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SOIL CONFERENCE 2023

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AFBI SOIL CONFERENCE

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Contents

Introduction

The Agri-Food and Biosciences Institute is delighted to host this important conference with a focus on soil health as we recognise that enhancing the health of our soils is foundational to optimising the sustainability of our food and farming systems and protecting our natural environment.

This conference is built on at least 90 years of excellent soil science in AFBI and its predecessors. Arguably, it is this long history of dedication to soil research and the impactful results from this work that has resulted in the Department of Agriculture, Environment and Rural Affairs having the confidence to invest millions in the world leading Soil Nutrient Health Scheme which is currently being rolled out by AFBI in partnership with DAERA and CAFRE.

This long history stretches as far back as 1921 where George Scott Robertson, the first professor of agriculture at QUB was a fertiliser/soil scientist. In 1925, six research divisions were founded by the Ministry of Agriculture with Agricultural Chemistry being one of these. However, the Agricultural Chemistry division was predominantly a soil science division. In the 1950s the division had senior scientists such as Dr Victor McAllister and Dr Stuart McConaghy establishing

an international reputation. They proposed and drew up the first Northern Ireland soil map in the 1960s. During the 1970's and 80's Dr Norman Adams specialised in the effects of liming soils. The work of these scientists primarily focused on soil fertility and the effects of fertilisers on soils. The classification and subsequent mapping of soils then followed -in the late 1980s and 1990s with the soil map of NI being formally launched in 1997. This map continues to be an authority on soil types across NI to this day.

The soil mapping exercise was managed by Professor Kerry Garrett, with Mr Jimmy Cruickshank, a very experienced soil geographer and surveyor appointed especially to deliver the project. In the more recent history, soil chemistry research continued through people like Jim Stevens, Catherine Watson, Crawford Jordan and John Bailey.

In more recent years, AFBI's extensive soil health research has integrated with both agricultural productivity and environmental outcomes to deliver important recommendations to both policy makers and industry.

Standing on the shoulders of previous leaders of soil science, the AFBI Soil Health Conference will showcase the latest scientific knowledge emerging from AFBI's current team of soil

scientists and this will be complemented with presentations from leading scientists working on soil health from across the UK and Ireland.

The conference will focus on policy and Legislation in a UK, EU, and Global context as well as research underpinning improvements in Soil Health which support both agricultural productivity and environmental protection. Discussion on Soil Health and Nutrient Management monitoring and measuring will also be presented.

This booklet provides the key messages from the conference as well as a detailed list of recently completed and ongoing projects which include work to further advance our knowledge on Soil Health and ways to improve it across Northern Ireland soil types.

We gratefully thank the Department of Agriculture and Rural Affairs for providing the underpinning funding for the AFBI soil research projects and platforms as well as the delivery of this conference.

We trust you will find this conference informative, and we appreciate your support for it.

Elizabeth Magowan and P-J Schön

Speaker biographies

Dr Rachel Cassidy, Soil Nutrient Health Scheme, Agri-Environment Branch, AFBI

Rachel Cassidy is a catchment scientist focussed on understanding and mitigating the impacts of agriculture on water quality.

Her expertise covers hydrology, geospatial modelling and optimisation of monitoring for diffuse nutrient and pesticide loss in agricultural landscapes. She is project lead for the Soil Nutrient Health Scheme in AFBI.

Dr Suzanne Higgins, Programme Leader, Sustainable Soil Nutrient Management research, Agri Environment Branch, AFBI

Suzanne has expertise in soil fertility, soil nutrient management and precision agriculture. Her research interests revolve around increasing the efficiency of soil nutrient management, to optimise production but minimise any detrimental environmental effects.

Suzanne manages a number of large soil projects, including EJP Soil, NI Countryside Survey, Multi4More and is a work package lead in the NI Soil Nutrient Health Scheme.

Dr Marcelos Galdos, Soil Carbon Specialist, Rothamsted Research

Marcelo is an experienced researcher in the areas of soil health and climate-smart agriculture, using crop, soil and climate monitoring and modelling and to assess the impact of land use and agricultural management practices on crop yields, soil organic matter, soil moisture, nutrient use efficiency and greenhouse gas fluxes.

His research combines novel sensors, digital soil mapping, precision agriculture, and Earth Observation to develop mitigation and adaptation strategies in agricultural systems, contributing to Net Zero targets, food security and environmental sustainability.

Marcelo currently leads research projects developing agricultural digital twins and agri-environmental sensor networks for decision support.

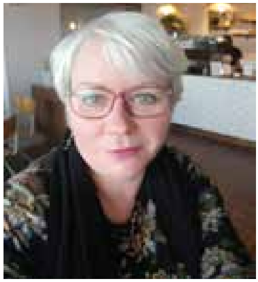
He is an Oxford Farming Conference Emerging Leader, and chairs the South East England Soil Discussion Group of the British Society of Soil Science.

John Williams, Head of the ADAS Soils and Nutrients Group.

John is a Chartered scientist with over 30 years' experience working on research projects focusing on improved nutrient management and the environmentally sustainable agricultural practices.

He is a Fellow of the British Society of Soil Science, FACTS qualified and Technical Adviser for the UK Water Industry's Biosolids Assurance Scheme and was chair of the organising committee of the recent RAMIRAN2023 conference in Cambridge

Dr Lisa Black, AFBI Crossnacreevy



Lisa Black is Head of the Plant Testing Station at AFBI Crossnacreevy, with oversight of statutory plant variety and seed testing and associated research. Lisa has over 30 years' experience in agronomy and started her research journey with a PhD in soil science at Aberdeen University. She is coordinator for multiple research initiatives including innovations in plant variety testing and the impact of land use on plant and soil health

Elizabeth Stockdale, Head of Farming Systems and Agronomy Research at NIAB

Elizabeth Stockdale has over 25 years' experience of research and knowledge exchange in soil management, nutrient cycling and environment impact.

Elizabeth recently led the AHDB/BBRO farmer-levy funded Soil Biology and Soil Health Partnership which developed practical on-farm tools for monitoring.

Dr Paul Cottney, AFBI Crossnacreevy

Paul Cottney works at AFBI Crossnacreevy and is Project Lead for grass and cereal variety performance testing for statutory and research purposes. As well as plant varieties, Paul's research activities include soil health, cover cropping and novel crops. His PhD was part of the DAERA Soil Health in Northern Ireland project and focused on identifying optimal cover crops for Northern Ireland and their effects on soil health.

Dr Archie Murchie, Applied Agricultural Entomologist, AFBI Newforge

Dr Archie K. Murchie obtained his PhD in biological control of crop pests in 1997 from Rothamsted Research and Keele University.

He is an Honorary Fellow of the Royal Entomological Society, and Honorary Senior Lecturer at Queen's University Belfast, with 26 years' post-doctoral experience of project managing research projects in agriculture and environmental sciences.

Archie's research is concerned with surveillance and monitoring of pests and pathogens, the use of functional biodiversity in sustainable agricultural production and the targeted management of pest species. He has worked on a wide range of issues including, biological control of pests in arable crops, targeting and monitoring of pesticides, integrated pest management, invasive flatworms, earthworms, forestry pests and pathogens, and midges and mosquitoes as vectors of livestock and human diseases.

His laboratory is responsible for plant health surveillance and bee health diagnoses in Northern Ireland.

Dr John Finn, Farmland Ecology, Teagasc Environment Centre

John Finn completed an undergraduate degree in Applied Ecology at UCC, and a PhD in community ecology before lecturing at both UCC and the University of Reading.

Since joining Teagasc, his research interests include: the design of multi-species mixtures for low-nitrogen and climate-resilient farming systems; farmland management to promote habitat and species diversity, and; the design and effectiveness of results-based agri-environment schemes.

He has recently discovered watercolour painting of biodiversity and landscapes.

Soil Nutrient Health Scheme

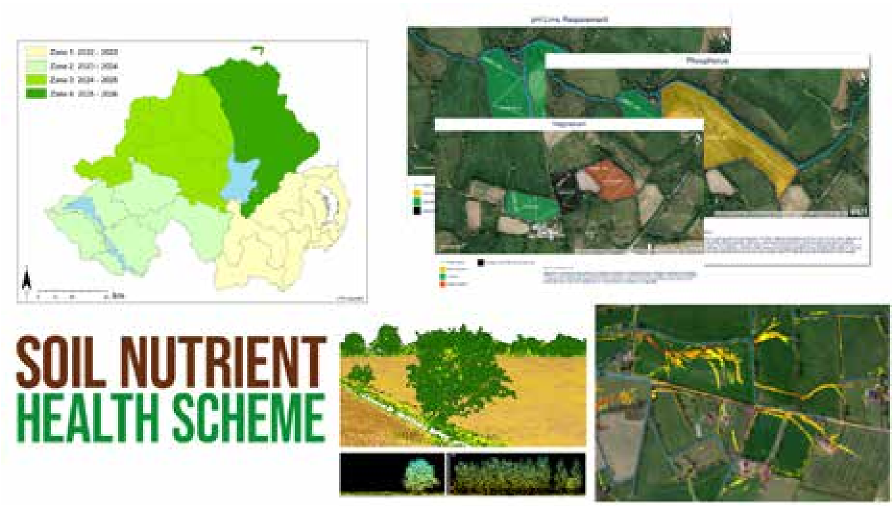
Rachel Cassidy, Alex Higgins, Colleen Ward[1]

[1]Agri-Environment Branch, Environment and Marine Science Division, Agri-Food and Biosciences Institute, Belfast BT9 5PX, Northern Ireland.

Abstract

Since its launch in March 2022, the Soil Nutrient Health Scheme has progressed towards its objective of providing a complete soil status and baseline carbon assessment for every farm business in Northern Ireland by 2026. Through detailed field-scale measurements and mapping this comprehensive regional programme aims to bring a focus to soil health, and enable all farmers to optimise crop nutrient applications, assess on-farm carbon stocks and build farm resilience.

Simultaneously it is expected that the scheme will provide a baseline for developing strategies for improving the sustainability of the region-wide soil resource, agriculture, and the natural rural environment. The Department of Agriculture, Environment and Rural Affairs (DAERA) is funding the £37M scheme, which runs from 2022-26 and is managed by AFBI.



Programme Scope

As sampling and analysis for Zone 1 of the Soil Nutrient Health Scheme (southeast NI) concludes, sampling teams are about to start work across Zone 2 (southwest) with over 92% of fields and farm businesses registered for sampling.

Farmers participating in the scheme will receive:

1. Detailed information on the nutrient and pH status for each field, and crop-specific recommendations for the year of application.
2. LiDAR-derived runoff risk maps highlighting sub-field scale hot-spots with potential for nutrient loss to waterbodies.
3. Estimates of C stored in soils and as above ground biomass on each farm.

Alongside the delivery of results and recommendations to farmers, a comprehensive soil nutrient training programme will be provided to all farmers by the College of Agriculture, Food and Rural Enterprise (CAFRE). This course will help farmers interpret their soil analysis results, provide an understanding of nutrient management planning and an overview on the role of carbon on farms.

All work on the scheme is supported by a comprehensive programme of research led by AFBI and with partners at both Ulster and Leeds Universities and covering soil, water quality, carbon, and behavioural research.

Soils Research

Basaltic soils cover nearly a third of the landscape of Northern Ireland and are characterised by high levels of Fe, Al, Ca, Mg, Cu, Cr and Ni. Research indicates that the Olsen P soil test, when applied to these soils, may be underestimating plant-available Phosphorus (P). As a result, SNHS encompasses a body of research dedicated to assessing nutrient interactions and grass nutrient uptake specific and uniquely to these basalt soils through plot experiments on farms across the northeast. The soil test developed from this work will be used to provide recommendations to farmers when this area is soil tested in Year 4 of the scheme.

Water Quality and Catchment Research

Nutrient enrichment of freshwaters by P is a primary cause of water quality impairment in NI, with agriculture a key source. In catchments with high rainfall, impermeable soils and steep slopes overland flow, or runoff, is the primary pathway by which nutrients and sediment are transferred to surface waters. High-resolution LiDAR digital elevation data provides the basis for modelling hydrological connectivity in the landscape, and identifying, in conjunction with soil permeability, those areas most prone to runoff and erosion.

A programme of water quality monitoring in agricultural sub-catchments across each Zone will be used to develop and relate soil nutrient status and runoff risk potential to water quality and contribute to the development of strategies for achieving water quality improvements.

Carbon Research

A high-resolution LiDAR scan of Northern Ireland will provide a basis of modelling activities to estimate above ground biomass held in trees, woodlands and the 120,000 km of hedgerows in the region.

SNHS is also gathering information on rates of soil C sequestration in grassland fields on selected commercial farms and along undisturbed field boundaries on different soil types in Northern Ireland (involving radio-carbon dating and soil microbiological assessments). Ongoing research will investigate how fungal and bacterial communities are affected by management and elucidate mechanisms and processes governing changes in soil C storage in grassland and hedgerow soils.

Information arising from this research will be used to update the UK soil C inventory, and to identify management strategies which enhance C capture by soil and above ground biomass.

Behavioural Research

An assessment of the extent to which participation in the various components of the SNHS scheme has influenced farmer awareness, attitudes and behaviour is an important component in monitoring and evaluation of overall impact.

