p \leq 0.005$, * $p \leq 0.05$; day 64 not sig.)**

In the second part of the study, the incubation of beads in soil resulted in a delayed release of DCD (Figure 3). DCD soil release significantly increased with time ($p \leq 0.0001$). Treatment also had a significant effect ($p \leq 0.0001$): rainfall caused more DCD release than soil moisture (WHC). This probably reflected the fact that beads were wet more quickly and thoroughly when water was applied from the top (rain) than when moisture had to diffuse up in the hydrogel. Finally, higher rates of rainfall or WHC significantly ($p \leq 0.0001$) increased DCD bead release. After seven days, incubation caused the release of 74 to 98% of the total DCD bead content. Some of the DCD remaining in the beads has been shown to be more durably trapped inside the beads.

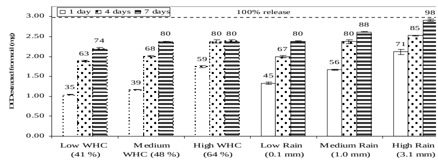

Figure 3. Amount of DCD (in mg ±SE) extracted from soil after incubation with 20 chitosan beads at 5 °C for up to 7 days under varying rates of rainfall or % of water holding capacity (WHC) (figures over bars represent the percentages of total DCD bead content released)

Conclusions

Soil type had a significant effect on the efficacy of DCD for inhibiting nitrification through effects on DCD degradation. For DCD to efficiently mitigate N losses to the environment, soil type specific application timings and rates need to be established. Alternatively, the use of a chitosan hydrogel has shown some potential to slowly release DCD in soil under moderate moisture conditions, but more research is needed to improve this new technology.

Acknowledgements

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Gaseous Emissions

AGRI-I: The Agricultural Greenhouse Gas Research Initiative for Ireland

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Introduction

The Agricultural Greenhouse Gas Research Initiative for Ireland (AGGRI-I) is an organizational and collaborative framework designed to a) build a critical mass of scientific expertise in GHG research and b) co-ordinate uniform measurement protocols.

Aims

The specific aims of the Initiative are as follows:

- Develop Tier 2 nitrous oxide emission factors
- Quantify C sequestration potential of managed grasslands across a range of soil types.
- Develop biogeochemical models that will allow for a move to Tier 3 emission factors.
- Further develop mitigation strategeis for enteric methane emissions from livestock.

In order to achieve these aims, the Initative workplan consists of four core projects.

Developing Disaggregated Nitrous Oxide Emission Factors.

This project is developing Tier 2 nitrous oxide emission factors. Specifically, emission factors are being disaggregated between N source (CAN, urea, urine, dung), soil type and temporally for different times of the year. This will allow for the inclusion of mitigation strategies in the inventories such as switching from CAN, altered fertiliser timing and low N dietary strategies. In addition, the effect of N inhibitors will be quantified for inventory inclusion. In addition, the effect of nitrification and urease inhibitors are also being measured in order to generate seperate emission facotrs for these chemicals, allowing their inclusion in inventory calculations.

Quantification of grassland C sequestration

This project is developing land-use factors (the C sequestration potential) associated with grassland and cropland systems across a range of soil types. This is the first step to pasture management inclusion in inventories and also quantifies gross sequestration for managed pasture for use in Life Cycle Analysis.

The project is also quantifying the effect of pasture management on C sequestration. The management options being explored include the effects of stocking rate, drainage, biochar application and organic manure application.

Biogeochemical Modelling of GHG emissions.

This project is developing process models to simulate GHG emissions at both the site and regional scale. Detailed models aid in the interpretation of experimental results and identify the consequences of the experimental set-up chosen and the key factors underlying the observations. Also these models aid in pinpointing the difficulties and uncertainties with inventories of greenhouse gas emissions on a regional or even higher scale) These models being useed include RothC/ Ecosse (Smith et al. 2007) as well as more complex models such as DNDC (LI et al. 2001) and DailyDAYCENT. These models allow for country-specific climateic conditions to be accounted for, as well as site/region-specific management and can be used as a tool for scenario-testing and policy development and is also developing the data archive for the Initaitive.

Understanding the development and control of stability in the rumen microbiome

This project addresses effects of management history on the interaction between the host and its microbiome and on methane production. This project will investigate the use of natural additives and alteration of colostrum/milk feeding and weaning strategies. The primary hypothesis is that the initial microbial implantation in the rumen influences the microbial ecosystem later in life. One aspect of this is transfer of the maternal microbiome to offspring. This may contribute to stability of the rumen microbiome in later life (e.g. reversion to the original community after rumen swapping). The project will extend the work on stability of the rumen microbiome to important diet transitions in growing/adult animals, such as the change from grazing to finishing diets. Work with twins will allow us to make comparisons against a common genetic background. This proejcy is an international collaborative project also being funded by the Joint Programming Initiative (JPI).

Acknowledgements

This initiative has been co-financed by COFORD and the Research Stimulus Fund.

Agricultural
Greenhouse Gas Research
Initiative - Ireland

Assessing Ammonia Volatilization as Influenced by Fertiliser Nitrogen Source, Urease and Nitrification Inhibitors

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Introduction

Calcium ammonium nitrate (CAN) is the most widely used straight nitrogen (N) source in Ireland. However, nitrate (NO_3-N) is vulnerable to leaching and de-nitrification loss pathways under the cool humid conditions of Ireland.

An alternative N source is urea-N which is less expensive per unit N compared with CAN. Currently Urea-N use is concentrated in the early spring with relatively little utilized later in the growing season.

A potential challenge with greater adoption of Urea-N potentially increased ammonia-N (NH_3-N) loss via volatilization. Such loss is problematic for several reasons: i) it represents an economic loss of N, ii) it contributes to eutrophication in aquatic and low-N input ecosystems through atmospheric transport and deposition, and iii) Ireland has committed to reduce emissions of gases including ammonia under the Gothenburg Protocol and the National Emissions Ceiling Directive (NECD) (2001/81/EC).

Some risk factors for increased volatilization loss include: i) increasing temperatures, ii) increasing wind speeds, iii) increasing solar radiation and iv) soil characteristics such as pH, moisture and residue or vegetation cover. Generally greater evaporation results in greater loss and 10 mm precipitation or more will slow NH_3-N loss (Meisinger and Jokela, 2000).

Precipitation is relatively dependable in the Irish climate. However, precipitation may not occur for several days following fertilizer Urea-N application, the period of greatest loss potential. Hydrolysis of Urea-N can be delayed using urease inhibitors such as N-(n-butyl) thiophosphoric triamide (NBPT) increasing the likelihood of a precipitation event to wash urea-N into the soil matrix before loss can occur.

This study will evaluate how NH_3-N loss potential is impacted by fertilizer N source, N source blending, and the use of N inhibitors.

Materials and Methods

This research is being conducted at three grassland sites, a loam soil at Johnstown Castle, Co. Wexford; a sandy loam soil at Moorepark, Co. Cork; and a clay loam at Hillsborough in Northern Ireland.

The experimental design is a randomised block, with three replicates. The fertiliser N sources being evaluated are CAN-N, Urea-N, and a CAN-N + Urea-N blend. The N inhibitor treatments being investigated are NBPT, DCD, and NBPT + DCD in combination with Urea-N.

Figure 1. Ammonia plot layout.

The total annual rates being examined are 0, 200, and 400, kg N ha $^{-1}$ applied in five equal splits following five grass harvests in a simulated grazing rotation. Ammonia emissions will be measured using a dynamic chamber technique for a period of 4 weeks following fertiliser N application.

Figure 2. Dynamic chamber.

Expected Results

Utilization of N source and N inhibitor combinations are expected to mitigate NH_3-N loss potential associated with Urea-N use in Irish agriculture. This work aims to assess N loss potential and mitigation for greater use of Urea-N which is less expensive than CAN per kg N and which as more concentrated N source provides a transport saving.

Acknowledgements

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

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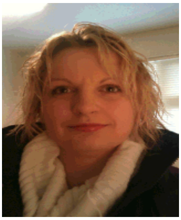

Greenhouse Gas and Ammonia Emissions from Manure Management

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Introduction

Animal production systems are the largest contributors to greenhouse gas (GHG) and ammonia (NH_3) emissions. In Ireland, the contribution to GHG emissions from agriculture are 70% as methane (CH_4), 28.5% as nitrous oxide (N_2O) and 1.5% as carbon dioxide (CO_2). Manure management represents 20% of methane emissions. The emissions from manure management are approximately 12.5% of Ireland's total agricultural GHG emissions.

Approximately 98% of Ireland's NH_3 emissions come from agriculture with 82% coming from cattle systems. Ammonia is released from many different farm activities: landspreading (39%), manure storage (4%), animal housing (40%) with the remaining 17% coming from grazing animals. Nitrous oxide emissions are lower from liquid manure storage systems than from solid manure stores (FYM).

In theory, gaseous emissions from manure storage are governed by the storage temperature, the length of the storage period, and the slurry characterisitics and composition.

The objective of this study was to assess the impact of manure storage temperature, animal type, diet and duration of storage on the emissions of NH_3, CH_4 and N_2O from a range of cattle slurries.

Materials and Methods

Two incubation experiments were conducted to assess the effect of temperature, diet and retention time on a range of different slurries during storage.

Slurry collection

Slurry was collected from four different animal types, each fed three different diets. The animals were two dry dairy cows, two dry suckler cows, two 13 month old steers and two eight month old heifers. The diets were i) 100% grass silage, ii) 50% grass silage and 50% concentrates and iii) ad lib concentrates and straw. The diets were fed for 10 days prior to collection. Collection period was for seven days or until 200 litres were collected from each animal-diet pairing.

Experiment 1 - *14 day storage period*

The experiment was conducted in four controlled environment rooms, with slurries incubated in a randomised block design with four replications for a two week incubation period. Each room was randomly assigned temperatures of 5°, 10°, 15° and 20°C, with a relative humidity of 80%. The manure was defrosted, then mixed and 4 kg of homogenised slurry was placed into 5 kg open chambers, labelled and placed into each room. Each animal - diet pairing was duplicated. Gas samples were taken on days 0, 5, 9, 14 with slurry samples taken on days 0 and 14.

Experiment 2 - *16 week storage*

The manures used in this experiment were subsampled from the manures collected during the initial collection period. The manures were incubated in 5 litre open cylinders at a temperature of 10° C and at 80% relative humidity. Each animal - diet pairing were stored in triplicate within the environmental room. Gas samples were taken on days 0, 5, 9, 14 and then once a week until day 112, with slurry samples taken on days 0, 14 and day 112.

Results and Discussion

Temperature had a significant effect on log-transformed CH_4 emissions at temperatures greater than 10°C. It was found that increasing TAN and DM content within manure increased NH_3 emissions but reduced CH_4 emissions. Methane increased over the first nine days of storage, NH_3 decreased over the same period, with no effect of storage time on N_2O emissions.

Diet three appears to have lower emissions associated with it. The younger animals had higher average CH_4 emissions across diet one and two but were lower on diet three. However, the older animals had higher average NH_3 emissions on all three diets when compared to the younger animals. Diet had varying effects on N_2O emissions. Agitation of the manures on day 112 caused a spike effect on CH_4 emissions and increased NH_3 emissions slightly, but had little effect on N_2O emissions.

Figure 1. Experimental set-up in the environment room

Conclusions

It was found that temperature had a significant effect on CH_4 emissions, with emissions also decreasing with increasing DM content. Temperature did not effect NH_3 or N_2O emissions. Ammonia emissions were significantly affected by TAN and DM content and N_2O emissions were unaffected by slurry characteristic, temperature or retention time.

Acknowledgements

This work has been co-financed by BATFARM Interreg-Atlantic Area Project (2009-1/071) with support from the European Union ERDF – Atlantic Area Programme and the Teagasc Walsh Fellowship Scheme.

Assessing the potential for carbon sequestration in grazed Irish grasslands

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Introduction

Climate change policy demands that environmental sustainability underpins future growth in the agricultural sector. Concerns about the impact of global climate change have led to the adoption of demanding emission reduction targets at an EU level, which include curbing greenhouse gas (GHG) emissions in the agricultural sector by 20%. The future expansion and intensification of the beef and dairy sectors envisaged in the Food Harvest 2020 Report (DAFF, 2010) must therefore be accompanied by a reduction in the GHG intensity of Ireland's agricultural activities and an enhancement of natural carbon storage. Grassland ecosystems in temperate climates are generally net carbon sinks, however grazing management, fertiliser input and climatic variability can have a significant impact on ecosystem carbon dynamics (Soussana et al., 2004). The aim of this research was to investigate the potential for carbon sequestration in grazed grasslands and to gain an understanding of the main drivers of carbon cycling in these ecosystems.

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 CO2, water and energy fluxes over an area of one to several paddocks (depending on atmospheric turbulence) (Figure 1).

Figure 1. 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 totals for net ecosystem exchange (NEE) of carbon at the 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.

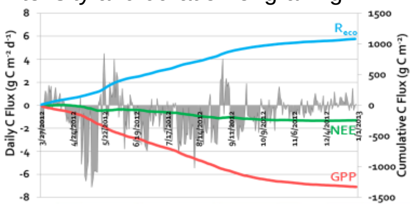

Figure 2. Daily totals of net ecosystem exchange (NEE) (grey trace) and cumulative sums of gross primary productivity (GPP), total ecosystem respiration (Reco) and NEE for the Solohead site.

C uptake also outweighed C release in the Johnstown Castle grassland, resulting in a net C sink over the 5-month period from August to December of -93 g C m-2. Comparison of cumulative ecosystem fluxes in both sites for the same time period showed very similar patterns, with the Solohead site providing a comparable net C uptake of -107 g C m-2.

Figure 3 shows daily Reco and GPP values averaged for each month of the measurement campaigns at Solohead and Johnstown Castle. C assimilation by the ecosystem through photosynthesis outbalanced respiratory release for all months up until December.

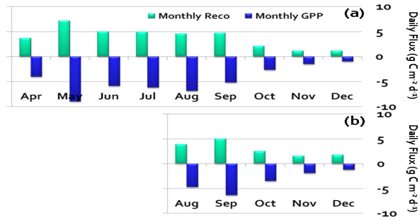

Figure 3. Monthly-averaged daily fluxes of R_{eco} and GPP at (a) Solohead and (b) Johnstown Castle.

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 had an influence on 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).

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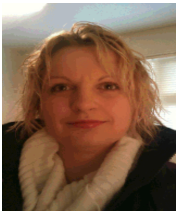

Greenhouse Gas and Ammonia Emissions from Animal Housing

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Introduction

In Ireland, methane emissions account for 70% of our National greenhouse gas (GHG) emissions, with 80% of CH_4 coming from enteric fermentation. Approximately 98% of Ireland's ammonia (NH_3) emissions come from agriculture with 82% coming from cattle, 40% of which come from animal housing. There are currently few empirical gaseous emissions studies on housing and storage systems in Ireland, and emissions inventories are currently generated using Tier 1 methodologies.

The objective of this experiment was to evaluate two beef farms (BFa, b) and two dairy farms (DFa, b) in Ireland with differing manure management systems and report on the CH_4 and NH_3 emissions associated with housing and storage from each management system.

Materials and Methods

Ammonia and CH_4 emissions were measured on four farms in Ireland. These comprised two beef farms and three dairy farms with varying diets, slurry management systems and animal types. One beef farm (BFa) had three under-floor slatted slurry tanks in naturally ventilated sheds. Emissions on the second beef farm (BFb) were measured from two separate tanks within the same naturally ventilated slatted shed, with each tank having the same animal type and diet, but differing in slatted surface, with one tank having concrete slats, and the other having curved slat mats fitted with valves designed to restrict air passage from the under-slat to the above-slat air space.

Housing on the first dairy farm (DFa) consisted of a naturally-ventilated shed with four separate tanks that were aerated four times daily. The second farm (DFb) had cubicle housing with slurry being removed by regular scraping into an outdoor open tank adjacent to the shed.

Figure 1. Diet and manure management system having an effect on ammonia emissions.

Results and Discussion

Ammonia emissions were observed to be highly variable across all farms, with daily mean fluxes ranging between 4.5 g NH_3-N 500 kg LW^{-1} d^{-1} and 33.1 g NH_3-N 500 kg LW^{-1} d^{-1}. The mean ammonia emission across all farms was 16.6 ± 8.4 g NH_3-N 500 kg LW^{-1} d^{-1}. The lowest emissions were associated with beef cattle housing that had employed slat mats with valves, where ammonia emissions were 60% lower than from the adjacent tank with no mats and valves. However, there were no differences in emissions associated with either grooved or curved mats on farm BFa. Emissions from the outdoor lagoon on dairy farm DFb were 70% lower than the mean NH_3 emission rate at the other dairy farm and this may be related to lower air temperatures associated with outdoor storage. In contrast, some of the highest ammonia emissions were associated with housing that had employed automatic aeration systems to agitate the slurry (DFa) as aeration promoted volatilisation.

The mean methane emission rate across all farms and cattle type was 112 ± 93 g CH_4-C 500 kg LW^{-1} d^{-1} with mean daily fluxes ranging from 44 g CH_4-C 500 kg LW^{-1} d^{-1} for steers and heifers on BFa to 300 g CH_4-C 500 kg LW^{-1} d^{-1} for steers on BFb. The highest emissions on farm BFb may be due to the fact that the measurement period encompassed several agitation events resulting in ebullition of methane from the slurry tank. Despite these high levels, slat mats and valves were ssociated with reductions in methane emissions of 35%. Methane emissions from dairy cows fed a predominantly maize diet were 41% lower compared to cows on a grass silage-based diet on Farm DFa. Emissions associated with a predominantly maize silage diet are likely to have resulted in reduced emissions due to changes in slurry C:N ratio. Comparably low methane values (45 - 47 g CH_4-C 500 kg LW^{-1} d^{-1}) were recorded on beef farm BFa and these emissions were independent of animal type. The effect of aeration on methane emissions was inconclusive.

Conclusions

Emissions were highly variable across all farms, with animal typre, diet and manure management system having an effect on emissions.

Acknowledgements

This work has been co-financed by BATFARM Interreg-Atlantic Area Project (2009-1/071) with support from the European Union ERDF – Atlantic Area Programme and the Teagasc Walsh Fellowship Scheme.

Reducing nitrous oxide emissions from grazed grasslands using animal intake of DCD

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Introduction

Nitrogen (N) losses from grazed pasture systems can be relatively large and in Ireland this is an important contributor to agricultural impacts on water quality and on greenhouse gas emissions. The main source of the N loss, via nitrate leaching and nitrous oxide (N_2O) emissions, is urine excreted by grazing animals in small localised patches at very high N rates. One of the few mitigation options available to farmers to decrease these N_2O emissions is use of the nitrification inhibitor dicyandiamide (DCD). Previous research in Johnstown castle has shown that DCD can significantly reduce N_2O emissions by up to 70%. However, the current expensive recommended practice is to broadcast DCD over grazed fields within 7 days of grazing. Potentially this can be greatly simplified and the costs reduced markedly by providing the DCD (which is non-toxic) directly to animals which is excreted in urine in an unaltered form. The proof-of-concept for this potential technology has been carried out and studies have shown that over 90% of the DCD ingested is excreted in urine and effectively inhibits nitrification of urine-N in soil.

Project objectives

The overall aim of the project is to investigate the efficacy of including DCD in cattle feed on DCD excretion in urine and the impact on reducing N_2O emissions. The project is comprised of 3 tasks:

1. Quantify the field deposition of DCD in urine from cows treated with DCD-amended feed. This will also include determination of the variability in rate of DCD deposited in urine patches in the field. The frequency distribution of the range of DCD rates in urine patches will be use in determining the optimum rate of administration to animals for subsequent studies
2. Quantify the efficacy of DCD excreted in urine on N_2O emissions across a range of conditions. This data will be included in modelling the implications for grazed systems in Ireland, New Zealand and Australia.
3. Modelling of data arising from the experiments using a range of national models from Ireland, New Zealand and Australia.

Methodology

DCD will be mixed with different animal feedstuffs and fed to dry cows. Approximately 50 urine patches will be identified in the field and sampled over a one-day period. The soil samples will be extracted and analysed for DCD concentration by HPLC. These data will be used to calculate the rate of DCD in the individual urine patches and develop a frequency distribution to determine the variability. Daily urine patch sampling and analysis will be repeated on several occasions so temporal variability can be examined. Average data for the DCD rate in urine, in conjunction with data on patch size and number of urinations, will be used to obtain an estimate of the proportion of the DCD provided in feed that is excreted in urine.

Figure 1 Efficacy of DCD fed to cows will be quantified using urine DCD application rates and emissions of nitrous oxide.

The potential of residual DCD contamination of the animals will be investigated through analysis of tissue, blood and milk will be conducted.

Urine will be collected from cows fed DCD and control cows with no DCD feeding. The urine will be applied to grassland plots and N_2O emissions will be quantified using the static chamber method (Fig. 2). Headspace samples will be analysed for N_2O using standard methods by gas chromatography.

Modelling will be used to examine a range of scenarios related to different rates and timing of DCD use in feed to grazing animals to develop optimum strategies for reducing N_2O emissions. Similar modelling of beef cattle systems will also be carried out. The existing Moorepark dairy model and Grange beef model will be used.

Figure 2 Field measurement of N_2O using static chambers.

Expected results

This project will investigate the potential use of DCD in animal feed as a cost effective mitigation method for reducing greenhouse gas emissions. The project will identify if there are any potential negative effects of DCD feeding on food quality.

