# SOIL SECURITY PROGRAMME

**OUTCOMES EVENT** · THE ROYAL SOCIETY

5 DECEMBER 2019 · WORLD SOILS DAY

# WELCOME...

A warm welcome to the *Outcomes Meeting for the Soil Security Programme*. The SSP is largest research investment in soils for a decade, funded by the Natural Environment Research Council (NERC), Biotechnology and Biological Sciences Research Council (BBSRC), Scottish Government and Defra.

Never has the need for understanding our soils been greater as the full extent of the environmental crisis is being revealed. Ensuring soil health and sustainable soil management will help to address many of the issues we are now facing, such as increased flooding, while providing solutions to longer term climate targets through the reduction of greenhouse gas emissions and storing carbon.

The overarching aim of the Soil Security Programme is to deliver improved forecasts of the response of the soil system by understanding its ability to **resist**, **recover** and **adapt** to land use change and hence to perform multiple functions in different contexts. Today we will demonstrate how we have risen to this challenge. We hope you enjoy the day and engage with all the fantastic science that has been produced to support our shared goal of sustainable soil management.

Happy World Soils Day!

Yours

Prof. Chris Collins
Soil Security Programme Coordinator

SSP Soil Security Programme



# AGENDA

| TIME | AGENDA ITEM | SPEAKER |
|---|---|---|
| From 12.30 | Lunch<br>Posters and Networking | |
| 13.30 | Welcome & Introduction to The Soil Security Programme | Prof. Chris Collins – Coordinator: Soil Security Programme |
| 13.40 | Policy, Research & Practice Perspectives on Soil Security | Simon Cowell – NFU Soil Farmer of the Year<br>Prof. Dieter Helm – Oxford University<br>Prof. Diana Wall – Colorado State University |
| 14.30 | Synthesis of The SSP Research Findings | Prof. Paul Hallett – Soil Plant Interactions<br>Dr Nicholle Bell – Peatland Degradation & Restoration<br>Prof. Jonathan Leake – Sustainable Soil Management |
| 15.20 | Coffee Break<br>Posters and Networking | |
| 16.00 | Addressing the present and future challenges to Soil Security | Panel Discussion and Questions |
| 16.30 | Reflections, achievements & Next Steps | Dr Simon Kerley, NERC, Head of Research, Terrestrial Ecosystems<br>Vicky Hird – Food and Farming Policy, Sustain |
| 16.50 | Concluding remarks: Prof Chris Collins | |
| 17.00 | Drinks Reception & Networking | |
| 17.30 | Close | |

**Sli.do**
During the event we encourage you to ask questions via Sli.do, an interactive Q&A platform.
Please go to **www.sli.do/** or Google *'slido'* and then enter the event code **#SSPoutcomes**.

**QR code readers**
The posters presented at the event all have QR codes that link to the SSP website for each project and contains additional resources relating to each project, as well as a project synthesis.
To access the information within these QR codes we would recommend downloading a QR code reader.
There are many QR code readers available for mobile devices on Android, iPhone, Windows and Blackberry.
Top picks include; **barcode.tec-it.com** **www.i-nigma.com**

# CONTENTS




written by Claire Asher
photos and design by Carey Marks


Recent flooding has been linked to poor soil management



# OUTCOMES

- Carbon dioxide and other greenhouse gas emissions from peatland soils are affected by the depth of the water table.
- Bare peat soils are vulnerable to erosion but vegetation can protect top soil and rebuild nutrients.
- More intensively managed soils have less organic matter, lower stability, and are more acidic.
- Grass-clover leys can rebuild soil structure by promoting earthworms and beneficial fungi, rapidly result in higher water absorption and holding capacity.
- Microbial communities in intensively managed soils are smaller and less active and tend to include more opportunistic, 'boom-bust' microbial species.
- Prolonged flooding has a severe impact on the soil microbiome, but microbial communities in less intensively managed soils tend to be more adaptable.
- Hairier roots tend to create larger soil pores, building soil structure and boosting water-storage capacity.
- Plant roots exude acids and gelling compounds that help plant uptake of phosphorus and other nutrients.