Research will apply a mixed-method approach using a questionnaire-based survey and qualitative semi-structured, in-depth interviews to explore farmers' awareness of the link between soil testing, improved productivity and water quality, and the role of experiential learning in adoption of best management practices for farm management.

Work will also examine how access to real-time water quality monitoring data from local rivers may serve to alter farmers' attitudes and behaviour toward water resources.

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SOIL NUTRIENT HEALTH SCHEME

Soil health and nutrient management

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Take Home Messages:

- Nutrient management is integral to soil health.
- AFBI research assesses soil nutrient management at multiple scales (regional, catchment, farm and field scale).
- At regional scale, dominant soil health indicators and broad drivers of soil health become apparent, for example geology and climate.
- The focus of catchment-scale research at AFBI is to minimise farm nutrient surpluses and implement measures to reduce nutrient loss into waterways.
- Both yield and nutrients can vary substantially at sub-field scale. The advancement of new technology facilitates precision in soil nutrient management and increased nutrient use efficiency. This will improve overall soil health.

Introduction:

Soil nutrient management is integral to soil health. In managed systems, soil health can be maintained, promoted or recovered through the implementation of sustainable soil management practices and avoiding soil degradation.

By soil health, we refer to the performance or functioning of a soil, as a dynamic, living resource. Indicators and thresholds defining soil health are site-specific and are sensitive to management practices (FAO, 2020). The Sustainable Soil Nutrient Management and Crop Nutrition Research Programme at AFBI measures and monitors soil nutrient management across a range of spatial scales (regional, catchment, farm and sub-field levels). The overall aim is to enhance soil fertility, sustain production and build soil resilience, while minimising nutrient losses to the environment. Healthy soil will have greater ability to adapt to existing conditions as well as to a changing environment, while supporting key ecosystem services. This paper summarises some of the soil health and nutrient management research currently ongoing at AFBI.

Overview of presentation's key messages:

At regional scale, the NI Soil Nutrient Health Scheme (SNHS) aims to soil sample ≈700,000 fields over a four-year period (2022-2026), thereby providing unique region-wide baseline information on soil pH (lime requirement), phosphorus, potassium, calcium, magnesium, sulphur and loss on ignition (soil C proxy). At this scale, dominant soil health indicators and broad drivers of soil health become apparent. For example, the interaction between our complex underlying geology and glacial history which has shaped many of our landscape features and influenced the geochemical properties of many of our soils. In addition, prevailing climatic conditions such as variation in rainfall totals between eastern and western counties, has an important influence on soil nutrient dynamics, crop growth, drainage, and vulnerability to soil compaction.

At catchment level, AFBI has combined high resolution water quality monitoring with soil sampling, runoff risk maps and whole-farm nutrient management advice as a means of improving fresh water quality and meeting policy targets. Included in this are recent revisions to fertiliser recommendations and Nitrates Action Programme guidelines for extensively managed farms. AFBI conducted agronomic field trials over three years on farms within the Blackwater catchment (Figure 1). These revised guidelines were incorporated into the 2019-2022 Nitrates Action Programme and Phosphorus Regulations. Farm-specific nutrient management plans and one-to-one advice resulted in a 42% reduction in inorganic P fertiliser use being achieved across participating farms in this study.

Figure 1: Agronomic fertiliser trails at extensively managed sites in the Blackwater catchment

Soil monitoring is an important component of research at AFBI. As well as national-level research such as the Environmental Change Network (ECN) and COSMOS UK network (cosmic-ray neutron sensors to continuously measure soil moisture at 50 sites across the UK, 3 of which are in NI), AFBI are also part of a number of larger European projects. For example, EJP Soil is a European Joint Programme on Agricultural Soil Management, which aims to address key societal challenges including climate change and future food supply.

EJP Soil builds collaborations among partner countries to strengthen research efforts and outcomes. Within EJP Soil, AFBI have led a study across 24 European countries (Figure 2) assessing how we measure nutrients in soils and formulate fertilisation recommendations. Published in the European Journal of Soil Science (Higgins et al. 2023), this paper discusses the potential for harmonisation of fertilisation guidelines between neighbouring countries and within similar environmental zones as a means of facilitating shared learning in best practice and fostering a collective approach to tackling environmental concerns.

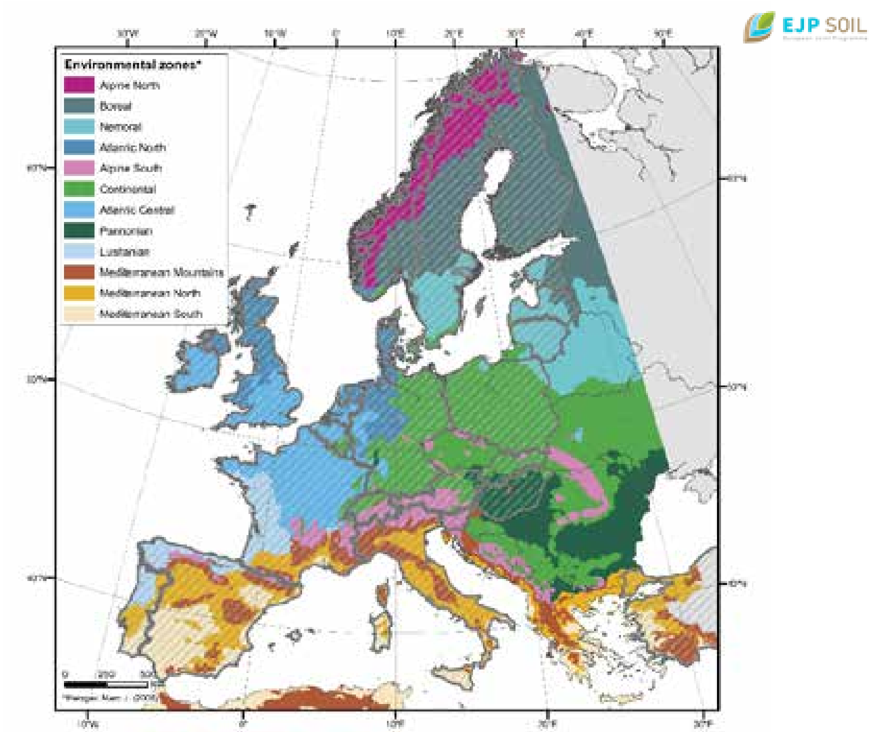

Figure 2: Map of European partners collaborating in an AFBI-led task within EJP Soil project, assessing the potential for harmonisation of fertilisation guidelines across Europe.

At farm- and sub-field-level, the focus of AFBI research is to improve overall farm nutrient balances, particularly of nitrogen and phosphorus; with the aim of reducing farm nutrient surpluses.

At a sub-field scale, grass dry matter yields can vary by as much as 2-4 t dry matter per hectare (Figure 3). Likewise, significant nutrient variations have been found, with a difference of up to 4 index values across fields being a common occurrence. This variability can be the result of topographic and drainage characteristics across a field, but also due to how nutrients are applied. Uneven application of nutrients can cause hotspots within a field which increases the risk of nutrient loss to the environment.

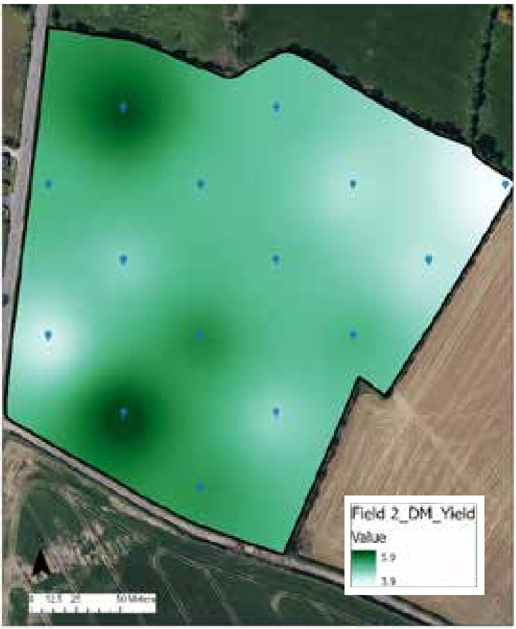

Figure 3: Variation in grass silage yield at sub-field scale

As technology improves, the ability to manage sub-field scale spatial variability in yield and nutrients increases. AFBI research investigates new and novel technologies that can be employed by local farmers to enhance nutrient use efficiency. The most accessible of these are GPS systems on tractors, which can help guide nutrient applications in real-time, enabling even nutrient application and minimising multiple overlapping passes within single fields.

References:

FAO (2020). Intergovernmental Technical Panel on Soils. Soil letters #1. "Towards a Definition of Soil Health". Food and Agriculture Organization of the United Nations. September 2020.

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The role of soil health in climate-smart agriculture

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Besides supporting food, feed, fuel and fibre production, soils provide ecosystems services such as storing carbon, filtering water, and maintaining biodiversity. Increased soil organic carbon (SOC) levels also improve both soil moisture retention and drainage; thereby improving agricultural resilience to extreme weather including floods and droughts. Soil carbon sequestration is one of the core global indicators agreed by the UN to monitor progress towards Sustainable Development Goal 15, Life on Land, through target 15.3; while links between land and climate are the focus of an ongoing IPCC Special Report.

Soil degradation is a threat to food security and environmental sustainability in the UK and globally. Fertile soil is being lost at a rate faster than it can recovered, and soil carbon stocks have declined. Reducing soil degradation and improving soil health are key aspects of the climate-smart approach, which includes maintaining or increasing yields, mitigating global warming, and adapting to climate change.

Sampling and analysing physical, biological, and chemical properties of soils at landscape and regional scales poses challenges due to spatial and temporal variability, and there is much uncertainty about how a changing climate will affect soil carbon dynamics. Agriculture involves complex interactions between crop, soil, water, and nutrient management, moderated by climate and land use, as well as by the edaphic soil properties. Understanding those interactions and their effects on agricultural production and soil health requires an integrated systemic approach. Process-based modelling represents an important tool to advance understanding and accurate forecasting of the spatial and temporal dynamics of crop yields, soil carbon and nutrients in agricultural systems under changing land use, management, and climate. Modelling has been used to develop "what if" scenarios for agricultural and environmental policy; to identify sustainable and climate-resilient agricultural systems; and to site- or region-specific estimates of carbon sequestration for carbon offset programmes. Additionally, advances in remote sensing technology and data availability have provided opportunities to assess the spatial and temporal dynamics of soil properties, and artificial intelligence and machine learning have enabled the analysis of large amounts of environmental data.

In this presentation, I will describe current work on monitoring and modelling agricultural systems at Rothamsted Research, providing examples from projects in the UK and abroad combining long-term experiments, on-farm observations, sensors, and process-based modelling to improve the sustainability and climate resilience of crop and livestock production.

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Organic materials: risks and benefits for soils and the environment

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Take home messages

- Organic materials are valuable sources of plant nutrients and organic matter which can improve soil quality and reduce the need for manufactured fertilisers to meet optimum crop needs.
- Nutrient management planning which accounts for crop need, soil nutrient status and crop available nutrient supply from manures is crucial to maximise the benefits and minimise nutrient losses to air and water.
- The impact of organic materials on soil properties will depend on their chemical characteristics and rate of application as well as the nature of the receiving soil.
- Investment in manure management infrastructure such as slurry storage, separation equipment, acidification and precision application techniques is important to maximise manure nutrient value and minimise impacts on the environment.

An estimated 90 million tonnes of livestock manure, 3.5 million tonnes of biosolids, 7 million tonnes of anaerobic digestate and 5 million tonnes of compost are applied to agricultural land in the UK each year.

The following steps should be followed to maximise the benefits from organic materials:

1. Understand the manure nutrient content

Several factors affect the nutrient content of organic materials including livestock diet, dry matter content, and for digestate the feedstock used for the AD process. AHDB's Nutrient Management Guide (RB209) provides typical figures for manure nutrient contents based on average values from databases of laboratory analyses (Table 1). Laboratory analysis of representative samples of manure can give more accurate estimates of manure nutrient content.

Table 1. Typical manure nutrient contents

Organic material	Dry matter (%)	Total nutrient content (kg/t fresh weight)				
		N	P_2O_5	K_2O	MgO	SO_3
Cattle FYM	25	6.0	3.2	9.4	1.8	2.4
Cattle Slurry	6	2.6	1.2	2.5	0.6	0.7
Pig FYM	25	7.0	6.0	8.0	1.8	3.4
Pig Slurry	4	3.6	1.5	2.2	0.7	0.7
Poultry manure	60	28.0	17	21	5.9	8.2
Biosolids*	25	11.0	11	0.6	1.6	8.2
Green compost	60	7.5	3.0	6.8	3.4	3.4
Food based digestate**	4.1	4.8	1.1	2.4	0.2	0.7

**Dewatered, anaerobically digested sewage sludge **Whole digestate derived from food waste feedstocks (i.e. not separated into liquid and fibre fractions)*

2. Minimise nitrogen losses

Ammonia emissions following application of organic materials account for around 34% of ammonia emissions from agriculture. The use of low emission application techniques such as band spreading and shallow injection have the potential to reduce ammonia losses by between 40 and 75% compared with surface broadcasting. For solid materials, soil incorporation within 6-12 hours of application can minimise ammonia losses.