Acknowledgments

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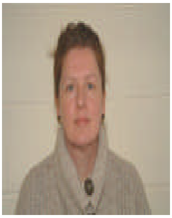

Fertilizer formulation and N2O emissions

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Introduction

Fertiliser use is the largest variable cost on Irish farms, currently accounting for over €400m annually. Nitrogen fertiliser is an important source of national greenhouse gas emissions, currently accounting for 2.9% of total annual emissions. Increasing nitrogen efficiency is also an important target for achieving the Food Harvest 2020 targets to ensure sustainability both in financial and environmental terms. The use of nitrate based fertilisers, under wet temperate conditions in Ireland, can result in fertiliser nitrous oxide (N_2O) emission factors of >10% compared to the default value of 1% (Watson *et al*. 2009). Switching from nitrate to ammonium based fertilisers has the potential to decrease direct N_2O emissions by up to 60%, improve nitrogen efficiency and reduce direct fertiliser costs. Whilst increased use of ammonium-based fertilisers could increase our national ammonia (NH_3) emissions, the use of urease inhibitors can decrease NH_3 emissions by up to 70%. Reducing national CAN use by 36%, by substitution with urea and inhibitors, could ultimately save Irish farmers €9.5m annually, representing a win-win solution for Irish farmers in reducing both costs and greenhouse gas emissions. The objective of this project is to evaluate the effect of switching from CAN to urea and urea with a urease inhibitor on nitrogen use efficiency, reducing fertiliser costs and nitrous oxide emissions. The project will also provide emission factors for different fertiliser types and application timings.

Materials and Methods

This experiment is taking place on permanent pasture at 2 sites: Johnstown Castle, Co. Wexford and Moorepark, Co. Cork. The experimental design at each site is a randomised block, with each block replicated five times. Fertiliser formulation treatments investigated include: 5 rates each of (a) CAN, (b) Urea and (c) Urea + Agrotain, at 100, 200, 300, 400 and 500 kg N Ha -1, one rate each of (d) Urea + DCD and (e) Urea + Agrotain + DCD at 200 kg N Ha -1 and (f) a control with no fertilizer applied. There are eighteen plots per block, each corresponding to one treatment.

Both the N2O production and the Agronomic yields for each fertiliser formulation are measured. N2O is measured using the static chamber method (Figure 1).

N2O will be measured for each treatment over a 12 month period in compliance with IPCC guidelines. Ammonia emissions also will be quantified using a dynamic chamber approach (see Figure 2).

Figure 1. Static Chambers

Agronomic measurements of dry matter (DM) yield and N uptake will be measured and used to quantify the nitrogen use efficiency of the different fertiliser treatments. The N2O emissions data will also be used to calculate the N2O emission factor for each fertiliser treatment.

Expected Results

Considering the opportunity to expand agricultural production, as forecast in Food Harvest 2020, and the requirement to meet future GHG and air quality targets, there is an urgent need to quantify strategies that will reduce reactive N emissions. In addition, strategies that optimise the use of N fertilisers will improve farm profitability whilst reducing the carbon footprint of agricultural produce. Although the addition of an inhibitor in the formulation of urea fertilisers would increase the unit cost of N, the current price differential between straight urea and CAN fertilisers would allow potential for an urea+inhibitor formulation to offer costs saving compared with CAN.

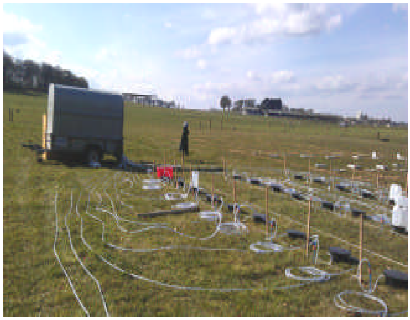

Figure 2. Dynamic Chambers

Examples of these products are becoming commercially available in Ireland. Information on relative value of these products based on N efficiency will be required by farmers and advisors. The data from this project will provide this information and advice.

Acknowledgements

This work is funded by the Walsh Fellowship Scheme and the Department of Agriculture, Food and the Marine Research Stimulus Fund.

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Nitrogen cycle processes and greenhouse gas balance in wetland in an urban landscape

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Introduction

Reactive nitrogen (N) emissions to air and waters greatly contribute to climate change and environmental pollution (Schepers and Raun, 2009). Researchers have measured surface emissions of N_2O, CO_2 and CH_4 in terrestrial ecosystems and have estimated watershed-scale greenhouse gas (GHG) emissions. However, they have not incorporated indirect emissions of dissolved N_2O, CO_2 and CH_4 in groundwater which adds significant uncertainty to their greenhouse gas assessments. Upon discharges to surface waters GHGs have significant effects on aquatic biogeochemistry and ocean acidification. The N cycle processes have been studied in agricultural and forest ecosystems but there remains a dearth of information on these processes in wetland in urban ecosystems (Figure 1).

Figure 1. A typical wetland (R. Harrington)

Moreover, wetland ecosystems services require better understanding of N cycle processes to estimate and mitigate reactive N deliveries to ground and surface waters. The research proposed here will measure N cycle processes and will estimate losses of C and N via groundwater along with surface and subsurface GHGs emissions. The data obtained will be used to estimate wetland C and N dynamics, refine Irish GHG inventories and C and N balances and suggest appropriate mitigation options for optimization of wetland ecosystem services.

Materials and Method

The experiment will be conducted in a wetland in urban landscape (Co. Waterford, Ireland). Rates of potential net N mineralization and nitrification, denitrification, and respiration will be measured in 10-day incubations of soils after treating with and without C sources. Soils will be placed in 946 mL "mason" jars with lids fitted with septa for gas sampling (Figure 2). After 10 days, the headspace of the jars will be sampled by syringe, and the gas samples will be analyzed for GHGs by gas chromatography with electron capture (N_2O) or thermal conductivity (CO_2) or flame ionization (CH_4) detection. Soil- atmosphere fluxes of GHGs will be measured using the in situ chamber method at a week intervals in two different seasons: winter and summer.

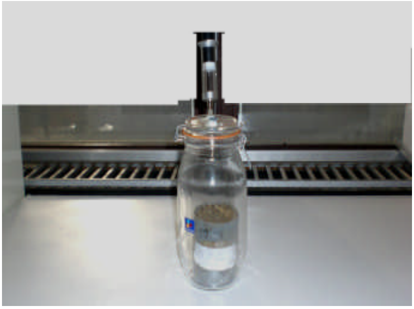

Figure 2. Gas sampling from an air tight jar with soil core inside

Gas samples will be transferred to evacuated glass vials, which will be stored at room temperature before analysis by gas chromatography. Leachate samples for DOC, HCO_3^-, dissolved CO_2, N_2O, and CH_4, NO_3^-, NH_4^+, DON, TN will be collected using zero tension lysimeters installed at 50 cm depth. Dissolved GHGs will be extracted using headspace extraction (Figure 3).

Figure 3. Extraction of dissolved gas

Denitrified N_2 in leachate will be analyzed using membrane inlet mass spectrometer (MIMS). Soil solution chemistry will be analyzed using standard methods and facilities available in Teagasc Environment Research Centre, Johnstown Castle, Ireland. Estimation of annual leaching losses will be calculated by using the volume of effective rainfall, estimated for the experimental site.

The wetland site under study has high ammonium conc. in groundwater (Table 1), indicating a potential threat to water quality. Study of C and N dynamics will elucidate the production processes and fate of ammonium and thus develop possible mitigation options of hazardous effects of the reactive N for an improved ecosystem services for wetland ecosystem.

Expected Results

Quantify the effect of using constructed wetlands for the treatment of contaminated water. Estimation of indirect N_2O, CO_2 and CH_4 emissions in wetland will reduce the uncertainty in regional and global GHG budgets. The work will also increase our basic science understanding of how greenhouse gas fluxes are linked to soil C and N cycle processes and of how the biogeochemical dynamics of reactive N (NH_4^+, NO_2^-, N_2O, denitrified N_2, NO_3^-) in soils/subsoils regulate delivery to surface waters.

Acknowledgements

This work is funded by the Irish Research Council and Teagasc through the Enterprise Partnership Postdoctoral Fellowship Scheme.

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Agricultural Ecology

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

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Introduction

The Aran Islands are an extremely important site for a number of priority terrestrial habitats under the Habitats Directive (Annex 1). Since the 1970s the Aran Islands have come under a succession of national and EU environmental designations, such that over 75% of the total land area of the Aran Islands is now designated as Natura 2000 sites.

However, changing agricultural practices threaten the conservation value of the islands' habitats. The area's farms have a highly fragmented and small structure. Herd size is low, with most herds numbering less than 10. Poor economic return from such small holdings is leading to a reduction of farming on the islands. The Dept of Agriculture estimates that the number of farms on the islands has decreased by more than 30% in the last 15 years. This is a result of abandonment and consolidation.

The main threats to the habitats on the islands are land abandonment, under-grazing, inappropriate management practices, loss of traditional farm knowledge and skills and lack of understanding and engagement among key stakeholders. Despite the wealth of information on the natural history of the islands there has been no targeted conservation effort in the project area.

This LIFE project represents the only large-scale, action-based nature conservation initiative ever to have been planned for the Aran Islands.

Objectives

1. Demonstrate best management techniques to both maintain, and bring sites to, favourable condition by addressing the threats of land abandonment, under-grazing, intensification, loss of traditional management systems and associated loss of knowledge.
2. Improve the conservation status of priority habitats on the islands e.g. Limestone pavement, Orchid-rich calcareous grasslands and Machair.
3. Enhance understanding, and appreciation of the key stakeholders with the conservation of priority habitats on the Aran Islands.
4. Recommend appropriate support mechanisms for farming on the Aran Islands that will address the issues that threaten the status of the priority habitats of the islands.

Figure 1. Orchid-rich calcareous grassland on Inis Oirr

Materials and Methods

A range of complementary actions will be required to meet these objectives, including:

- Demonstrating the best management techniques for the sustainable management of priority habitats, through the maintenance of optimal grazing on the grazed land of the Aran Islands.
- Reintroducing specific management systems that are integral for the sustainable management of the priority habitats, such as targeted optimal grazing and scrub and bracken control.
- Awareness-raising, education and outreach programmes.
- Submission of recommendations on optimal management practices for the target habitats to relevant Government Agencies and Departments, for their use in the formulation of all relevant national and local policies.

Expected benefits

- An improvement in the conservation status of priority habitats comprised of Limestone pavement, Orchid-rich calcareous grasslands and Machair.
- Tested and evaluated methodologies for the sustainable management and utilisation of priority terrestrial Habitats Directive Annex 1 habitats of the Aran Islands.
- The sustainable management of priority habitats on the Aran Islands, with the demonstration of the above techniques to up to 220 farmers on the Aran Islands.
- The distribution of best practice guides to encourage more effective ecologically sensitive management of priority habitats.
- A raised awareness and appreciation amongst the island community and other stakeholders of the conservation importance of the natural heritage on their farmland.
- Upskilling of up to 220 farmers on the conservation techniques required in order to maintain and further enhance condition of priority habitats within their farms.

Acknowledgements

This work is funded by EU LIFE+

Figure 2. Small fields on Aran Islands

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

Sward diversity benefits yield and weed suppression over 3 years

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Background

There is increased interest in the agronomic and environmental benefits of multi-species mixtures. We investigated a number of basic questions about the relationship between diversity and ecosystem functions in an agronomic model system. It was hypothesised that (a) multi-species mixtures can outperform monocultures both in terms of productivity and weed suppression, (b) the diversity benefits will be persistent through time, and (c) the diversity benefits will be consistent across a wide geographical scale.

Materials and Methods

A common experiment was established at 31 sites across Europe and Canada. At all sites, mixtures consisted of two legumes (L1 and L2) and two grasses (G1 and G2); with the species chosen for each location from one of four standard species-groups. Using a simplex design (Kirwan et al. 2007), 15 communities were sown with systematically varying proportions of two fixed levels of overall initial abundance (seed biomass) of the four species (Fig. 1).

Results

The yield of the sown species (excluding weeds) in mixtures typically exceeded the average yield of monocultures, and transgressive overyielding (better than best-performing monoculture) occurred at 70% of sites with a ratio of mixture to best-performing monoculture = 1.18 (Fig. 3).

Figure 1. Harvesting of plots.

Within each year, there was a highly significant relationship ($p<0.0001$) between sward evenness (quadratic relationship) and the diversity effect (excess of mixture performance over that predicted from the monoculture performances of component species) (Fig. 2). At lower evenness values, increases in community evenness resulted in an increased diversity effect, but the diversity effect was not significantly different from the maximum diversity effect across a wide range of higher evenness values.

In mixtures, median values indicate <4% of weed biomass in total yield (sown species + weeds), whereas the median percentage of weeds in monocultures increased from 15% in year 1 to 32% in year 3.

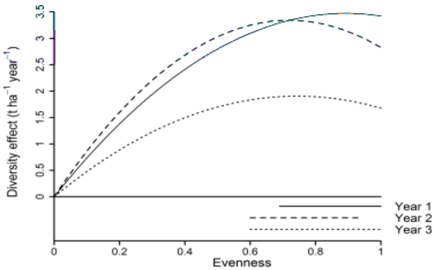

Figure 2. Predicted diversity effect (yield of sown species) from quadratic evenness model over three years and across all sites. Horizontal lines below the regression curves indicate the range of evenness over which the diversity effect was not significantly (p > 0.05) smaller than the maximum diversity effect.

Conclusions

Four-species mixtures generally yielded more than the best-performing monoculture at each site. Mixtures maintained a resistance to weed invasion over at least three years. The relationship between the diversity effect and sward evenness indicates the robustness of the diversity effect to changes in species' relative abundances.

Acknowledgements

Supported by the EU Commission through COST Action 852. L.K. supported by an award from Science Foundation Ireland (09/RFP/EOB2546).

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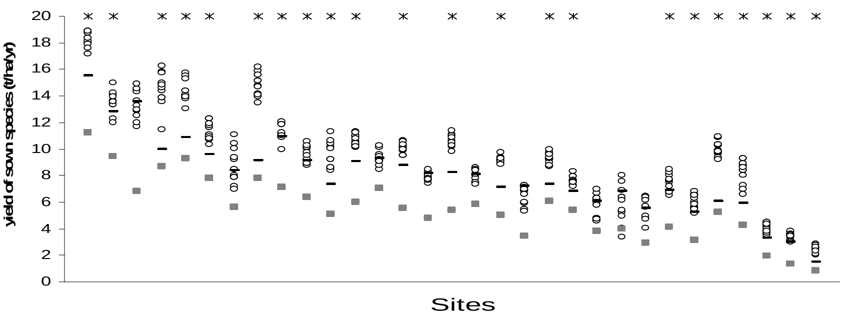
Figure 3. (Below) Average annual yield (dry matter) of sown agronomic species (excludes weeds) at each of 31 sites. Open circles represent the eleven mixture communities that differed in their relative abundance at sowing; horizontal bars represent the yield of the best-performing monoculture; boxes represent the mean monoculture performance. Significant transgressive overyielding indicated by the * symbol over a site at the top of each panel.



Plant biodiversity hotspot identification in Ireland

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Introduction

Halting the loss of biodiversity is an important goal for the European Union (EC, 2008). In the UK statutory protected areas cover less than one third of the total number of occurrence records for Red List plant species (Jackson and Gaston 2009). This shows that in the wider countryside there are areas that are important for plant biodiversity. However, in Ireland there is a lack of knowledge on the distribution of plant biodiversity outside of protected areas. Knowing the current distribution of plant biodiversity would allow more effective monitoring and targeted plant conservation measures (Balmford et al, 2005) e.g. through agri-environment schemes. A national map would allow easy identification of high biodiversity areas that may need to be taken into account when making planning or land-management decisions and areas of low biodiversity that should be targeted for restoration or specific conservation measures. This research aims to create a national map of plant biodiversity at a tetrad (2x2km) scale.

Materials and Methods

Plant species distribution records were obtained from the Botanical Society of the British Isles (BSBI). The records were digitized using ArcInfo 10.0. There are records for over 2000 plants in the database for Ireland. County Waterford had the most comprehensive records per tetrad and overall coverage so analyses focused on this area. From a conservation point of view all plants are not equal. We focused on native plants for our analysis (Figure 1).

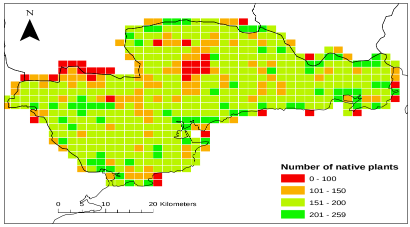

Figure 1. Number of native plant records per tetrad for County Waterford.

We assigned a conservation value to each native plant by applying the following criteria; if the plant was native it received a value of one, if the plant was a semi-natural habitat indicator it received a value of two, if the plant was an Annex I habitat indicator it received a value of three and finally, if the plant was rare it received a value of four (Table1).

We also took into account the plant distribution across the country assigning values between 1 and 6.This was done using BSBI hectad level (10x10km) data. For example, plants that occurred in more than 80% of the hectads in the country were considered common and received a low distribution score (see Table 1). A matrix was created and the final values ranged from 1 (lowest plant conservation value) to 24 (highest plant conservation value). Using these values and the detailed data for County Waterford we calculated an average plant conservation value per tetrad for the county.

Plant status		**Plant dist**	
Rare	4	0.07-10%	6
Annex I ind	3	10.1-20%	5
Semi-natural ind	2	20.1-40%	4
Native	1	40.1-60%	3
		60.1-80%	2
		80.1-100	1

Table 1. Criteria used to evaluate the conservation value of the native plants in Ireland.

Results and Discussion

The average plant conservation value per tetrad for County Waterford can be seen in Figure 2. These results show that the coastal areas have high average conservation values.

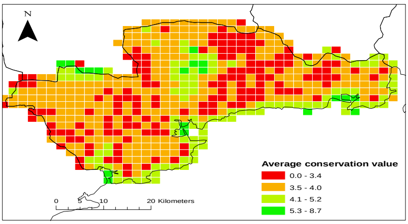

Figure 2. Average plant conservation values per tetrad for County Waterford

This would be expected as the coastal areas have many semi-natural habitats such as sand dunes and slacks. The green tetrads in the middle of Waterford correspond to the Comeragh Mountains. Despite a lower number of plant species per tetrad the conservation value of these upland areas is quite clear. The next objective is to identify the environmental factors that are influencing the different conservation values in Waterford using modelling techniques and to use these data to create a national map of plant conservation values.

Conclusions

Using plant conservation values for County Waterford and modelling techniques a national plant biodiversity map can be generated.

This map will aid decision making for policy-makers and land managers. It will also highlight areas of low biodiversity that should be targeted for restoration or specific conservation measures such as agri-environment schemes.

Acknowledgements

This work is funded by the Irish Research Council. Data was provided by the BSBI. In particular, we would like to acknowledge Paul Green's dedication to plant recording.

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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 agri-environment 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 characterisation 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

Using plant biodiversity records to support spatial targeting of agri-environment schemes

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Introduction

Protected area networks and agri-environment (AE) schemes are important conservation instruments within the European Union. The European Commission has recommended better targeting of AE measures and the European Court of Auditors has identified the geographic targeting of AE funds as a necessary requirement for improved justification of AE expenditure (Auditors, 2011; Commission, 2010).

Important areas of biodiversity outside of protected areas are a potential target for AE schemes. However, there is a lack of information on the location of Important Areas of Plant Diversity (IAPD) in Ireland. This project aims to identify these areas. The work outlined here represents the preliminary steps in identifying IAPD by first mapping areas that contain rare and threatened plant species. The aim of the study was to assess the occurrence of rare plants in relation to the Natura 2000 (N2K) network of protected sites.

Material and Methods

Distribution records of rare and threatened plant species for the island of Ireland were obtained from the National Parks & Wildlife Service (NPWS), the Northern Ireland Environment Agency (NIEA), and the Botanical Society of the British Isles (BSBI). These were collated into a single plant distribution database. Plant species that are on the Flora Protection Order of Ireland (FPO), the Irish Red Data Book (RDB), the Northern Ireland Wildlife Order (WO), and the Northern Ireland Priority Species List (PS) are considered to be rare and threatened (See Figure 1 for examples).

Figure 1. Examples of rare and threatened plant species. Left: *Gymnocarpium robertianum* (Limestone fern). Right: *Pyrola rotundifolia* (Round-leaved Wintergreen).

Tetrads containing these plant species were mapped and their location with respect to the N2K network of protected areas was examined (Figure 2). Two different scenarios were investigated.

Scenario 1: only tetrads containing 0% cover by N2K were classified as being outside of the protected areas.

Scenario 2: tetrads with less than 10% cover by N2K were also classified as being outside protected areas.

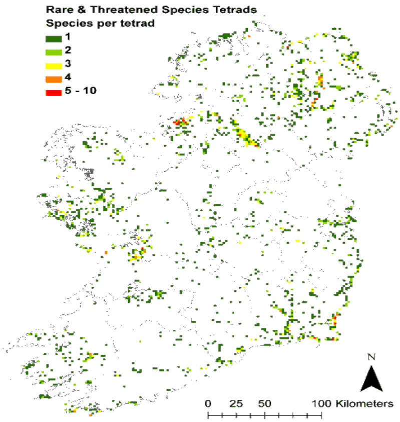

Figure 2. Tetrads containing rare and threatened plant species in Ireland.

Where a tetrad has only partial coverage by the N2K network a species can occur within the tetrad but outside of the N2K site (Figure 3). Finally, the proximity of non-designated tetrads in scenario 1 to the protected area network was also examined.