# NEW TOOLS & TECHNIQUES

- Light reflectance measurements to estimate soil stability.
- Chemical signals of degradation to evaluate peatland restoration programmes.
- InSAR satellite monitoring, an inexpensive large-scale surveying method for identifying degraded areas of peatland and changes in peat condition.
- A bioinformatics portal to provide information about the key players in the soil microbiome.
- A mathematical model for evaluating soil health combining measurement and expert judgement.

# RECOMMENDATIONS & ACTIONS

- Key traits for evaluating and monitoring soil health should include organic matter content, earthworms, bulk density, the stability of soil crumbs when wet, acidity and the efficiency of microbial processes.
- Improved understanding of carbon dynamics is needed to design land management strategies that promote soil health and minimise greenhouse gas emissions.
- Raising the water table in cultivated peatlands over the winter will reduce greenhouse gas emissions without negatively affecting crops.
- Planting cover crops on cultivated peatlands can protect them against natural erosion and extreme weather events.
- Switching to reduced intensity cultivation approaches will rebuild degraded soils, enhance carbon sequestration and flood prevention, and produce a soil microbiome more resilient to extreme weather.
- Land management interventions should target intensively managed arable soils which have greater potential to improve soil health.
- Plant-breeders should focus on root hair traits when selecting for new crop varieties to improve absorption of key nutrients like phosphorus thereby reducing fertiliser use.
- Rotating a larger variety of crops and selecting those that support a healthy rhizosphere could have substantial benefits for long term soil health and crop yields.
- Reducing arable soil disturbance by growing legume-rich leys for 3 years followed by direct drilling improves soil health, giving better crop nutrient use efficiency and yield, including improved resilience to drought and flood.
- Reintroducing legume-rich leys into arable rotations supports soil communities that suppress crop diseases.

# OUTPUTS

- **PDRAs** trained = 37
- **Papers published** = 54 (8 in review)
- **Presentations to international conferences** = 91
- **Presentations to farmers/public** = 126. Edinburgh Festival, Planet Earth -nationwide museums event, Cereals Event, Channel 4 Food Unwrapped, Farming Today
- **Further grants** = 31. These have arisen from SSP findings, where soils form one component of the grant.
- **Policy and practice documents** = 11. Submissions to Environmental Audit Committee Inquiry into Soil Health, Defra Consultations on the 25 year Environment Plan, Defra Review of Environmental Land Management options for public goods from healthy soils, Systematic Review of Soils Research for Defra, ADHB factsheets



# SPEAKER BIOGRAPHIES

**Chris Collins**

Chris is Chair of Environmental Chemistry at the University of Reading. He is the Natural Environment Research Council Soils Coordinator overseeing a multi-million pound research investment to improve our understanding of how soils resist, recover and adapt to land use and climate change. Chris chairs the Department for Environment, Food and Rural Affairs Hazardous Substances Advisory Committee providing expert advice to the UK Government on how to protect the environment, and human health via the environment from chemicals.

He is also a member of the UK Natural Capital Committee which supports the implementation of England's 25yr Environment Plan. His research focuses on determining the factors controlling exposure of biota to environmental pollution. This combines experimental data with process description models and development of assessment tools. Recent research focuses on the role of soil organic carbon in modifying pollutant exposure and the parallels between pollutant and carbon cycling in soils.

**Simon Callow, farmer**

Simon farms heavy, high magnesium clay soils on the East coast of Essex where much of his land is below sea level and has very little natural topsoil. He won the 2018 Soil Farmer of The Year competition organised by Farm Carbon Cutting Toolkit and Innovation for Agriculture.