Slurry and digestate acidification can be effective at reducing ammonia emissions by c. 75% compared with unacidified materials. Slurries and digestates typically have alkaline pH and reducing pH to c. 5.5 alters the NH_3:NH_4^+ total ammoniacal nitrogen (TAN) ratio to a point where NH_4^+ accounts for >98% of TAN. However, estimates from a recent Defra funded study suggest that costs of installing and maintaining the acidification equipment on a commercial pig farm can exceed benefits resulting from improved fertiliser value and reduced ecosystem damage costs by around £110,000 per annum.

Application timing is key to minimising nitrate leaching losses with autumn applications of high readily available N manures (e.g. poultry manure, slurry and digestate) likely to increase the risk of losses. However, the risks of phosphorus and ammonium losses to water can be significant following applications of slurry and digestate to wet soils in spring as the potential for the contamination of drain flow and surface runoff is likely to be greater than following applications to dry soils in the autumn. Ensuring sufficient slurry storage to ensure that applications are made when soil and weather conditions are appropriate will reduce the risk of nutrient losses to water.

3. Estimating crop available N supply

Guidance provided in RB209 and in the MANNER-*NPK* decision support tool accounts for application method, delay between application and soil incorporation, soil type, excess rainfall and contribution from mineralisation of organic N to estimate the crop available N supply from different organic materials.

4. Spread accurately and evenly

Uneven and inaccurate application of organic materials can cause either over supply of nutrients which increases the risks of losses to the environment or inadequate supply of nutrients which will reduce yields. Application rate can be quantified by measuring the forward speed and discharge rate of the spreader and the area over which the material is applied.

5. Develop a nutrient management plan

It is important that the nutrients supplied by organic materials are accounted for when planning manufactured fertiliser application rates. Soil sampling to identify fields with low soil P and K levels is an important step in maximising the value of organic materials. Typical application rates of farmyard manure, biosolids and poultry manure will supply more phosphorus than is taken off in crop material (Table 2).

Table 2. Fertiliser requirement for winter oilseed rape and nutrient supply from 35t/ha of pig farmyard manure

	N	P_2O_5	K_2O
	kg/ha		
Crop requirement	190	50	40
Manure nutrients	25	210	280
Fertiliser requirement	165	0	0
Balance for the next crop		+160	+240

On soils where P levels are above target it is important to manage organic material applications to ensure that P supply is matched or exceeded by P offtake over the rotation to reduce the risk of increasing P losses to water (Figure 1).

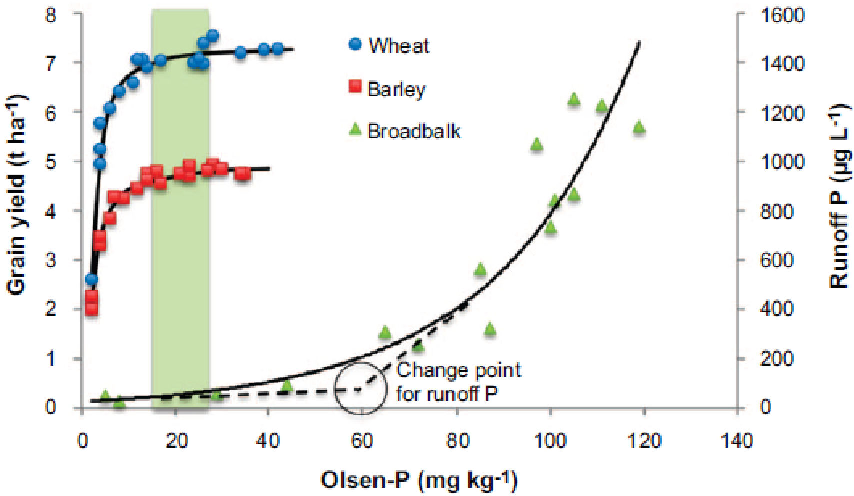

Figure 1. Impact of increasing soil P levels on crop yield response and losses to water (taken from Withers et al., 2017).

Organic matter

Organic materials are excellent sources of organic matter which is key to supporting and maintaining soil structure, water holding capacity and biological activity.

The quality and quantity of organic matter supplied will vary according to manure type (Table 4). Liquid manures (e.g. livestock slurry and digestate) will apply small amounts of organic matter due to their low dry matter content. Compost typically supplies stable organic matter whilst farmyard manure typically contains a mixture of stable and volatile organic compounds.

Table 4. Organic matter supplied by typical application rates of contrasting manure types

Organic material	Dry matter	Application rate (t/ha) NVZ 250kg N/ha	Organic matter (t/ha)
Cattle FYM	25%	42	5.5
Broiler litter	60%	8	2.5
Green compost	60%	33	4.5
Green/food compost	60%	22	5.0
Digested cake	25%	20	3.5

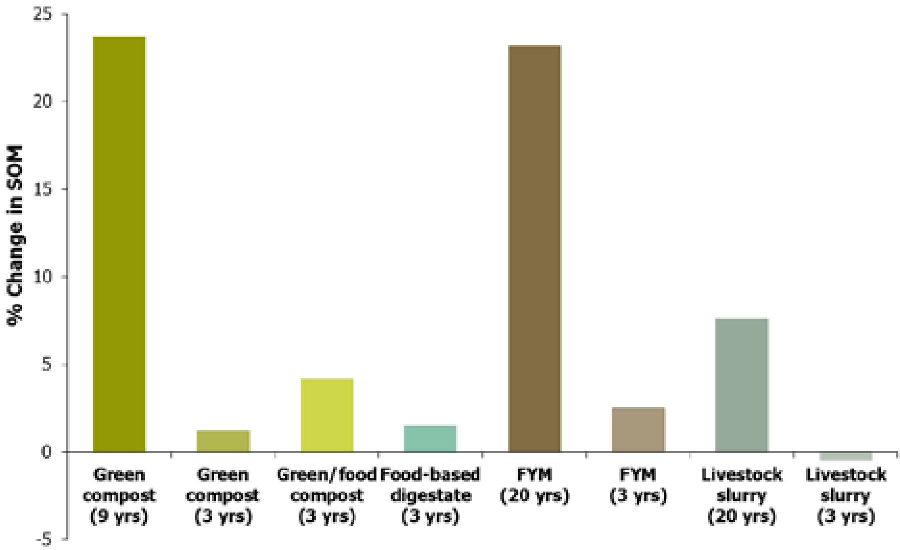

Figure 2. Impact of contrasting manure types applied to arable soils on soil organic matter levels

Bhogal et al. (2018) reported results from a series of long-term experiments where different organic materials had been applied to arable soils over a range of timescales. They found that whilst compost increased soil organic matter levels at a higher rate than farmyard manure (Figure 2) it did not produce the same level of improvement in soil microbial biomass as a similar increase in SOM produced by farmyard manure (Figure 3). They concluded that measurable changes in soil biological and physical functioning are dependent on supplying sufficient organic matter that is biologically available.

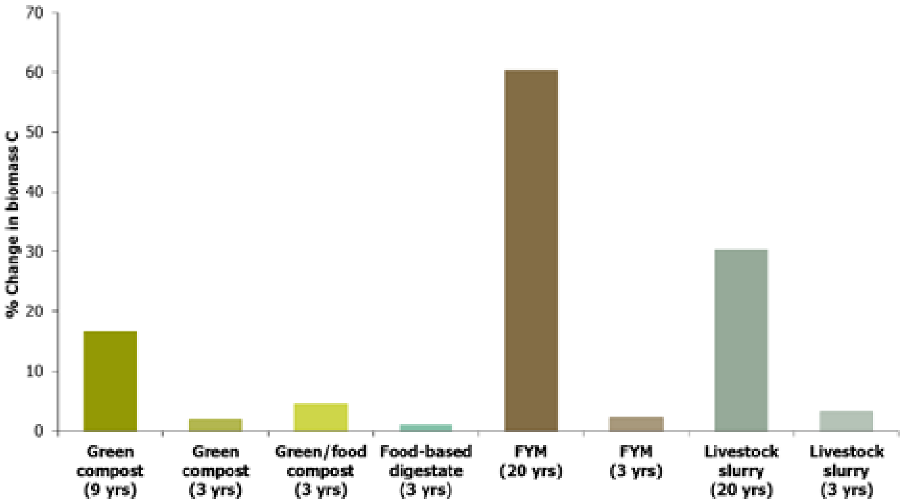

Figure 3. Impact of contrasting manure types applied to arable soils on soil microbial biomass

Impacts of these soil quality benefits on crop performance have been difficult to detect due to the confounding influence of the nutritional benefits. Yield benefits are often only seen with short season or spring sown crops, such as potatoes, maize, sugar beet and spring barley, or in years where yields are low due to climatic stress (e.g. drought).

References:

Bhogal A., Nicholson F.A., Rollett, A., Taylor, M., Litterick, A., Whittingham, M. & Williams, J.R. (2018) Improvements in the quality of agricultural soils following organic material additions depend on both the quantity and quality of the materials applied. Frontiers in Sustainable Food Systems, Waste Management in Agroecosystems 19 April 2018. https://doi.org/10.3389/fsufs.2018.00009

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Overview of soil health and the role of soil biological parameters

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Take home messages:

- Soil health research is an emerging, complex, and extensive discipline covering aspects of soil chemistry, physics, and biology. Consensus is yet to be reached on how to define soil health and is stakeholder dependent.
- International research has largely been focussed on soil chemical and physical parameters and, to a lesser extent, soil biological indicators of soil health.
- Determining how to assess soil biological health is critical to safeguarding global soils.
- AFBI research has focussed on evaluating soil biological traits which have the potential to indicate soil health.
- Results to date indicate that quantifying soil enzymes and soil respiration can indicate change in soil C, acting as a proxy for monitoring soil health the impact of land-use.
- Further work is needed on the impact of plant species and varieties on soil health.

Introduction

The definition of soil health is a topic of much debate and varies across regions. The Food and Agriculture Organisation of the United Nations defines soil health as the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems (FAO, 2020). In Northern Ireland, soil health is defined as a soil's ability to function and sustain plants, animals, and humans as part of the earths' ecosystem (DAERA, 2018). To function sustainably, soils need to be in good chemical, biological and physical condition (EC, 2021). Soil biological parameters are underrepresented in international evaluation of soil health (Bispo, et al., 2023) and this is highlighted by the new EC Soil Health Law (EC, 2023) which demonstrates the importance of identifying ways to monitor soil health, including biological parameters, and to harmonise methodology. Recent work at AFBI has a focused on identifying the value of soil biological traits in understanding the impacts of land-use on soil health. A healthy soil, in an intensively used agricultural system such as Northern Ireland, is one that accumulates, or at least maintains, organic C. If organic C in a range of soils can be linked to specific chemical, physical and/or biological traits, then this could give insight into organic C changes in soils without historical data through measurement of associated properties.

Soil parameters

Work carried out in AFBI in recent years has evaluated a range of soil parameters as potential indicators for soil health in grassland and arable fields across Northern Ireland and in AFBI long-term experimental trials.

Parameters measured include chemical and physical, with a focus on biological traits such as soil enzyme activity, soil microbial biomass, earthworm numbers, organic matter and Solvita CO_2 soil respiration test.

Emerging results

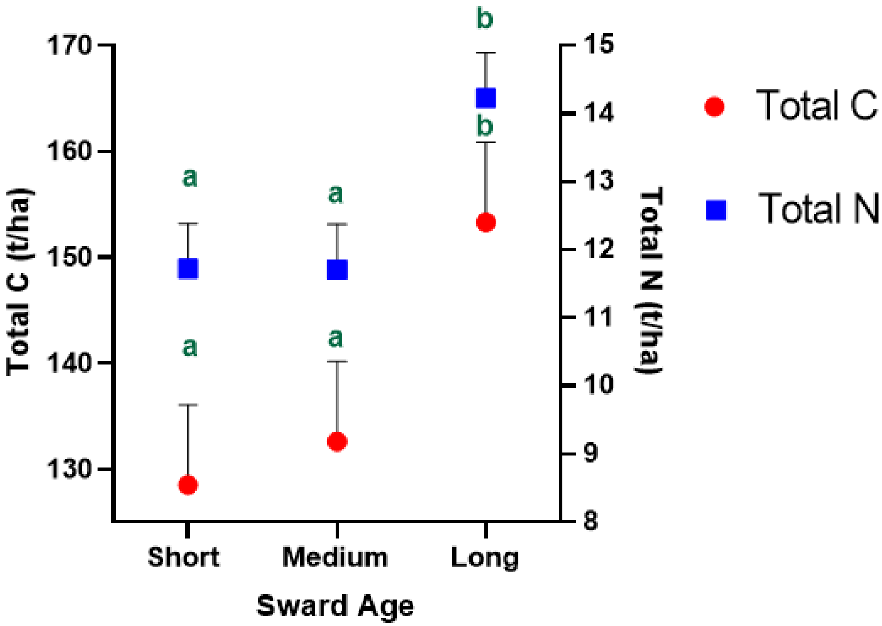
Results from AFBI work show that grassland sward age impacts soil C storage. Percentage C was assessed on samples from fields across Northern Ireland, ranging in time since reseeding (Table 1).

Table 1. Classification of swards depending on the number of years post reseeding

Classification	Years since reseeding	Sample number	Average sward age	Standard deviation
Short-term	<5	16	2.7	2.42
Medium-term	5-10	26	7.9	1.44
Long-term	>10	12	23.1	8.08

Soil % C was significantly ($p<0.05$) affected by sward age (Figure 1). The long-term sward topsoil had significantly ($p<0.05$) more tonnes of C than the medium- or short-term swards. Likewise, soil % N was significantly affected by sward age ($p<0.05$). The long-term sward had the highest level of soil % N (0.52 %), significantly ($p<0.05$) higher than the short-term sward (0.39 %).