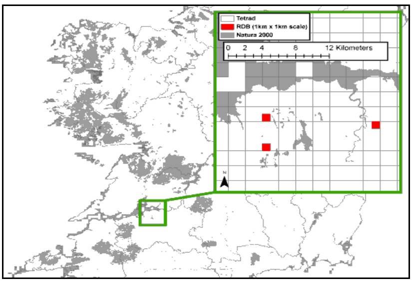

Figure 3. Example of the occurrences of rare & threatened species outside of N2k that would be classified as being inside of N2K in Scenario 1.

Results and Discussion

Scenario 1 revealed that a significant percentage of tetrads that contain rare and threatened plant species occur outside of N2K sites. More than half of these tetrads occur within 5km of the N2K network. Analysis of scenario 2 showed marked increases in the percentage values of tetrads found outside of N2K. The development of the IAPD identification method will be a continuation of this work. This research highlights areas that could be targeted through new AE scheme measures that specifically address rare plant conservation.

Conclusions

Rare plants frequently occur outside of protected areas. These areas could be targeted through specific AE scheme measures. The analysis also shows that that most of these areas outside of N2K are within 5km of the network's boundaries. For this reason areas in proximity to N2K may be more desirable targets for conservation.

Acknowledgments

We wish to acknowledge the BSBI, NPWS and NIEA for supplying plant records. This project is funded by the Teagasc Walsh Fellowship Scheme.

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The ecological conservation value of riparian management in an intensive agricultural grassland landscape

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Introduction

Reducing the loss of biodiversity and achieving good water quality are important agri-environmental targets in Europe. Riparian habitats can play a significant role achieving good water quality and also in protecting and enhancing farmland biodiversity.

The appropriate management of natural riparian zones can provide numerous ecosystem services within an agricultural landscape e.g. protecting water quality, increasing carbon sequestration, reducing compaction, regulating storm water, and enhancing regional biodiversity.

Riparian margin Agri-Environment (AE) measures are considered important in providing multiple environmental benefits, including halting biodiversity decline, maintaining water quality and combating climate change (DAFF, 2010). As a result, riparian margin measures have been included in the Rural Environment Protection Scheme (REPS), and the more recent Agri-environmental Options Scheme (AEOS

The aim of the current study was to assess the conservation value of riparian habitats within farmland managed under agri-environment schemes in Ireland; and assess the impact of riparian AE measures on instream biotic and abiotic parameters.

Figure 1: Cattle access drinking point

Objectives

- Assess the impact of riparian vegetation type on carabid, spider and plant assemblages.
- Do streamside habitats typical of intensive grassland provide a suitable habitat for riparian and wetland associated species.
- Identify to what extent cattle drinking access points impact aquatic macroinvertebrate communities, water quality parameters and bedload sediment.

Materials and Methods

This study was conducted in the southeast of Ireland.

Riparian margins

The work-package was conducted on ten beef/dairy pasture farms managed under the REPS scheme in Co. Wexford, SE Ireland. Cattle were excluded from a 1.5m distance from the watercourse bank by fencing and chemical fertiliser and pesticide application was prohibited within this zone. All farms consisted of intensively managed grassland through which flowed streams 1-6m wide. Each farm contained representative plots (20m long and 1.5m wide) of each riparian vegetation type (grassland, scrub and woodland), separated from each other by at least 50m. Intensive invertebrate and botanical surveys were undertaken at each site.

Cattle Drinking Access Points

This work-package was carried out on 40 CDAPs, on tributaries mainly draining improved grassland. Macroinvertebrate sediment and water chemistry sampling was carried out upstream and downstream of each CDAP. Additional water quality samples, local environmental variables and landscape variables within the stream catchment were recorded.

Figure 2: Fenced 'grassy' riparian margin

Results and Discussion

Riparian margins

Proportional abundances or frequencies of riparian or wetland species for carabids and spiders were low when compared to the national fauna and other studies. Distinct assemblages were identified in each habitat type (grassy, scrubby and woody) for plants and spiders but not for carabids. There were higher abundances of carabids and spiders in grassland margins while scrub margins provided the highest regional species richness.

These results indicate that riparian margins in intensively farmed areas may have a low potential for specialised fauna being dominated by generalist species.

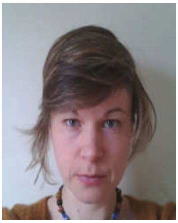
Cattle Access Drinking Points

Results in relation to cattle drinking points did not show any significant differences in any water chemistry, sediment or macroinvertebrate parameters between upstream and downstream sites. The majority of sampled streams returned a Q-value below 4 and has low small Stream Risk Scores (SSRS), with only 10% of streams producing good water quality scores. The majority of streams in our study were of low water quality, irrespective of any local inputs at drinking points.

Our results suggest that measures to mitigate potential small local inputs of nutrients and sediment in agricultural catchments (e.g. complete removal of cattle access to watercourses) may not be cost-effective in intensive agricultural grassland systems where streams may be impaired from diffuse catchment-wide inputs.

Acknowledgements

This work is funded by the Department of Agriculture, Fisheries and Food Research Stimulus Fund 2006.



Development of indicators of farmland wildlife habitats on intensive grasslands

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Introduction

Under the current EU Common Agricultural Policy (CAP) reform and the Department of Agriculture Food Harvest 2020 initiative, there is a drive towards sustainable intensification of agriculture. Protecting against biodiversity loss and loss of wildlife habitats is one aspect of sustainability of agricultural landscapes, along with efficiencies in use of water, energy, fertilizers and pesticides and GHG emissions. Approximately 80% of agricultural land in Ireland is devoted to grass-based feeding systems including dairy, beef and sheep grazing as well as silage and hay production. Intensification of these systems has led to losses of biodiversity.

Figure 1. Intensive grassland field

However, very little is known of the proportion and quality of wildlife habitats that still exist on intensive grassland farms in Ireland. Studies that have been carried out report that Ireland has a greater percentage of wildlife or semi-natural habitat present (up to 15%, Sheridan et al., 2011) when compared with other European countries such as the Netherlands (5.3%, Manhoudt & Snoo, 2003). Ireland's intensive grazing systems have a natural advantage and potential to produce high quality output while maintaining and improving their relatively high proportion of wildlife habitats. This may be harnessed by 'Brand Ireland' and Harvest 2020 in promoting Ireland as a leading producer of 'green' food and sustainable agricultural practice.

This project aims to measure the quantity and quality of wildlife habitats on 80 intensive grazing farms in the south and south east of Ireland. From this benchmark, objective and transparent tools for measuring biodiversity and wildlife habitats at the farm scale will be developed in order to underpin food quality assurance schemes that include measures of environmental sustainability.

Methods

A review of food branding, labeling and accreditation schemes aimed at sustainable agricultural systems and biodiversity will be conducted. This will inform an overview of the alternative methodology used for biodiversity and wildlife habitat indicators.

A habitat survey of 80 farms in the south and south east of Ireland will be carried out over spring / summer 2013 and 2014. These farms are located in counties Cork, Tipperary, Waterford, Kilkenny and Wexford and are representative of intensive grazing systems in this region. They consist of approximately 30 dairy farms, 30 beef and 20 sheep farms. A field survey of each farm will be conducted on foot and all semi-natural habitats will be digitally mapped using ArcGIS in order to calculate the proportional land cover. More detailed surveys of habitat quality for hedgerows, field boundaries and semi-improved grasslands will also be undertaken including measures of species richness, presence of native species, presence of rare species or species of conservation concern. A questionnaire of farmer knowledge of and attitudes to biodiversity and wildlife habitats on their own land will be conducted. Further information on farming methods and farming intensity such as stocking density and nitrogen inputs will be collated and used in analyses.

Based on the habitat data collected, the farmer questionnaire and the farm data, a model will be developed, calibrated and validated to be used as an indicator of wildlife habitats on dairy, beef and sheep farms of ranging agricultural intensity. It will incorporate suitable and suggested improvement measures for improvement of wildlife habitats and biodiversity on individual farms.

Figure 2. Hedgerow wildlife habitat on an intensive grassland farm

Expected Benefits

This project will provide data on the percentage of land covered by wildlife habitats on intensive grazing farms in the south and south east of Ireland and on the quality of these habitats. The developed practical indicators for wildlife habitats and measures for their improvement can be incorporated into the design of food quality assurance schemes and will have benefits for biodiversity on intensive farmland.

Acknowledgements

This work is funded by the Research Stimulus Fund through the Department of Agriculture Food and the Marine.

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The impact of acute and chronic 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 (Directive 2000/60/EC) 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 2015.

For the agriculture sector in Ireland, 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, and that stream hydromorphology can limit WFD ecological status.

The study will help identify how stream ecological communities react to agricultural and non-agricultural acute and chronic stressors at different times of the year. By identifying the impact of these stressors, the study will help inform how agriculture in Ireland can be intensified sustainably with respect to implications for water quality in headwater 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 use types 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.
- Identify whether variations in hydromorphological factors in stream ecosystems are a more significant driver in determining ecological community than chemical variations.
- 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 will examine the stream ecological response to acute and chronic stress. Furthermore, the temporal impact of stress (including at periods of high ecosystem activity) on stream ecological community structure and the implications for the WFD will be examined.

The study will be a combination of literature review, controlled environment experiments and catchment scale field studies along with some conceptual modelling.

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 (Anon, 2006) 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 (p. 63) to: provide evidence-based knowledge to support policymakers in designing, implementing and evaluating programmes for agri-environment products and services.

Figure 2. Farm-scale implementation and the voluntary nature of AE Schemes has limited their potential effectiveness in maintaining the health of freshwater ecosystems

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, i.e. protect water resources and protect biodiversity. Furthermore if agriculture is to achieve its production targets (set in Food Harvest 2020) 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

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Biodiversity and integrated pest management of eucalyptus foliage and forestry plantations

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Introduction

The genus Eucalyptus is a fast growing exotic, selected species of which are proving useful in the timber, biomass and florist foliage industries in temperate Europe. Ireland's climatic advantage, coupled with its proximity to mainland European markets has enabled a fledgling foliage industry to expand into an economically rewarding sector with projected future growth.

The accidental introduction of the leaf beetle pest, *Paropsisterna selmani* into Ireland from south Australia, seriously threatens these industries. This is the first paropsine leaf beetle to become established in Europe. In the absence of any natural enemies, foliage growers are forced to resort to insecticidal applications. These chemicals are disrupting the already established biological control agent, a parasitic wasp *Psyllaephagus pillosus* of the blue gum psyllid, *Ctenarytaina eucalypti*, necessitating further insecticidal usage to ensure viable economic returns.

The use of foliar applied pesticide is not an option for the biomass or forestry industries, due to lack of access once crops are established. It is therefore desirable to find a suitable biological control agent to reduce the damaging effects of the leaf beetle below the economic injury threshold in these three crop situations.

This study proposes to (a) assess the suitability of the egg parasitoid *Enoggera nassaui* as a biocontrol agent of the leaf beetle *P. selmani* in commercial eucalyptus foliage, biomass and forestry plantations in Ireland, (b) determine the extent of the host range of the egg parasitoid, testing native fauna, to fulfill the risk assessment required prior to a release application, (c) examine how the use of insecticides affect the biological control of the blue gum psyllid, (d) investigate the invertebrate diversity of Eucalyptus plantations comparing it to native woodlands to establish the impact of managed exotic crops on native fauna in Ireland.

Methods and Materials

The life history of the egg parasitoid, *E. nassaui,* will be examined under quarantine conditions using standard bioassays. The conditions under which the eggs of the host, *P.selmani are* exposed to the parasitoid will be manipulated to establish the stage specific mortality schedules and thus the efficacy of the agent on *Eucalyptus* species relevant to each industry.
In order to determine the potential establishment of the biological agent in Ireland, temperature based trials will be conducted at temperatures between

15-25 degrees Centigrade using specialised growth chambers.

Host specificity screening will be carried out by exposing the agent to the eggs of native beetle species that are ecological similar, phylogenetically/taxonomically related to the target, beneficial and rare species utilising choice and no choice tests

It is proposed to carry out insecticidal application field trials on formerly unsprayed Eucalyptus plots to determine impact on both the pest *C. eucalypti* and the parasitoid *P. pillosus.* Blocks of trees will be chosen within selected plantations, using a randomised block design. Sampling will take place before and after pesticide applications to establish pest and parasitoid incidence.

Invertebrate diversity in managed plantations and native woodland will be examined utilising passive sampling techniques, coupled with the use of interception traps, knock down sampling and timed searches, collecting eggs, larvae and adults. Plantations will be selected to reflect typical management regimes.

Expected outcomes

This study will determine the suitability of *E. nassaui* as a biocontrol agent of the leaf beetle pest *P. selmani* in Ireland. The research will provide the necessary information to apply for the field release of this egg parasitoid, fulfilling the requirements of a risk assessment. This study will also determine how well the biological control agent of the psyllid pest, *C. eucalypti* is doing in Ireland and what effects the chemical control methods currently employed are having on the management of this pest, informing the value of biocontrol as a management tool. The biodiversity assessment will provide information on the value of exotic plantations as habitats for native invertebrates.

Benefits to the industry will be two fold:

a. Control of the defoliating leaf beetle pest, improving the value of foliage produce, growth of biomass and short rotation forestry plantations.
b. Resumption of the biological control of *C. eucalypti,* with positive implications for the environment and value of the product.

In addition to the benefits to Irish industries, the establishment of a natural control agent for the beetle will reduce the likelihood of spread of this pest to the UK and main Europe. In the event of spread, this study will inform control strategies considered in these areas.

Figure 1. Eucalyptus foliage

Acknowledgements

This work is funded by a Teagasc Walsh Fellowship Scheme

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Effects of using drought on yield of multi-species mixtures

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Background

Permanent grassland makes up 33% of the total utilised agricultural land in the EU and 76% of utilised agricultural land in Ireland. Further to this 76% of permanent pasture, over 90% of agricultural land in Ireland is used in forage production or rough grazing (O'Mara, 2008). European grasslands produce forage that supports dairy, beef, sheep and goat production. In order to continue to produce this forage in the face of climate change, grassland agriculture needs to adapt.

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; Kirwan *et al.* 2007). This builds on previous work which showed that higher plant diversity in semi-natural ecosystems could lead to increased biomass production and increased production stability.

Biodiversity and ecosystem function research to date has largely focused on biomass production and its interaction with species richness. Less is known about how plant diversity affects ecosystem stability and its interactions with environmental perturbations, such as climate change. Some studies have shown that higher diversity can lead to increased resistance to climatic perturbations. However not all agree and more work is needed to better understand the processes at work (Hooper *et al.* 2005).

Figure 1. Field trial at Johnstown Castle (August 2012), where drought resistance of different grassland mixtures is being tested.

Objectives

This project aims to examine if modest increases in plant biodiversity in agricultural grassland swards can help mitigate the effects of climate change. Here the focus will be on the grasslands ability to maintain productivity and quality of forage when subject to drought (resistance). Recovery following a drought event (resilience) will also be monitored.

Materials and Methods

The main field experiment, located at Johnstown Castle (Figure 1), uses four grassland species that are of agronomic importance in European forage production; *Lolium perenne*, *Cichorium intybus*, *Trifolium repens* and *Trifolium pratense*. The experiment comprises split plots, with mixtures of varying sown species abundances and varying numbers of species. In order to induce an experimental drought, 'rain-out' shelters will be placed over half of the plots in a random stratified design, in accordance with statistical techniques. The effects of induced drought on the productivity, chemical composition and physiology of the mixtures will be monitored. As well as monitoring initial resistance to the drought treatment, recovery from the treatment will also be assessed. Other measurements that focus on plant rooting behaviour will also be made.

Figure 2. Glasshouse experiment located at Johnstown Castle to investigate how different levels of drought affect plant productivity and physiology.

Glasshouse based pot experiments are also being conducted (Figure 2). These smaller scale experiments allow for an in-depth look at the mechanisms which underpin the stabilising effects associated with increased biodiversity. These pot experiments enable better control of environmental conditions in a more rigorous manner than the field scale experiments located near by.

Expected Outcomes

To fulfil project objectives, mixtures of four plant species mixtures will be assessed in their ability to mitigate the effects of induced drought stress. This will lead to better understanding of how these effects occur through use of a combination of long term field and glasshouse experiments. Further knowledge in this area will benefit agricultural forage production and help inform agricultural management to the most favourable practices in the future.

Acknowledgements

This work is funded by the Animal Change project in association with the Teagasc Walsh Fellowship Scheme and University College Dublin.

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Effects of drought on nutrient dynamics in multi-species mixtures

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Introduction

Benefits of grassland mixtures over monocultures are believed to be due to facilitation and niche complementarity among plant species. One potential mechanism for which there is little evidence in agricultural systems is soil niche complementarity between deep-rooting and shallow-rooting species. This may be of particular importance under drought stress, when soil nutrients may be less available in dry top layers compared to the wetter deep layers.

Below-ground niche differentiation can be assessed by injecting tracers at different soil depths, and comparing the resulting tracer concentrations of plant species. Additionally, ^{18}O stable isotope methods allow for the assessment of the contribution of different soil depths to plant water uptake.

The objective was to assess the below-ground niche differentiation of shallow-rooting and deep-rooting species in grassland mixtures and monocultures under benign and drought conditions using both a tracer method and natural abundance ^{18}O technique.

Materials and Methods

The experiment was conducted on two sites in Switzerland: Tänikon, in 2011 and Zürich-Reckenholz in 2012. Monocultures and mixtures of *Lolium perenne* (Lp), *Cichorium intibus* (Ci), *Trifolium repens* (Tr) and *Trifolium pratense* (Tp) were sown in 66 plots of 3×5 m in a simplex design with 3 replicates. Using rainout shelters (Figure 1), half of the plots were subjected to a drought treatment of 10 weeks summer rain exclusion.

Tracer method: In 2011, a solution containing Rb+ was injected at 25 points at 5 and 35 cm depth in two sub plots (50 × 50 cm) per plot. Plant material was harvested after four weeks, at the end of the drought period and sorted into the four species. The proportion of Rb uptake (RbU) from 35cm was calculated as RbU_{35} / (RbU_5 + RbU_{35}).

δ^{18}O method: In 2012, stem bases were collected for eight tillers of all four species per plot. Samples were taken from two replicate plots of all the monocultures and the 4-species mixture. Three 2 cm diameter soil cores were taken to 40 cm depth per plot and divided into 5 segments (0-5, 5-10, 10-20, 20-30 and 30-40 cm). Water from the soil and plant samples was extracted using cryogenic extraction and the extract was analysed for ^{18}O. The IsoSource stable isotope mixing model was applied, to determine the proportional contribution of each of the 5 soil layers to the plant stem water δ^{18}O signature.

Results and Discussion

Tracer method: The proportion of RbU_{35} was on average 6.6 times greater for drought compared to control plots (Figure 2), indicating a shift of nutrient uptake to deeper soil layers under drought conditions. Additionally, the proportion of RbU_{35} was on average 1.9 times greater for the deep rooting species Ci and Tp and the shift to deeper layers under drought conditions was stronger for these two species. Growing the species in monoculture or mixture had no effect on the proportion of RbU_{35}, for the different species.

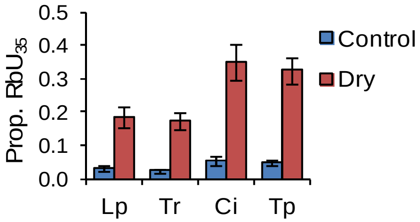
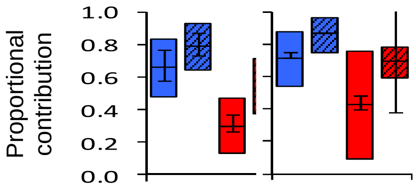


Figure 2. The proportion of RbU_{35}

$\delta^{18}O$ method: The mean proportional contribution to water uptake of the 0-10 cm soil layer (PC_{0-10}) was on average 0.48. The PC_{0-10} was larger for the shallow-rooting species Tr and Lp. Drought reduced the PC_{0-10} from 0.56 to 0.42 on average, confirming that the species shifted their water uptake to deeper layers under drought conditions. The PC_{0-10} of Tp was lower in mixtures compared to monoculture, whereas the opposite was true for the other species.



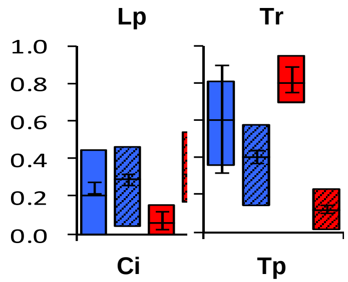


Figure 3. Box plots of the proportional contribution of 0-10 cm soil layer to plant water uptake. Lower, middle and upper boundaries are 1st, 50th and 99th percentile. ■ control, ■ Drought, ▨ Mix

Conclusions

Both methods confirm that the grassland species in this experiment occupied distinct niches in relation to the depth of soil water and nutrient uptake. These niches changed in reaction to drought and the $\delta^{18}O$ method also indicated an effect of whether species were grown in mixture or monoculture. The next step will be to determine whether these findings translate into i) yield advantages of deep rooting species under drought stress and ii) yield advantages of combining deep and shallow rooting species in mixtures.

Acknowledgements

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Cost effectiveness of selected agri-environment measures for habitat conservation

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Introduction

Between the period 1994 – 2011 in excess of €3.67 billion has been spent on REPS in Ireland (DAFM, 2011) with a further €243 million being spent on AE schemes in 2012 (Irish Government News Service, 2012). Under Article 16, EC Regulation No. 746/96, all member states are required to monitor and evaluate the environmental, agricultural and socio-economic impacts of agri-environment programmes (Mauchline *et al*, 2012). It is essential that these schemes provide value for money through the protection and enhancement of the natural environment.

