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Soils special

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Irish Soil Information System

Teagasc
Agriculture and Food Development Authority

Three generations of soil science

Three generations of soil science at Johnstown Castle, from left to right: photograph of Dr Tom Walsh, the first director of An Foras Talúntais, with the first Edition Soil Map of Ireland (1969); Dr John Lee (retired) and Pat Sills with the Second Edition Soil Map (1980); and Dr Rachel Creamer and Iolanda Simo, authors of the Third Edition ISIS map (2014).

"The demands of people all over the world are changing (…) The world itself is becoming a much smaller place because developments in communication and transportation (…) New countries are emerging, world population is expanding but the overall production of food lags behind (…) It is unnecessary to stress the excellence of Irish conditions for the production of meat and dairy produce, and knowledge now coming from our studies on intensive grassland production suggests that we can become one of the most efficient producers of these products per unit of land in the world."

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At first glance these comments appear to be a contemporary quote from Ireland's *Food Harvest 2020* Strategy. But it is not. It is a vision laid out in a 1967 speech entitled 'Food in the Future' by Dr Tom Walsh, the first director of An Foras Talúntais, the predecessor of Teagasc that initiated the National Soil Survey.

As we celebrate Dr Walsh's centenary year, it is striking how his vision has become reality today, almost half a century later. He recognised the untapped potential of Irish soils to cash in on a growing global demand for food and made it his mission to "grow two blades of grass where only one grew before". Today, the importance of agriculture is once again recognised, following a lull of more than two decades in which food was cheap and plentiful. The global 'Food Price Crisis' in 2008 awoke the world once again to the need to invest in agriculture, and to make the most of the limited area of fertile soil available to humankind. Ireland has shown itself to be well positioned to rise to this challenge: earlier this year, Bord Bia reported that Irish food and drink exports have increased by 40% since 2009, approaching €10 billion for the first time in history, which places agriculture at the heart of the national recovery.

This success story did not write itself. As Europe emerged from the war, Ireland's economy was on its knees. Eager to build a farming economy, the Government of the day looked to New Zealand scientists for advice. They reported that Irish farming was in such poor condition that "you couldn't possibly grow less grass under an Irish sky" and pointed the finger at Ireland's low soil fertility, poor soil drainage and, most crucially, lack of knowledge.

Enter young Tom Walsh, who had just returned home from the US, with a PhD in Soil Science under his arm. Determined to bring agriculture into the twentieth century through "the objective findings of fact", he convinced the Government to invest in scientific research. He knew that key to producing more food was to optimise soil conditions. Recognising the diversity of Irish soils, he initiated the National Soil Survey, which published the First Edition Soil Map of Ireland in 1969. That legacy lives on to this very day: this autumn the Third Edition is launched jointly by Teagasc and the Environmental Protection Agency at Johnstown Castle, as part of the Irish Soil Information System, which has combined traditional soil surveying techniques ('digging holes') with the latest digital technologies.

The publication of the Irish Soil Information System opens a new chapter in agricultural and environmental research. For the first time, after three generations of soil science, we have a complete picture of the diversity and properties of soils in Ireland. Figuratively speaking, this is equivalent to 'sequencing Ireland's soil genome'. In this special issue of *TResearch*, we show how the Soil Information System is already providing the foundation for the fourth and future generations of soil science.

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Follow Rogier Schulte at @RogierSchulte

A special lecture will be held on December 5, World Soils Day, to mark the centenary of the birth of the late Dr Tom Walsh. The lecture will be delivered by Professor John Ryan on the 'Evolution and Achievements of Irish Soil Science'.

For more information see: www.teagasc.ie/events/2014/20141205.asp

DR THOMAS WALSH (1914-1988)
MAgrSc, DSc, PhD, LLD, ScD, MRIA.

Dr Tom Walsh, a native of Piercestown, Co. Wexford, graduated from University College Dublin in 1937 with an honours BAgrSc degree. He received the MAgrSc the following year, his PhD in 1941, and he was awarded the DSc in 1947 for his published work. He was awarded honorary doctorates by the National University of Ireland in 1972 and by Trinity College Dublin in 1980 and was elected to the Royal Irish Academy in 1955. When An Foras Talúntais was established in 1958, he was appointed by the Government as its first Director, following a career as a soil scientist at University College Dublin and the Department of Agriculture. He was appointed the first Director of ACOT in 1980 and he retired from the public service in 1983.

Dr Walsh participated actively in a large number of scientific organisations. He was founder member and President of the Agricultural Science Association and of the Fertilizer Association of Ireland, and President of the Soil Science Society of Ireland and the Irish Grassland Association. He was Chairman of the National Council for Educational Awards and of the State Agency Development Co-Operation Organisation (DEVCO). He was Senior Vice-President of the Royal Irish Academy (RIA) and served as RIA Secretary for seven years.

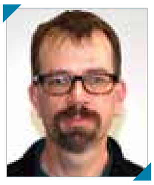
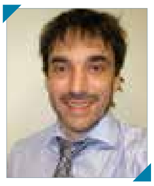
But his interests and expertise stretched well beyond agricultural science. He was a member of the Commission on Higher Education and Chairman of the Garda Training Review Body. His membership of boards and councils of other Irish bodies included the Economic & Social Research Institute, the Nuclear Energy Board, the School of Ecumenics and the Commission for Justice & Peace.

Source: Scientific Papers Dr Tom Walsh Volume I: 1941-1953

The Irish Soil Information System



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The Irish Soil Information System combines traditional and cutting-edge technologies to bring all data on Irish soils together in one map and open-access information system. Dr Rachel Creamer and her team explain the long road to the completion of this third edition, National Soil Map.

Soil: the foundation of 'Smart Green Growth'

Ireland faces the contemporary challenge of meeting a range of agri-environmental objectives, in the context of increasing food production in a post-quota environment. Examples include the need to obtain 'good quality' status for all waterbodies, as specified by the Water Framework Directive, the need to protect biodiversity under the Habitat and Birds Directives, the potential for offsetting agricultural greenhouse gas (GHG) emissions through carbon sequestration and the need for sustainable recycling of nutrients under the Nitrates and Sewage Sludge Directives. It has been well documented that the capacity of land to deliver on each of these requirements depends primarily on soil properties and, hence, soil type. Therefore, a comprehensive knowledge of Irish soils is prerequisite to meeting the premise of 'Smart Green Growth' as formulated in the *Food Harvest 2020* strategy. This includes an inventory of the diversity of soils and their properties, as well as their geographical location and extent.

The need for a Soil Information System

Until recently, approximately half of Ireland had been mapped in detail by the National Soil Survey of An Foras Talúntais, the predecessor of Teagasc, in the form of detailed county soil maps. The General Soils Map was based on an amalgamation of soils information from 12 detailed county maps and an understanding of the soil landscape relationships existing in areas previously not surveyed in detail. This map, created in 1980 by Gardner and Radford, was available digitally at a scale of 1:575,000.

A review of soils data in Ireland found that spatial soils data in Ireland was no longer fit-for-purpose. Data usage of soils maps has developed significantly in the last 34 years since the publication of the second generation General Soils Map. This realisation led to the establishment of the Irish Soil Information System, co-funded as part of the STRIVE programme of the Environmental Protection Agency and coordinated by Teagasc, in collaboration with Cranfield University (UK) and University College Dublin. The objectives of this project were: (1) to develop a new soil map for Ireland at 1:250,000 scale; (2) to identify new and existing soils; and, (3) to provide a detailed description and classification system for all the soil types present in Ireland. This resulting map forms the basis of the soil information system for Ireland and is publicly available at http://soils.teagasc.ie

Developing a soil map

The detailed work completed by An Foras Talúntais, specifically the county maps at a scale of 1:126,720, were used as the building blocks of the new map and information systems. More recent map products, such as the Indicative Soil and Subsoil map completed by Teagasc in 2009, were also included. This wealth of soils information allowed the development of predictive mapping techniques, which are statistical models that describe the variation of soil within and between landscapes. These models were used to predict the location of soil types in geographical areas, which have previously not been described in detail (Figure 1).

These soil-landscape models were generated for the counties of Carlow, Clare, Kildare, Laois, Leitrim, Limerick, Meath, Offaly, Tipperary South, Waterford, Westmeath, Wexford, West Cork, West Mayo and West Donegal.