Figure 1. C and N (t/ha) in the top 30 cm soil profile under short, medium, and long-term grassland swards. Error bars represent SED. Means with differing letters are significantly ($p<0.05$) different to each other.



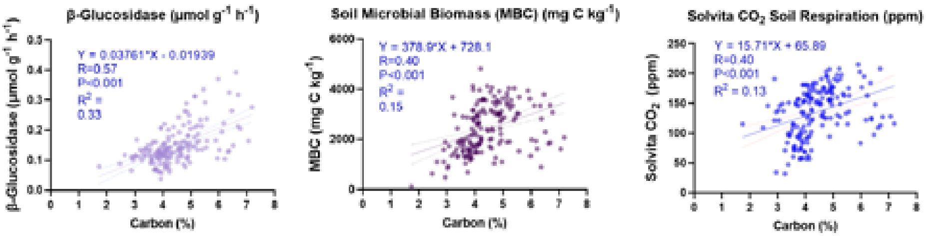
Sward age also significantly ($p<0.05$) affected β-glucosidase and the Solvita soil CO_2 respiration test ($p<0.05$) (Table 2). β-glucosidase increased with sward age, the long-term sward having a 65 % higher ($p<0.05$) value than that of the short-term.

Table 2. Years from grassland reseeding impact on soil biology

Treatment	Earth-worm biomass ($g\ m^2$)	Earth-worm count (n)	β-gluco-sidase $\mu mol\ g^{-1}$ h-1	Microbial biomass C ($mg\ C\ kg^{-1}$)	Solvita CO_2 respir-ation test (ppm)
Short-term	10.30	31.60	0.155a	2288	139.7ab
Medium-term	8.10	20.90	0.198ab	2980	145.3b
Long-term	10.83	20.20	0.255b	2683	125.3a
Statistical analysis:					
FPR	0.90	0.80	**0.018**	0.068	**0.041**
SED	6.47	18.90	0.036	293.5	8.36
SE	2.64	7.70	0.015	120.2	3.42

The relationships between soil organic C and microbial traits, using data from a range of soils and land use types (Figure 2), suggests that soil biological traits have potential as indicators of soil health. All three traits, β-glucosidase, soil microbial biomass and Solvita soil CO_2 respiration, showed highly significant ($p<0.001$) correlations with soil % C. β-glucosidase showed greatest correlation with both soil % C and % N.

Figure 2. Relationship between soil C and different measurements of soil biology in a range of grassland and arable soils (n = 170) in Northern Ireland.



An important consideration for improving soil health is land-use and a fundamental to this is the species of plant grown. Globally, intensive grasslands serve two main purposes, provision of forage from livestock, and a sink for carbon (C) (Iepema et al., 2021; Stockmann et al., 2012). Food production, however, necessitates crops other than grass, even in intensive livestock production areas such as Northern Ireland. A strategy to mitigate against the impact of conversion of grassland to alternative land-use could be varietal selection.

The InnoVar project (EC, CORDIS 2019) (https://www.h2020innovar.eu/) is coordinated by AFBI and focuses on wheat. Emerging results from partners CREA-DC suggest that soil biological function is impacted by plant variety and by crop management. Significant varietal differences ($p>0.05$) in the activity of soil enzymes associated with the soil C, phosphorus and sulphur cycles were detected in bread wheat trials. In addition, the soil microbial biomass of soil was found to be significantly ($p<0.05$) lower in plots receiving pesticides, compared with those without inputs. Going forward, identifying ways to produce crops with reduced inputs is important not only for human health, but also for soil health.

Summary

Recent work carried out by AFBI, and collaborators, has shown the importance and potential for soil biological characteristics to be indicators for soil health. Land-use, including cultivation, organic manure inputs, agrochemical use, plant species grown, and varieties selected all have a role to play in maintaining or improving the health of our soils.

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Measuring and managing soil health for farming systems in GB – research to practice

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Take home messages

- Good soil health requires attention to the physical, chemical and biological status of the soil.
- Management practices interact to determine the soil health.
- The Soil Health Scorecard helps to identify the key constraints to production and possible routes to soil improvement.
- The best soil husbandry is site and season-specific, where each action is informed by observation.

Introduction

Soils have a range of inherent properties, texture, depth and stoniness; this soil type/ character determines yield potential and many of the environmental risks for any site. Interventions through tillage, manures, drainage, species /

mixture choice in crops and cover crops then interact to determine soil health. It is widely recognised that soil physics, chemistry and biology are interlinked, and all play a role in maintaining productive agricultural systems.

Interest in soil health has been increasing and a range of indicator measures for chemical, physical and biological characteristics have been developed through research. These indicators, however, often have not been produced in parallel with the necessary guidance and tools to allow them to be used effectively to support management decisions on farm.

Between 2017 and 2022, the Soil Biology and Soil Health (SBSH) Partnership was farmer levy-funded through AHDB and BBRO; its key aims were to:

Improve understanding of the factors affecting soil biology and identify management options to improve soil health;

Develop and evaluate molecular tools for measurement of soil microbial communities; and,

Develop approaches for on-farm measurement of soil health to support practical decision-making.

Approaches

At the outset, the SBSH Partnership updated existing scientific reviews of soil biology and soil health, to summarise how management practices affect the biological, physical and chemical properties of soil and overall soil function (Figure 1).

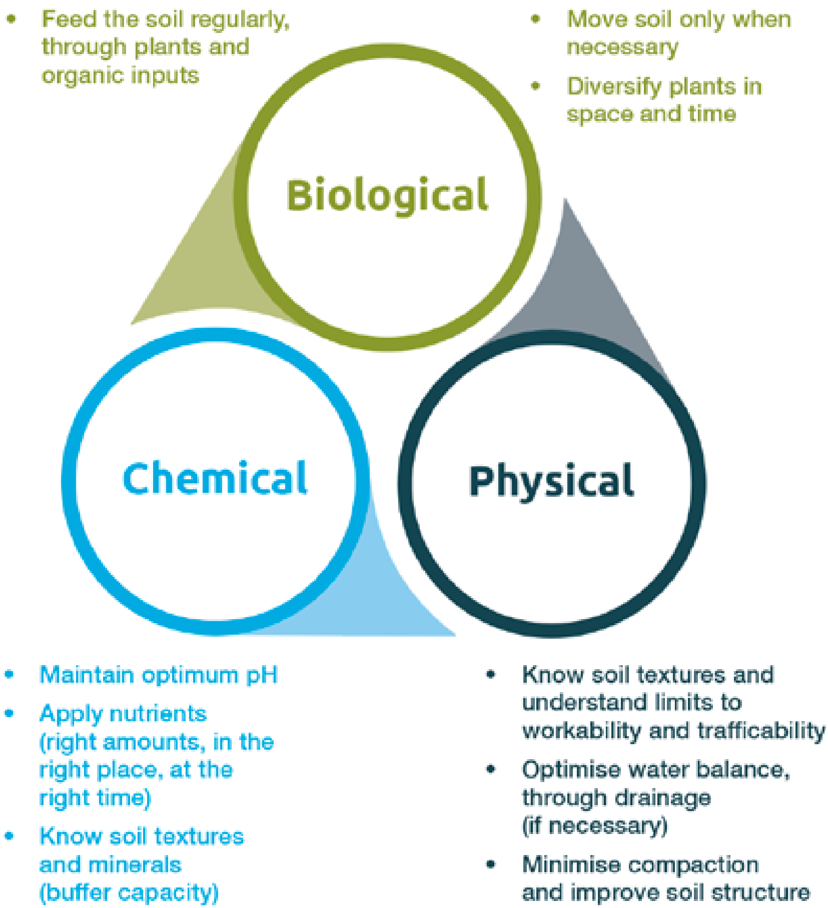

Figure 1: Key management actions to support soil health

The SBSH Partnership evaluated 45 biological, physical, and chemical indicators and considered how these could be integrated into a soil health scorecard to give a 'snapshot' overview of soil health (akin to a car MOT or school report), designed to be repeated in the same place rotationally. The indicators were scored using a logical sieve approach considering relevance to both agricultural production and environmental impact and practical aspects including sampling; sensitivity; ease of use; throughput; cost; standardisation and UK availability. A 'traffic light' system was used to provide a visual overview of the status of each indicator to help identify the key constraints to other impacts of sub-optimal soil conditions/ function (e.g. environmental risk where available P is very high) and options for soil improvement. The SBSH Partnership also used simple site characteristics (rotational land use, soil texture group (light, medium, heavy) and climatic zone) to support more detailed benchmarking where data were available and the indicator measurement showed distinctions as a result of these factors; this was most marked for soil organic matter (OM).

Within the SBSH Partnership, seven existing long-term experimental sites with treatments giving differences in OM, pH and drainage status/ structure were studied covering a range of soil and agro-climatic conditions and crop rotations. Crop yield and quality were assessed, and topsoil soil health assessments were undertaken in the autumn, at least once at each site. Measurements included: visual evaluation of soil structure (VESS), pH, extractable P, K & Mg, OM, earthworm numbers (the main Soil Health scorecard measures), together with CO2-C burst, potentially mineralisable N, microbial biomass, bulk density and penetrometer resistance. Detailed measurements of the soil mesofauna and microbial communities were also made.

The SBSH Partnership worked closely with the AHDB Cereals and Oilseeds Monitor Farms and eight farmer-research innovation groups, including 75-100 farmers and advisers involved in, or interested in, implementing innovative management practices to enhance management for better soil health, from a wide range farming systems across the country. Farmers within the groups have implemented a range of practices, at least partly to improve soil health. These are mainly system-oriented approaches (i.e., increasing OM input, reducing tillage intensity, increasing cropping/sward diversity); but have also included some tactical interventions, such as slurry inoculation, application of molasses or compost teas; companion cropping and CTF systems. The farmer-research innovation groups evaluated and applied the Soil Health scorecard approach to compare/ contrast different management approaches and to collate data on the impacts of changed management. 287 Soil Health scorecards were collected on farm across a range of farm system and soil types, together with 22 sites in orchards. Direct engagement with the farmer groups during the process also helped to shape the SBSH Partnership outputs, identify research and KE gaps as well as to shape new research questions.

Outcomes

The integrated measures of soil health together with detailed measures of soil microbial and mesofauna communities collected across the sites/ years by the SBSH Partnership showed clearly and consistently that differences between sites were greater than differences between management practices at a single site. Inherent soil characteristics together with site factors such as slope, climate and hydrology establish the 'potential' of any site, whether expressed in terms of yield, soil health or the size, activity and diversity of soil biological communities.

The following conclusions can be drawn about the impacts of management practices from the trials carried out within the SBSH Partnership:

- Optimising pH (6.5) maximises nutrient availability, biological activity and crop productivity.
- Inclusion of grass leys (2–3 years) improves soil organic matter, nutrient status, biology and structure.
- Organic materials (particularly bulky, high dry matter materials) are a valuable source of organic matter and nutrients and promote soil biological activity when used regularly. The findings suggest that low-clay soils may be more responsive to organic amendment treatments.
- Short-term application (often a single application) of organic amendments had little effect on soil health, and no measurable impact on crop disease or crop performance. Multiple applications integrated into the rotation are likely to be required before any effect is measurable.
- Ploughing in a long-term no-till field reduced microbial activity and functional diversity (i.e. the range of different substrates that the microbial population could break down). However, the ploughed plots in no-till fields did not have a different overall soil health status compared with direct drilling. These data suggest that a strategic tillage operation, e.g. to control weeds, in an otherwise no-till rotation need not lead to a significant decline in soil function.

The SBSH Partnership was able to show a positive relationship between grain yield and some indicators, particularly soil organic matter (SOM), and nutrient status across the long-term organic amendment trials.

At other sites, it was also possible to directly link measures of 'sub-optimal' soil health with poorer yields e.g. low pH, compaction (high VESS score).

The SBSH Partnership developed guidance on taking soil samples and making field records as part of a farm's overall soil health plan. These protocols also include detailed information about benchmarks for physical, chemical, and biological indicators of soil health. Due to variations in the approaches required across GB regions, separate protocols for England and Wales, and Scotland are available. Benchmarks for Northern Ireland are currently under review.

Further reading

Access the final reports of the Soil Biology and Soil Health Partnership at: https://ahdb.org.uk/soil-biology-and-soil-health-partnership

Access the practical information on soil management developed through the Soil Biology and Soil Health Partnership and other AHDB-funded research at: https://ahdb.org.uk/greatsoils

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Strategies to Improve Soil Biological Health in Arable

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Take home messages

- AFBI's Soil Health work has measured the soil chemistry, physical structure, and soil biology across a range of land uses from long term experiments and farmers' fields in Northern Ireland.
- Potential indicators of soil biology suitable to the soils of Northern Ireland have been evaluated.
- Data gathered can be used to determine how land management practices, such as use of organic manures and cover crops, influence aspects of soil health.
- Repeated applications of organic manures can improve soil microbial respiration, signalling improved soil health.
- Cover crops' main function in Northern Ireland is to sequester nutrients, potentially reduce the need for inorganic fertiliser inputs, and return carbon to soil.