The aim of this project is to provide evidence-based support for the design, implementation and assessment of practical options for AE measures to support biodiversity goals, and to quantify the benefits of innovative AE measures. The primary objective of this research is to investigate whether current AE schemes are cost-effective and to identify whether there are alternative ways to achieve biodiversity goals, particularly in relation to grassland and hedgerow habitats, that could potentially be more effective and less costly.

Materials and Methods

Study sites will consist of pastoral, drystock farms selected from the midlands region i.e. Offaly, Laois, Longford and Westmeath where drystock production accounts for approximately 69% of all farming systems (CSO, 2010) and where REPS participation accounted for approximately 9.86% of national participation across all REPS schemes in 2011 (DAFM, 2011).

Grassland diversity

To assess the type of botanical diversity being supported through current schemes, 20 1 x 1m quadrats will be taken within 20 randomly selected farms receiving payments for each of the following:

1) AEOS payment for Species Rich Grassland (see Figure 1).
2) AEOS payment for Traditional Hay Meadow
3) Natura 2000 payment for Species Rich Grassland

Figure 1. Species rich grassland

Abundance values will be assigned to all vascular plants rooted within each quadrat according to the Domin Scale (Kent and Coker, 1992).

Hedgerow Diversity

As management and age both play critical roles in determining the potential biodiversity value of hedgerows, different growth stages and management practices will be sampled. Hedgerow biodiversity will be investigated within each of the following:

1) Planted young hedge, 5-10 years old

2) Coppiced hedge that is 8-12 years old

3) Coppiced hedge that is > 12 years old

4) Control hedges will take the form of conventional hedges. These will take the form of two sub-groups, i.e. stockproof and non-stockproof.

The floristic composition of 100m of each hedgerow will be recorded and the percentage cover of each tree and shrub species will be recorded according to the DAFOR scale (Kent and Coker, 1992)

The hedgerow ground flora will be surveyed using five randomly selected 0.5m x 0.5m quadrats along the same 100m stretch. Abundance of all plant species within these will be recorded according to the Domin Scale.

Invertebrate diversity of the hedgerow canopy will be investigated using both fogging and beating methods. This will facilitate a comparison of the efficacy and appropriateness of each method for sampling canopy invertebrates. The hedge will be beaten with 2m poles for two minutes along the selected 100m stretch, to dislodge any arthropods into the collecting trays. All biomass collected will be counted for each of the main orders, with spiders being identified to family.

Expected Benefits

The implementation of agri-environment schemes in Ireland as in many other countries e.g. Switzerland, Germany, Sweden, has followed a horizontal approach, unlike other countries which have followed a more targeted, zonal approach e.g. Spain and the UK, (Kleijn and Sutherland, 2003). This research will identify measures that can target the expenditure of the limited funds available at areas of highest conservation concern. It will identify the biodiversity status of existing and newly planted hedges, facilitating the comparison of the two and the associated costs.

Acknowledgements

This work is funded by the Teagasc Walsh Fellowship Programme.

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Ideal-HNV: Identifying the Distribution and Extent of Agricultural Land of High Nature Value

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Background

High Nature Value (HNV) farmland has been defined as "those areas in Europe where agriculture is a major (usually the dominant) land use and where agriculture sustains or is associated with either a high species and habitat diversity (See Figs 1 and 2), or the presence of species of European conservation concern, or both" (EEA, 2004). The European Community's 'Strategic Guidelines for Rural Development 2007 – 2013' includes HNV farming and forestry systems as one of seven community priorities. Member States are required to:

- identify areas with HNV farming practices in each Member State;
- support and maintain HNV farming through Rural Development Programmes, and;
- monitor changes to the HNV area over time (CEC, 2006).

Here, we describe a new project involving collaboration between Teagasc and IT Sligo on HNV farming systems in Ireland. The main objectives of the project are to:

- estimate the national distribution and extent of potential HNV farmland in Ireland.
- examine the use of remote sensing methods to identify HNV areas at the farm scale.
- develop bottom-up decision-support tools to assist field- and farm- scale identification of HNV farmland.
- analyse the socio-economic and policy implications of identification of HNV farmland.

Materials and Methods

We will develop geo-spatial methods to estimate the national extent and distribution of potential HNV farming systems. This methodology will use available geo-spatial data on vegetation type, farming systems, designated areas, farming intensity and land use/cover.

Figure 1. Semi-natural habitat on farmland in County Mayo

We will also investigate an innovative methodology that combines new high-resolution satellite imagery with other datasets and will apply this to a case study area (5000 km^2) to assess its ability to more directly measure the nature value of farms.

A ground-truthing exercise will provide training data for the GIS-based models and will assess the accuracy of the project output, based on a combination of manual interpretation of colour aerial photography, existing habitat/farm-survey data, and new surveys of selected case study areas.

Figure 2. Wet meadow in County Meath

We will develop and validate (using field surveys in case study areas) a decision support system for field- and farm- scale identification of HNV farming systems. For representative case study areas, we will describe their primary HNV characteristics and pressures. We will also analyse the potential implications (positive and negative) of HNV policies from the perspective of farm socio-economics and consequences for other policies. The results of the project will be disseminated to key stakeholders.

The project will provide a methodology that will contribute to the baseline indicator for HNV farming for Ireland under the Common Monitoring and Evaluation Framework (CMEF).

Overall expected impact

The project will provide a methodology that will contribute to the baseline indicator for HNV farming for Ireland under the Common Monitoring and Evaluation Framework (CMEF). The objective methodology (Task 1) can be repeated in future, and used to measure change over time. Thus, the project will allow for measuring changes in quantity (and quality, to a lesser extent) of HNV farmland and of HNV farming systems as required for the CMEF HNV farmland results indicator. The project can also support analysis of the effects of RDP measures (RDP measures and Direct Payments post-2014) on the changes observed under the CMEF HNV farmland impact indicator.

This project will develop and apply novel methodology to quantitatively identify the extent and distribution of HNV farmland in the Republic of Ireland. When completed, the project will have addressed an important knowledge gap for policymakers about the national scale distribution of potential HNV farmland areas, as well as improved knowledge of their typical characteristics and threats. This will facilitate policy assessment of the extent to which policies have effective objectives and implementation, and the extent to which financial supports are targeted to HNV farmland. Thus, the outputs of the project will help achieve national and international RDP requirements to identify HNV farmland, and can underpin justification of HNV payments in future CAP schemes and greening measures.

Acknowledgements

Supported by the Research Stimulus Fund of the Department of Agriculture, Food and the Marine (11/S/108).

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Soils

Mapping Soils in Ireland

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Background

Farming activities have long been heralded as being a critical developer and shaper of the rural landscape and environment which we enjoy in Ireland today.

Comparison of soil information at a European scale has led to the requirement for the harmonisation and coordination of soil data across Europe, and, in light of the demands for soil protection on a regional basis within member states there is a growing need to support policy with harmonised soil information.

Critical to the successful development of such strategies is the knowledge on the location of our soils, and their associated properties. To date, Ireland has a national soil map at a scale of 1:575,000, with only half the country mapped in significant detail.

Objectives

The Irish Soil Information System (ISIS) project is currently developing a national soil map of 1:250,000 and an associated digital Soil Information System (SIS), providing both spatial and quantitative information on soil types and properties across Ireland. Both the map and the information system will be freely available to the public through a designated website in 2014.

Materials and Methods

The Irish Soil Information System (ISIS) project will uniquely combine the latest spatial mapping technologies with tried-and-tested ground-truthing: soil pits, at a national scale.

This project has collated, generalized and harmonized all the available data from the An Foras Taluntais soil survey of the 1970s and 80s to a map scale of 1:250,000.

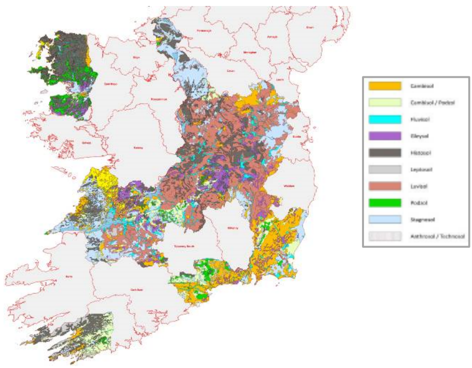

Figure 1. Harmonised map of Terra Cognita (1:250,000). Data derived from An Foras Taluntas soil survey.

Using this data and associate mapping datasets such as; satellite imagery, digital terrain mapping, and other geo-environmental GIS layers, this project is able to predict soil associations (mapping units of groups of soils occurring in a landscape) into areas which had previously not been surveyed (Terra Incognita) where similar landscapes existed. Geo-statistical inference engine models are used for the prediction process these include; Random Forest, Bayesian Belief Networks and Neural Networks. Three models have been used to assess the most appropriate. The final draft output in the form of a predictive map is currently being validated by field survey data (approximately 12,000 auger records) collected over a 2.5 yr period.

The field auger survey took place in 13 counties which had not previously been surveyed in detail. The auger survey comprised of an on-the–spot classification of the soil down to a depth of 80 cm. It was only possible to spend 3 days on each 10 x 10 km map sheet, to ensure complete coverage of Terra Incognita. This was accomplished over a range of land-uses and landscape types. The auger survey was completed in October 2012 and the data has undergone a process of data quality checks.

To assess the accuracy of the predicted maps, the auger bores are spatially mapped over the predicted associations and comparison between expected and observed soil series allows for final map validation.

In addition to the auger survey, 300 soil profile pits are currently being sampled and classified to provide a detailed profile description with associated chemical physical data for the main soil types of Ireland. Samples are measured for pH, OC, C/N, Cation Exchange Capacity, Base Saturation, Extractable Fe and Al, Texture and Bulk Density. These analyses are being completed by laboratory staff in Johnstown Castle.

Figure 2. A Gley soil profile

Future Developments

This project will form the basis for more accurate soil data in Ireland at a national scale and will provide to the public data which to date has not been accessible. This will provide the opportunity for soil specific nutrient advice and better research opportunities in spatial soil mapping and modelling in the future.

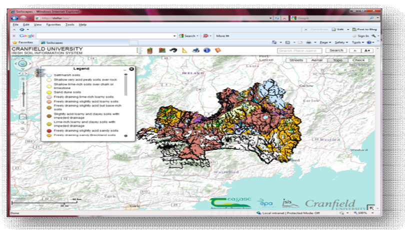

Figure 3. Soil map viewer of SIS.

Acknowledgements

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Developing and Evaluating Indicators for Biodiversity: The EcoFINDERS Project

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Introduction

The majority of soil processes are mediated by the soil biota. Soil biodiversity is the engine driving soil based ecosystem services such as food production, nutrient cycling, carbon sequestration, and water purification (Wardle et al. 2004). The European Commission (DG ENV) acknowledge the importance of soil biodiversity in the role of ecosystem functioning and the Commission's soil strategy is to protect and enhance soil based ecosystem services, with a view to promoting sustainable intensification of agriculture. There is, however, not enough information available on soil biodiversity across Europe to allow informed policy decisions (Creamer et al. 2010).

The EcoFINDERS (FP7) project was set-up in 2011 to identify soil threats, harmonize methods for measuring biodiversity and to generate European datasets of soil biodiversity and ecosystem function. Teagasc is the lead partner in the work package dedicated to developing and evaluating such indicators.

Both known and novel indicators are being assessed across a range of land-uses and European climate zones. Large-scale sampling campaigns are underway to determine the normal operating range (NOR) of potential biodiversity indicators and their sensitivity to soil threats.

Materials and Methods

Indicators were selected by a vigorous sifting process known as a logical sieve which allowed the selection of indicators that would provide information meaningful and useful to end-users, such as policy makers and land managers (Ritz et al., 2009). The logical sieve was applied to a large pool of indicators culled from the literature. This took place at a workshop of experts gathered together in December 2011 and resulted in a list of indicators to be tested (Table 2)

Table 1. Indicators selected by Logical sieve and assessed by sampling LTOs and Transect sites

<table>
<tr><th>Biodiversity</th><th>Function</th></tr>
<tr><td>TRFLP (DNA)</td><td></td></tr>
<tr><td>Protozoa (DNA)</td><td></td></tr>
<tr><td>PLFA</td><td></td></tr>
<tr><td>Fungi (ergosterol)</td><td></td></tr>
<tr><td colspan="2">FG nitrification (DNA)</td></tr>
<tr><td colspan="2">FG denitrification (DNA)</td></tr>
<tr><td colspan="2">Earthworms</td></tr>
<tr><td colspan="2">Enchytraeids</td></tr>
<tr><td colspan="2">Micro-arthropods</td></tr>
<tr><td colspan="2">Nematodes</td></tr>
<tr><td></td><td>Bait Lamina</td></tr>
<tr><td></td><td>Water infiltration</td></tr>
<tr><td></td><td>Resilience</td></tr>
<tr><td></td><td>Nitrification</td></tr>
<tr><td></td><td>HW-C & PM-N</td></tr>
<tr><td></td><td>Micro-resp</td></tr>
<tr><td></td><td>Enzyme Activity</td></tr>
<tr><td></td><td>FG Supressiveness</td></tr>
</table>

Using partner owned sites of long standing (Long Term Observatories or LTOs), the sensitivity of indicators to soil threats across 6 sites were assessed. The sites used incorporated different land uses and management practices.

In addition, a transect of 81 sites across Europe of varying land use and climatic zone were sampled for the presence of biodiversity indicators. Sites ranged from Mediterranean arable soils to Boreal forest soils and included Alpine pastures and wet Atlantic soils.

Results and Discussion

A list of most appropriate to measure indicators selected at the logical sieve workshop can be seen in Table 1 and was used in the Indicator-LTO testing.

The indicator-LTO sampling campaign was successfully carried out in the autumn of 2012. Six LTO sites were visited and samples taken from control plots and plots of the most extreme treatment (Table 2).

Table 2. Indicator-LTO sites

Land use	Treatment	Climate zone
Arable	conv/organi c	Continental
Arable	till/no-till	Atlantic
Arable	till/no-till	Pannonian
Arable	cereal/fallow	Mediterranea n
Grass	Intensive /extensive	Continental
Grass	Intensive /extensive	Atlantic

The Transect sampling campaign was successfully carried out in the Autumn of 2012. 81 sites were sampled over 3 months and analyses are currently underway across Europe at partner institutions (Figure 1).

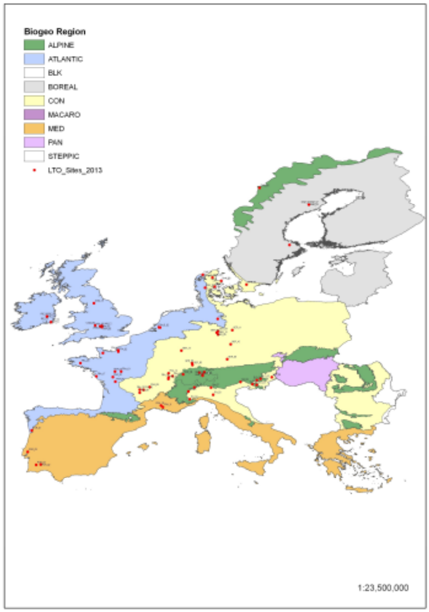

Figure 1. Transect sample map

Conclusions

The dataset collected in this large-scale sampling campaign will allow the EcoFINDERS project to recommend specific indicators of biodiversity and ecosystem function to the EU for the purposes of policy development.

Acknowledgements

This work is part of the FP7 funded project EcoFINDERS.

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Integrating soil characteristics, land management and soil microbial communities

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Introduction

Soil ecosystems are highly complex and contain a huge abundance and diversity of microbial species. These soil microbial populations play an important role in numerous ecosystem functions, including, nutrient cycling, organic matter decomposition and energy fluxes. However, relatively little is known about below-ground microbial community structures in Ireland.

Studies indicate that biotic and abiotic factors including organic matter, soil C and N, moisture content, soil type and soil pH along with land-use and management and above ground vegetation influence below ground microbial community structures and abundance.

This project aims to correlate soil chemical and physical data (collected on the Irish Soil Information system (ISIS) project) to soil microbial diversity and abundance as well as biomass and respiration data. This will help gain a better understanding of soil community structure and evaluate the role abiotic factors and land management play in determining soil community structure.

Materials and Methods

Soil horizon samples are being collected from 250 soil pits throughout Ireland and a variety of methods are applied to evaluate the genetic, phenotypic and functional properties of microbial communities in these samples.

Figure: 1. Horizon profiles of 3 different sample sites in Ireland.

1. Phospholipids are essential parts of bacterial cell membranes and they exist in varied forms. By extracting these lipids through Phospholipid Fatty Acid analysis (PLFA) specific fatty acid profiles for each soil sample can be generated. Different profiles can then be compared and assumptions made regarding the diversity and abundance of microbial organisms. This phenotypic method is also being used to reveal information about total microbial biomass.

2. Functional activity is being measured by using the MicroResp™ method. This Community level physiological profiling (CLPP) method uses a microtiter plate design to asses catabolic activities of whole soil samples. A range of 7 carbon substrates differing in complexity are

being applied at a concentration of 30mg/g H_2O. An indicator dye plate will detect CO_2 emissions through 6 hour incubation at 25C. Absorbance is being read at 560nm and respiration rates are calculated (per g dry soil per hour) by using parameters generated through a calibration procedure where gas sample results were directly related to absorbance readings.

Figure: 2. Microresp™ device

3. DNA based methods including T-RFLP (terminal restriction fragment length polymorphism) and q-PCR (quantitative-PCR) are chosen to visualize microbial diversity and abundance on the genetic level as well as investigate the abundances of genes involved in nitrogen cycling.

All microbial data obtained will be related to the comprehensive physicochemical, soil type and land use data set provided by the Irish Soil Information System.

Results

Preliminary results indicate that top-soil respiration rates are influenced by soil types, physicochemical properties, microbial biomass and land-use, suggesting that individual sample sites have distinct microbial fingerprints. The most important driving factors are currently being identified.

Microbial biomass generally correlates positively with respiration data. Grassland shows the most varied responses out of all land use types whereupon horizons high in organic matter are the most active regarding carbon catabolism.

Further research questions

1. What factors in Irish soils are predominant in influencing microbial diversity and abundance?

2. How does the microbial community change through the soil profile (depth: A-C horizon) and what are the driving forces?

3. Are there distinguishing profiles with regards to the microbial fingerprints for different soil types?

4. How does the abundance of soil nitrifying bacteria differ between soil types and land uses?

Conclusion

It is anticipated that results obtained from this research will broaden our knowledge of below-ground microbial activities and community structures in Ireland. Furthermore this study will provide a baseline for future research, resulting in the identification of possible biological indicators of soil types and soil quality.

An improved understanding of soil microbial communities is imperative due to their role in carbon and nitrogen cycling, ecosystem interactions, ecosystem functioning and global climate change. By generating an extensive knowledge base regarding below ground processes this study will play an important informing how to maintain and increase soil fertility in a sustainable manner (as required under Food Harvest 2020) whilst protecting soil as a vital resource for future generations.

Acknowledgement

This research is funded by the Teagasc Walsh Fellowship Scheme.

Survival of Bacterial Pathogens in Soil and Sewage Sludge Microcosms

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Introduction

Sewage sludge is the accumulated solids collected during sedimentation in the wastewater treatment process. It is rich in nutrients and organic matter (OM), which can be utilised as a sustainable substitute for mineral fertilisers in agricultural systems. Therefore, it provides a cost-effective alternative to chemical fertilisers. However, it can also contain heavy metals, chemical contaminants, pharmaceutical products and pathogenic microorganisms. The treatment process which waste water and its derivatives undergoes aids in reducing the presence of these hazardous materials. However, there is evidence to suggest sludge-derived pathogens may survive for extended periods of time in the natural environment. Thus, there are continuing concerns regarding the potential of these pathogens to persist, and subsequently entering the food chain.

The research reported here considers the importance of sewage sludge loading (i.e. proportion of sludge to soil) on the persistence of inoculated model pathogenic bacteria in soil. It is one aspect of the END-O-SLUDG consortium, which seeks to facilitate the development and treatment of sewage sludge within the policies already outlined by the EU. It was hypothesised that there would be a positive correlation between increasing ratios of sludge to soil and the survival of inoculated bacterial pathogens.

Materials and Methods

The top 0-30 cm of loamy, Eutric Cambisol supporting a pasture used for silage at Johnstown Castle, Ireland (53°20'N, 6°15'W) was sampled following a random sampling method. The sewage sludge, a dewatered cake with a dry solids content of 35%, was provided by United Utilities, UK.

Aliquots (0.1 ml) of cell suspensions containing 2.18×10^8 CFU/ml *E. coli* and 1.18×10^9 CFU/ml *S.* Dublin, derived from overnight culture, were added to the sludge and shaken in gently. The sludge was then incorporated into the soil to establish treatments as follows: 100 % soil; 75% soil to 25% sludge; 50% soil to 50% sludge; 25% soil to 75% sludge; 0% soil to 100% sludge; sterile control; 100% soil control; 100% sludge control. The microcosms were then incubated over a 2 month period at 10 °C. The number of surviving cells was determined in 3 independent replicates incubated overnight at 37°C, on successive occasions over two months. A modified protocol (Troxler, *et al*, 2012) was followed for the extraction. Quarter strength Ringers (10 ml) was added to the microcosms. They were then shaken gently by end-over-end rotation at a speed of 100 rmp for 30 minutes and vortexed for 10 seconds. Serial dilutions of the extracts were made up using a 1 in 10 dilution series. Selected dilutions were plated on to Sorbitol MacConkey agar and Xylose Lysine Deoxycholate agar. Death rates were then calculated from the resulting data, which were then analysed using a Students T-test analysis.Results and Discussion

The death rates for both *E. coli* and *S.* Dublin were reduced when sewage sludge was present within 25% sludge to 100% sludge, though the amount of sludge used did not significantly alter the death rates. The death rate for 75% sludge, when inoculated with *S.* Dublin, was significantly lower compared with 100% soil. Data also indicated that presumptive *E. coli* within the sewage sludge may have negatively affected the survival of the inoculated bacteria, as can be seen in the high variability of death rates for *E. coli* (Fig. 1).