Simon's interest in soil and its biology began twenty years ago when he set about the challenge of improving his difficult to manage soils by stopping all tillage, making and applying highly biologically active compost and building mycorrhizal fungi populations. To prove the theory that a balanced soil food web can provide all the nutrients a crop needs, he hasn't applied any phosphate or potash fertilisers in all that time and has started experimenting with cutting out nitrogen applications as well.

**Professor Dieter Helm**

Dieter is an Official Fellow in Economics at New College, Oxford and Professor of Economic policy at the University of Oxford. He is Chair of the Natural Capital Committee.

Dieter completed the Helm Review on *The Cost of Energy* for the British Government in 2017.

Dieter's recent books include: *The Carbon Crunch - revised and updated edition* (2015), *Natural Capital - Valuing The Planet* (2015), and *Burn Out: the endgame for fossil fuels* (2018), all published by Yale University Press. Green & Prosperous Land was published in March 2019 by William Collins.

# SPEAKER BIOGRAPHIES

**Diana Wall**

Diana is the founding Director of the School of Global Environmental Sustainability and a University Distinguished Professor at Colorado State University. She is an ecologist and environmental scientist recognized for her work on soil biodiversity and climate change. Her research emphasizes how life in soil, from microbes to invertebrates, contributes to healthy soils and ecosystem services.

She is internationally renowned for her studies of climate change impacts on soil nematode dynamics, functions, and survival in the Antarctic dry valleys. Her pioneering global scale studies of soil biodiversity are hallmarks of her career. She has been president of the Society of Nematologists and the Ecological Society of America and currently is the science chair of the Global Soil Biodiversity Initiative. She received the Tyler Prize for Environmental Achievement, the Ulysses Medal from University College Dublin, and is an elected member of the National Academy of Sciences.
She earned her PhD at the University of Kentucky.

**Paul Hallett** is a Soil Physicist working on solutions to food and environmental security, mainly focussed on the interactions between plants, microorganisms and the physical behaviour of soil. His work spans from understanding the fundamental processes driving changes in soil physical properties by biology, through to applied research examining soil degradation and the underlying causes.

He has several projects currently running that study the capacity of different plant root traits to physically engineer soil (BBSRC SARISA, EPSRC), solutions to improve soils in Ethiopia (ESRC), developing decision support tools to address environmental and agricultural challenges in China (NERC/NSFC) and next generation soil sensors (UKRI/NSF - SiTS).

**Nicholle Bell** completed her PhD in 2015 as a University of Edinburgh Principal's Career Development Scholar. In 2016, she started her NERC Soil Security Fellowship to develop new molecular metrics to assess the health of UK peatland soils. Earlier this year, she was awarded a NERC Independent Research Fellowship to unravel the synergies and relationships between the drivers of carbon cycling in peatlands across the UK, Canada and Sweden.

Nicholle has a passion for outreach. She set up the RSC Spectroscopy in a Suitcase scheme and popularised NMR in schools and industries across Scotland. For her outreach work she was awarded the 2014 Principal's Medal for Service to the Community and the 2017 RSC Joseph Black Award. As an SSP fellow, she has continued to take part in outreach events including NERC UnEarthed 2017, International Science Festival 2018, Royal Society Summer Exhibition 2018 and Nature Live 2018.



# SPEAKER BIOGRAPHIES

**Jonathan Leake** has over 30 years of experience researching reciprocal interactions between plants and soils. He led two NERC Soil Security Programme grants SoilBioHedge and MycoRhizaSoil which investigated the effects of reintroducing grass and clover leys into intensively cultivated arable soil to improve soil quality.

He now leads the BBSRC-SARIC project Restoring soil quality through re-integration of leys and sheep into arable rotations. His research is providing evidence to guide development of sustainable approaches to soil management in croplands. He is a member of the Scientific Advisory panel of the Sustainable Soils Alliance, and has active collaborations with UK farmers.