Introduction – Arable in Northern Ireland

In 2022, the total agricultural crop area was 45, 700 ha accounting for only 4.6 % of the total area farmed in Northern Ireland (NI).

This is a drastic reduction compared to 392, 988 ha of crops produced in 1847. Despite the low area of crops, arable production is important in NI due to directly reducing the need for imported animal feeds, acting as a sink for organic manures and providing landscape scale diversity.

Challenges of arable land management for soil health

Soil carbon (C) is the primary energy and material source for soil biology which in turn, impacts soil fertility and structure (Billings et al., 2021). Not only is enhancing soil C desirable for improving the function and health of the soil, but also to act as a sink for C. However, the conversion of grassland to arable production typically results in a loss of soil C (Tang et al., 2019). Arable land management typically involves tillage, monocultures with limited rotations, routine applications of fungicides, a high dependence of inorganic fertiliser, extended fallow periods, and low organic matter return. These practices impact all pillars of soil health, in particular soil biology. However, mitigation strategies to maintain and enhance soil health in arable rotations include:

1. Use of organic manures
2. Cover crops
3. Optimising soil pH
4. Incorporation of straw
5. Diverse rotations
6. Reduced tillage

The suitability of each mitigation strategy is regional and farm structure dependent. AFBI has conducted research on the mitigation factors including the use of organic manures in arable crops and cover cropping. This abstract will consider work which provides supporting evidence for the first two mitigation strategies.

Organic manures – Long term trial in arable (4 years of repeated applications)

Organic manures are essential in arable production to offset inorganic nutrient requirements and are a key source of C. An experiment assessed the effect of repeated application of various organic manures on soil biological metrics in a continuous spring barley trial (Table 1). The results are a snapshot obtained after 4 years of organic manures applied at 50 t/ha, in comparison to a NPK fertiliser regime and a control.

Table 1. The impact of organic manures and NPK fertiliser on soil biology after four years of repeated applications

Parameter	Treatment					Statistical Analysis	
	Control	Cattle	Digestate	Inorganic (NPK)	Pig	P-Value	SED*
β-Glucosidase (μmol g-1 h-1)	0.109	0.119	0.101	0.110	0.099	NS	0.013
Soil microbial biomass (mg C kg-1)	1526	1650	1759	1650	1748	NS	155.2
Solvita CO2 respiration (ppm)	70.9a	92.6b	91.9b	69.3a	92.44b	**P<0.01**	7.279
Earthworm Biomass (g/m2)	19.9	26.1	29	24.1	27.7	NS	6.25
Earthworm Count /quadrat	179	180	193	185	181	NS	40.1

**SED = Standard error of difference*

The Solvita CO_2 (carbon dioxide) respiration test is a simple, proxy measure of soil biological activity. It measures the release of CO_2 when dried, sieved soil is wetted. It was the only method evaluated that showed significant differences between the land management treatments. Table. 1 shows that when organic manures are used it significantly increases soil microbial respiration compared to the NPK or unfertilised control. The Solvita method is positively correlated to soil C, soil N and microbial biomass (Chahal et al., 2021). Therefore, an increase in Solvita values indicate an improvement in soil health associated with desirable land management practices.

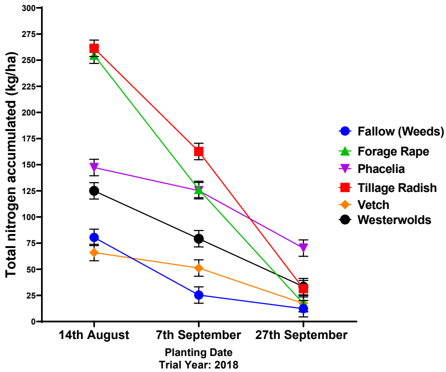
Cover crops

Cover crops (CCs) are species of plants that are typically grown over-winter, between two commercial crops, rather than leaving land fallow. They are then reincorporated back into the soil. Their primary functions are to act as a physical barrier to protect soil from rainfall and to sequester nutrients. In turn, this reduces nutrient leaching over winter with the residue being an effective biofertiliser returning major and minor nutrients, including C, back to the soil for the next commercial crop.

Major findings include:

1. CC performance as a biofertiliser to sequester nitrogen (N) and C is dependent on species choice and sowing date (Figure 1 & 2).
2. Where land is left fallow a considerable amount of leachable nutrients, particularly N, would otherwise be lost to the environment.
3. Cover crops suppress weeds and act as armour on the soil to reduce the impact of severe rainfall and therefore have key role to protect soil structure and contribute to improved soil health.

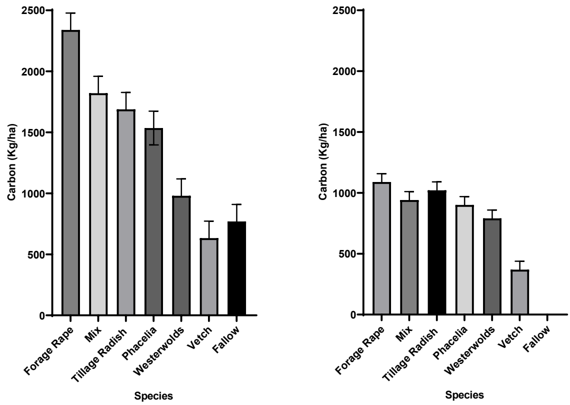
Figure 1. Cover Crop Nitrogen Uptake (kg/ha) of different species planted at different sowing dates



Nitrogen accumulation (CC + roots + weeds) by sowing date and species (kg N/ha)

Errors bars represent standard error of the mean (SEM)

Figure 2. Carbon (C) accumulation (kg/ha) of different cover crops species in the trial years of 2018 & 2019 sowing dates



Carbon accumulation (CC + roots + weeds) (kg C/ha)

Errors bars represent standard error of the mean (SEM)

Sown 14th August 2018 **Sown 10th September 2019**

Overview

There are more microbes in a teaspoon of soil than people on the planet (Shah et al., 2021). Therefore, the scale, complexity, and diversity of the soil biological community present issues for researchers. This makes it difficult to find suitable methods to measure and interpret change. It is paramount, in agriculture, that measurements of soil biology can be interpreted to guide management practices for improving soil biology (Chahal and Van Eerd, 2019; Liptzin et al., 2022). The Solvita CO_2 respiration test, is simple, repeatable, scalable, and cost-effective for farmers. Wider evaluation of this method across land use and soil types is needed to guide recommendations.

One of the fundamental improvements in land management, to enhance arable soil health, is to ensure that a sufficient and diverse range of C is being returned to soil using organic manures and cover crops.

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Safeguarding the ecosystem services provided by earthworms to NI grass and crop production

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Take home messages

- Earthworms are the dominant soil fauna in Irish agriculture.
- Earthworm populations consist of several common species existing in different niches but which interact in the soil.
- Earthworm feeding and burrowing activities recycle nutrients, aerate and drain the soil and drive microbial decomposition.
- Earthworm activity increases crop yield significantly.
- Application of organic manures, including slurry, and even inorganic fertilisers is beneficial to earthworm populations.
- Soil tillage and the invasive New Zealand flatworm are harmful to earthworm populations.

- Intercropping and multi-species swards can enhance earthworm populations.

Introduction

The term 'soil health' implies a living function and it is widely appreciated that soil organisms contribute to the fertility and sustainability of soils. However, the roles of soil animals in the recycling and release of nutrients for plant uptake are not fully understood and hence valued. In Irish agriculture the dominant soil macrofauna are lumbricid earthworms. This paper seeks to outline the contribution to soil ecosystem services and crop yield from earthworms, the threats facing them and how we safeguard earthworm functions.

There is not just one earthworm

The numbers and densities of earthworms varies considerably but typically there are 200-600 earthworms m^{-2} of pasture (Curry 1994) equivalent to 2 to 6 million worms ha^{-1}.

In Northern Ireland, 14 species of earthworm were found in pasture fields during a survey for the New Zealand flatworm. The most prevalent species were: *Aporrectodea caliginosa*, *Allolobophora chlorotica*, *Lumbricus rubellus* and *Lumbricus terrestris*; whereas the rank order for percentage biomass was *L. terrestris* greatest followed by *Ap. caliginosa*, *L. rubellus* and *A. longa.*

Earthworm species vary greatly in size: for example, an adult *L. terrestris* at 3.2 g is 10x heavier than a *Ap. caliginosa*. Earthworm species can also differ in their positions within the soil and are traditionally divided into three basic ecotypes dependent on which ecological niche they inhabit. These are: 'anecic' which are large earthworms such as *L. terrestris* that have vertical semi-permanent burrows; 'epigeic' or surface dwelling earthworms (e.g. *L. rubellus*) that are litter feeders and have a high reproductive rate; and 'endogeic' earthworms (e.g. *Ap. caliginosa*), which are subsurface horizontal burrowers.

What do earthworms do?

Earthworm feeding and burrowing activities recycles and redistributes nutrients within the soil, stimulates microbial decomposition, aerates and drains the soil, and creates soil aggregates (Blouin et al. 2013). Keith & Robinson (2012) classified the ecosystem services provided by earthworms into four main groups as follows:

1. Waste recycling and detoxification

- Soil process >> Decomposition
  - Breakdown of dead plant material /dung / slurry through feeding
  - Incorporation of plant material / dung / slurry into the soil
  - Stimulation of microorganisms

2. Carbon and nutrient regulation

- Soil process >> Nutrient cycling
  - Release of nitrogen in casts
  - Nutrient transformation
  - Stimulation of microorganisms

3. Water flow regulation

- Soil process >> Soil pore creation
  - Vertical burrows
  - Horizontal burrows

4. Soil structure maintenance

- Soil process >> Soil aggregate formation
  - Excretion of mucus
  - Modified soil in casts

The role of earthworms in carbon sequestration is contentious and has been termed the 'earthworm dilemma'. On one hand, earthworms increase incorporation of carbon into soil aggregates but on the other, they increase soil respiration leading to release of CO_2 and N_2O (Lubbers et al. 2013; Zhang et al. 2013). The balance between these two processes will determine whether earthworms are net contributors to greenhouse gas production.

In addition to soil processes, earthworms form the basis of the food-chain for many familiar farmland birds and mammals, including some, such as hedgehogs, lapwings and redwings, which are listed as vulnerable on the UK and EU Red Lists.

From ecosystem services to crop yield

Fonte et al. (2023) recently sought to quantify the global contribution of earthworms to crop yield. They found that earthworms contribute c. 6.5% of grain production and 2.3% of legume production. They based their methodology on the meta-analysis of van Groenigen et al. (2014), which utilised 58 studies reporting the effects of earthworms on crop yield. In Northern Ireland, grass is the predominant crop underpinning the dairy and beef industries. In the van Groenigen et al. (2014) meta-analysis, earthworm presence increased above-ground grass biomass by an average of 24%.

Impact of tillage

Earthworms are vulnerable to damage from tillage, either through direct physical damage, desiccation, destruction of their burrows or exposure to predation (e.g. 'gulls following the plough'). For this reason, earthworm densities tend to be substantially greater in permanent pasture or low till / no-till arable systems compared to conventionally cultivated crops (Briones & Schmidt 2017). In an experiment to assess the effects of organic manures on cereal production, the biomass of earthworms recovered in the Hillsborough situated plots (minimum tillage) was approximately 5x that of the AFBI Crossnacreevy study (conventional tillage). However, much depends on the cultivation system used, the time-span between soil disturbances and the responses of individual species, with epigeic earthworms tending to recover faster than their longer-lived anecic counterparts.

Impact of slurry applications

Slurry application often results in an initial earthworm kill close to the soil surface due to the high concentrations of ammonia and inorganic salts. However in a long-term study that examined the effects of continual seasonal applications of slurry and fertilisers to a ryegrass sward over 33 years, earthworms largely benefitted from slurry application (Murchie et al. 2015). There were differences in species-specific responses. Epigeic earthworms responded most positively to cattle slurry applications, whereas epigeic juveniles were most abundant in the inorganic fertiliser treatment. Lumbricus terrestris responded best to lower slurry application rates than the epigeic species.

Impact of the New Zealand flatworm

The New Zealand flatworm (Arthurdendyus triangulatus) was first detected outside of its native habitat in Belfast in the 1960s and is now widely distributed in Ireland, Scotland, northern England and the Faroe Islands. The flatworm is an obligate predator of earthworms and potentially harmful to their populations. In a replicated field experiment, flatworm populations of 0.8 per m2 resulted in a 20% reduction in overall earthworm biomass but a disproportionate reduction in anecic earthworm biomass of 74% (Murchie & Gordon 2013).

Steps to enhance earthworm populations

Earthworms benefit from the input of decomposing organic manures to the soil as food. Use of inorganic fertilisers can also benefit some earthworm species as they increase plant growth and hence leaf litter deposition. Good agronomic practices in grassland such as appropriate drainage and liming will also benefit earthworms. In arable cropping, tillage has a major impact on earthworms, so no-till, minimum or conservation tillage benefit earthworms. A combination of reduced tillage and intercropping wheat with clover resulted in exceptionally high earthworm populations (Schmidt et al. 2003). Similarly, multi-species swards have also been found to have greater earthworm populations compared to predominantly ryegrass swards.