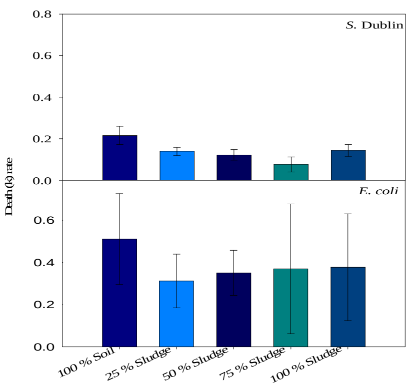

Figure 1: Death rates for *S*. Dublin and *E. coli* in microcosms containing mixtures of sewage sludge and soil (n=3, ±SEM).

Conclusions

This work endeavoured to clarify parameters affecting the survival of pathogens, using environmentally appropriate conditions. These conditions include relevant temperatures and unaltered sludge and soil matrices. Overall, there were no significant correlations between varying proportions of sludge to soil and the survival of the inoculated pathogens. Thus the initial hypothesis proposing a positive correlation between increasing ratios of sludge to soil and the survival of inoculated bacterial pathogens was rejected. However, the presence of presumptive *E. coli*, apparently indigenous to the treated sewage sludge, may have skewed the results by interacting with the inoculated lab strain of *E. coli*.

Acknowledgements

We would like to acknowledge End-O-Sludg and the Walsh Fellowship Scheme for funding this project, as well as the staff and students within Teagasc, Johnstown Castle for their continued support. We would also like to thank Andrew Sprigings and Katherine Miller, from the Process Technology Team at Ellesmere Port, who provided us with the sludge cake with which this research was conducted.

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For further information on the End-O-Sludg project, visit www.end-o-sludg.eu

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END-O-SLUDG: Wastewater transformed for good

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Introduction

The EU is responsible for producing 9.4 million tonnes of sewage sludge each year. The environmental and economic costs of sludge disposal are significant. Although agricultural recycling is typically the most sustainable method of disposal, currently in Europe only 50% of sludge is recycled. The remainder is thermally destroyed. It is recognized that the amount of sludge produced across Europe is set to rise; however our ability to manage the issue is limited by a lack of efficient treatment processes; poor knowledge of nutrient management and negative public perception.

END-O-SLUDG is a collaborative research project involving 14 European partners drawn from industry, academia and Government establishments. The project addresses the challenges by concentrating on the development of novel processes for sludge volume reduction, more efficient treatment and downstream processing for high quality marketable sludge derivatives together with application protocols and assessment of the risks of pathogen, micro-pollutants and long term soil impact for greater public confidence.

Project objectives

1. Dissolved air flotation (DAF) and adsorption processes will be developed for enhanced COD and P removal from wastewater to reduce surplus activated sludge and energy consumption.

2. Improved volatile solid destruction will be sought by augmenting Enzymic Hydrolysis with physical sludge pre-treatments. Microbial ecology of digested cake will be manipulated to prevent *E. coli* resurgence.

3. Membrane and adsorption processes will be evaluated for nutrient recovery. Demonstration of bio-granule and organo-mineral fertilizer (OMF) products manufacture using waste heat from combined heat and power (CHP) system will be undertaken.

4. Quality protocols will be developed for new sludge derivatives leading to the End-of-Waste plus farm-scale trials of new products along with the development of nutrient management protocols for European crops.

5. Micro-pollutant and pathogen micro-pollutant transmission will be evaluated and risk assessment models will be devised to promote public health and environmental protection.

Methodology

1. A series of planned experiments will be carried out to investigate factors affecting COD and P removal from wastewater. Optimum conditions will be used in a pilot demonstration.

2. Bench scale fermentation will be used in conjunction with sludge pre-

treatment methods to achieve enhanced volatile solids destruction. Suitable bacterial cultures will be raised for the inoculation of digested sludge to suppress *E. coli* growth in the cake product.

3. A pilot plant comprising digested cake granulation, waste heat recuperation, and granule dehydration will be designed, built, installed and operated to produce sludge derivatives for farm-scale trials and demonstration.

4. End-of-waste criteria will be established with stakeholders for OMF products for pan-European acceptance. Plot and farm-scale trials will be conducted to provide data for the development of appropriate nutrient management protocols.

5. Fate of pathogens and micro-pollutants in soil and risks to environment and public health will be studied/modelled using soil samples with a wide range of sludge application history. Integrated assessment of sustainability will include life-cycle assessment (LCA), environmental impact assessment (EIA), strategic environmental assessment (SEA), etc.

Expected results

Taken together, the numerous project activities will contribute to achieving the goal of sustainable sludge management. Specific results to be expected include:

• A reduction in Greenhouse Gas Emissions due to gains in energy efficiency and conversion of renewable carbon of 4, 490, 870 t CO_2e pa for the EU by 2020.

• End-of-Waste status achieved for at least one major sludge derivative (OMF).

• Greater public confidence in agricultural recycling of sludge as shown by greater demand for sludge products and better understanding of the long term risks involved in the application.

• Overall reduction in the cost of treating and disposing sludge by at least €100/tDS sludge treated.

• A new market for environmental equipment, worth an estimated €17.5 billion to European industry.

• A more informed approach to sludge treatment and management.

Acknowledgments

This work is funded by the EU Seventh Framework Programme.

Environmental Engineering

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The Big Picture

Even after best management practice implementation on an agricultural landscape incidental and critical nutrient and greenhouse gas losses are inevitable. A sound understanding of the physical and chemical controls on such losses is needed. This helps in the design of engineered solutions to remediate these losses along the nutrient transfer continuum. In Figure 1 below - the loss pathways and key landscape positions where different technologies may be situated on an agricultural landscape are presented.

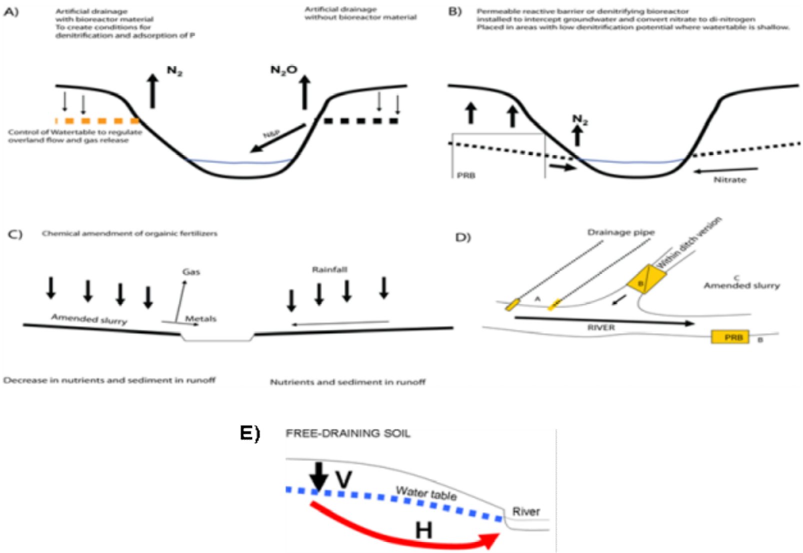

Figure 1. A Nutrient and gas losses in runoff, ditch and drainage pathways, B Permeable Reactive Interceptors; C Chemical amendment and sorbing materials; D Landscape position of environmentally engineered technologies; E Time lag

Major publications in this area in 2013 are as follows:

1. Lucid, J.D. et al., Estimation of maximum biosolids and meat and bone meal application to a low P index soil and a method to test for nutrient and metal losses. Water, Air and Soil Pollution.
2. Ibrahim, T.G. et al., Loads and forms of nitrogen and phosphorus in overland flow and subsurface drainage on a marginal land site in south east Ireland. Biol. & Environ.
3. O' Flynn, C.J. et al., Chemical amendment of pig slurry: control of runoff related risks due to episodic rainfall events up to 48 hours after application. Environ. Sci Poll.

Figure 2: **Picture of pilot scale denitrifying bioreactor test facility (10*4*1.5 m) containing aquifer and woodchip cells. It has the capacity to inject contaminated water, remediate this water and investigate removal in a holistic way**.

Unsaturated zone time lags: method development using centrifuge

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Introduction

Under the European Water Framework Directive (EU WFD), all surface and groundwater bodies must achieve 'at least good water quality status' by 2015 with the implementation of programmes of measures (POM) in 2012. In Ireland, the agricultural POM is the Nitrates Directive. It is known that there is a 'time lag' between implementation of farm practices and water quality change. Assumptions with respect to the effectiveness of POM should not be made until the estimates of vertical time lags on vulnerable sites are known. SWCCs, in combination with equations from Van Genuchten and Mualem, can be used to elucidate soil hydraulic parameters and hence vertical time lags. Traditional methods such as the pressure plate are time consuming, taking up to several months to determine a single curve. An alternative, which has not been tested in Ireland, is the centrifuge method, which should only take days to determine a single curve. The objectives of this study are to (1) examine the suitability of the centrifuge method as an alternative to the pressure plate method, and (2) to estimate hydrological time-lags for various soil types using this method.

Materials and Methods

Intact soil cores from different textural classes will be collected in the field. To avoid air entrapment, which could potentially distort the SWCCs, cores will be saturated from the base under vacuum using deaerated 0.005 M $CaSO_4$ (Dane and Topp, 2002). Cores are then transferred to bespoke containers and placed in a Sigma 4-15 centrifuge (upper speed = 4500 rpm). Pore liquid is extracted from the saturated soil cores.

The suction exerted on the pore fluid inside the soil core is calculated according to (Gardner, 1937):

$$\psi = \frac{\rho\omega}{2g}\left(r_1^2 - r_2^2\right) \text{ [Eqn. 1]}$$

where ψ is matric suction (kPa), ρ is density of the pore fluid (g cm^3), ω is angular velocity (rads) and r_1 and r_2 are the radial distance (cm) to a point within the soil sample and the free water surface, respectively. The cores will be subjected to centrifugation at various angular velocities corresponding to matric suctions ranging from 0 to -1500 kPa (the permanent wilting point). A porous ceramic column will be inserted at the base of the soil sample to extend the r_2 parameter, thereby increasing the maximum matric suction that can be attained. Centrifugation will be conducted until equilibrium is reached, whereupon the weight of the sample shall be recorded and centrifugation at the next pressure step will begin. The SWCCs obtained from both methodologies will be compared. Finally, Hydrus 1D will use all the SWCC data and vertical time lags will be estimated for a range of soil profiles. Actual weather data will be used as input to Hydrus.

Future plans will be to roll out this high throughput technique to soils in areas presently failing WFD water quality targets. However, this technique due to its speed has many applications e.g. vertical and lateral unsaturated travel

Progress

Work to date includes: 1) literature review; 2) initial method setup including production of custom-made centrifuge adaptors to achieve appropriate suction and 3) initial field site selection at Johnstown Castle and across Ireland based upon fieldwork and analysis of vulnerability/soil maps.

Further developments are expected using the centrifuge technique in combination with nutrient attenuation and soil testing. This will involve a much bigger team.

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Runoff Solutions - Chemical amendments for the treatment of various types of organic fertilizers

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Introduction

Land application of dairy cattle slurry, pig slurry and dairy soiled water (DSW) can result in incidental phosphorus (P) and sediment losses to runoff, as well as emissions of greenhouse gases (GHG). Incidental P and nitrogen (N) losses are dependent on factors such as: the amount and type of fertilizer or manure applied, timing of the rainfall event after application of fertilizer or manure, the volume of runoff generated, antecedent hydrologic conditions and field position, flow path length, vegetative cover and surface slope. Such transfers from agriculture to water can lead to eutrophication of water bodies, particularly if rainfall occurs within 48 h of land application. On-going holistic research at Johnstown Castle uses a combination of batch, laboratory and plot-scale studies to investigate the effectiveness and feasibility of chemical amendments in reducing losses following land applications of various types of agricultural wastewater.

The overall aim of this research is to identify suitable amendments for addition to three types of wastewater (dairy cattle slurry, pig slurry and DSW) in order to reduce surface runoff of nutrients and suspended sediment (SS) in runoff.

Results and Discussion

Taking into account pollution swapping in conjunction with effectiveness, poly-aluminium chloride (PAC) was the most successful treatment for dairy cattle and pig slurries, whereas alum was most effective for DSW. The effectiveness of amendments, however, is soil-specific, and is affected by P buffering capacity and soil composition (O' Flynn et al., 2012). There was no difference in GHG emissions (methane, CH_4; nitrous oxide, N_2O; carbon dioxide, CO_2) following land application of either chemically amended pig slurry (O' Flynn et al., 2013) or dairy cattle slurry (Brennan et al., 2012) and their unamended forms. The validity of the 48-h rule (under SI 610 of 2010) was also interrogated by applying rainfall at time intervals of 12 and 24 h after land application (O' Flynn et al., 2013). Elevated concentrations of P and SS at time intervals of less than 48 h indicated that the current 48-h restriction in Ireland is prudent. It is, of course, likely that as the time interval between application and heavy rain widens further, P losses are likely to decrease due to further interaction with the soil and plant uptake.

Under the European Union (EU) Water Framework Directive (WFD) (EU WFD; 2000/60/EC, OJEC, 2000), the water quality of surface and ground waters should be of 'good status' by 2015. Small amounts of P losses may contaminate large quantities of water and, therefore, incidental losses are of concern, in particular, for flashy events during baseflow conditions. Chemical amendment of dairy and pig slurry ad DSW has been shown to be effective in this regard. Moving from laboratory to field scales allows incidental losses to be simulated using in-situ soil and drainage conditions. The impact of slurry and amended slurry on soil pH, infiltration and runoff volumes, concentrations and loads, are all important when assessing the feasibility of a particular amendment.

Due to high costs involved, use of chemical amendments in slurry and DSW for land application can only be justified on a targeted basis, in particular: (1) soils with high mobilisation potential, STP and hydrological transfer potential to surface water i.e. a critical source area (CSA); and (2) at times when storage capacity becomes the critical factor, i.e. towards the end of the open period when unpredictable weather conditions would normally prohibit slurry spreading. In these cases, the adoption of the use of chemical amendment of slurry as part of a program of measures would be justified. However, chemical amendments should only be used on soils that are suitable. The difference in removals experienced by O' Flynn et al. (2013) point to future refinement of areas suitable to receive chemically amended slurry within a CSA (the area of which changes due to a modification of infiltration and saturation excess areas across rainfall event magnitudes and time based on soil suitability to receive amended slurry.

In future, farm nutrient management must focus on examining all farms within a catchment and identifying areas which pose the greatest risk. It is possible that P mitigating methods, such as chemical amendment of dairy cattle slurry, may be used strategically within a catchment to bind P in cow and pig slurries. These preliminary experiments have shown that PAC and alum have potential as amendments to agricultural wastewaters to reduce surface runoff. Due to the high cost of amendments, their incorporation into existing management practices can only be justified on a targeted basis where inherent soil characteristics deem their usage suitable to receive amended slurry. It is prudent for farmers to adhere, whenever possible, to the 48-h rule (SI 610 of 2010) to reduce the risk of surface runoff of nutrients and sediment.

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The Phosphorus Chemistry of Mineral and Peat Grassland Soils

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Introduction

Phosphorus (P) is an essential nutrient for the agriculture and food sector. In productive agricultural systems it is vital for crop growth and animal health and is supplied by the soil in a plant-available form either through native soil P reserves or fertiliser and manure additions. Where native soil P levels are low, additional P through phosphate fertiliser is essential for increased soil fertility and maximising crop yields. Farmers need to optimise fertiliser use across their farms by applying it to soils where needed so that they can keep production costs low, and minimise potential losses to water. Essential to optimising fertiliser is the soil P test; this is a measure of available P and indicates to farmers and advisors if additional P is required. Furthermore, farmers rely on soil testing to meet the requirements for applying for derogation under the Nitrates Directive. Whilst the soil P test provides an indicative measure of available P advice for farmers there is now a need for soil and site specific advice on to meet the needs of sustainable production on Irish farms. Research on soil phosphorus chemistry has shown that soil P dynamics can vary across soil types depending on factors such as soil pH, organic matter and exchangeable ions. For example, Soils with high organic matter content (>20%) have poor adsorption capacity for P compared to mineral soils and this research has been incorporated into our latest fertiliser P recommendations for grassland.

Research on the dynamics of soil phosphorus in different soil types increases our understanding of how this element behaves in different soils and how this affects availability of P to plants.

Research Objectives

The objective of this research is to further our understanding of phosphorus chemistry in grassland soils so that we can refine our nutrient advice for farmers and offer soil specific recommendations for nutrient efficiency. In addition to understanding how the chemistry works we can use out data to looks at differences across soil types and identify the soil attributes controlling the mechanisms of P uptake and release in soil.

Research Approach

The research approach to this work is based on exploring the P chemistry across a range of soil types through laboratory analysis. Analytical methods that measure rates of P adsorption and release from soil help us to understand how these mechanisms work within the soil matrix. General soil characteristics that can be analysed in the lab such as pH, organic matter content and exchangeable ions, can be correlated with P chemistry and when this soil information is combined it can be used to model P dynamics across different soil types. Laboratory based experiments on soils can provide a lot of information on soil P chemistry and much of the data that describes the process of P uptake in soil can be derived from sorption isotherms. Sorption isotherms produced over a range of soil types can illustrate how P binding energies and sorption capacities differ across soil types. This information helps us to understand how the rate of P uptake differs in soils and identify the factors controlling this mechanism in soil. Our research has shown that soil type factors such as pH and extractable aluminium and iron are highly correlated with phosphorus chemistry in mineral soils and with this data we not only model the sorption mechanism but begin to delineate out specific soil type to develop out soil specific nutrient advice.

Future Developments

Future research will focus on linking P chemistry of major soil groups with nutrient efficiency on farms. Continuing to identify soil attributes that affect P chemistry will refine our predictive models for P sorption and release and will contribute to practical advice for farmers and advisors. Incorporating novel and emerging spectroscopic methods into soil analysis has shown promising results and with further research could provide the basis for more rapid, non-destructive soil P testing methods.

Water Quality

Sequestration of P & N from agricultural wastewaters using natural zeolite amendments and the reuse of phosphorous on nutrient-poor soils

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Introduction

Land application of dairy cattle and pig slurry, as well as dairy parlour washings (referred to as dairy soiled water, DSW) can result in incidental phosphorus (P) losses to a waterbody (Carpenter et al., 1998), which may cause eutrophication. This project examines the effectiveness of natural zeolite to adsorb P and nitrogen (N) from three different agricultural wastewaters: dairy slurry, pig slurry and DSW, as well as synthetic (syn) wastewater. It will also examine the ability of the amendment(s) to desorb the sequestered nutrients for subsequent reuse.

Materials & Methods

Dairy slurry and pig slurry were collected and stored at 10°C prior to testing. The wastewaters were fully characterized for a range of water quality parameters, including total nitrogen, total phosphorus and dry matter. The synthetic wastewater was made up using either K2HPO$_4$ or NH_4Cl. The zeolite was of Turkish origin, and was sieved to a particle size of less than 2 mm prior to conducting the tests.

Adsorption isotherms were conducted by adding 4 g of zeolite to 40 ml of varying concentrations of wastewater and placing the mixtures on a reciprocating shaker for 24 hr at 250 rpm. The supernatant water was tested for ammonium (NH_4-N), ortho-P (PO_4-P) and nitrate-N (NO_3-N) before and after mixing using a nutrient analyser.

Batch studies were carried out by adding zeolite at varying loading rates to 40 ml of the wastewaters.

Results and discussion

Linearised Langmuir adsorption isotherms were established and the results are summarised in Table 1.

Table 1 Linearised Langmuir Isotherms characteristics for adsorption of PO_4-P and NH_4-N.

Slurry Type	qmax (mg/g)		K (mg/l)		R^2	
	PO_4-P	NH_4-N	PO_4-P	NH_4-N	P	NH_4
Dairy	0.31	2.68	1.040	0.058	0.76	0.94
Pig	0.06	7.88	-0.467	0.005	0.73	0.74
DSW	0.18	2.25	0.357	0.014	0.84	0.25
Syn P	0.33	-	0.005	-	0.19	-
Syn NH_4	-	12.1	-	0.003	-	0.85

The effect of zeolite loading on P and N removal was established. Zeolite was effective in reducing NH_4-N (Figure 1), but was not as effective in PO_4-P removal.

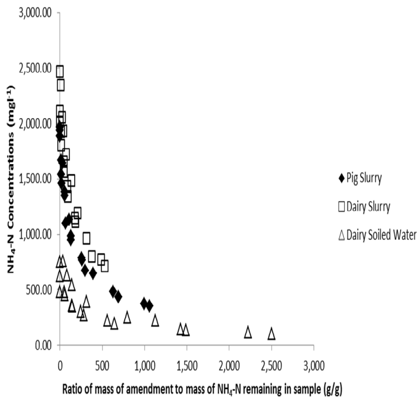

Figure 1 Effect of zeolite loading on NH_4-N removal from pig slurry, dairy slurry and DSW.