Validating the predictive map

The use of predictive mapping to create a soil map is a novel method and Ireland is the first country to use this method on a national scale. Therefore, we conducted a traditional soil survey for 2.5 years to validate the accuracy of the predicted map, resulting in a confidence map. This validation involved the collection of soils data at more than 11,000 locations across the country. This traditional soil survey consisted of two steps. In the first instance, surveyors sampled down to a depth of 80cm to make a field description of the soil type to validate the predicted polygons on the map. In completing this initial survey, a number of new soil types were identified, which had previously not been described. These were particularly prevalent in counties Cork and Donegal, which represented soil-landscape models that had not been described in detail previously.

Having established the degree of accuracy and confidence in the predicted map, we then conducted a second, detailed survey, in which we dug 225 soil pits to describe these 'reference soils' in full detail. These pits were sampled at all horizons down the profile and a suite of laboratory analyses were conducted to allow the classification of the soils, using both the Irish classification system and the World Reference Base (WRB) system, the main unifying classification system used in Europe. Such analyses included: pH, texture; organic matter; total nitrogen; extractable iron and aluminium; bulk density; Cation Exchange Capacity (CEC); and base saturation. In addition, samples were also taken for a number of associated PhD projects measuring carbon sequestration in soils, biological diversity, bulk density ranges etc.

The final map and information system (online database) has been created using a unique combination of new and traditional methodologies and brings together soils data from both the An Foras Talúntais survey and the Irish Soil Information System project. The new soil map of Ireland consists of 58 associations (excluding areas of alluvium, peat, urban, rock or marsh) that are made up from 213 soil series. The information system that supports the map has been designed to hold the complete set of information deriving both from the Irish Soil Information System field programme, as well as the previously existing legacy soils information available for Ireland.

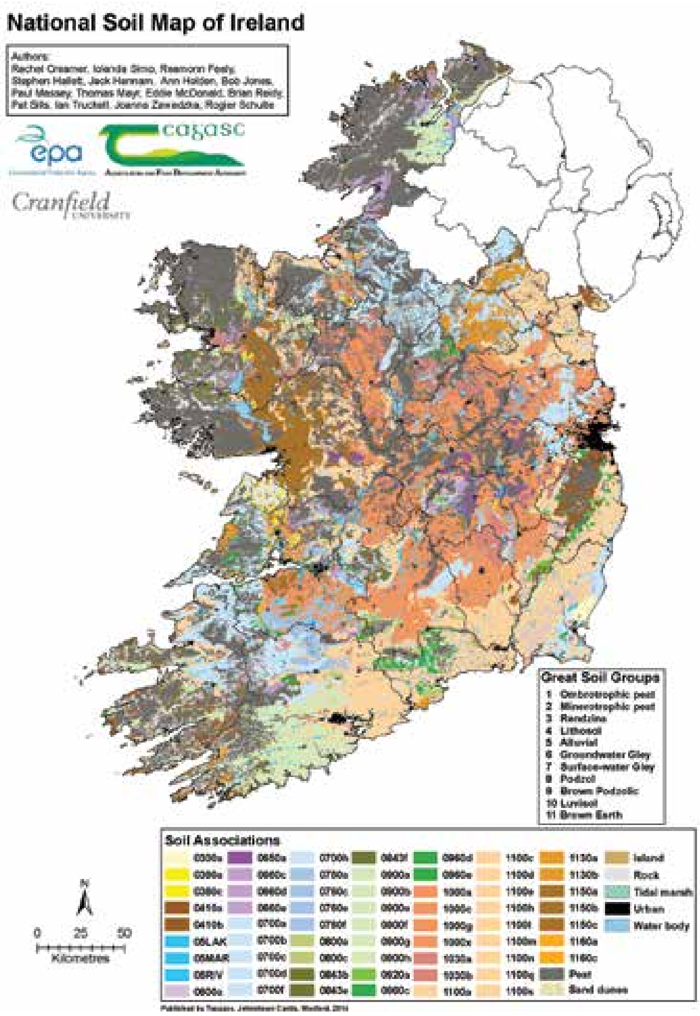
Applications

The new soils map and information system will be an invaluable tool in developing solutions for sustainable land management and the agri-environment into the future. Practical examples of the utility of the Irish Soil Information System map for policy and practice include:

- the facilitation of a migration from Tier 1 to Tier 3 GHG reporting to the United Nations Framework Convention on Climate Change;
- the Department of Agriculture, Food and the Marine will utilise attribute maps, developed by Teagasc, of soil properties derived from the 3rd edition soil map to delineate Areas of Natural Constraints (see pages 16-17 in this issue);
- the facilitation of the development of soil-specific nutrient advice by soil subgroup;
- the facilitation of the development of targeted and context-specific agri-environmental schemes; and
- the identification of priority areas and more targeted actions in the ongoing development and review of the River Basin District Management Plan.

Funding

This project was co-funded by Teagasc and the Environmental Protection Agency (STRIVE Research Programme 2007-2013).



Soils – the nutrient reservoir

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Nutrient cycling in agricultural systems

Increased nutrient efficiency is a key requirement for farmers if Irish agriculture is to meet production growth targets as set out in *Food Harvest 2020* in an environmentally sustainable manner. When used efficiently, nutrient inputs help to attain target crop yields and ultimately a satisfactory return on investment. However, inefficient nutrient input use can erode farm income and lead to negative environmental impacts on our atmosphere and water bodies in the cases of nitrogen (N) and phosphorus (P) respectively. It is, therefore, important that Irish food production maintains its 'green' image, which results in significant marketing and trading advantages. Improving nutrient-use efficiency requires the adoption of management practices on farms that will increase the proportion of these nutrients recovered in farm output and reduce the amount that is lost to water and the atmosphere. To achieve this, it is essential to balance the nutrients available in the soil, originating from the soil's own supply and fertilizers, with grassland and crop requirement and off-take. Nutrient inputs are expensive with farmers spending approximately €613 million in 2013 on fertilizers, one of the biggest single, direct inputs costs on Irish farms.

Making nutrient cycling work on the farm

Plant-available forms of macro- and micronutrients are relatively scarce in the soil. Nutrient cycling is important in order to minimise the adsorption of these nutrients into inert forms or their loss into sensitive environments. Cycling is also imperative to make prudent use of the finite global reserves of nutrients such as P. Soils play a vital role in this cycling; ideally, soils can: 1) safely accept residues from farms, industries and private households and make maximum use of the nutrients in these residues; 2) sustain the biological fixation of N; 3) match the mineralisation of nutrients to seasonal crop demand; 4) maximise the recovery of nutrients by crops as determined by yield limiting factors such as the availability of other micronutrients; and 5) minimise the risk that the nutrients in crops will, in the end, not be effectively harvested and returned to society. Soil properties affect each of these five aspects of nutrient cycling, and the nutrient efficiency research programme at Teagasc, Johnstown Castle is continuously developing new understanding of the extent to which these interact.

Towards soil-specific nutrient advice

Different soils have varying capacity to produce grass and crops mainly due to certain physical and chemical characteristics, and the biology and climatic environment in which they reside. For example, recent research has revealed that Irish grassland soils have the capacity to supply large quantities of N (23kg to 114kg N ha^{-1}, Figure 1) in the absence of N fertilizer inputs (McDonald *et al.*, 2014) through biological N mineralisation processes. Similarly, studies have shown that different soil types have varying capacities to supply P; this opens the scope for soil-specific fertilizer advice (Wall *et al.*, 2012). Therefore, the requirement for external inputs can be reduced per unit of productivity, by increasing the efficiency with which nutrients are acquired by the crop.