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Soil-based processes underpin benefits of multi-species swards

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Take home messages

- Higher yields in multi-species mixtures are strongly related to % clover, and associated symbiotic nitrogen fixation (root- and soil-based processes)
- Emissions intensity of nitrous oxide from soil reduced by plant diversity.
- Legacy effects on soil fertility associated with multi-species mixtures strongly related to % clover.
- Soil nematode diversity strongly related to plant diversity in multi-species swards.
- Plant diversity enhanced drought resilience in multi-species swards.

Introduction

There has been renewed focus on the incorporation of legumes into intensive grassland-livestock systems, either as grass-clover or as grass-clover-herb multispecies mixtures.

Multiple benefits associated with multispecies swards include: higher yields (with lower nitrogen application), high weed suppression, lower nitrous oxide emissions, enhanced drought resilience, improved livestock performance, and higher soil biodiversity.

Four-species grass-clover mixtures consistently yielded better than the average of the four monocultures, and even yielded more than the best-performing monoculture in a majority of cases (Finn et al., 2013). Grass-legume mixtures receiving 150 kg ha^{-1} yr^{-1} of inorganic N fertiliser (N) yielded higher than a grass monoculture receiving 450 kg ha^{-1} yr^{-1} of N (Nyfeler et al., 2009). Six-species mixtures of grasses, legumes and forbs (with 150 kg ha^{-1} yr^{-1} of N) outyielded a perennial ryegrass monoculture with 300 kg ha^{-1} yr^{-1} of N (Grange et al., 2021). Plant diversity in mixtures is also strongly related to weed suppression (Connolly et al, 2018; Grange et al. 2021).

Nitrous oxide (N_2O) is a potent greenhouse gas and is strongly associated with losses from inorganic nitrogen (N) fertiliser applied to grassland. Multispecies grasslands can reduce N_2O emissions intensities. The annual greenhouse gas emissions per unit output (N yield in harvested forage) from multi-species mixtures (at 150 kg ha^{-1} yr^{-1} of N) were lower than those from perennial ryegrass receiving the same or higher N levels 150 or 300 kg ha^{-1} yr^{-1} of N (Fig. 1) (Cummins et al. 2021).

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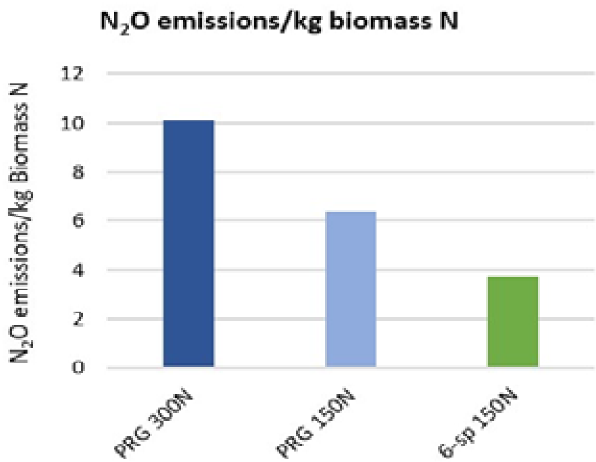


Fig. 1. N_2O emissions intensity from soil was lower under 6-species mixtures (calculated as annual N_2O emissions per unit yield of N in annual harvested forage) (modified from Cummins et al. 2021). (PRG 300N = perennial ryegrass with 300 kg ha-1 yr^1 of N; PRG 150N = perennial ryegrass with 150 kg ha^{-1} yr^1 of N; 6-sp 150N = equi-proportional six-species mixture with 150 kg ha^{-1} yr^1 of N.)

Research from the Teagasc Environment Research Centre at Johnstown Castle demonstrated that higher plant diversity of intensively managed multi-species swards enhanced belowground soil biodiversity and health. As grassland plant diversity increased up to six species of grasses, clovers and herbs, soil-dwelling nematode communities also had increased diversity and improved performance across a range of ecological soil health indices. Soil nematodes are often used as indicators of soil health and ecosystem functioning. Compared to monocultures of forage plants, multi-species grasslands with six species had a higher abundance of predatory nematodes, which can be beneficial for the biocontrol for plant pests (Fig 2). Conversely, there was a lower abundance of herbivorous nematodes in multi-species grasslands, the presence of which can negatively affect plant performance (Ikoyi et al. 2023).

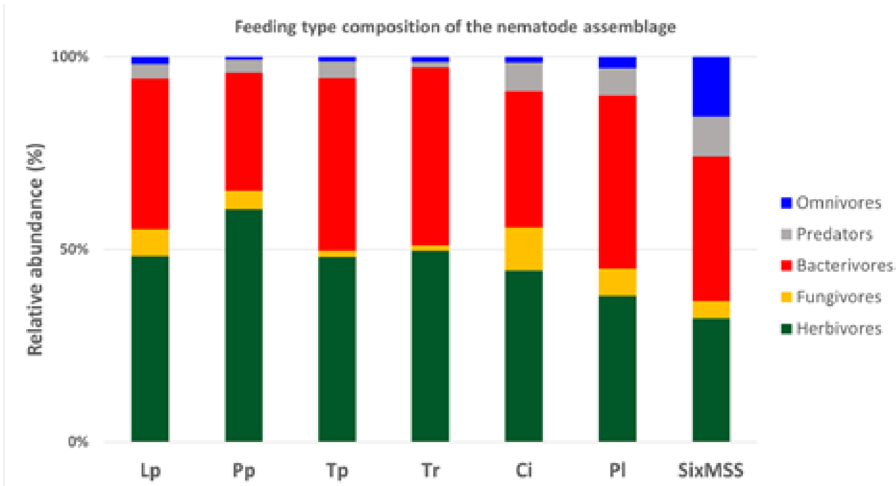
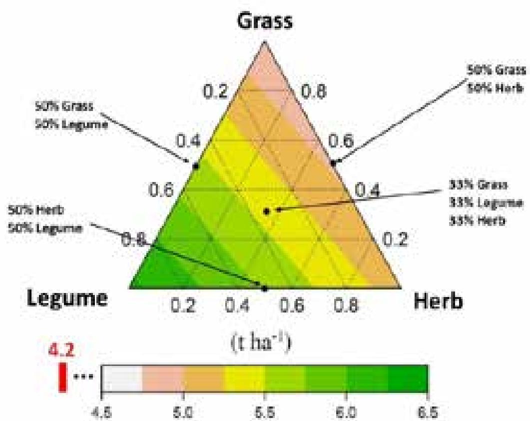


Fig. 2. Mean relative abundances (%) of the nematode feeding groups in the monocultures and the equi-proportional six-species multi-species swards (from Ikoyi et al. 2023). (Lp = perennial ryegrass, Pp = timothy, Tp = red clover, Tr = white clover, Ci = chicory, Pl = plantain, SixMSS = equi-proportional six-species mixture.)

Grange et al. (2021) varied the diversity of six-species grassland ley communities from monocultures to 6-species mixtures (systematically varying three functional groups of grasses, legumes and herbs). All plots received 150 kg/ha/yr of nitrogen fertiliser; they also included a perennial ryegrass monoculture with additional nitrogen fertiliser (300 kg ha^{-1} yr-^{1} of N). The grassland communities were replaced with a monoculture of Italian ryegrass, and the legacy effect of grassland ley diversity on transfer of soil fertility was measured as yield of the follow-on crop of Italian ryegrass. The effect of plant communities on yield (t/ha) of the follow-on crop was strongly related to the proportion of clover in the preceding grassland community (Fig. 3). (See also Fox et al. 2020.)



(300N).

Fig. 3. Legacy effects of changes in functional group composition (relative proportion of grasses, herbs and legumes) in a grassland ley on yield of the Italian ryegrass follow-on crop (in a model crop rotation) (from Grange et al. 2022). The legacy effect of the 300N L. perenne monoculture is indicated in red in the colour bar.

Ongoing research as part of the DAFM/DAERA funded Multi4More project will further investigate the effects of zero to high N levels on forage yield and quality from grasslands with different diversity, as well greenhouse gas emissions. Multi4More will also investigate effects of multi-species mixtures on livestock performance, as well as above- and below-ground biodiversity (https://multi4more.ie)

Acknowledgements

The research on soil nematodes by Israel Ikoyi was funded by the EU Horizon research and innovation programme under the MASTER project (grant agreement No. 818368). The Teagasc Walsh Scholarship programme funded Guylain Grange and Saoirse Cummins. The contribution of JF to this article was through the DAFM/DAERA Multi4More project (ref: 2021R456).

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Current and recently completed AFBI soil projects

Completed Projects

Reference	Project title	Contact
DAERA	Soil Health in Northern Ireland	lisa.black @afbini.gov.uk
DAERA	Long-term effects of slurry dressings on grassland	jonathan.holland @afbini.gov.uk
DAERA	ECOSWARD - An investigation of the potential for multi species swards to enhance ecosystem services within sustainable livestock systems.	david.patterson @afbini.gov.uk
DAERA	Effects of reseeding and liming on soil carbon stocks under intensively managed grassland in Northern Ireland	alex.higgins @afbini.gov.uk
DAERA	The potential benefits of extended use of GPS for improving performance and precision in grass and grass silage production	suzanne.higgins @afbini.gov.uk

Current Live Projects

Reference	Project title	Contact
DAERA	Evaluating the impact of a range of organic manures applied to arable land on soil, crop and NI agriculture	lisa.black @afbini.gov.uk
DAERA	Effects of long-term slurry (LTS) dressings on grassland including GrassCheck plot monitoring	jonathan.holland @afbini.gov.uk
DAERA	Soil Nutrient Health Scheme	rachel.cassidy @afbini.gov.uk
DAERA	Countryside survey	suzanne.higgins @afbini.gov.uk
DAERA-DAFM	Land-Use, Agriculture and Bioenergy Measures for the Abatement of Climate Change and inclusion in Marginal Abatement Cost Curve Analyses (LAB - MACC)	john.mcilroy @afbini.gov.uk
DAERA-DAFM	Transforming pasture-based livestock systems through improved design of multi-species mixtures under reduced nitrogen regimes (MULTI4MORE)	suzanne.higgins @afbini.gov.uk
H2020 - InnoVar	Next generation variety testing for improved cropping on European farmland (InnoVar)	lisa.black @afbini.gov.uk

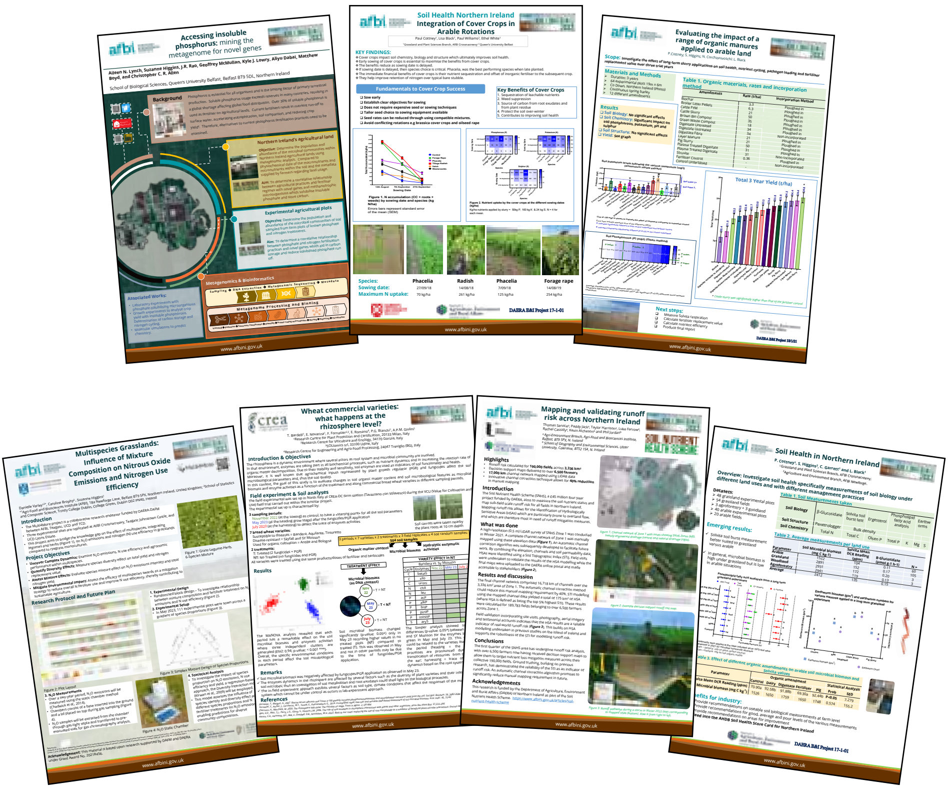
Reference	Project title	Contact
H2020 - EJP Soil	Towards climate-smart sustainable management of agricultural soils (EJP SOIL) • Internal research projects involving AFBI: - CarboSeq (Jonathan Holland) - MixRoot-C (Jonathan Holland) - SensRes (Suzanne Higgins) - (SIREN, iSoMPE, PRACT2LIV are stocktake projects, with very minor input from AFBI)	suzanne.higgins @afbini.gov.uk
DAERA/ US-Ire	Dual-function engineered biochar for excess soil phosphorus sorption with subsequent slow release for cost effective and sustainable crop production (Duo-Biochar)	suzanne.higgins @afbini.gov.uk
SBRI (Innovate UK)	Innovative solution to deliver the real time monitoring of soil health	erica.chisholm @afbini.gov.uk

Proposed projects

Reference	Project title	Contact
DAERA	DeepRoots – the potential for farm woodland to contribute to attaining net zero	diane.burgess @afbini.gov.uk
DAERA	AGROFORESTRY: Responding to climate change – Adaptation and mitigation	rodrigo.olave @afbini.gov.uk
DAERA	SUSTAIN: Building Resilience into Grassland and Delivering Ecosystem Services	david.patterson @afbini.gov.uk
DAERA	An investigation of emission factors, mitigation strategies and the sequestration potential of high organic matter soils managed under intensive grazing in Northern Ireland (PEAT-NI)	naomi.rutherford @afbini.gov.uk

Posters

Posters for this event can be viewed on the AFBI website at this LINK



Soil Health in Northern Ireland

P. Cottney[1], S. Higgins[2], C. Garrett[1] and L. Black[1]
[1] Grassland and Plant Sciences Branch, AFBI Crossnacreevy;
[2]Agriculture and Environment Branch, AFBI Newforge.