**Simon Kerley**

Simon is the Natural Environment Research Council's (NERC) Head of Domain for Terrestrial, Freshwater and Earth. He joined NERC in June 2013 and is one of the 'Heads of' responsible for leading the delivery of NERC strategy within the Terrestrial, Freshwater and Earth portions of the NERC remit. Simon's role is to be a principal interface between NERC and its community, and is responsible for developing the value-managed relationships with researchers, users and funders in this portfolio. In working with the community and colleagues in NERC, Simon helps to develop NERC as a science-led organisation, and deliver an integrated portfolio across funding streams. He also links to multi-partner initiatives including Global Food Security. Previously, Simon worked for BBSRC in the agri-food and then underpinning health areas, and prior to that he was a research scientist in the soil rhizosphere/plant physiology area at Rothamsted, North Wyke and Sheffield.

**Vicki Hird**

Vicki is an award-winning campaigner, author, strategist and senior manager who has been working on environment, food and farming issues for 30 years. As part- time head of the Farming Campaign at Sustain, Vicki currently manages the policy and related campaigning, providing comment and guidance on these issues, whilst also running her own consultancy. Prior to this role, she was director of Campaigns and Policy at War on Want and led the Land use and Food team for Friends of the Earth, where one of her most successful campaigns was the getting the Groceries Code Adjudicator.

Vicki has launched many campaigns, from local to global in scope, blogs frequently and published numerous reports and articles on food systems. She has published one book Perfectly Safe to Eat? (Women's Press, 2000) and is writing a new one for 2020.

# MAP


# POSTERS

### PEAT

| | | |
|---|---|---|
| 1 | David Large | A new method to map peatland condition |
| 2 | Richard Bardgett | Microbial resilience to multiple global changes in upland peat soils |
| 3 | Davey Jones | Saving our Lowland Peatlands |

### RHIZOSPHERE

| | | |
|---|---|---|
| 4 | Gary Bending | Roots of decline? Assembly and function of the rhizosphere microbiome in relation to yield decline |
| 5 | John Hammond | Rooting out the phosphate |
| 6 | Jonathan Leake | MycoRhizaSoil |
| 7 | Paul Hallett | Rhizosphere by design: Breeding to select root traits that physically manipulate soil. |
| 8 | Wilfred Otten | Resilience of below-ground fungal communities: a mechanistic and trait-based approach |

### SOIL MANAGEMENT

| | | |
|---|---|---|
| 9 | Aiden Keith | Resistance to perturbation in agricultural land: Identifying & fingerprinting functional soil conditions across scales |
| 10 | Rob Griffiths | Distributed land use change effects on soil biodiversity and function |
| 11 | Jonathan Leake | The Restorative Power of Leys |
| 12 | Andy Whitmore | Quantifying Soil Quality & Health, SQH |
| 13 | Richard Bardgett | Controls on the stability of soils, their functioning under land use and climate change |
| 14 | Gary Bending | Extreme rainfall: Unravelling the importance of new climate-rhizosphere feedbacks across contrasting land use systems |
| 15 | Ian Pattison | COMPACT |

### PRACTICE

| | | |
|---|---|---|
| 16 | Jackie Stroud | #Wormscience: Working together to improve soil health |
| 17 | Rob Macklin | Soil Health Metrics for Environmental Land Management Schemes (ELMS) |
| 18 | David Robinson | My Soil |
| 19 | Aidan Keith/ Matt Aitkenhead | Monitoring & Sensing of soil organic matter in agricultural systems of the future |
| 20 | Phil Lambert | Soil Artist |

# SYNTHESIS PAPERS

Declining soil health is a major issue facing humanity globally. Healthy soils underpin countless vital services that we rely on for food, clean water, climate and flood management, but our soils are under threat. Soils worldwide are threatened by myriad factors from erosion to pollution, compaction, nutrient leaching, and loss of biodiversity. Managing these threats and improving the health of soils must be a top priority for governments worldwide.