Getting the balance right

Agriculture cannot be sustained without the replenishment of nutrients removed by crops, as plant growth is dependent upon a continuous supply of mineral nutrients from the soil. Fertilizers are applied to grassland and crops to produce an appropriate level of soil fertility that supports adequate crop

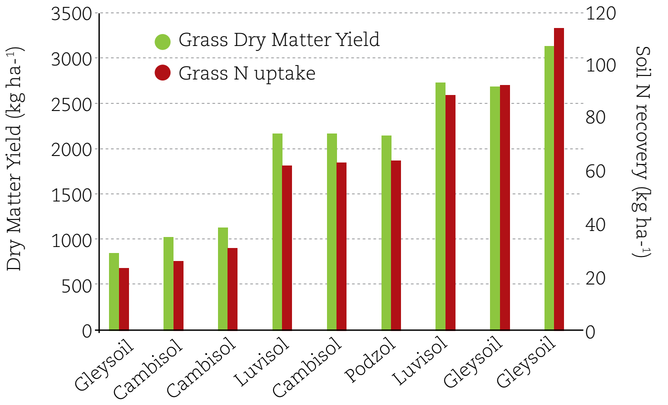


Figure 1. Average soil nitrogen recovery and grass dry matter yield for a range of Irish grassland soils over a five-week grass growth interval under optimised growth conditions

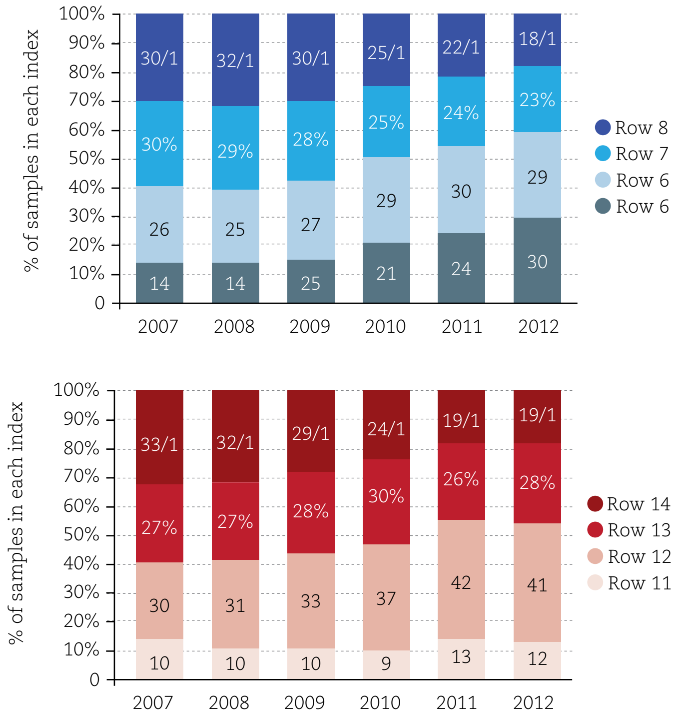
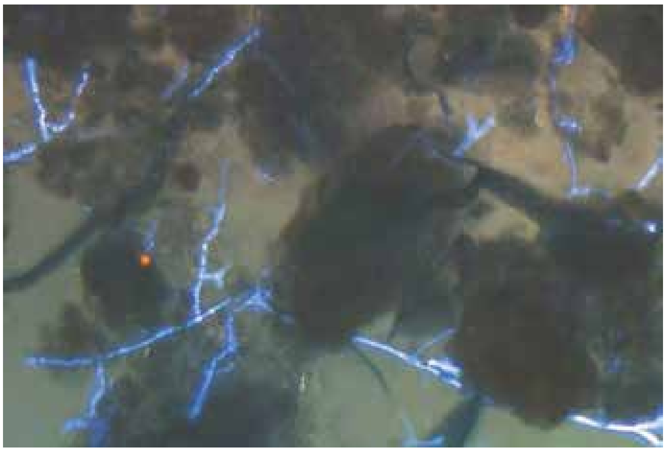


Figure 2. National soil P (blue) and K (red) fertility trends between 2007 and 2013, represented by circa 38,000 soil samples submitted for analysis through Teagasc annually.

growth (and animal performance) and maintain an adequate level of soil fertility by replacing all nutrient off-takes, be they in the forms of milk, meat or crops, (grass/silage). Nutrient deficiency, particularly N, P, Potassium (K) and Sulpher (S) will dramatically reduce output (reduction in annual grass DM production estimated to be ~1.5t DM ha^{-1} when operating at sub-optimal P and K indices [Index 1 and 2]). At the same time, Ireland has strict targets to meet under the Water Framework Directive (WFD), which requires coherent action by all sectors to reduce nutrient losses to water bodies. The Agricultural Catchments Programme (ACP) evaluates the overall efficiency of the on-farm measures, aimed at minimising the risks from N and P losses from agricultural systems, in six agricultural catchments. A recent census of the soil P status in five of these catchments showed that there was large spatial variability both between and within farms, which reflects historic and current management intensities. Between 74% and 94% of catchment soils had P status at optimum (Index 3) or lower (Index 1 and 2) levels, which have lower risk of P loss (index 4 soils pose a higher P loss risk). These data corroborate an emerging trend in soil fertility at a national level, showing an overall decline in soil P and K status (Figure 2, Lalor and Wall, 2013). Therefore, it is crucial to get the balance right and maintain soil fertility at optimum levels that allow optimum production while minimising nutrient losses to water.



Fungal mycelia (showing blue on this image) facilitate nutrient transport through the soil matrix to plants. Photo: Professor Karl Ritz.

It has been the responsibility of research staff at Teagasc, Johnstown Castle since the 1940s to develop and help disseminate major and micro-nutrient advice for productive agricultural crops. This is contained in the 'green book'. This work underpins all farming systems from the most intensive dairy systems to the more extensive beef and sheep rearing systems, with the aim of sustaining high and environmentally sustainable levels of production

Funding

This research is funded by the Department of Agriculture, Food and the Marine and the Teagasc Walsh Fellowship Programme.

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Creating a baseline:

Assessing the carbon sequestration potential of Irish soils





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The implementation of *Food Harvest 2020* poses challenges both in terms of meeting the ambitious production targets and meeting sustainability criteria, most notably greenhouse gas (GHG) targets. The EU Climate Change package envisages a 20% reduction in emissions from the Irish non-Emission Trade Sectors (ETS) by 2020. Considering that agriculture comprises 40% of these emissions, there is a clear challenge to increase production in compliance with climate change targets. In addition, both markets and consumers are demanding that agricultural produce generates lower carbon footprints.

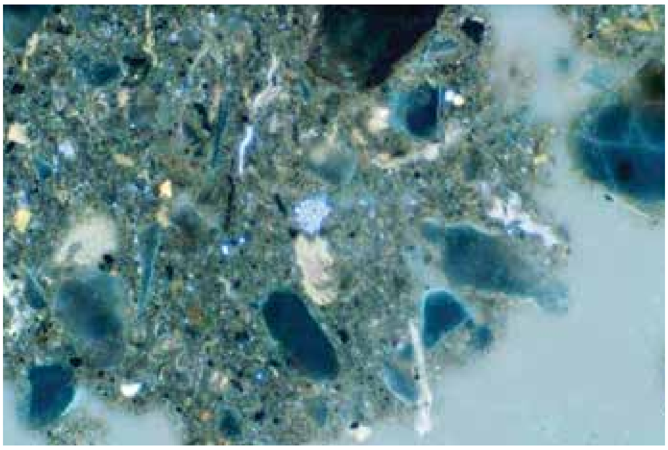
The capacity for the sector to reduce emissions by the abatement of methane and nitrous oxide, the principal GHG's generated from agriculture, is limited to approximately 8% of current emissions (Teagasc, 2011). However, soils play an important role as a potential sink of carbon (C). Globally, terrestrial systems can hold up to 2,200 billion tonnes of C, which is five times the C present in the biosphere and 3.5 times the C in the atmosphere. As a result, offsetting agricultural emissions via carbon sequestration is considered one of the primary tools for meeting global climate targets.

For Ireland, C sequestration is attractive as a mitigation option, as management of grassland systems (e.g. fertilisation, grazing) generally enhances sequestration. Indeed, practices that sequester C in grasslands normally increase productivity, which places C sequestration as a win-win strategy. European temperate grasslands have been shown to be a carbon sink, with annual sequestration rates of approximately 1 tonne C per hectare. Considering that grassland comprises 4 million hectares, or 90% of agricultural area, the size of Irish grassland sinks may be considerable. Initial results show that optimising the intensity of herbage utilisation through grazing, cutting and maintaining good nutrient status (nitrogen (N) and phosphorus (P)) increases soil C sequestration rates in temperate grasslands. As a result, the inclusion of C sequestration into life-cycle assessment of dairy and meat products can reduce the emissions intensity of the produce by over 40%. However, the potential for using soil C sequestration as a mitigation strategy is currently limited by methodological difficulties in both establishing baselines and verifying the strength and permanence of carbon sinks.