Conclusions

Zeolite is an excellent adsorbent of NH_4-N, but is not as effective in PO_4-P removal. Preliminary optimum loading rates for the various slurries have been established. Desorption studies are required in order to establish regeneration possibilities of the nutrients.

Future work will involve incorporation of zeolite into a sequential permeable reactive interceptor to solve pollution swapping in end of pipe solutions.

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Nutrient losses from drained marginal grasslands

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Introduction

Food Harvest 2020 focuses on increasing productivity while enhancing the environmental sustainability of agricultural land. In 2015, the dairy sector is expected to expand with the abolition of EU milk quotas. Around 29% of Irish grasslands have poorly-drained soils, and the water table in floodplains or in areas of perched aquifers is often shallow. In these areas, drainage systems may be installed to allow for expansion. Such a move may lead to increased nutrient losses to aquatic ecosystems. Thus, a greater understanding of the controls (fertilizer inputs and hydrological and chemical processes) on nitrogen (N) and phosphorus (P) losses is needed. This study focuses on grassland used for silage, with poorly drained soils, shallow glacial aquifers and a low soil-P index, for a pre- and post-fertilisation period. Such conditions elucidate the "baseline" controls on flow and nutrient patterns in grassland systems.

Materials and Methods

Food Harvest 2020 focuses on increasing productivity while enhancing the environmental sustainability of agricultural land. In 2015, the dairy sector is expected to expand with the abolition of EU milk quotas. Around 29% of Irish grasslands have poorly-drained soils, and the water table in floodplains or in areas of perched aquifers is often shallow. In these areas, drainage systems may be installed to allow for expansion. Such a move may lead to increased nutrient losses to aquatic ecosystems. Thus, a greater understanding of the controls (fertilizer inputs and hydrological and chemical processes) on nitrogen (N) and phosphorus (P) losses is needed. This study focuses on grassland used for silage, with poorly drained soils, shallow glacial aquifers and a low soil-P index, for a pre- and post-fertilisation period. Such conditions elucidate the "baseline" controls on flow and nutrient patterns in grassland systems.

Results and Discussion

A decrease in plot size (up to 52.2%, Table 1) and water table depth between Plots 5-6 and Plots 1-2 linked to an increase in runoff coefficients (ratio of total flow versus rainfall (Figure 1) for an event, Figure 2) of 16.9 to 42.5%. Runoff coefficients also increased with increasing amounts of rainfall during and before the events. Subsurface drain flow patterns were more variable, but plots with shallow water table had greater increases in runoff coefficients with wetter pre-event conditions.

Increase in flow induced greater P and N losses. Subsurface drain flow usually generated smaller loads of N and P than overland flow (Figure 3). For N, this linked with a smaller volume of water generated by the drains. For P, retention in the soil possibly enhanced this process. Nitrogen losses were dominated by

DON, but the proportion of DIN was higher in the drains. In overland flow, a shallower water table implied a switch from DRP to DUP-dominated water. In subsurface drains, DUP generally dominated with a shallow water table; otherwise PP dominated. Fertilization resulted in DRP being the dominant P fraction in overland flow.

Conclusions

An integrated assessment of controls on flow and nutrient patterns in hydrologic paths are important when assessing management impacts.

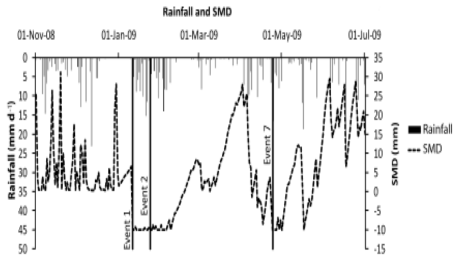

Figure 1. Rainfall and SMD variations for the study period.

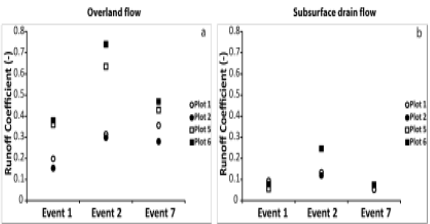

Figure 2. Runoff coefficients (ratio of total runoff (mm) and rainfall depth (mm)) for the events and plots.

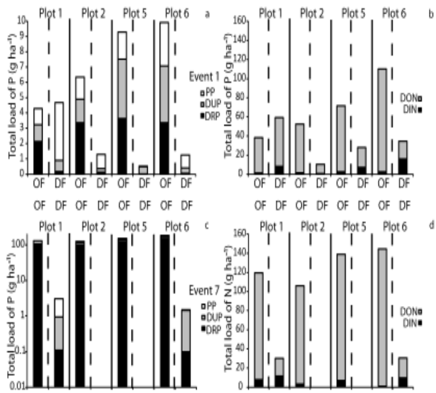

Figure 3. Loads of nutrient losses in overland flow (OF) and subsurface drain flow (DF) for Events 1 and 7.

Acknowledgements

We acknowledge the Department of Agriculture and Food Stimulus Fund 07 525 for financial support.

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Permeable Reactive Interceptors

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Introduction

Food Harvest 2020 has set targets for sustainable intensification of the Irish agriculture. To achieve this goal, a large range of tools need to be developed and tested to better control nutrient inputs and losses in farms. In the coming years, such a sustainable intensification will likely result in an increase in drained land areas. By reducing opportunities for water to interact with soil and subsoil sediments, drainage often increases nutrient losses to water-bodies and greenhouse gases (GHGs) emissions. Such losses, even if they can be reduced through better drainage design, are often inevitable. This project tackles this issue by developing an enclosed remediation technology (Permeable Reactive Interceptor (PRI), Fenton et al., 2013) designed to intercept and remediate mixed-contaminant sources. Initially, denitrifying bioreactors, where a carbon source is used to enhance denitrification in water, are tested in lab and field-controlled environments. This provides the basis for the development of a real farm scale PRI design 1) targeting mixed contaminant sources (i.e. phosphorus (P) in addition to nitrate (NO_3^-)), 2) producing limited pollution swapping (i.e. contaminants produced by the PRI) and 3) favoring nutrient and carbon recycling.

Materials and Methods

A preliminary lab column study (0.8 m long columns, Figure 1) aimed at testing the NO_3^- removal capabilities of mixture of different carbon media and sediments, by circulating water spiked with NO_3^- at different flow rates and sampling its chemistry at the inlet and outlet and at ports along the columns (Healy et al., 2012). Then, a field-scale semi-controlled bioreactor was installed at the Teagasc Environment Research Centre. A 7 x 3 x 1.5 m tank was divided in seven cells alternatively filled with fine sand and willow woodchip and open on alternate sides, and NO_3^- spiked water was pumped into the tank (Figure 2). This novel design allowed for manipulating flowpath lengths to optimize denitrification with limited pollution swapping. Variations in hydraulic gradients, hydrochemistry (including dissolved gases) and GHG emissions along flowpaths were monitored using multi-level samplers, wells and static chambers. A tracer test using bromide allowed for water transit times to be assessed and microbial sampling was undertaken. Finally, a PRI is being implemented at the outlet of a karstic spring draining >80% of the area of the Kilworth farm (Co. Cork), where a high resolution NO_3^- sensor provides evidence of long-term breaching of NO_3^- maximum admissible concentrations (11.3 mg L^{-1} as NO_3-N). A novel inlet design distributes the spring discharge towards a maximum of three PRIs, therefore tackling the issue of temporal variations in spring flow, either following storm events or across seasons. Zeolite will be used as an additional remediation sequence to sequestrate any ammonium (NH_4^+) or P either lost from the spring or produced by the PRIs; when saturated with nutrients, such a media can be used as a fertilizer.

Progress

The column experiment showed that all carbon media performed well in terms of nitrate removal, with most of the remediation occurring in the first quarter of the columns. Nevertheless, pollution swapping always occurred, either due to solute leaching from the media (e.g. P leaching) or to biogeochemical activity (e.g. NH_4^+ production through dissimilatory nitrate reduction to NH_4^+ in areas of high C/N ratios or methane (CH_4) production at low redox potential). Similarly, in the field-scale semi-controlled bioreactor, full denitrification in the first two cells was linked to nitrous oxide (N_2O) production and losses to the atmosphere, while further downgradient, large production of NH_4^+, carbon dioxide (CO_2) and CH_4 was observed. A tracer test allowed for linking horizontal and vertical redox gradients and leaching patterns to variations in water and solute transit times across the bioreactor. These results suggested that even if this novel design can allow for manipulating transit times to achieve full denitrification and low pollution swapping, additional remediation sequences such as soil capping might be needed to prevent N_2O losses in the denitrification area. At the Kilworth farm, an initial experiment using a small scale bioreactor aims at assessing denitrification rates using willow woodchip to appropriately dimension the full scale PRIs. An additional NO_3^- sensor at the outlet of the PRIs, as well as a total dissolved gas probe and manual hydrochemical sampling, are implemented to assess dynamics of denitrification and pollution swapping.

Figure 1. Column study setup

Figure 2. Semi-controlled bioreactor

AQUAVALENS: Protecting health by improving methods for the detection of pathogens in drinking water and water used in food preparation

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Introduction

Safety of drinking water is critical for the protection of human health. The Galway city *Cryptosporidium* outbreak in 2007 highlighted the economic implications of pathogenic contamination of drinking water. The foodborne outbreak of *E. coli* O104:H4 in Germany where over 50 people died, also highlighted the importance of microbial contamination in food processing. Traditionally microbial organisms indicative of faecal contamination (*E. coli*) have been used by water providers to identify water unfit for consumption. Early detection of pathogenic organisms in water used as drinking water or in food production is required to safeguard human health. This recently funded multidisciplinary project is the first collaborative project between the environment soils and land use (Johnstown Castle Environment Centre) and food safety (Ashtown Food Research Centre) departments

AQUAVALENS focuses on developing suitable advanced detection methods that harness the advances in new molecular techniques to permit the routine detection of waterborne pathogens and improve the provision of hygienically safe water for drinking and food production that is appropriate for large and small systems throughout Europe. Whilst in recent years there has been considerable developments, especially in molecular technology, very few systems are available that meet the needs of water providers. Consequently, and unless it proves essential, rather than necessarily develop new technologies, the key focus will be to adopt and, where appropriate, adapt existing technologies to develop these detection systems.

Project objectives

The overall aim of AQUAVALENS is to reduce the incidence of waterborne and foodborne infectious diseases and improve public health for all citizens of Europe by developing new techniques for monitoring water quality that are robust and suitable for routine application by those responsible for supplying safe food and water for consumption.

Primarily this will be achieved through the development, validation and application of quantitative detection and identification technologies for waterborne microbial pathogens based on nucleic acids.

Teagasc are leading work package 12; the objectives of which are:

1. Use the technologies developed within other work packages for the assessment of pathogens in irrigation water, processing of ready to eat fruit and vegetable products and bottled water

2. Obtain knowledge of the occurrence and abundance of pathogens during processing activities

3. Assess the use of results from the developed platforms to inform water quality management decisions.

4. Provide methods and tools to support control in the bottled water industry and for pre and post-harvest processing of fresh produce

Methodology

1. Implementation of developed technologies in assessing irrigation water quality. Irrigation water will be spiked with non harmful strains of key pathogens (pathogenic *E. coli* and *L. monocytogenes*). In addition non spiked irrigation water will be analysed at sites across Europe using new technologies over a period of one year.

2. Implementation of developed technologies in the ready to eat food industry. Samples of post harvest processing water (either on farms or central processing facilities) will be collected at representative sites across Europe and new technologies will be compared against conventional methods (source water and water post washing).

3. Implementation of developed technologies in the bottled water industry. Samples will be collected at the water source and after bottling.

Expected results

This project will identify which of the developed technologies would be suitable for quantifying a range of pathogenic organisms in water used for consumption and food processing.

It will identify risk factors associated with pathogen occurrence in different water supply types.

Acknowledgments

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Analysing persistent organic pollutants (POPs) in groundwater

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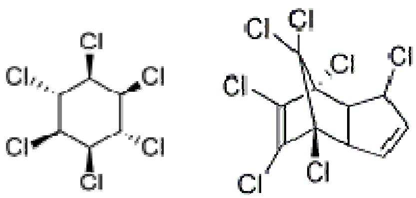
Introduction

In 2009 the Stockholm Convention listed several organochlorine active substances (a.s.) once used in plant protection products (PPPs) as persistent organic pollutants (POPs). These included the insecticides lindane and heptachlor which were banned in Ireland as PPP in the 1980's (Figure 1). The physio-chemical properties of lindane and heptachlor render them persistent in the environment for several years. Whilst in environmental compartments, such as water and soil, these a.s can exert their detrimental toxic effects to unintended organisms. They can also degrade to more toxic and stable compounds. Heptachlor degrades to the transformation products (TPs) *exo-* and *endo-*heptachlor epoxide, with *exo-*heptachlor epoxide the more stable and persistent form in the environment.

As part of the European Union Water Framework Directive (WFD) all water bodies, including groundwater, must achieve good chemical status by 2015.



(a) (b)

Figure 1. The active substances (a) lindane and (b) heptachlor.

A quantitative analytical method was developed, validated and applied to groundwater samples to help achieve the requirements of the WFD and in accordance with permitted limits stipulated in EU Drinking Water legislation 98/83/EC. The permitted limits for lindane is 0.1 µg/L and 0.03 µg/L for heptachlor and its two TPs.

Development and validation

Solid phase microextraction was optimized for the choice of fibre, NaCl saturation, extraction temperature and extraction time. Polyacrylate SPME coatings gave the best recovery for all four compounds of interest (Figure 2), 30% w/v NaCl was the optimum ionic strength for the four compounds, and a SPME extraction temperature of 50°C and extraction time of 45 min gave the best precision for fortified water samples.

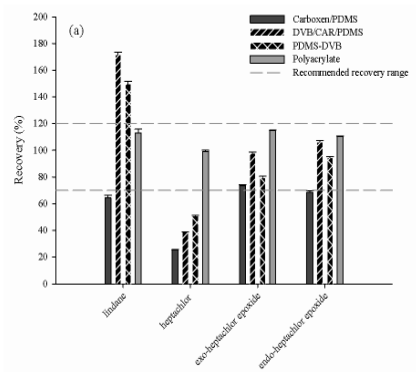


Figure 2. Fibre choice for SPME optimization.

The method was validated in accordance with EU Directive 2002/857/EC. Calibration curves were linear and not forced through the origin with correlation coefficients of 0.9936 or greater. Peak to peak signal to noise ratios for each of the five points along the calibration curve were greater than 10. The retention times of each analyte did not change more than 2.5% during the within laboratory repeatability (WLr) study of 33 samples at three concentrations. Recoveries from the WLr study for all four analytes of interest ranged between 96-101%.

Method procedure

Groundwater samples collected using low-flow purging techniques were analysed within five days of receipt to the laboratory. Five mL of sample was transferred into a 10 mL headspace vial with 2.5g of NaCl.

Clean up was achieved using SPME carried out on a CTC Combi-pal auto-sampler at 50°C for 45 min with agitation at 250 rpm. Desorption of the fibre took place in splitless mode for 4 min following extraction. The split was initially on at a ratio of 10 and then turned off following injection. After one min the split was turned on at a ratio of 10 for four min. Following desorption, the fibre was baked out at 250 °C to prevent cross contamination. Disposable PA SPME fibres lasted 51 injections including a six-point calibration curve (Figure 3).

Detection and quantification was achieved using a GC-MS ion trap in electron impact mode with selective ion storage (SIS). Chromatographic separation was achieved using a Zebron ZB-5 capillary column (30m × 0.25 mm I.D., film thickness 0.25) with Grade A Helium used as a carrier gas at 1.0 mL/min. The oven temperature was set as follows: 50°C held for two minutes and then increased to 280°C at 8°C/min.

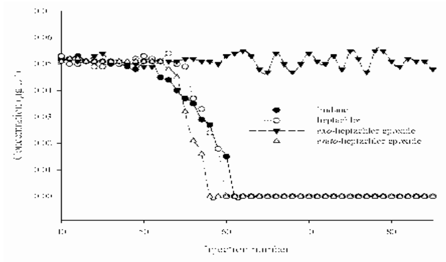


Figure 3. Fibre longevity following repeated injections of fortified samples at 0.05 µg/L.

SIS optimised the MS by using only the dominant ions for each compound based on their fingerprint. Table 1 details the quantification ions used and the main fragmentation ions.

Table 1. Characteristic ions used for SIS.

Analyte	Quantification ion (*m/z*)	Main fragmentation ion (*m/z*)
Lindane	183	148+109
Heptachlor	272	100+237
exo-hetachlor epoxide	353	237+81
endo-heptchlor epoxide	253	183+217+135

Acknowledgements

This work was funded by the Department of Agriculture Research Stimulus Fund 2005 (RSF 07-544).

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Agricultural Catchments Programme

The Agricultural Catchments Programme: Evaluating policies on nutrient management and water quality at the catchment scale

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Introduction

Prudent use of plant nutrients such as nitrogen (N) and phosphorus (P) is essential to optimize farm outputs and maximize profits. Farmers must also take care to minimise the risk to water quality from potential nutrient losses in managing their farms. These losses can cause eutrophication (over-nourishment and leading to ecological changes and decreases in amenity. Excessive N in drinking water can render it unsuitable for consumption. The EU Nitrates Directive was transposed into Irish law in 2006 and regulates the management of N and P with the aim of maintaining productivity whilst reducing the risks of their loss to water.

In order to meet cross compliance requirements for single farm payments farmers must comply with the package of mitigation measures laid out in the National Action Programme (NAP) introduced under the Nitrates Directive. The measures include for example:

- an organic N limit of 170 kg ha^{-1} with a derogation available to farm at 250 kg ha^{-1} N granted subject to environmental conditions
- N and P applications limited to crop requirement and closed periods for fertilizer and manure applications
- minimum manure storage requirements and buffer zones for applying organic or chemical fertilisers along water courses.

These measures are recognised as the agricultural contribution towards helping to implement the Water Framework Directive objectives in Ireland. Implicitly, the evaluation included an investigation of the efficacy of the derogation.

On an EU level, it is proposed that the NAP in Ireland is a highly regulated and progressive programme of measures to mitigate diffuse pollution from agricultural sources. The hypothesis tested in the ACP is that the NAP is addressing these issues satisfactorily.

Phase 1 of the Programme

The first four-year phase of the Agricultural Catchments Programme (ACP) was completed at the end of 2011. It was concerned with the establishment of the experiment, and providing an agri-environmental baseline of agricultural activity and water quality response in the years following the implementation of the measures in the NAP.

The ACP integrates bio-physical with socio-economic processes in the evaluation of the impacts of NAP measures. Conducted at the catchment scale, the evaluation is more concerned with the water quality response of the package of NAP measures in agricultural catchments, rather than individual measures. However, the status of some of the individual measures, as obligated under the NAP, is being investigated.

While Phase 1 of the ACP provided a project design and base line, Phase 2 is concerned with validation (of assertions from Phase 1), modelling (key bio-physical and socio-economic processes) and assessment of policy impacts.

Six catchments were instrumented to monitor nutrient sources and loss pathways to surface and groundwater bodies. Intensive biophysical monitoring was conducted according to a common experimental design with the aim of evaluating the effect of changes in farm management practices on the transfer of nutrients from source to water and their impact on water quality. Measurements, modelling and socio-economic studies were used to evaluate the efficacy of the measures and aspects of their cost effectiveness and economic impact.

Farmer attitudes to implementation of regulations, adoption of nutrient management practices, provision of ecosystem services and the economic impacts of efficient nutrient management were also investigated.

Outcomes

The accompanying articles provide an overview of the results from Phase 1 which have been published in a series of peer-reviewed scientific papers.

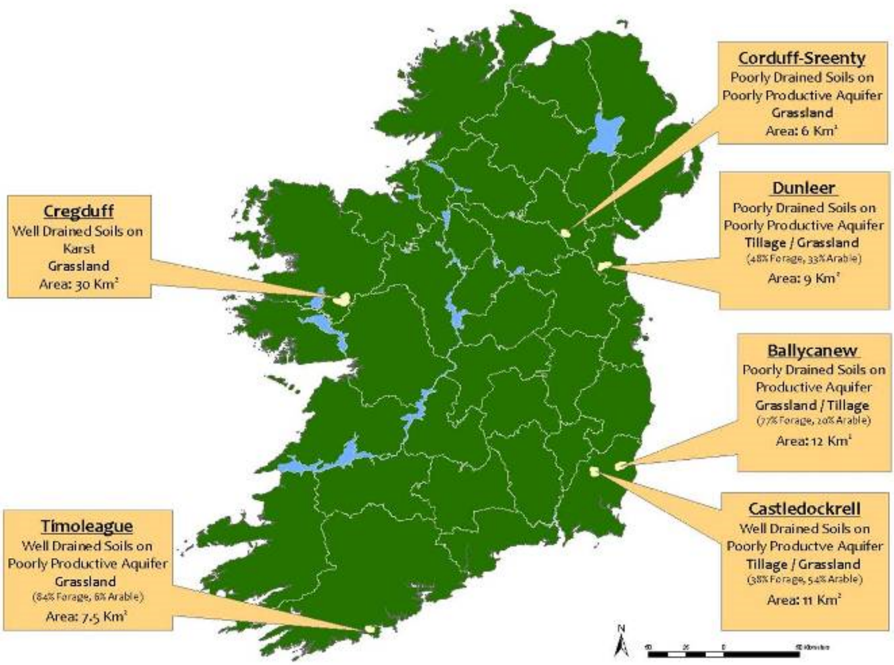

Figure 1. Location and description of the six catchments

Nutrient transfer pathways

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Introduction

Understanding how nutrients may be mobilised and transferred *via* different pathways from source to receiving water bodies is important as this knowledge will improve management strategies and measures to abate nutrient transfer.