The UK Soil Security Programme has supported fifteen core research projects and 3 research fellowships focussed on three main areas in policy and practice: peatland restoration, the soil microbiome, and arable land management. Bringing together the vast amount of work achieved by these academics over the last 5 years, the programme will publish a synthesis paper in each of these three focus areas.

The main messages of each synthesis paper are distilled for a non-specialist audience in the three following popular science articles, titled: 'For Peat's Sake', 'Root of the Problem', and 'Under New management'. Together, we hope these articles will help the programme's findings reach a broader audience both within the academic community and among policy-makers, land managers, and the public.

Each article includes a list of implications and recommendations that could be applied to police and practice to support healthier soils that are better equipped to resist, adapt, and recover from whatever the future climate has to throw at them.

Drastic soil erosion in Monduli Ju, west of Arusha in Maasai protected land of Tanzania. This photograph show the extent of the land being lost and damaged, much of it irreparable, to soil erosion. The catalyst being climate change and many other socio-environmental changes. Photo: Carey Marks. This photograph has selected for the inaugural **Science Photographer of the Year** Exhibition at London's Science Museum .



# UNDER NEW MANAGEMENT

## Reduce disruption to heal degraded soils, experts say

*Soils need less intensive, less disruptive land management to flourish in the face of climate change*

By Claire Asher

**Introduction**

A move towards less intensive, less disruptive land management practices could be key to maintaining vital natural services and ensuring healthy soils long into the future, according to research conducted as part of the UK Soil Security Programme.

Soil provides essential nutrients to crops as well as ecosystem services such as reducing flood risk, providing clean water, and absorbing carbon from the atmosphere, but intensive land management practices have degraded many arable soils. Experts say the fastest way to help the soil recover and to ensure long-term food security and resilience against climate change is to use less intensive land management systems.