From an agricultural point of view, Soil Organic Carbon (SOC) is important because of its central role in soil functioning. SOC acts as a supplier of nutrients for the plants: through mineralisation of SOC carried out by bacteria, nutrients such as N, P, potassium (K), calcium (Ca) are transformed from organic forms (unavailable to plants) to inorganic forms, which can be absorbed by the roots. SOC also adsorbs nutrients onto its surface. The strength of adsorption of nutrients onto the SOC surface is strong enough to reduce leaching and weak enough to facilitate uptake by plant roots. In addition, SOC creates a better structure in the soil as a result of its interactions with the mineral part of soils, creating and maintaining aggregates. Soil aggregation is important for the formation of micro and macro pores, which in turn enhance water holding capacity, aeration, and plant rooting. A better structure also reduces the risk of erosion and appearance of crusts at the soil surface.

The challenge of measurement

Current input rates of organic C into most soil systems are hard to measure, as input rates of 0.25 tonnes of C are being introduced into a soil pool that typically contains between 70 to 200 tonnes C per hectare. Furthermore, the residence time of C sequestered into the soil may range from days to



The architecture of soil aggregates determines whether soil microbes (in the centre of the picture) can reach and break down organic matter. Photo: Professor Karl Ritz

millennia. To date, the fundamental mechanisms involved in sequestration are still subject to research and, thus far, there are no methodologies available to quantify the distribution of C between 'fast' and 'slow' turnover pools. As a result, the reliable assessment of the effects of management on soil C stocks and pools requires the development of methods that establish the potential of soils to permanently sequester C in different fractions

The role of aggregates in sequestering carbon

The decomposition and conversion of organic material into aggregates is one of the principal C sequestration mechanisms. These aggregates are formed initially by root exudates (such as polysaccharides) and fungal and plant debris. This particulate organic matter (POM) is a temporary binding agent as it is easily degradable by bacteria. Decomposition reduces the size of these aggregates (micro-aggregates), which subsequently become encased in clay particles. Occluded organic matter has a slower turnover than free organic matter, which means that it will have a longer residence time into soils. Eventually, some of the C is incorporated into complexes with soil particles, leading to further stabilisation. Hence, although macro-aggregates contain more organic matter than micro-aggregates, it is more labile than micro-aggregates organic matter, which is less available for decomposition by bacteria. Therefore, a soil that contains a higher proportion of micro-aggregate carbon will contribute more to long-term carbon sequestration, because its carbon will remain longer in soils.

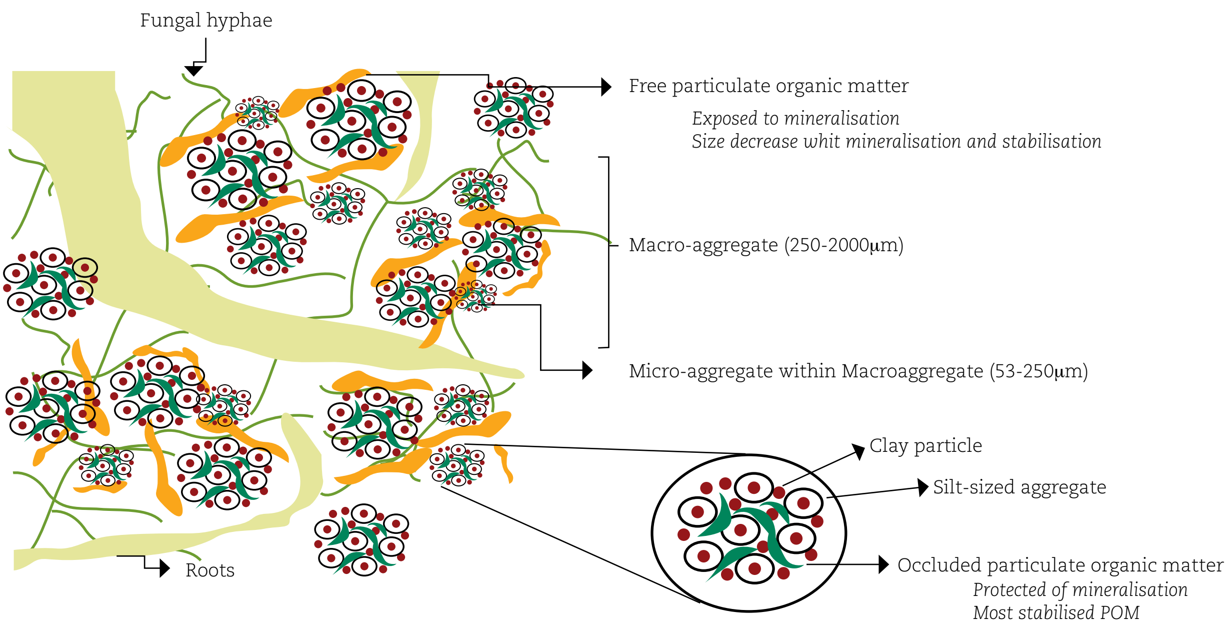
Current Teagasc research by the Irish Soil Information System in conjunction with the Agricultural Greenhouse Gas Initiative for Ireland (AGRI-I) is focused on assessing the quantity and quality of C in soil organic matter. The principal research questions include:

- What are the SOC stocks in agricultural soils and what is the effect of soil type and management on C quantity and quality?
- At what point does 'saturation' of soil C occur and what controls this?
- What is the link between management intensity and rates of sequestration and can we manage grazed pasture systems to increase the rates and absolute amounts of C sequestered?

In summary, C sequestration offers considerable potential to help achieve future climate targets, while also improving soil functioning. Researching the mechanisms of sequestration and developing 'early warning systems' to predict the direction and size of C loss/gain will assist in developing new strategies to both maintain and enhance current stocks.

Funding

This research is funded by the Teagasc Walsh Fellowship scheme, in collaboration with the Irish Soil Information System (co-funded by the STRIVE Programme of the Environmental Protection Agency) and AGRI-I (funded by the Stimulus Programme of the Department of Agriculture, Food and the Marine).



Visualisation of aggregates and organic matter within the soil matrix

Soil time lag and water quality

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What is time lag and how long will it last?

The Water Framework Directive (WFD) in Europe aims, inter alia, to achieve at least 'good' water quality status by 2015 by mitigating the causes of pollution. However, with the implementation of programmes of measures in 2012, many catchments may not achieve good water quality status within this timeframe due to the time lag of nutrient transport from source to receptor. A 'time lag' is the delay that takes place between implementation of new agricultural practices (e.g. improved nutrient management) and the ultimate response by aquatic ecosystems to these changes. This delay reflects the time it takes for nutrients to travel to the waterbody via hydrological and hydrogeological pathways and can range from days to decades. Given this variation, an appraisal of catchment time lag issues offers a more scientifically based timescale for expected water quality improvements in response to mitigation measures implemented under the WFD.

In 2011, Teagasc published a simplified methodology for the calculation of nitrate time lag in a variety of Irish hydrogeological scenarios, based on unsaturated vertical and aquifer flushing times required to reach environmental quality standards (Fenton *et al.*, 2011). The results showed that achievement of good water quality status in the Republic of Ireland for some waterbodies may be too optimistic within the current timeframe of 2015 targets but improvements are predicted within subsequent six- and 12-year cycles. Uncertainty analysis showed that the efficacies of mitigation measures are unlikely to manifest themselves for up to 10 years. The Teagasc Agricultural Catchments Programme aims to pick up on early changes (trends) in water quality and, in doing, so can give guidance with regard to the efficacy of measures before the time lag period has occurred.

We are currently quantifying the first component of time lag – the residence time of water in the soil. We are using a holistic approach, which includes simple (back of the envelope) and complex (modelling and tracer experiments) methods to estimate in situ time lags.

How can we estimate time lag?