The objective of this work is to link nutrient sources with the movement of water through the pathways from field to streams leaving the catchments 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 water recharge 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.

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.

Materials and Methods

This work combines detailed pathway studies from focused study sites (Fig. 1) with catchment integrated studies in the stream outlet. The focused study sites consists of topographical transects of multilevel monitoring wells equipped with groundwater leveloggers. Water from the wells and from drains, ditches and streams are sampled for water quality analysis on a monthly basis. The catchments outlets are equipped with flat-v weirs, leveloggers and bankside-analysers for high temporal resolution stream water discharge and quality measurements. In each catchment rainfall is measured at two sites and standard meteorological parameters at one site.

End Member Mixing Analysis was applied to baseflow conditions at the focused study sites and a *Loadodgraph Recession Analysis* method was introduced, to identify and quantify integrated delivery transfer pathways for events.

Figure 1. Focused study site for nutrient transfer pathway in Co. Wexford.

Results and Discussion

While it was generally found that quick-flow P transfer pathways dominated poorly drained catchments and below-ground N transfer pathways dominated in well-drained catchments, substantial below-ground P loss was found in well-drained catchments and poorly drained catchments produced N loss via ephemeral ditches. This suggests that below-ground transfer pathways need to be considered when mitigating both N and P loss to receiving waters and highlights the importance of considering catchment-specific nutrient transfer pathways when assessing mitigation measures. In catchments with permeable soils and geology, measures targeted at nutrient sources (soils and nutrient inputs) may be a better long term strategy than those targeted at overland pathways such as buffer strips and critical source areas for runoff (Mellander et al. 2012a)

For a karst aquifer it was found that high P source and aquifer vulnerability did not elevate P in the emergent groundwater due to the attenuation processes within small fissure transport pathways (Mellander et al. 2012b).

Conclusions

In catchments with permeable soils and geology, measures targeted at surface nutrient sources may be a better long term strategy than those targeted at overland pathways such as buffer strips and critical source areas for runoff. In such catchments, baseflow can deliver substantial loads of both N and P, which may persist into ecologically significant periods and a long recession in water flow and nutrient delivery from an event may become significant for the ecological status of receiving rivers. The definitions of risk and vulnerability for P delivery in karst systems need further evaluation

Acknowledgements

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

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Nitrogen Attenuation along Delivery Pathways in Agricultural Catchments

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Introduction

Nitrate is regarded as one of the dominant contaminants affecting freshwater quality worldwide. Increased awareness over the detrimental effects to both human health and environmental quality has resulted in the implementation of the Nitrates Directive into Irish law. The directive introduces measures to reduce the effect of agriculturally derived nitrogen on the environment.

The nitrate ion is both highly mobile and dynamic within a groundwater system. In order to evaluate the success of these measures therefore, it is essential to understand the evolution of nitrogen as it passes through subsurface pathways from source to receptor.

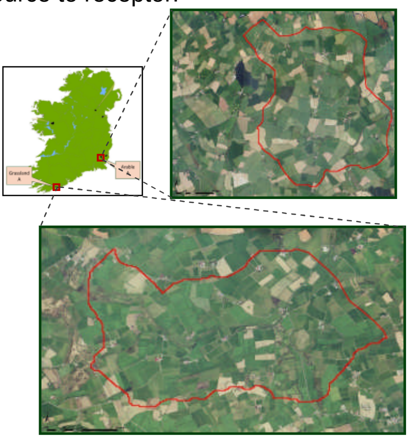

Figure1: Study catchments location

This PhD research project is being undertaken from 2012 to 2016 in two intensively managed catchments in Co. Wexford and Co. Cork (Figure 1). Both catchments are dominated by well drained soils and relatively permeable geology but have contrasting prevailing land-use.

Objectives

The focus of this work is to investigate nitrogen attenuation processes within the saturated aquifer and stream hyporheic zones of four instrumented hill slopes. Each hillslope contains three multilevel monitoring wells; penetrating various geological horizons and spanning the entire length of the hillslope. The specific aims of the project are to:

❖ Calculate the discharge of groundwater from the top of the hill slope to its base where it insects with the stream hyporheic zone (*Year 1*).

❖ Describe the nitrogen loads within each hillslope.

❖ Investigate the capacity for denitrification within the saturated zone.

❖ Identify the degree to which hyporheic processes act to attenuate nitrogen.

Methods (Year 1)

<u>Groundwater flow</u>

The groundwater discharge through each well transect will be calculated numerically using MODFLOW. Figure 2 illustrates the basic outline of the modelling approach.

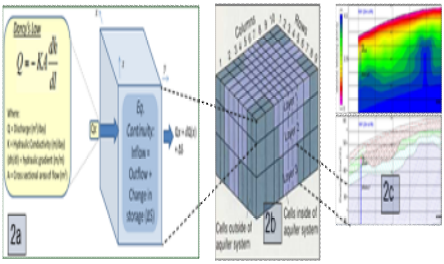

Figure 2: Input parameters for the grid based approach to groundwater modelling

High resolution geophysical data will be used to create a 3D groundwater flow grid (Figure 2c). MODFLOW is a cell based approach, where the governing equations of groundwater flow are constrained within each model node (Figure 2b). The model applies finite difference theory to the partial differential groundwater flow equations and iteratively calculates discharge through each cell, i.e. the value of the one cell determines the value in all other cells in contact with it.

Figure 2a illustrates the parameters required for the calculation of groundwater flow through each model cell. Saturated hydraulic conductivity (K_{sat}) will be derived from a series of slug tests within each geological layer (Figure 3).

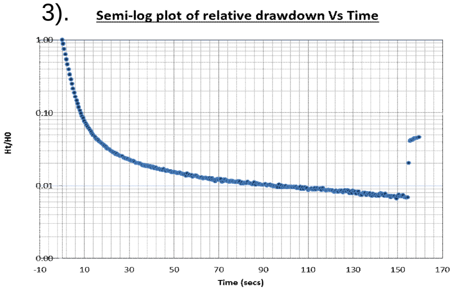

Figure 3: Normalised hydraulic head vs. time from slug test experiment

Cross sectional area of flow (A) will be calculated from geophysical x,y & z data, while temporal horizontal and vertical hydraulic gradient data is provided by pressure transducers installed within each piezometer.

Methods (future work)

- Time Domain Reflectometry probes will be installed within the unsaturated zone allowing the response of the aquifer to recharge to be calculated.

- Groundwater discharge calculations from year one will be combined with monthly low flow physic-chemical data to estimate the nitrogen loads from groundwater.

- "Push pull" tests will be undertaken at each piezometer transect allowing the nitrogen attenuation capacity of the aquifers to be determined. The method consists of the pulse type injection of a test solution (containing a conservative and reactive tracer) followed by the extraction of the test solution/groundwater mixture from the same well.

- A network of multilevel mini-piezometers will be installed in the streambed adjacent to the well transects. Pressure gradient data will be used to map the flow path direction and magnitude within the streambed. Nitrogen species data and environmental parameters affecting the rate of attenuation will be interpreted along each flow path.

Acknowledgements

This study is part of the Agricultural Catchments Programme funded by the Irish Department of Agriculture, Food and the Marine and the Teagasc Walsh Fellowship Scheme.

Nutrient delivery to streams, and stream biological quality

Alice Melland, Phil Jordan and the ACP team

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Introduction

In Ireland, the chemical and biological quality of streams is compared with EU targets. The Agricultural Catchments Programme is measuring these water quality elements and calculating nutrient fluxes in streams to firstly compare with EU standards and to secondly identify linkages in space and time with farm practice. Where these links occur, there is potential for farm management, including the Nitrates Directive National Action Programme (NAP) measures, to influence water quality.

Materials and Methods

State-of-the-art technology was used to measure total phosphorus (TP), total reactive phosphorus (TRP), total oxidised nitrogen (TON), turbidity (as NTU), electrical conductivity and temperature continuously at sub-hourly intervals in bankside kiosks (Fig. 1) at the outflows of six catchments. Low profile Corbett V-weirs combined with customised stage-discharge rating curves were used to calculate stream discharge.

Longitudinal stream sampling was conducted monthly during baseflow to identify spatial variations in stream water quality. Twice yearly surveys (late spring and late summer) of benthic macroinvertebrates and diatoms as well as fish and hydromorphological surveys were conducted by the UCC Aquatic Services Unit.

Results and Discussion

Nutrient loss

Annual TP exports were low to moderate and not defined by landuse in contrast to models which use export coefficients. For example, two grassland catchments exported 0.541 kg/ha/yr and 0.701 kg/ha/yr and the two arable catchments exported 0.175 kg/ha/yr and 0.785 kg/ha/yr (Jordan et al. 2012). Suspended sediments (3 t/km^2 to 15 t/km^2) were low to moderate despite high rainfall in the two arable catchments. Higher losses of TP and sediment were associated with higher rainfall and with catchments with less permeable soil and geology (Melland et al. 2012).

Figure 1. Water quality is analysed continuously by instruments housed on the stream bank.

Point and diffuse nutrient sources

Longitudinal stream and multi-depth groundwater testing identified both agricultural and non-agricultural potential point source surface inputs and little groundwater input of TRP to one of the arable catchment streams (Fig. 2, Melland et al. 2012). High TRP concentrations during biologically sensitive summer periods were attributed to loss of dilution of these rural point sources (Jordan et al. 2012).

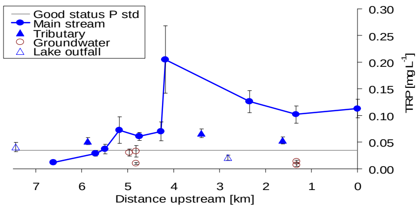

Figure 2. Spatial trends in average TRP concentrations in stream baseflow and in groundwater.

Seasonality and NAP measures

Due to a close relationship between stream flow volume and stream nitrate flux, the nitrate-N flux lost during the closed slurry spreading period (approximately 25% of the year) was disproportionately high at 47 to 57 % of the 2009-10 and 2010-11 annual fluxes in the two arable catchments (Fig. 3). Similar to TP, the results support the utility of a closed period for avoiding incidental losses.

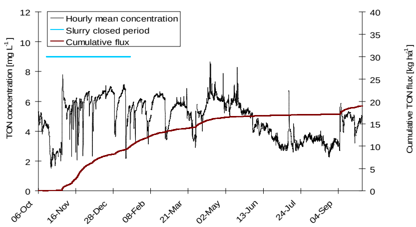

Figure 3. Temporal trends in TON concentration and flux in 2009-10 in a partially permeable arable catchment.

Stream biological quality

The 'potential' WFD macroinvertebrate status ranged from Poor to High (Q-value 3 to 4-5) across sites, seasons (late spring and late summer) and years. Whilst good status was attainable in the intensively farmed catchments, the karst limestone catchment was the only catchment (on average) without trophic impact. During late spring samplings there was often an improvement in biological health, despite these samplings following the winter periods of proportionately highest nutrient loss to streams, but 50 - 60% of sites remained 'at risk' of not reaching EU 'good' water quality targets (unpublished data).

Conclusions

Further decreasing nutrient and sediment losses from each catchment will likely be more successful if nutrient and sediment losses during higher flows can be attenuated, as is targeted by several of the NAP measures. The summer impact of poor dilution of point sources, however, will not be alleviated under NAP regulations.

Acknowledgements

This work is funded by the Irish Department of Agriculture, Food and the Marine. The dedication of ACP staff (technicians, technologists, advisors, administration) and postgraduate students, and the collaboration of over 300 catchment farmers was essential and is appreciated.

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Socio-economic studies of nutrient management

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Introduction

To-date the Agricultural Catchments Programme (ACP) has explored a range of socio-economic issues and laid the groundwork for longer-term studies concerning farmer attitudes, economic impacts and uptake of nutrient management practices. Research to-date has used data gathered as part of the ACP as well as national datasets, and is outlined below.

Materials and Methods

With the ACP framework, Q methodology was used to investigate farmer subjective opinions of the operation of the EU Nitrates Directive regulations after the first 4 year National Action Programme phase. Q methodology also explores the level of acceptance and refutation of measures from the view of farmers own knowledge and experience of land stewardship. Using data generated from a survey of catchment farmer with land adjacent to a watercourse, the willingness of farmers to adopt a riparian buffer zone was investigated. The research was based on a proposal to install a 10 meter deep riparian buffer zone on a five year scheme and the analysis was based on principal components analysis, contingent valuation methodology and a generalized tobit interval model.

Using Teagasc National Farm Survey (NFS) data, research was undertaken to investigate whether there is room to reduce chemical nitrogen and phosphorus fertilizer applications and imported feeds by exploring the extent to which application rates may have exceeded optimum levels using data envelopment analysis and productivity analysis methodology. The investigation concentrates on specialist dairy and tillage farms in the Republic of Ireland, stratified by land use potential. Using NFS data and a multinomial model the willingness of the farming population to import pig and poultry manures was investigated. Finally a survey of manure application and storage practices was undertaken across farms in the National Farm Survey in 2009.

Results and Discussion

Results from Q methodology analysis indicate 4 main opinion groups. A "Constrained Productionists" group remain unconvinced about the appropriateness of certain EU Nitrates Directive measures from a farm management, environmental and water quality perspective. A second group, "Concerned Practitioners", share these concerned but are generally more positive regarding other farm management and environmental benefits accruing from the regulations. A third group, "Benefit Accepters", indicated quite an environmentalist position and are generally very positive towards regulation implementation and associated environmental and farm management benefits. The final group, "Regulation Unaffected", have some concerns but are mostly unaffected by the regulations. Results suggest skepticism remains around the validity of certain measures, especially, in the area of temporal farm practices, however, there is acceptance among some farmers of environmental benefits accruing from the regulations.

Results indicated that famers' willingness to supply a riparian buffer zone depended on a mix of economic, attitudinal and farm structural factors. A total of 53% of the sample indicated a negative preference for provision. Principle constraints to adoption include interference with production, nuisance effects and loss of production in small field systems. Of those willing to engage with supply, the mean willingness to accept based cost of provision for a 10 metre riparian buffer zone was estimated to be €1513 ha^{-1} per annum equivalent to €1.51 per linear metre of riparian area.

Results across specialist dairy and tillage farms in the NFS demonstrate some inefficiency in the utilisation of nitrogen and phosphorus fertilizers compared to benchmark farms across these systems. Average over application of chemical fertilizers ranged from 22.8 to 32.8 kg N ha^{-1} and 2.9 to 3.51 kg P ha^{-1} in 2008. Potential cost savings on chemical fertilizers across all systems on average ranged from €38.9 ha^{-1} to €48.5 ha^{-1}. Additionally, potential cost reductions on imported feeds of €65 to €84 per livestock were indicated for dairy farms versus efficient cohort benchmark farms. Average excess of imported feedstuffs equated to 5.82-7.44 kg LU^{-1} of N and 0.92-1.17 kg LU^{-1} of P.

Based on a nationally representative survey (NFS) between 9 and 15 per cent of farmers nationally would be willing to pay to import poultry and pig manures manure respectively and a further 17 to 28 per cent would import if offered on a free of charge basis. Demand is strongest among arable farmers, younger farmer cohorts and those of larger farm size with greater expenditure on chemical fertilizers per hectare and who are not restricted by an EU Nitrates Directive derogation.

An NFS based nationally representative survey (Hennessy et al., 2009) of manure application and storage practices on farms in 2009 estimated that 52% of all slurry was applied between the end of the closed period in January and April 30th in total volume terms. This contrasts with a 2003 survey which found that 35% of slurry was applied in the spring season (Hyde et al., 2008). Across all farm systems approximately 71 percent of slurry was estimated to be applied to conservation ground (hay/silage), 26 percent to grazing land with the remaining 3 percent applied to maize or tillage crops. These figures indicate a trend toward greater slurry application on land used for livestock grazing compared to a 2003 survey where 80 percent of the slurry applications was to hay or silage land and 16 percent was on grazing land. The report also indicates an increasing number of farmers are starting to engage with newer slurry application technologies. A total of 6 per cent of dairy farmers reported using the trailing shoe method of slurry application.

Acknowledgements

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Nutrient Sources in Agricultural Catchments

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Introduction

Farm nutrient management is primarily focused on increasing farm productivity. However, nutrients can form a source for loss to water or air which can have both economic and environmental implications. Optimising nutrient use can both increase farm productivity and decrease environmental impacts; a win-win scenario leading to more sustainable farming. The nutrient SOURCES component of the Agricultural Catchments Programme (ACP) is concerned with assessing the management, magnitude and mobilisation potential of N and P sources in agricultural catchments, assessing how the Good Agricultural Practice (GAP) measures affect these sources and how this, in turn, affects farm productivity and nutrient mobilisation and transport.

Materials and Methods

Some of the SOURCE research areas are highlighted here.

- Soil nutrient census: characterising the spatial distribution of soil P status (Fig. 1) and also K and pH status at a resolution of < 2 ha. Excessive soil P status can be an indicator of P loss risk. The census is being repeated to assess how soil P status has changed over 3-4 years.

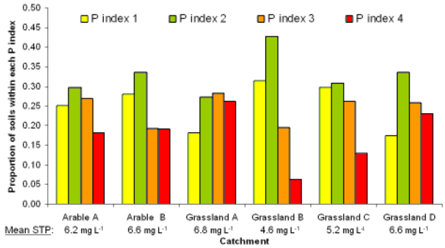

Figure 1. Proportion of soils in each soil P index.

- Nutrient management and flows: fertilizer use, feed, fertilizer and livestock import and export and farm products exported are recorded at the field and farm scale. This information is used to calculate N and P balance and use efficiency at the field, farm and catchment scales (Fig. 2).

- Catchment soils: characterized physically (soil texture, bulk density etc) and chemically (pH, organic matter, P sorption/desorption, etc). Soil-landscape models are being developed based on field soil survey, topographic analysis of digital elevation models (DEMs) and other data sources.

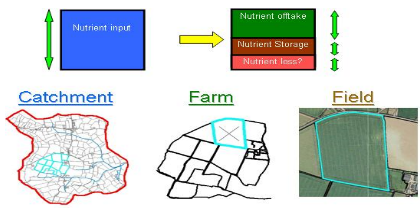

Figure 2. Nutrient balances at the catchment, farm and field scales.

Critical Source Areas (CSAs): a range of CSA factors are being investigated to determine the key factors that would allow mapping of CSAs, e.g. soil P status, soil type, slope and hydrologic connectivity to water receptors. High resolution (25 cm) Light Detection and Ranging (LiDAR) DEMs are being applied for this purpose.

Results and Discussion

Some of the SOURCE research results are highlighted here (Wall et al. 2013).

In 5 ACP catchments, between 6 and 26 % of soils had excessive P status (Index 4), showing the legacy of historic P surpluses (Fig. 1). Between 74 and 94 % had optimal P status, or lower. For the grassland catchments, soil P status reflected land use intensity with 26 % of soils in Index 4 in the intensive dairy catchment, decreasing to 16 and 6 % with decreasing land use intensity in the other two grassland catchments. The arable catchments had a similar proportion in Index 4, at 18 and 19 %.

Large spatial variability was found in soil P status both across a catchment and between individual fields on the same farm (Fig. 1). This indicates that there is plenty of scope to correct nutrient imbalances with better nutrient management and redistribute P to lower status soils, potentially increasing P use efficiency and decreasing P loss risk.

Higher P exports from two catchments were attributed to lower soil permeability in these catchments, leading to flashier runoff (and P mobilisation into fast pathways), more so than to landuse or the magnitude of the P source (soil P status). This shows the importance of soils and hydrology in determining risks of nutrient loss to water.

Field-level inorganic P fertiliser inputs revealed a large range across fields, from zero to maximum rates (55 kg ha^{-1} for grassland and 68 kg ha^{-1} for arable crops) in excess of the maximum allowed under the NAP. These excessive applications are likely to increase the risk of P loss.

Trends in soil P status, fertiliser P inputs and surplus P availability can be misrepresented at larger scales (national, catchment, farm scale) and may be better represented at smaller scales (field, soil process scale) where management and soil factors can be considered.

Conclusions

The ACP will continue to monitor nutrient sources in the catchments and assess the impact of the GAP measures. Areas of focus will include CSA modelling, changes in soil P status over time and sustainability of intensive dairy production under derogation, for example.

Acknowledgements

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

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Sediment dynamics in small agricultural catchments

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Introduction

Sediment is an essential component of freshwater ecosystems, providing many key nutrients for good ecological functioning. Excessive sediment delivery to rivers and high suspended sediment loads during flood events can however cause degradation of habitat quality through blocking of spawning gravels, resulting in decreased biodiversity.

Accelerated delivery of sediments to streams is commonly caused by intensive land uses such as forestry and agriculture. Bare soils (Figure 1) and/or poaching of river banks (Figure 2) destabilize soils, increasing erosion risk during rainfall events. Further intensification as suggested in the Food Harvest 2020 strategic initiative may implicate the achievement of Water Framework Directive water quality targets (2000/60/EC). WFD aims to achieve “good” ecological and chemical water quality by 2015, prevent longer term degradation of water quality and consequently prioritize the management of sediment inputs from agriculture.

Figure 1. Bare arable soil after ploughing.

Figure 2. Poaching of channel bank.