Overview: Investigate soil health specifically measurements of soil biology under different land uses and with different management practices

Datasets:
- 48 grassland experimental plots
- 54 grassland fields
- 3 agroforestry + 3 goodland
- 40 arable experimental plots
- 20 arable fields

Table 1. Soil Measurements taken

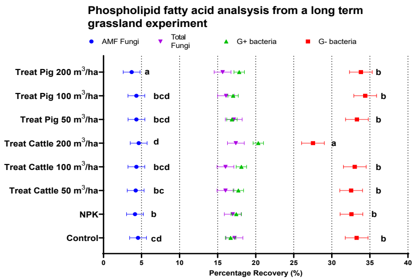
Soil Biology	β-Glucosidase	Solvita soil burst test	Ergesterol	Phospholipid fatty acid analysis		Earthworms	
Soil Structure	Penetrologger	Bulk density					
Soil Chemistry	Total N	Total C	Olsen P	Total P	K	Mg	S

Emerging results:

- ✓ Solvita soil burst measurement better suited to grassland versus arable
- ✓ In general, microbial biomass is high under grassland but is low in arable situations

Table 2. Average measurements per land use

Parameter	Soil Microbial biomass (mg C kg-1)	Solvita Mean DCR Reading (ppm)	B-Glucosidase (µmol g-1 h-1)	N =
Arable	1522	104	0.11	60
Grassland	2891	152	0.17	105
Woodland	2931	172	0.20	3
Agroforestry	2941	119	0.13	3
Average	2412	135	0.15	



Treatments were applied at the rates indicated since 1970 and were measured in 2021 for microbial community structure
Gram – bacteria rely on plant carbon sources
Gram + bacteria rely on soil organic matter

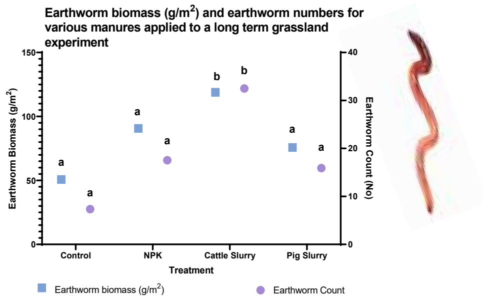
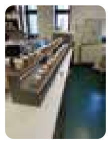


Table 3. Effect of different organic amendments on arable soil microbial biomass and Solvita values

Parameter	Organic amendment					Statistical Analysis	
	Control	Dairy	Digestate	Fertiliser	Pig	Prob	SED
Solvita Mean DCR Reading (ppm)	70.90a	92.58b	91.88b	69.30a	92.44b	**P<0.05**	7.279
Soil Microbial biomass (mg C kg^{-1})	1526	1650	1759	1650	1748	0.574	155.2



Benefits for industry:

- ❑ Provide recommendations on useable soil biological measurements at farm level
- ❑ Provide recommendations for good, average and poor levels of the various measurements
- ❑ Provide recommendations on areas for improvement
- ❑ **Feed into the AHDB Soil Health Score Card for Northern Ireland**

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Evaluating the impact of a range of organic manures applied to arable land

P.Cottney; S. Higgins; N. Corchionivoschi; L. Black

Scope: **Investigate the effect of long-term slurry applications on soil health, nutrient cycling, pathogen loading and fertiliser replacement value over three trial years**

Materials and Methods

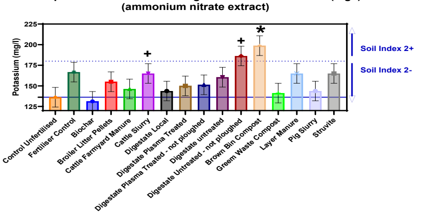
- Duration: 3 years
- 64 experimental plots 19m x 6m
- Co Down, Northern Ireland (Photo)
- Continuous spring barley
- 12 different amendments

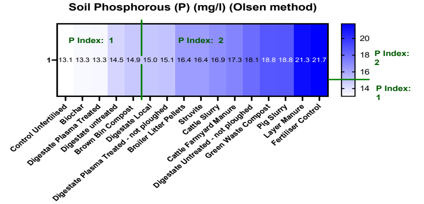
Results

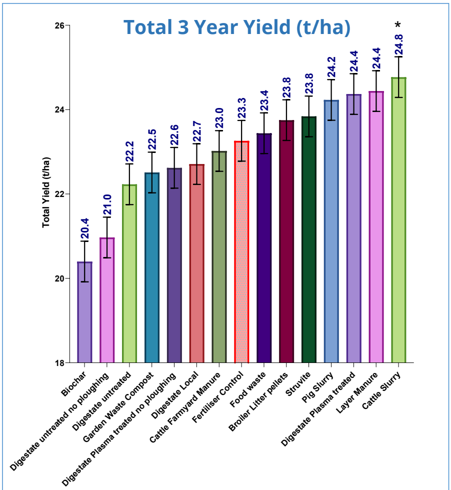
- ❑ **Soil Biology: No significant effects**
- ❑ **Soil Chemistry: Significant impact on soil phosphorous, potassium, pH and sulphur**
- ❑ **Soil Structure: No significant effects**
- ❑ **Yield: See graph**

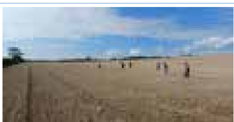
Table 1. Organic materials, rates and incorporation method

Amendments	Rate (t/ha)	Incorporation Method
Biochar	3.3	Ploughed in
Broiler Litter Pellets	6.3	Ploughed in
Cattle FYM	21	Ploughed in
Cattle Slurry	50	Ploughed in
Brown Bin Compost	35	Ploughed in
Green Waste Compost	18	Ploughed in
Digestate Untreated	34	Ploughed in
Digestate Untreated	34	Non-incorporated
Digestate Fibre	21	Ploughed in
Layer Manure	21	Ploughed in
Pig Slurry	50	Ploughed in
Plasma Treated Digestate	31	Ploughed in
Plasma Treated Digestate	31	Non-incorporated
Struvite	0.36	Ploughed in
Fertiliser Control	-	Non-incorporated
Control Unfertilised	-	-









Next steps:

- ❑ Measure Solvita respiration
- ❑ Calculate fertiliser replacement value
- ❑ Calculate nutrient efficiency
- ❑ Produce final report

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DAERA E&I Project 18/1/21

Soil Health Northern Ireland Integration of Cover Crops in Arable Rotations

Paul Cottney[1], Lisa Black[1], Paul Williams[2], Ethel White[1]

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KEY FINDINGS:

- Cover crops impact soil chemistry, biology and structure which ultimately improves soil health.
- Early sowing of cover crops is essential to maximise the benefits from cover crops.
- The benefits reduce as sowing date is delayed.
- If sowing date is delayed, then species choice is critical. Phacelia, was the best performing species when late planted.
- The immediate financial benefits of cover crops is their nutrient sequestration and offset of inorganic fertiliser to the subsequent crop.
- They help improve retention of nitrogen over typical bare stubble.

Fundamentals to Cover Crop Success

- **Sow early**
- **Establish clear objectives for sowing**
- **Does not require expensive seed or sowing techniques**
- **Tailor seed choice to sowing equipment available**
- **Seed rates can be reduced through using compatible mixtures.**
- **Avoid conflicting rotations e.g brassica cover crops and oilseed rape**

Key Benefits of Cover Crops

1. Sequestration of leachable nutrients
2. Weed suppression
3. Source of carbon from root exudates and from plant residue
4. Protect the soil over-winter
5. Contributes to improving soil health

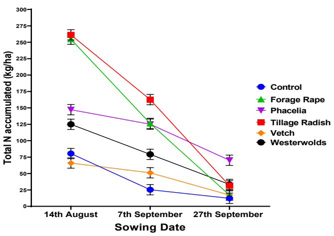

Figure 1. N accumulation (CC + roots + weeds) by sowing date and species (kg N/ha)

Errors bars represent standard error of the mean (SEM)

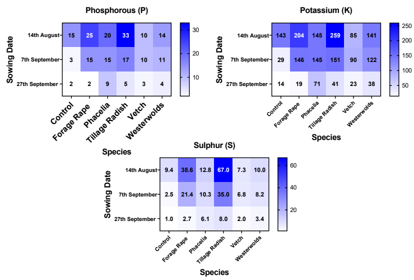

Figure 2. Nutrient uptake by the cover crops at the different sowing dates (kg/ha)

Kg/ha nutrients applied by slurry = 50kg P, 160 kg K & 24 kg S. N = 4 for each mean.





Species:	**Phacelia**	**Radish**	**Phacelia**	**Forage rape**
Sowing date:	27/09/18	14/08/18	7/09/18	14/08/19
Maximum N uptake:	70 kg/ha	261 kg/ha	125 kg/ha	254 kg/ha

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Multispecies Grasslands: Influence of Mixture Composition on Nitrous Oxide Emissions and Nitrogen Use Efficiency

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Introduction

- The Multi4More project is a collaborative research endeavor funded by DAERA-DAFM between AFBI, Teagasc, UCD and TCD.
- Three experimental sites are replicated at AFBI Crossnacreavy, Teagasc Johnstown Castle, and UCD Lyons Estate.
- This project aims to bridge the knowledge gap on the effect of multispecies, integrating legumes and herbs (Figure 1), on N_2O emissions and nitrogen (N) use efficiency in grasslands compared to ryegrass monocultures.

Figure 1: Grass-Legume-Herb, 6-Species Mixture

Project Objectives

- **Uncover Complex Dynamics:** Examine N_2O emissions, N use efficiency and agronomic performance within multispecies.
- **Quantify Diversity Effects:** Measure species diversity effect on total yield and nitrogen replacement value.
- **Assess Mixture Effects:** Evaluate species mixture effect on N_2O emissions intensity and total nitrogen yield.
- **Mitigate Environmental Impact:** Assess the efficacy of multispecies swards as a mitigation strategy to reduce overall N fertiliser use and improve N use efficiency, thereby contributing to sustainable agriculture.

Research Protocol and Future Plan

Figure 2: Plot Layout

1. Experimental Design

- Randomised block design – To investigate relationship between mixture composition and fertiliser treatment on N_2O emissions and N use efficiency (Figure 2).

2. Experimental Setup

- In May 2023, 111 experimental plots were sown across a gradient of species proportions (Figure 3).

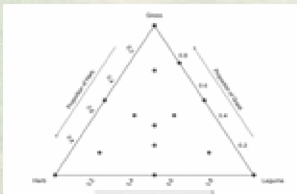

Figure 3: Simplex Mixture Design of Species Proportions

3. N_2O Measurements

- Over a two-year period, N_2O emissions will be measured using the static chamber method (Chadwick *et al.*, 2014).
- Chambers consist of a base inserted into the ground and a lid placed on top during gas sampling (Figure 4).
- N_2O samples will be extracted from the chamber through gas-tight septa and transferred to pre-evacuated vials for gas chromatography analysis.

Figure 4: N_2O Static Chamber

4. Statistical Analysis

- To investigate the impact of species proportion on N_2O emissions, N use efficiency and yield, a regression-based approach, the Diversity-Interaction model (Kirwan *et al.*, 2009) will be employed.
- This model assesses the influence of species identity and diversity effect across different species proportions and N fertilizer treatments on N_2O emissions, enabling predictions for diverse community compositions.

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Kirwan, L. *et al.* (2009) 'Diversity–interaction modeling: estimating contributions of species identities and interactions to ecosystem function', *Ecology*, 90(8), pp. 2032–2038. doi: 10.1890/08-1684.1.

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Wheat commercial varieties: what happens at the rhizosphere level?

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Introduction & Objectives

The rhizosphere is a dynamic environment where several actors as root system and microbial community are involved.
In that environment, enzymes are taking part in all biochemical processes, such as nutrient dynamics and in increasing the reaction rate of organic matter decomposition. Due to their stability and sensitivity, soil enzymes are used as indicators of soil functionality and health.
Moreover, it is well known that agrochemical inputs represented by plant growth regulator (PGR) and fungicides affect the soil microbiological parameters and, thus the soil quality.
In this context, the goal of this study is to evaluate changes in soil organic matter content and soil microbiological features as microbial biomass and enzyme activities as a function of the treatment and along commercial bread wheat varieties in different sampling periods.