Ideally, time lag is measured via tracer tests, in which a dye or chemical is applied to the soil surface and its progress through the soil profile is monitored. However, in many cases this approach is prohibitively time consuming and costly. An alternative is to employ computer simulations in which water flow and solute dispersion equations are coupled with soil hydraulic and meteorological input data to simulate contaminant transport (Figure 1). These simulations mimic tracer tests and produce solute breakthrough curves, indicating the removal of contaminant from the soil profile over time (Figure 2). Such curves can be divided into four sections: first occurrence corresponds to the initial breakthrough of the solute at the base of the profile (indicating when trend analysis should be initiated), peak breakthrough (indicating the highest concentration of solute observed), centre of mass (indicating when the bulk effects

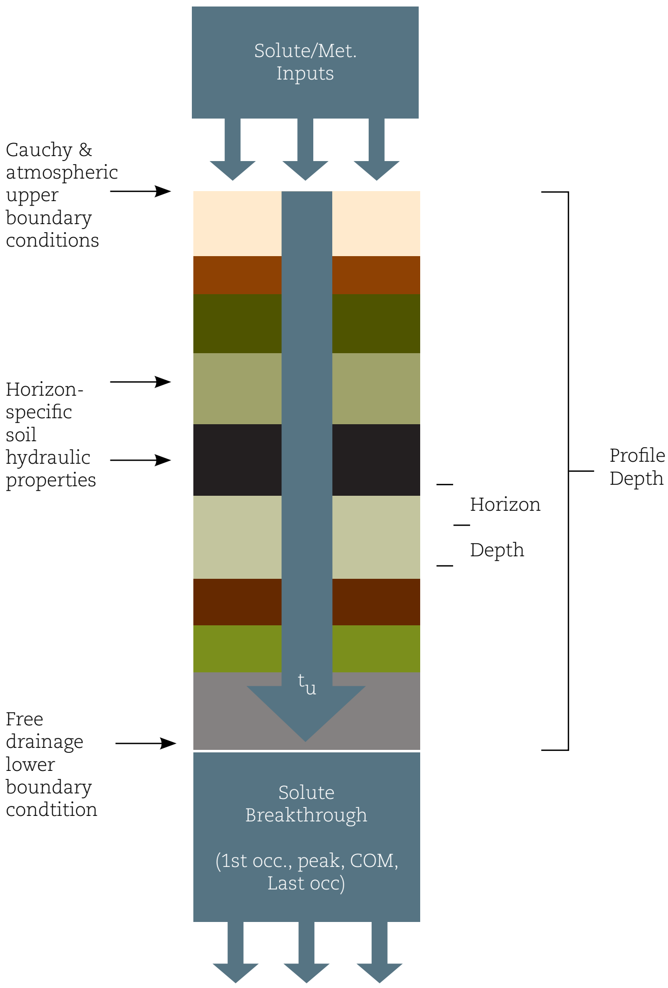

Figure 1: Unsaturated hydrological model.

of programmes of measures have taken effect), and last occurrence, which is the total exit of solute from the profile.

Vero *et al*. (under review) found that the temporal resolution of meteorological data used in computer simulations influences the shape of the resulting breakthrough curves and, consequently, time lag estimates. It is recommended that hourly, rather than daily, meteorological data should be employed where available. Regarding the soil hydraulic parameter inputs, the study found that results obtained from laboratory tests (e.g. measuring the soil water characteristic curve) as opposed to generic soils data (such as textural class), better reflected in-situ soil conditions and hence improved estimates of time lag. This demonstrates one application of the high quality soil data collection provided by the Irish Soil Information System.

Why is time lag important for agriculture?

Unless we account for time lag, there is a real risk that any failure to meet water quality objectives may be erroneously equated to either a lack of compliance, or inadequacy of existing measures. In that case, legislation would effectively stipulate that water quality targets are approximated at a rate that exceeds the maximum rates as dictated by hydrology, which is of course physically impossible. Therefore, it would be prudent to assess the expected timelines for meeting water quality objectives, accounting for time-lags, before proposing progressive changes to the current Programmes of Measures currently implemented in the River Basin District Management Plans.

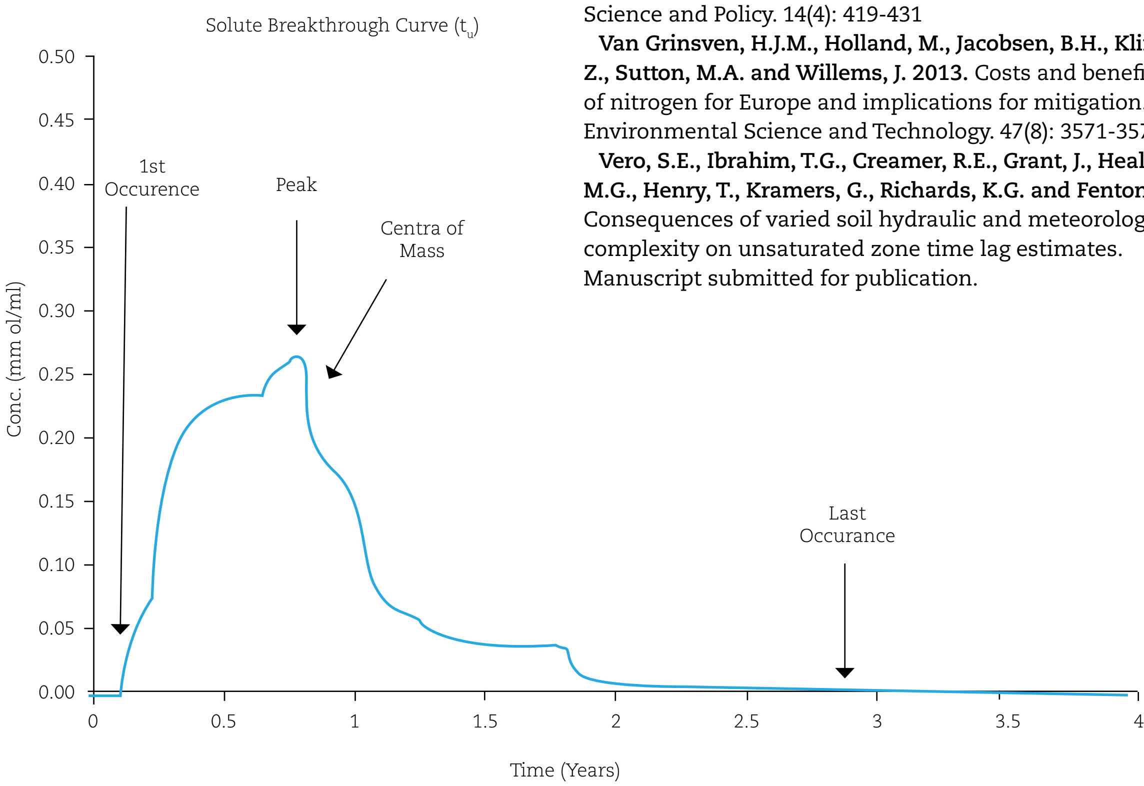

Figure 2: Solute breakthrough graph, showing 1st occurrence, peak, centre of mass and last occurrence.

The speed at which nutrients are transported and, hence, the time lag time depends on the pore network in the soil. Photo: Professor Karl Ritz.

Future objectives

The results, presented by Vero *et al*. will be validated using field tracer studies within two vulnerable catchments. This project and the groundwater transport project conducted by the Teagasc Agricultural Catchments Programme will work together to provide a comprehensive analysis of total hydrologic time lag, which may act as a guide for policymakers, a tool for river basin district managers and promote a better understanding of nutrient transport.

Funding

This project is funded by the Teagasc Walsh Fellowship scheme.

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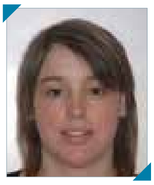
Sequencing Ireland's 'soil genome'

Does location matter?

Using a multidisciplinary approach, Andrea Richter is identifying links between microbial community structures, soil types, land use and environment.