This study aims to address the need to better understand sediment transport in intensive agricultural catchments across a range of land uses. Specifically the study addresses the following issues:

- Does land management impact the magnitude and duration of sediment events in rivers?
- How much sediment is transferred from the land surface to watercourses?
- Can sediment fingerprinting be used to quantify the relative contribution from upstream sources on the basis of hillslopes versus channel banks or according to land use patterns
- How does the contribution from sediment sources alter seasonally?
- Do non-agricultural sediment sources contribute to in-stream sediments? (e.g. road and fluvially eroded channel bank sediments)

Materials and Methods

High resolution sediment flux data are collected by the Agricultural Catchments Program, Teagasc in six intensive agricultural catchments in Ireland. The current project focuses on three catchments, over a gradient of land-use.

Sediment quantity

Sediment quantity is assessed through high-resolution sediment flux monitoring using calibrated proxy turbidity readings. The event, seasonal and annual responses at multiple catchment positions provides data regarding the spatial availability, magnitude and duration of events.

Soil loss

Radionuclide assessments of soil cores from catchment fields using caesium (137-Cs) indicate medium term soil loss rates. Comparison of core transects from contrasting land uses will indicate affects of land-use type on soil loss.

Source tracing/ sediment fingerprinting

Characterization of all potential sediment source areas through geochemical, magnetic and radionuclide analysis create distinct fingerprints for each source type, i.e. land-use, bank. Assuming in-stream sediment are a mixture of these sources, analysis of multiple passive sediment samplers (Figure 3) provide spatial and temporal source area information.

Figure 3. In-stream suspended sediment samplers.

Results and Discussion

Better quantification of in-stream sediments using high-resolution data will highlight the impact of land-use on the transfer of particles to watercourses. Our research on sediment fluxes, loads and yields will provide event, seasonal and annual data for national and international comparison of water quality status.

Land-use specific soil loss data will provide important information on the key erodible areas and additionally, the ability of the landscape to retain eroded particles in interception and buffering features. This is achieved through comparison of soil loss from the land and receipt of sediment in-stream.

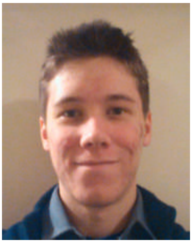
Identification of sediment sources (both spatially and seasonally) will provide key data relating to 'at-risk' periods for specific land-uses and additionally allow consideration of field-based sediment losses compared to non-agricultural sources. These data will help inform sediment mitigation measures.

Conclusions

Integrated analysis of soil loss, sediment quantity and source tracing in multiple agricultural catchments will create sediment budget assessments over a gradient of land use types. This will improve knowledge on the land to water sediment dynamics from soil loss to the efficacy of transport to watercourses and subsequent downstream transport. These results will inform how soil loss and sediment mitigation can be better targeted for protection of water quality.

Acknowledgements

This work is funded by the Teagasc Walsh Fellowship Scheme.



Defining critical source areas of nutrient transfer in agricultural catchments

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Background

Critical source areas (CSAs) of phosphorus (P) are defined as hydrologically active zones within a catchment where P sources, mobilisation and hydrological connectivity to surface waters coincide, resulting in areas exporting disproportionate quantities of P that can lead to eutrophication.

As Food Harvest 2020 is promoting increased Irish agricultural production, intensification in some areas is likely. At the same time, Water Framework Directive (WFD) water quality obligations must be met. A tighter definition of CSAs of P, founded on an integrated CSA metric based on catchment science precepts (Figure 1), may be useful to target mitigation measures in an efficient and effective manner. This PhD project aims to develop such a CSA model for Irish catchments, and is integrated in the Agricultural Catchments Programme (ACP) evaluating the efficacy of the Good Agricultural Practices measures aimed at reducing nutrient losses.

Defining hydrological connectivity and CSAs must include the influence of sub-metre scale ditch networks and runoff producing features that are not effectively captured in conventional, coarser resolution Digital Elevation Models (DEMs). These networks and features are where nutrients from CSAs are first mobilised and transferred to surface waters, and are therefore crucial for accurate CSA identification. This project investigates the application of high resolution (25 cm) Light Detection and Ranging (LiDAR) DEMs for modelling CSAs.

Runoff flashiness has been found to be a controlling factor for P transfers during the closed period for fertilizer spreading. As soil properties will influence runoff flashiness, this will also be investigated and incorporated into a CSA definition.

The potential applications for an improved CSA definition include targeted mitigation measures. These could be used as an alternative to supplementary WFD measures such as riparian buffer zones which farmers may be reluctant to adopt and which may be prone to hydrochemical bypassing and pollution swapping. The acceptability and cost of adopting CSA measures as apposed to riparian buffer zones will therefore be explored.

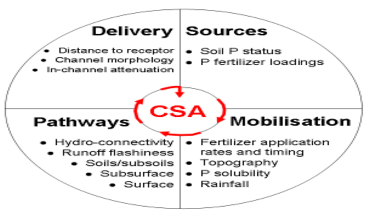

Figure 1. CSA conceptual diagram

Objectives

Research questions that will be addressed include: (i) are only sub-metre DEMs suitable for defining hydrological connectivity and CSAs of P transfer in agricultural catchments? (ii) do catchments with lower hydrological connectivity and runoff flashiness have a reduced risk of P transfer even in circumstances of high P source pressures? (iii) will adoption of CSA mitigation measures be more acceptable to farmers and less expensive than adoption of riparian buffer zones?

Materials and Methods

Five intensively monitored agricultural catchments from the ACP have been selected, namely Timoleague, Castledockrell, Ballycanew, Dunleer, and Corduff-Sreenty. These catchments represent typical land use, soil-landscape and environmental conditions found in Ireland. Existing data from the ACP geodatabase will be used for this research, including surface water discharge and P concentrations, P fertilizer application records and soil P status at the field scale, precipitation, soil types and properties, a 5m INTERMAP DEM and a new state-of-the-art 0.25m LiDAR DEM (Figure 2).

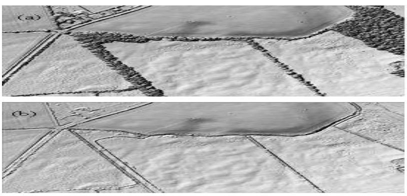

Figure 2. LiDAR DEMs (a) with vegetation and (b) without vegetation

Mobilisation risk and hydrological connectivity will be modelled from the 0.25m and 5m DEMs in SAGA GIS, using TOPMODEL, SCIMAP and other topographic algorithms. Differences in modelled mobilisation, flow path, and hydrological connectivity risks will be compared to determine if predictions of P transfer risk improve using the sub-metre DEM. Risk metrics of hydrological connectivity, runoff flashiness, P source pressures (loadings and soil P status), topography and soil properties will be created and integrated into a metric of CSAs. Calibration and validation of metric weightings will be undertaken to determine the influence of metric components such as hydrological connectivity or mobilisation risk on P transfers in catchments experiencing different nutrient source pressures. An improved CSA definition will be created on the basis of this CSA metric.

Survey data on adopting CSA mitigation measures will be collected from farmers. Questions will include level of participation, attitude, peer group factors and a contingent valuation willingness to accept (WTA) question to establish the minimum amount of compensation the farmer would be prepared to accept (in € ha^{-1} equiv. per annum) for the change of land use to a CSA buffer zone. Results will be compared with previous ACP attitudinal surveys on riparian buffer zones (Buckley et al., 2012), to determine if the adoption of CSA measures would be more acceptable and less expensive.

Acknowledgements

This work is funded by the Teagasc Walsh Fellowship Scheme.

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Microbial Source Tracking in Rural Catchments

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Introduction

In Ireland, bacterial pathogens from continual point source pollution and intermittent pollution from diffuse sources can impact water. Establishing the source of faecal pollution is imperative for the protection of water quality and human health. Microbial source tracking, an important emerging molecular tool, is applied to detect host-specific markers in faecally contaminated waters. The aim of this study is to detect the presence of ruminant and human-specific faecal *Bacteroidales* and *Bacteroides* 16S rRNA genes within rural river catchments in Ireland. Monitoring for bacterial pathogens during storm and non-storm periods will help to investigate hydrological transfer dependencies.

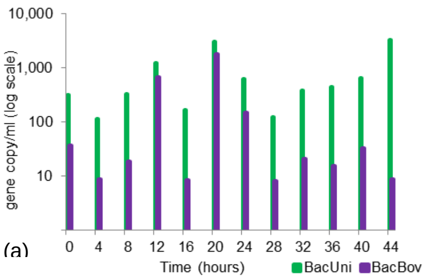
Methods

The two catchment areas selected and monitored for this project are located in Cregduff, Co. Mayo and Dunleer, Co. Louth. These two sites differ on numerous levels. Cregduff is underlain with well-drained soil on karstic bedrock. Dunleer, however, consists of mostly poorly drained tillage soils in 70% of the catchment. This results in high nutrient losses both of phosphorus via overland flow in poorly drained soils and nitrogen leaching on the more freely drained soils. There is little surface runoff in the Cregduff catchment as this type of karstified landscape is subject to hydrologic movement via groundwater pathways. The Dunleer catchment is more influenced by surface flow pathways (Melland et al 2012). Cregduff is predominantly livestock farming with little tillage. Dunleer has both considerable tilled land (30%) and livestock farming (50%).

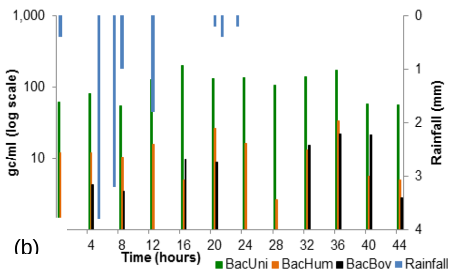
Large (5-20L) untreated water samples were collected from outflows from the two catchments sites during storm events and non-storm periods. An autosampler (Hach Sigma 900 Max Portable Sampler) also collected a 1L sample every 2 hours for a 36-96 hour period. Samples were filtered through 0.2µm nitrocellulose filters which then underwent chemical extraction of total nucleic acids. Aquifer response to rainfall events was assessed by monitoring coliforms and *E. coli* occurrence using the IDEXX Colisure® Quanti Tray®/2000 system in conjunction with chemical and hydrological parameters. A qPCR assay targeting universal *Bacteroidales* (BacUni-UCD); a ruminant specific *Bacteroidales* qPCR assay (BacBov-UCD); and a human specific *Bacteroidales* qPCR assay (BacHum-UCD) were then applied to the faecal and water samples.

Results & Discussion

Positive amplification was achieved by BacUni-UCD and BacBov-UCD from water samples taken from the Dunleer outlet over a 44 hour non-storm period (Fig.1a). No human faecal contamination was detected. The concentration of the universal assay peaked at 3.36 x 10^3 gc/ml. The concentration of the bovine assay peaked at 1.79x 10^3 gc/ml. BacHum-UCD was not detected during this period. For the storm event (Fig. 1b), the concentrations of the BacUni-UCD, BacHum-UCD and BacBov-UCD were much lower suggesting a possible dilution effect of faecal pollution due to rainfall. It can be seen that that values of all three assays change over both of these Spring/Summer (2011) 44 hour periods. None of the assays have detected contamination in the water samples taken from Cregduff.



(a)



(b)

Figure 1. BacUni-UCD, BacHum-UCD (only (b)) BacBov-UCD amplicons of water samples from Dunleer outlet during a 44 hour spring/summer non-rain period (a) and rain event (b).

Coliforms and *E. coli* peaks were higher in Dunleer, than in Cregduff, for summer non-rain periods (Results not shown but available on request). Phosphorus concentrations were an order of magnitude higher in Dunleer than in Cregduff. In Dunleer the concentrations exceeded the Irish Environmental Quality Standard of 0.035mg mgL^{-1}. When comparing non-rain periods in both catchments, it can be seen that the level of pollution was higher in Dunleer.

Conclusions

Host-specific assays and the chemical parameters of the water may complement *E. coli* as a faecal indicator. It is necessary to determine the relationship between the occurrence of faecal pollution, pollution source and hydrology in order to create an accurate representation of contamination in environmental water. The microbial source tracking techniques and hydrodynamic model that will be designed by this project will be of importance for water quality control in Ireland.

Acknowledgments

This project is funded by NUI Galway and the Teagasc Walsh Fellowship Scheme.

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Evaluation of a surface hydrological connectivity index in agricultural catchments

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Introduction

Targeted management of agricultural catchment areas prone to diffuse phosphorus (P) loss may help to improve downstream water quality. Phosphorus is primarily transported in surface or near surface flow, so delineating critical source areas (CSAs) for P loss requires characterisation of the hydrological connectivity of surface flowpaths. This study investigated the potential for a topographically derived model, the 'Network Index' (NI) (Lane et al., 2004), to predict surface hydrological connectivity at field and subcatchment scales. The importance of agricultural surface ditches in mediating predicted surface connectivity was also evaluated.

Materials and Methods

The model was evaluated in two hydrologically contrasting agricultural catchments (*ca*.1200 ha); well drained Catchment A and poorly drained Catchment B. The NI was applied using a 5m digital elevation model (DEM), and also using a 5m DEM which was hydrologically corrected to account for the observed ditch and stream channel network. Digital elevation models and connectivity predictions are referred to as 'original' and 'modified' when using the uncorrected and corrected DEMs, respectively. The 95th percentile of the distribution of grid NI values within a subcatchment or field was chosen to represent surface connectivity or surface saturation, respectively, for that area. Modelled surface connectivity at the subcatchment scale (ca. 130 ha) was validated using observed ditch and stream channel densities. Modelled surface connectivity at the field scale (ca. 2 ha) was evaluated using four indicators of observed field connectivity; surface water extent and flow activity and channel length and flow activity per field perimeter.

Results and Discussion

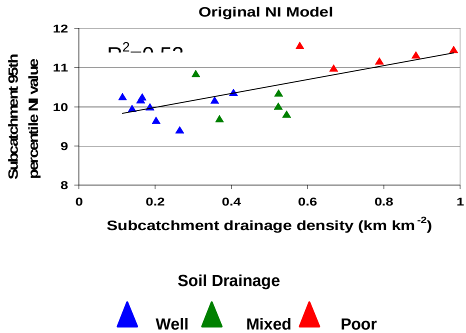

Figure 1. Predicted connectivity (95th percentile NI values) vs. observed connectivity (channel density) for subcatchments across both catchments using the original NI model.

At the subcatchment scale, modelled surface connectivity matched observations reasonably well (Fig. 1). This was partially attributed to the correlation between soil type and topographically-controlled connectivity in these catchments. Information on artificial sub-surface drainage features may further explain the NI predictions.

Information on ditch location was required to accurately delineate subcatchment boundaries (Fig. 2) and thus predict the extent of critical source areas.

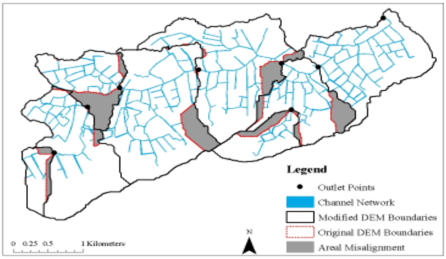

Figure 2. Grey areas highlight misalignment of subcatchment boundaries predicted with (black lines) and without (red lines) channel location information in Catchment B

At the field scale, the original NI model has potential for discerning the most connected from the least connected fields which is valuable for identifying where CSA-based management should be targeted. (Fig. 3)

Conclusions

The NI has potential for facilitating CSA-based P management in agricultural catchments at scales where CSAs offer greatest potential for P loss management. A 5 m resolution DEM was sufficient for capturing the primary topographic controls of surface connectivity in the studied subcatchments.

Acknowledgements

This research funded by the Department of Agriculture, Food and the Marine

(DAFM) through the Agricultural Catchments Programme and the Teagasc Walsh Fellowship Scheme.

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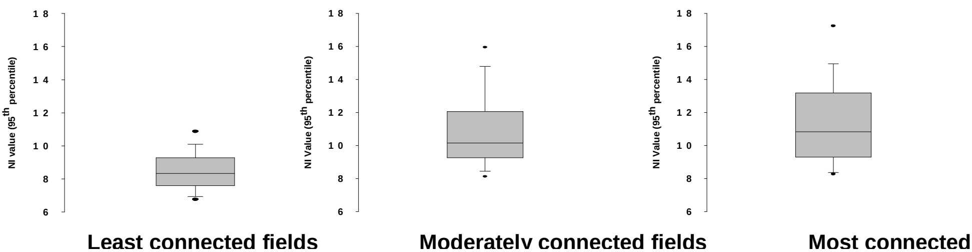
Figure 3. Distribution of 95th percentile original NI values for a) least connected fields (where 3 out of 4 indicators < 25th percentile; n = 153), b) moderately connected (fields not included in the well or poorly connected classes; n = 80) and c) most connected fields (where 3 out of 4 indicators >75thpercentile; n = 35). Horizontal 'dash' = median, box represents inter-quartile range, whisker represents upper and lower limits.



Phosphorus load apportionment in the management of eutrophic water-bodies

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Introduction

The aim of this study is to investigate the phosphorus (P) load apportionment patterns and processes to two *at risk* water-body types; rivers draining a mixed use agricultural catchment on heavy soil types and drumlin grassland; and an inter-drumlin lake as the receptor in a second drumlin grassland catchment.

For rivers, the loads under investigation are *point* and *diffuse* which are apportioned using numerical modelling methods, called Load Apportionment Models (LAMs). For the lake, the focus is on *external* and *internal* loads. Lakes become eutrophic as a result of three loading processes: firstly, as a result of increasing external P loads from the catchment, the net concentration of which remains in the water column; secondly the remainder of the external P load accumulates as bed sediments before becoming biologically available due to resuspension from summer anoxia; or thirdly due to wind induced rolling, dependent on lake morphology.

The rate of recovery from eutrophication for the two water-bodies will be investigated and compared with approaching Water Framework Directive (WFD) deadlines.

Methodology

The project employs two methodologies. The load apportionment of P in rivers is based on simple LAMs, where the relationship between river discharge rate and P concentration is used to determine the source of P at that time.

Two LAMs have been developed in recent years, the first based on a power function relationship between river discharge and P concentration (Bowes Model) and the second using simple polynomial linear regression (Greene Model). Along with quantifying the load from each source, new datasets of varying sampling frequencies developed from high frequency data (courtesy of the Agricultural Catchments Programme) (Wall et al., 2011) , are being used to determine the variation in the outcomes of these simple models to provide an estimate of uncertainty.

Conversely, the lake requires empirical data collection. Two buoys have been deployed fitted with data-sondes (Fig. 1), one at the shallow eastern end and two at surface and 9m depth at the western/central section.

Figure 2 Data-sonde maintenance

Each data-sonde is fitted with sensors for temperature, chlorophyll a, turbidity, pH, redox and conductivity measurement on an hourly basis. A thermistor chain measures the temperature at each metre interval on a 15 minute basis. Finally, samples for P and N analysis are also collected on a monthly basis. The data collected is examined and relationships between different variables determined, particularly the impact of changes in P and N and the chlorophyll a response.

Results and Discussion

Rivers

The P load apportionment was calculated for each site. For example, site 1 was predominately affected by point sources (57%), particularly during summer (88%) due to low flow according to the Bowes Model while the Greene model estimated a much higher percentage from diffuse sources (Fig. 2).

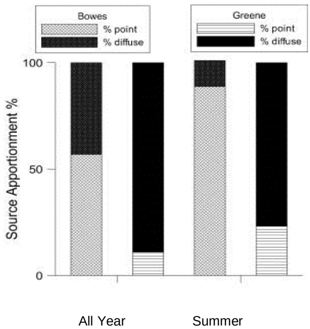

Figure 3 Site 1 P load apportionment

Lake

Chlorophyll a and TP levels in Lough Namachree have confirmed a meso- to eutrophic water quality status. Proxy catchment P monitoring indicates up to 0.3kgha^{-1} entered the lake from external sources in 2011 while internal loads have been estimated at 0.0246 kgha^{-1} as a result of lake turnover in September 2011. While external loads may be larger in magnitude, they usually enter the lake during winter months when growing conditions are not appropriate for algal blooms. However, these loads do enter sediments each year and are therefore available for release during summer months.

Quantifying internal release of P is difficult with a low frequency, monthly sampling regime. A relationship between P release and conductivity was identified for both summers, 2011 and 2012 and resulting modeled SRP values are shown in figures 3 and 4. Using conductivity values it is possible to determine when P release has occurred which aids the quantification of internal P released from sediments.

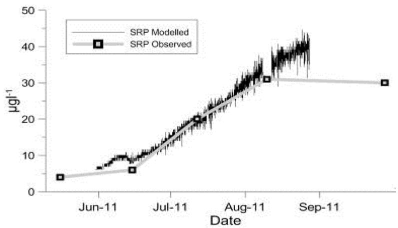

Figure 4 Modelled SRP 2011

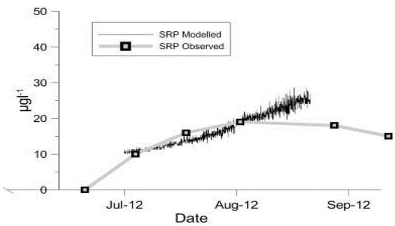

Figure 5 Modelled SRP 2012

Conclusions

Both sites are significantly impacted by P contamination but from different sources. LAMs require a thorough quantification of their uncertainty after obtaining differing results from the two models. Lough Namachree is receiving P from a variety of sources and the quantification of such is aided by the use of the high frequency sensors.

Acknowledgements

The Agricultural Catchments Programme and the Walsh Fellowship Scheme for funding and support. TCD Geography for academic support.

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