Field experiment & Soil analyses

The field experimental was set up in North Italy at CREA-DC farm station (Tavazzano con Villavesco) during the VCU (Value for Cultivation and Use) field trial carried out within the InnoVar project.
The experimental set up is characterised by:

Soil carrots were taken nearby the plant roots at 10 cm depth

3 sampling periods:
- November 2022 (at the sowing) as control, to have a «starting point» for all the soil parameters
- May 2023 (at the heading grow stage) after the fungicides/PGR application
- July 2023 (at the harvesting) to detect the trace of enzymes activities

7 bread wheat varieties:
- Susceptible to diseases = Bandera, Aquilante, Tintoretto
- Disease-resistant = Skyfall and SY Moisson
- Used for organic cultivation = Antille and Bologna

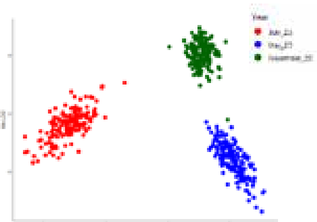
2 treatments:
- T: Treated (2 fungicides + PGR)
- NT: No Treated (no fungicides and PGR)

All varieties were treated using the same products/doses of fertilizer and herbicides

3 periods x 7 varieties x 2 treatments x 3 field replicates x 4 soil random samples: **504 soil samples**

Organic matter content — **Microbial biomass** — **Hydrolytic enzymatic activities**

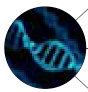
Results



The MANOVA analysis revealed that each period has a remarkable effect on the soil microbial biomass and enzymes activities where three independent clusters are generated (Eta2: 0.94; p-value: < 0.001 ***).
Overall, the specific environmental conditions in each period affect the soil micobiological parameters.

TREATMENT EFFECT

Microbial biomass (as DNA content)



- Nov 22 • T = NT
- May 23 • **T < NT**
- July 23 • T = NT

Soil microbial biomass changed significantly (p-value: 0.05*) only in May 23 recording higher values in no treated plots (NT) compared to treated (T). This was observed in May and not in other periods may be due to the time of fungicides/PGR application.

VARIETY EFFECT in NT

Bandera *vs.* Sy Moisson

Cycle	Enzymes	Nov 22	May 23	July 23
C	betaG			
C	xilo		green	
C	uroni			
N	chit			
N	leu			
P	acP			
P	alkP		green	
P	bisP			green
P	piroP			
P	inositP		green	
S	aryS			green

The Simper analysis showed significant differences (p-value: 0.05*) between Bandera and SY Moisson for the enzymes labeled in green in May and July 23. This variability could be related to the varieties itself and on the period (heading = the microbial processes are pronounced due to the translocation of resources from the root to the ear; harvesting = trace of enzymes dynamics based on the root system.

Remarks

- ✓ Soil microbial biomass was negatively affected by fungicides/PGR application as observed in May 23.
- ✓ The enzymes dynamics in the rhizospere are affected by several factors such as the diversity of plant varieties and their interaction with soil microbes; thus an investigation of soil metabolities and root exudates could shed light on the biological processes.
- ✓ The in-field experiment appoach exhibits several factors as soil type, climate conditions that affect the responses of the microbiological system which cannot be under control as occurs in lab-experiment approach.

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Accessing insoluble phosphorus: mining the metagenome for novel genes

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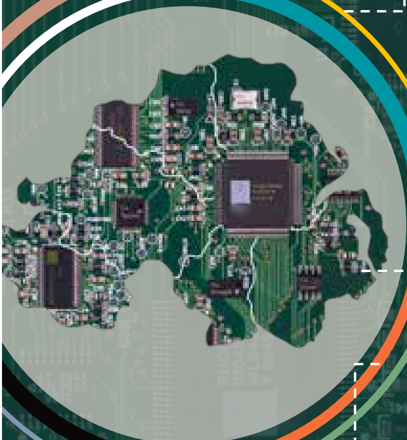
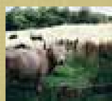
Background

Phosphorus is essential for all organisms and is the limiting factor of primary terrestrial production. Soluble phosphorus usage exceeds reserves in many countries, resulting in a global shortage affecting global food distribution. Over 30% of soluble phosphorus is used as fertiliser on agricultural lands. Current fertilisers result in nutrient run-off to surface water, accelerating eutrophication, soil compaction, and reducing crop yield[2]. Therefore, alternatives to current phosphorus fertilisation practices need to be examined.



Northern Ireland's agricultural land



SOIL NUTRIENT HEALTH SCHEME

Objective: Determine the population and abundance of the microbial communities within Northern Ireland agricultural lands using metagenomic analysis. Compared to physiochemical data of the macronutrients and micronutrients within the soil and the metadata supplied by farmers regarding land usage.

Aim: To determine a correlative relationship between agricultural practices and fertiliser regimes with novel genes and methanotrophic microorganisms which solubilise insoluble phosphate and store carbon.

Experimental agricultural plots

SOIL NUTRIENT HEALTH SCHEME

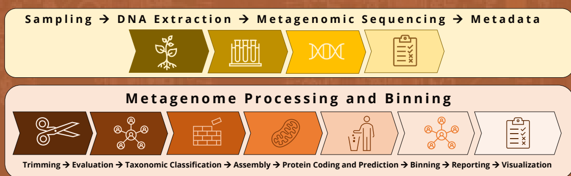
Objective: Determine the population and abundance of the microbial communities of soil sampled from farm plots of known phosphate and nitrogen treatments.

Aim: To determine a correlative relationship between phosphate and nitrogen fertilisation practices and novel genes which aid in carbon storage and reduce solubilised phosphate run off.

Associated Works:

- Laboratory experiments with phosphate-solubilising microorganisms
- Growth experiments to analyse crop yield with insoluble phosphorous. Determination of carbon storage and nitrogen cycling.
- Molecular simulations to predict chemistry.

Metagenomics & Bioinformatics



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Mapping and validating runoff risk across Northern Ireland

SOIL NUTRIENT HEALTH SCHEME

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Highlights

- Runoff risk calculated for **190,000 fields** across **3,336 km²**
- Decision support maps delivered to over **6,500 farmers**
- **17,000 km** channel network mapped using LiDAR data
- Innovative channel correction technique allows for **40% reduction** in manual mapping

Introduction

The Soil Nutrient Health Scheme (SNHS), a £45 million four-year project funded by DAERA, aims to measure the soil nutrient status and map sub-field scale runoff risk for all fields in Northern Ireland. Mapping runoff risk allows for the identification of Hydrologically Sensitive Areas (HSAs) which are particularly prone to overland flow, and which are therefore most in need of runoff mitigation measures.

What was done

A high-resolution (0.5 m) LiDAR survey of SNHS Zone 1 was conducted in Winter 2021. A complete channel network of Zone 1 was manually mapped using these elevation data (***Figure 1***). An automatic channel correction algorithm was subsequently developed to facilitate future work. By combining the elevation, channels and soil permeability data, HSAs were identified using a Soil Topographic Index (STI). Field visits were undertaken to validate the results of the HSA modelling while the final maps were uploaded to the DAERA online portal and made accessible to stakeholders (***Figure 2***).

Results and discussion

The final channel network comprised 16,718 km of channels over the 3,336 km^2 area of Zone 1. The automatic channel correction method could reduce this manual mapping requirement by 40%. STI modelling using the mapped channel data yielded a total of 175 km^2 of HSA (where HSA is defined as being the top 5% highest STI). These results were calculated for 189,783 fields belonging to over 6,500 farmers across Zone 1.

Field validation incorporating site visits, photography, aerial imagery and testimonial accounts indicates that the HSA results are a reliable indicator of real-world runoff risk (***Figure 3***). This builds on HSA modelling undertaken in previous studies on the island of Ireland and supports the robustness of the STI for modelling runoff risk.

Conclusions

The first quarter of the SNHS area has undergone runoff risk analysis, with over 6,500 farmers now having received decision support maps to allow them to target nutrient loss mitigation measures across their collective 190,000 fields. Ground truthing, building on previous research, has demonstrated the reliability of the STI as an indicator of runoff risk. An automatic channel correction algorithm promises to significantly reduce manual mapping requirement in future.

Acknowledgements

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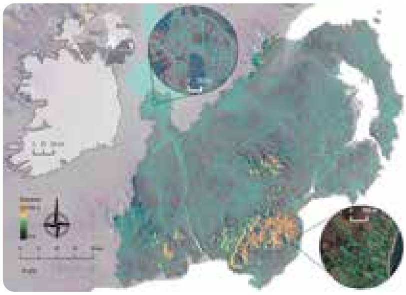

Figure 1: Channel network of Zone 1 with insets showing SNHS Zones (left), heavily-engineered drainage (centre) and natural drainage (right).

Figure 2: Example decision support runoff risk map.

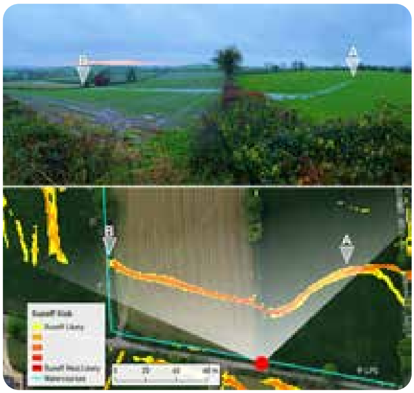

Figure 3: Runoff pathways during a storm in Winter 2022 (top) corresponding to mapped HSAs (bottom). Flow is from right to left.

Independent Emergence of Pathogenic Lifestyles Uncovered by Comparative Genomics of plant associated *Pantoea* spp.

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Key messages

- *Pantoea* strains, whether phytopathogenic or symbionts, present very similar percentages of Plant Growth Promoting Bacteria (PGPB) traits.
- Phylogenomic analysis of the phytopathogenic and phytobeneficial lifestyles distribution revealed that beneficial traits came first, and that the acquisition of pathogenicity was a recent evolutionary phenomenon that occurred independently in different species of this genus at different times of their evolution.

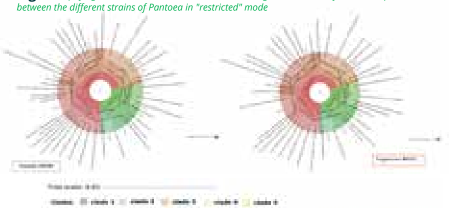
1. Intro

The *Pantoea* genus includes soil dwelling bacteria capable of colonizing different plant species, establishing pathogenic or beneficial symbiont relationships[2]. Using phylogenomics and comparative genomics[3], we investigated the complex evolutionary relationships between plant-related *Pantoea* species, focusing on their ability to either promote plant growth or exhibit phytopathogenic tendencies.

2. Methods

- **A dataset of 30 selected strains from the Plabase platform[5].** **https://plabase.cs.uni-tuebingen.de/pb/plabase.php**
- **Phylogenomics through the 'Type Strain Genome Server' TYGS[4] platform https://tygs.dsmz.de/ based on dDDH and GC%**
- **The distribution of genes encoding Plant Growth Promoting Bacteria (PGPB) traits using data from PlaBa-db.**
- **The origin of pathogenicity and the beneficial lifestyles based on phylogenomics super trees.**

Fig.1 *The phylogenetic tree based on 16S rRNA illustrating the evolutionary relationships between the different strains of Pantoea in "restricted" mode*



3. Results and discussion

While certain strains within this genus possess inherent genomic capabilities to enhance plant growth, through direct and indirect mechanisms, resulting in a significant positive impact on plant health and productivity; surprisingly such positive genomic traits are shared with other pathogenic *Pantoea* strains **(fig. 1).**

P. agglomerans GB1 strain is misidentified as *P. ananatis* GB1.
Curtobacterium plantarum strain, classified as a Gram-positive bacteria, presented a close genetic similarity to the *P. pleuroti* and *P. agglomerans* strains. We suggested that this strain actually belongs to the genus *Pantoea*. We also propose 2 sp. nov. based on genomic data (dDDH < 70%): *Shigella* sp. 1.19 and *Pantoea* sp. AS-PWVM4 **(fig. 2, fig. 3).**

Based on the phylogenomic analysis, the pathogenic lifestyles of several strains from different *Pantoea* species seem to have appeared recently, compared to original beneficial strains from the remaining species, which leads us to believe that phytopathogenicity has independently emerged multiple times within the *Pantoea* group **(fig. 4).**

Fig.2 *Restricted phylogenomic tree of Pantoea spp. by the GBDP approach*

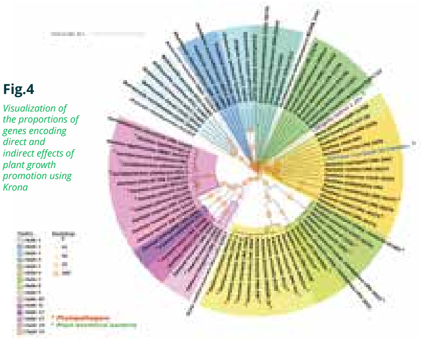


Fig.4 *Visualization of the proportions of genes encoding direct and indirect effects of plant growth promotion using Krona*

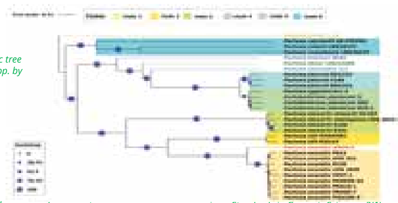


Fig.2 *Extended phylogenomic tree of Pantoea spp. by the GBDP approach*

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