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Soil biodiversity: 'The below ground Amazon'

Soil ecosystems are highly complex and among the most diverse environmental systems on Earth. One gramme of grassland soil can contain more than a billion organisms, with a diversity of greater than 10,000 different bacterial and fungal species. These organisms are recognised as key players in ecosystem functioning, and are the engine behind most of the processes that take place below the soil surface. Microbes are the drivers of nutrient cycling, they improve plants' ability to absorb nutrients but also protect from environmental stress and disease. Microbes also recycle waste products, get rid of contaminants, purify water by denitrifying nitrates and they are the gatekeepers in the soil carbon cycle. Understanding microbial dynamics, community structure and functioning is essential in order to deliver on the premise of 'smart green growth' identified in Ireland's *Food Harvest 2020*.

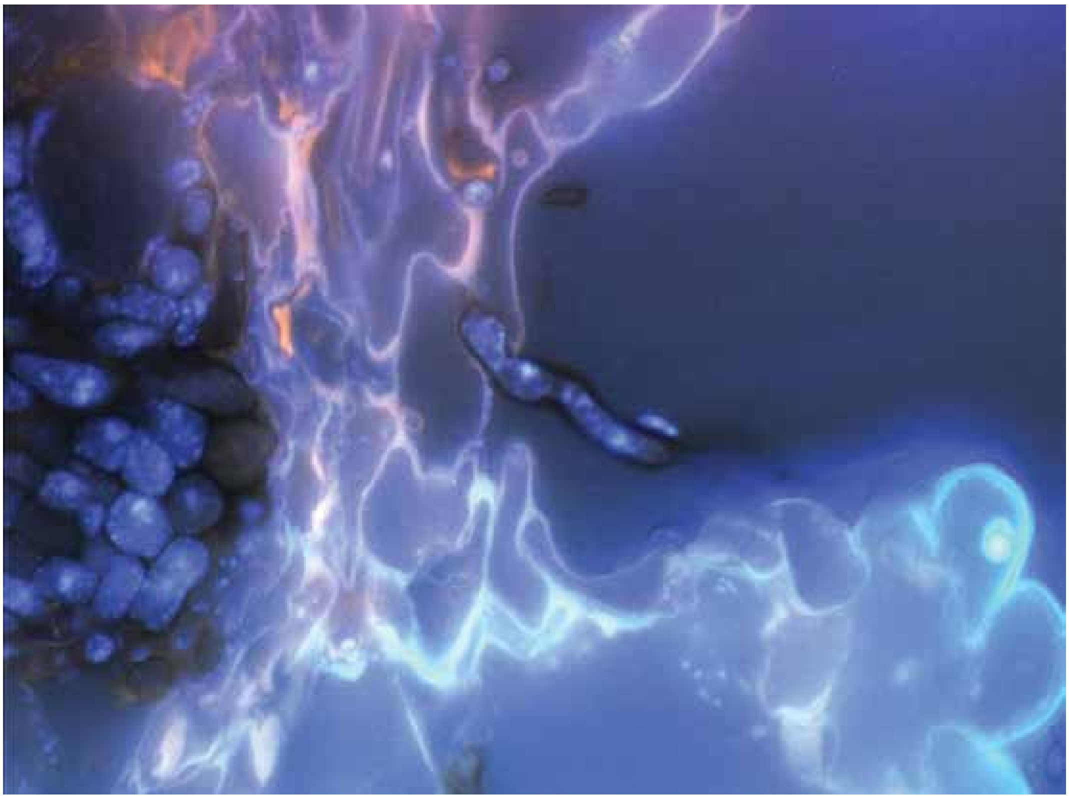
A joint, large-scale, biogeographical study by Teagasc and University College Dublin (UCD) is establishing how the functionality of soil organisms depends on soil type, land use and geographical location in association with the Irish Soil Information System project. Soil samples for biological analysis, including surface and subsurface soils, were collected over two years at 240 different locations across Ireland.

Microbial respiration

Microbes have a fast regeneration time and are, therefore, good indicators of environmental change. By using soil biology as bio-indicators, changes in soil ecosystems can be identified before an effect on physicochemical properties may be visible. We used the MicroResp™ method to study how different soil biological communities respond to a range of carbon sources found in soil. Seven carbon sources, varying in complexity, were used as substrates for 150 surface soil samples. Results show that abiotic properties, such as total nitrogen, organic matter and pH, significantly enhance the response of a microbial community to a range of soil carbon sources. No clear trend was visible to distinguish between different soil types per se but multivariate analysis of respiration profiles showed a significant effect on the drainage class, indicating that poorly drained soils with high biomass show an overall lower respiration rate per unit biomass. Unimproved grassland sites followed a similar trend when compared to grassland-improved sites. This difference in respiration rate suggests the presence of a biological community associated with the slower turnover of carbon in soils, whereas communities in improved grassland sites are adapted to larger nutrient fluxes as a result of fertilisation regimes.

Digging deeper: microbial community structure across soil depths

Our understanding of soil microbial communities is still relatively limited when we are looking at specific soil types or layers below the surface horizon.



The 'engine room' of agriculture: soil biota are responsible for most of the processes taking place below ground.
Photo: Professor Karl Ritz.

Subsurface horizons play a major role as carbon sinks and form an environment in which microbes can perform essential functions related to soil formation, contaminant degradation and non-labile carbon cycling. We are now determining if microbial communities of subsurface horizons are specialised for specific environmental conditions or more related to the location of the sample. In other words, this project asks the question: does location matter or, are the abiotic properties more important in shaping the microbial community present? We selected a subset of 270 horizon samples from 80 Irish soil profiles and we are currently comparing community structures using the analysis of phospholipid fatty acids (PLFA) (found as building blocks in microbial cell membranes, which differ between microbial groups) and marker genes (genes present in all living organisms but with slight variations between microbial groups).

Key species

It is generally believed that a medium to high diversity of microbes in agricultural soils is a good indicator of soil quality. However, recent research findings suggest that species diversity may not be as important as previously thought. The functionality of a soil (i.e. the presence of certain microbes to perform a particular function, such as N mineralisation) may instead rely on only a few key species, rather than the whole soil microbial community.

By measuring the abundance of functional genes, which are known to enhance nitrification and denitrification, we are now assessing how abiotic soil properties impact on these key species and, therefore, on the nitrogen cycle.

Conclusion

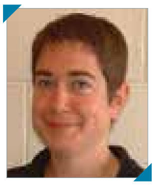
The main aim of this study is to benchmark the range of microbial communities in Ireland and assess their potential function in nitrogen cycling and carbon respiration across a spectrum of soils and soil depths under improved and unimproved grasslands in Ireland.

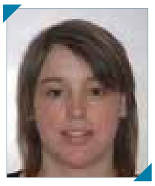
The information gathered will help us gain a better understanding of below ground soil community structures. It will provide a baseline for future research, with the aim of identifying indicators of soil quality and functionality.

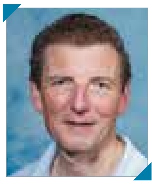
Funding

The Teagasc Walsh Fellowship Programme funds this project.

Breaking new ground on soil biodiversity across Europe



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The EcoFINDERS project is opening the black box of soil processes and studying how below-ground organisms govern the functionality of soils across Europe. The increase in knowledge from this large-scale sampling campaign, co-led by Teagasc, is priceless for policy development in the area of soil health and productivity, explains Dr Dorothy Stone.

Soil provides a wide range of services, including primary productivity, water purification, carbon sequestration and nutrient cycling, all of which have been described in the preceding articles. The majority of these soil processes are mediated by soil biota, which are the driving forces behind most soil based ecosystem services. The European Commission acknowledges the importance of soil biodiversity in the role of ecosystem functioning and the Commission's soil strategy is to protect and enhance soil-based ecosystem services, with a view to promoting sustainable intensification of agriculture. However, while we have a good idea of the role of soil organisms in many of the processes that take place in soils, there is very little information on the geographical distribution and variation in soil biodiversity or the functional capacity of these below-ground communities.

In light of this, the EcoFINDERS (FP7) project was set up in 2011 to address this lack of spatial information on soils and to generate European datasets of soil biodiversity and ecosystem function. Teagasc is the lead partner in the work package dedicated to developing and evaluating indicators of ecosystem functioning, based on the combined knowledge of experts from across Europe. These indicators were measured at 81 sites across Europe: a sampling campaign of unprecedented scale for soil biodiversity. The sites cover a range of biogeographical zones, representing climatic regions that include: Atlantic, Continental, Boreal, Alpine and Mediterranean. Encompassed in these zones are a range of land uses: arable, grass and forestry and a large spectrum of soil properties (represented by pH, organic carbon, total nitrogen and texture).

Selecting indicators

We selected a range of biological methods that provide information on the abundance, diversity and functional capacity of organisms found in soils across Europe. There are many biological methods available and therefore, it was essential to select methods that: (1) provide good descriptive information; (2) are cost-efficient; and, (3) are not too laborious to carry out in the field (at time of sampling) or laboratory (during analysis). Table 1 describes the range of methods selected and how they relate to biodiversity or soil functioning. Here, we give three examples that describe the microbial, faunal and functional behaviour of organisms in soil across Europe. These include: (1) fungal diversity; (2) the diversity of Enchytraeid (potworms); and, (3) respiration.

Fungal diversity (an example of microbial diversity)

Soil fungal diversity across Europe varies in terms of number of species, their relative abundance and distribution according to land use (forest, grassland and arable), soil and climatic parameters. Fungal diversity (Shannon index) was lowest in forestry sites and greatest in arable soils. The highest abundances of DNA (measured by quantitative qPCR) were found in Boreal forestry sites and

Biodiversity	Function
Microbial diversity by TRFLP (eDNA)	
Microbial diversity by PLFA	
Functional Genes [nitrification] (eDNA)	
Functional Genes [denitrification] e(DNA)	
Enchytraeid species diversity	
Micro-arthropod species diversity	
Nematode species diversity	
	Bait Lamina
	Nitrification potential
	Microbial Respiration: MSIR (Micro-resp)
	Enzyme Activity

Table 1. Indicators selected

lowest in Mediterranean soils and in arable sites. Soil pH had a significant impact on the community structures of fungal diversity, showing a positive response to diversity and a negative response to the abundance of fungi.

Enchytraeid diversity (an example of soil fauna diversity)

Enchytraeidae (Oligochaeta, Annelida), also known as potworms, were measured as a key faunal group. More than 30,000 specimens of enchytraeids were extracted from 518 soil cores. Specimens were identified to species in vivo and then fixed for morphological scrutiny or DNA barcoding. About 170 species were registered, 79 of which had not previously been described. Most of the new species were found in previously unstudied regions of France, Slovenia or Portugal. Diversity patterns showed a regional component at the species but not at the genus level. Changes in enchytraeid communities (such as species abundance patterns) correlate with changes of soil parameters such as pH and C:N ratios, and they are strikingly paralleled by changes in the microbial communities, which suggest that patterns of soil biodiversity across Europe can be predicted based on soil properties and land use.

Soil respiration (a measure of soil functioning)

Photo 1. Enchytraeus albidus.

Soil respiration was measured using the MicroResp method, which measures the respiratory response of the soil microbial community to a range of carbon sources. We applied seven different carbon sources, from readily available carbon such as glucose, to complex recalcitrant carbon sources such as alpha ketogluterate. The Microresp method measures the microbial response to the range of carbon sources; microbial communities that can respire a wider range of carbon sources are considered to have a better functional capacity in relation to C cycling. Respiration was greatest in the forest soils of the Boreal region. This was due to the high organic status of these soils. pH and soil texture also had a significant impact on the respiration potential of the soils.

Implications

The data collected as part of this project has significantly increased knowledge of soil biodiversity and functioning across Europe. This information is vital to inform policy decisions on the quality of biodiversity in soils across Europe. In addition, this extensive sampling and analyses of soil biodiversity and function, has provided a blueprint of possible indicators for soil quality monitoring at both national and European scale.

Acknowledgements

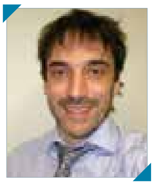
This work is part of the FP7 funded project EcoFINDERS.

Paper in nature

EcoFINDERS recently hit a high note when it published in Nature Climate Change on a new guild of microbes that mediate against climate change. Nitrous oxide (N_2O) is a major greenhouse gas and at least 30% can be attributed to microbial cycling of nitrogen in agriculture. Although the reduction of N_2O to nitrogen gas (N_2) by microorganisms is critical for mitigation, it remains uncertain what determines a soil's capacity to act as a source or sink for N_2O. A key experiment in EcoFINDERS, using soil from Teagasc experimental farms, demonstrated that the soil N_2O sink capacity is mostly explained by the abundance and phylogenetic diversity of a newly described N_2O-reducing microbial group, which mediate the influence of edaphic factors. These microbes convert N_2O to N_2, which is the benign component of atmospheric nitrogen. Analyses of interactions and niche preference similarities suggest niche differentiation or even competitive interactions between organisms with different types of the enzyme that converts N_2O to N_2 The study was recently published in *Nature Climate Change*: Jones *et al.* (2014) recently identified microbial guild mediates soil N_2O sink capacity. DOI: 10.1038/NCLIMATE2301

Overcoming disadvantage:

the role of Irish soils data in underpinning evidence-based policymaking



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Introduction

With a proposed spend of €1,370 million, accounting for approximately 30% of total budget over the 2014 to 2020 programming period of the new Rural Development Programme (RDP) and currently extending to over 75% of utilisable agricultural area in Ireland, the Areas of National Constraint (ANC) Scheme is a vital support to the majority of farmers in the State. Payments under the scheme (formerly known as the Disadvantaged Areas Scheme) are targeted at ensuring the maintenance of both productive and environmentally sustainable farming in areas with significantly adverse environmental conditions.

While very important at national level, the ANC Scheme is also one of the European Union's Rural Development Policy with the aim of improving the environment and the countryside by supporting sustainable land management. Areas of constraint are defined as areas "where agricultural production or activity is more difficult because of natural handicaps, including steep slopes in mountain areas, or low soil productivity". The payment scheme has been in place since 1975 to support farming and countryside management in these areas, and to reduce the risk of widespread land abandonment. Currently, 57% of the Utilisable Agricultural Area in the EU is classified as areas of natural constraint, with c. 1.4 million farms receiving direct support under the scheme.

A new delineation of disadvantaged areas in the EU

In 2003, the European Court of Auditors criticised the designation of areas of disadvantage for farming and the lack of targeting of aid arising from inconsistent use and application of definitions of "disadvantaged area" across Member States. In response, the scheme was reviewed and redefined as those areas suffering exclusively from natural handicaps, and the previous use of socio-economic criteria in classifications was removed. The justification of this approach was based on the contention that economic and social development in rural areas should be achieved through rural development and cohesion policy measures. The focus of the redefinition was, therefore, to move justification of payments under the less favoured areas (LFA) Scheme solely towards a basis in land maintenance and achievement of sustainable agriculture.

Following expert review and consultation, the European Commission proposed eight criteria for the new delineation of areas of natural constraint based exclusively on limiting biophysical criteria. These were: low temperature; heat stress; soil drainage; soil texture and stoniness; rooting depth; soil salinity, sodicity and gypsum contents; soil moisture balance; and slope.

Impact of excess soil moisture conditions on farming practices in Atlantic climates

A central challenge to the operation of the initially proposed biophysical criteria in an Irish setting was that the natural handicaps envisaged under the agro-meteorological definitions were primarily based on the effects of higher temperatures, lower precipitation and accordingly low soil moisture content and/or drought type conditions. In Western Europe, however, and particularly in Ireland, the inverse, namely soil moisture excess, is a primary natural handicap.

Excess soil moisture conditions arise from a complex interaction between climatic and pedological variables, including the distribution, intensity and frequency of precipitation, the rate of evapotranspiration by crops and soil, the infiltration and percolation rates of soils, and groundwater and surface water dynamics resulting from landscape topology. Under Atlantic conditions, precipitation is high and annual precipitation exceeds annual evapotranspiration, resulting in positive annual water balances.

In isolation, neither climatic nor pedological variables alone can adequately describe the

impact of excess soil water on the interaction between soils, crops and nutrient dynamics. For example, soils with a low infiltration rate may not be subjected to prolonged excess-soil water conditions in low-rainfall areas, or in areas where high precipitation is limited to short periods of time. Conversely, soils with high infiltration rates may experience extended periods of excess soil moisture in extreme, high-rainfall climates, or in climates where precipitation exceeds evapotranspiration for prolonged periods of time during the growing season.

Implications for definitions of ANCs

A review was undertaken by Teagasc scientists to examine the impact of excess moisture on farm operation in Atlantic regions in the context of the newly proposed ANC biophysical criteria. This scientific review concluded that excess soil moisture conditions constrain farm practices in challenging farming environments in three primary ways:

1. By constraining grass growth directly, and thereby primary farm productivity;
2. By constraining the utilisation of available herbage by grazing animals or silage harvesting through reduced trafficability of soils, leading to increased requirements for the indoor housing and feeding of farm animals, which is associated with higher direct costs to the farmer; and,
3. By constraining nutrient applications.

Together, these constraints have a significant impact on farm practices and ultimately farm viability.

This review of the proposed criteria, applied to the prevailing biophysical conditions in Ireland, found that none of proposed biophysical criteria, nor any combination of these, satisfactorily described the geographical delineation of areas in Ireland where agricultural productivity was known to be limited (Schulte *et al*., 2008). The review concluded that the "soil drainage" biophysical criterion for the new delineation of LFAs failed to adequately describe areas subjected to frequent and prolonged excess soil moisture conditions, while the "soil moisture balance" criterion, as proposed, had only been adequately defined for scenarios of soil water deficits and not conditions of soil water excess. The authors contended that the proposed table of criteria was biased towards delineating LFAs in more continental and Mediterranean climates.

The conclusions of this review were used to support representations to the European Commission on the matter of the proposed criteria for ANC delineation as initially proposed and their inadequacy for application in settings such as Ireland. Based on the strength of the scientific arguments underpinning these representations, a revised set of criteria was issued by the European Commission in 2013 which now include a new criterion, specifically addressing for the first time the issue of excess soil moisture acting as a constraint on farm productivity in Atlantic regions.

Conclusion

The classification, mapping and delineation of eligible areas of natural constraint is a matter for Member States of the EU and is exclusively conducted in Ireland by the Department of Agriculture, Food and the Marine. However, the scientific support provided by Teagasc scientists has ensured that the unique biophysical conditions prevailing in the Atlantic region are fully taken into account in the newly evolving regulations. The proposed restructuring of the eligibility criteria in the programme ensures recognition of the challenges faced by farmers in a situation of excess soil moisture leading to the maintenance of an equitable application and disbursement of funds and the maintenance of future viable farming activity and rural development in Ireland.

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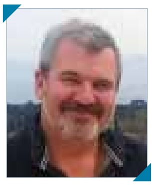
The Soil Framework Directive is history.

So, what is the future?

The proposed European Union Soil Framework Directive was officially withdrawn earlier this year. This, however, marks the beginning rather than the end of an era of soil-related policies. Francesca Bampa, Dr Arwyn Jones (European Commission) and Dr Rachel Creamer explain what lies ahead.



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A brief history of the Soil Framework Directive

The proposal for a Soil Framework Directive is part of the 2006 'EU Thematic Strategy for Soil Protection'. This non-legislative approach introduced the concepts of soil protection across the EU, its sustainable use, the preservation of bio-physical functions and the prevention of degradation. It summarised the ecosystem services that soils provide to humankind into five soil functions: 1) production of food and biomass; 2) nutrient cycling; 3) carbon storage; 4) water purification; and 5) providing a habitat for biodiversity. The proposal for a Soil Framework Directive was adopted by the European Parliament, the Committee of the Regions and the Economic and Social Committee. However, discussion in the European Council repeatedly ran into a blocking minority of Member States. In October 2013, the Commission noted that the proposal for a Soil Framework Directive had been pending for eight years during which time no effective action has resulted and would, therefore, examine whether the objective of the proposal would be best served by maintaining or withdrawing it, thus opening the way for an alternative initiative in the next mandate of the Commission and the Parliament. Discussions in early 2014 indicated that protecting soils remained an important objective for the Union, despite the fact that, in its present format, the proposal for a Soil Framework Directive could not be agreed by a qualified majority. Consequently, the Commission on April 30, 2014 took the decision to withdraw the proposal for the Directive.

Emerging soil policies

However, in taking its decision, the Commission stated that it remained committed to the objective of the protection of soil and will examine options on how to best achieve this during the mandate of the next college. This is reflected both in the EU's 7th Environment Action Programme, which guides EU environment policy until 2020; and in an increasing awareness of the importance of soil in other EU policy areas such as agriculture, climate change, development, energy and regional policy. The 7th Environment Action Programme recognises soil degradation as a serious challenge and calls for a binding legal framework to maintain soil quality, using a targeted and proportionate risk-based approach. One example is the Good Agricultural and Environmental Condition (GAECs) of the Common Agricultural Policy, which sets obligatory standards in respect of reducing soil erosion and maintaining soil organic matter levels for farmers in receipt of payments.

A new approach: land as a resource

During the United Nations 2012 conference on Sustainable Development, known as Rio+20, world leaders agreed on a sustainable goal for land, resulting in a sustainable development goal: zero net land degradation. The goal needs to be achieved by 2030 and relies on the commitment of both public and private sectors. The EU acknowledged Rio+20 with a framework for actions in the 2011 Resource Efficiency Roadmap – Europe 2020 Strategy. As part of this Strategy EU policies must account for their direct and indirect impact on, and use in, Europe and globally by 2020. This includes the ambition to reduce the rate of 'land-take' (conversion of farmland to e.g. residential areas) to zero by 2050, to reduce soil erosion, increase organic matter levels and commence significant remedial works on contaminated sites. Responding to the roadmap, the European Commission is working on a Communication on 'Land as a resource', expected for 2015, that will provide a new framework for sustainable and appropriate land management across the EU. This Communication is aimed at accelerating actions in the context of valuing land as a resource for ecosystem services, filling the gap between demand and availability of land and setting synergies and trade-offs between competing land functions.

Towards Functional Land Management

Among the reasons that the original Soil Framework Directive was not supported was its strong focus

on threats to soil quality: erosion; decline in organic matter; contamination; soil sealing; compaction; decline in biodiversity; salinisation; floods; and, landslides. Some argue that the functionality of soils in providing ecosystem services, while increasing agricultural productivity in a sustainable way, became marginalised in this context. This focus on threats resulted in opposition among several stakeholders, specifically farmers, who welcomed the Thematic Strategy for Soil but rejected the administrative burden that could be associated with the Directive, despite the relative light reporting obligations that were proposed.

In response, the soil science community has introduced the concept of 'functional soil management'. Put simply, functional land management means that each soil is managed so that it performs the functions that it is good at. Indeed, it is our experience that farmers generally understand and manage the functionality of soils in providing goods and services (be it in the form of food or in the form of maintaining the rural environment) and welcome initiatives and incentives that further enhance this functionality. What is lacking both at EU and national level is a comprehensive framework to bring together the diverse policy tools that are aimed at optimising each of the soil functions. A multidisciplinary team of Teagasc researchers recently published a paper on the concept of functional land management, which quantifies the supply and demand for soil functions at national level. This could be used as a case-study for a similar approach at EU level.

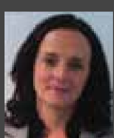
Next steps

Since the global 2008 food crisis, soil has received renewed worldwide attention as a future resource. Unlike most farmers, many sectors of society are unaware of the role of soil in food security, carbon storage, water provision, nutrient cycling and biodiversity. Therefore, the next steps will focus on public awareness raising. In this context, 2015 will be a highly significant year; it will be the International Year of Soils as designated by the United Nations, which, in combination with the recently adopted Global Soil Partnership Action Plans from FAO, will offer a broad calendar of dedicated activities. In May, the World Expo 2015 in Milan will open its pavilions to the public under the banner: Feeding the Planet - Energy for life. In Ireland, Teagasc will develop educational packs for schools as part of the soil status project, in collaboration with the Soil Science Society of Ireland and the Environmental Protection Agency. Many other activities will be run at international and national level, all with the same motto: *healthy soil for healthy life*. At EU level, a specific new proposal on soil itself could follow after the nomination of the new European Commission college later this year. Therefore, new thinking on the role and place of soils in our society is extremely timely.

Funding

The project 'Soil Status' is funded by the Environmental Protection Agency STRIVE Research Programme.

Contents



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