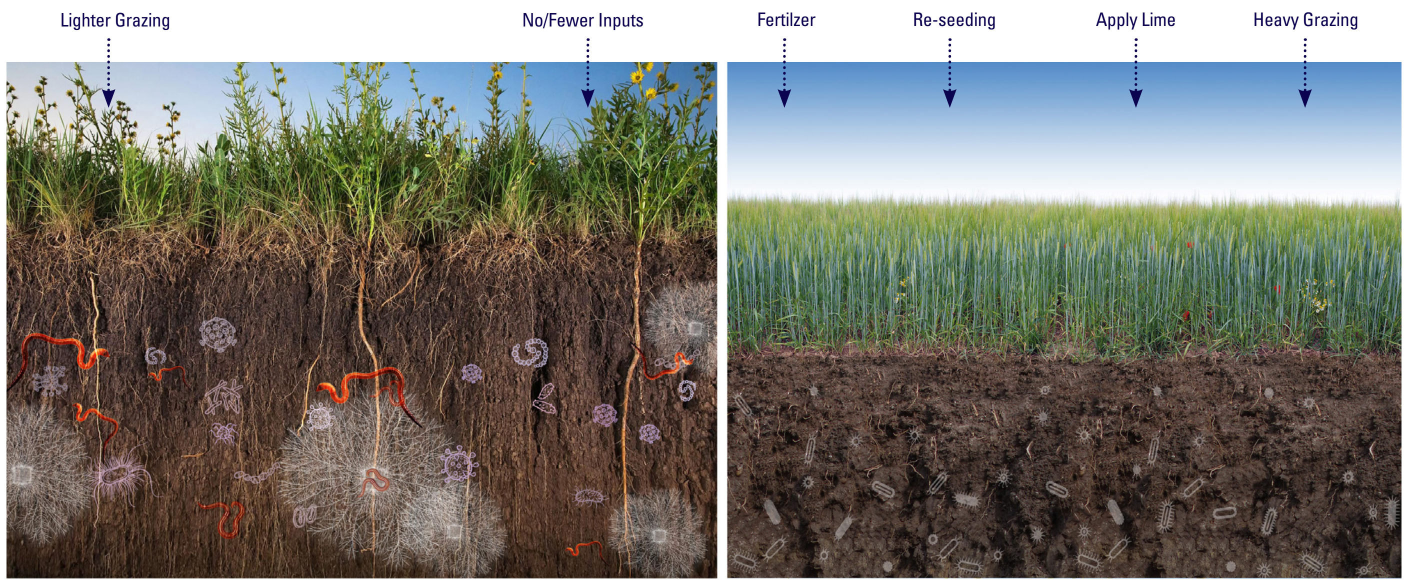
**Probing soil structure**

Soil is not the homogenous powder it appears to be at first glance – soils have a complex internal structure of air gaps called pores, which allow space for water and living creatures to move around. Ploughing disrupts this structure, while the physical weight of farm machinery compacts the soil, pushing the air out of it and reducing its capacity to absorb and hold water. Research by Ian Pattison, a physical geographer at Heriot Watt University in Edinburgh and his colleagues has shown that arable and pasture soils tend to be more compacted than unmanaged grasslands.

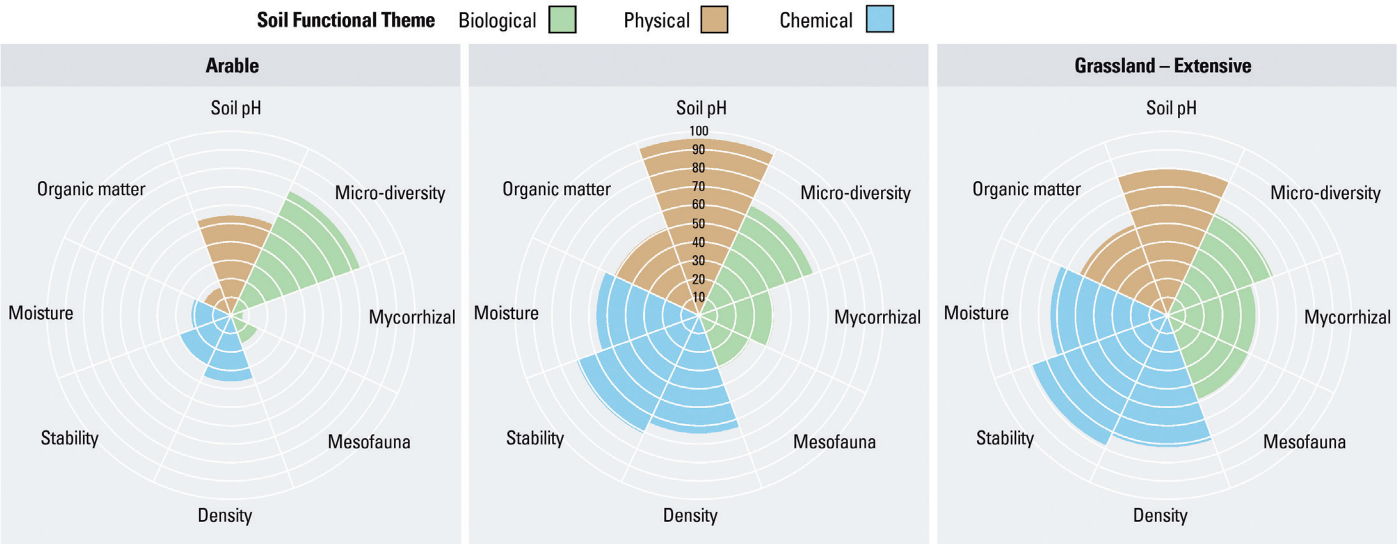
Arable soils also tend to be less able to withstand erosion by the wind and compaction by farm machinery. A team of researchers led by Aidan Keith a soil ecologist at the Centre for Ecology and Hydrology (CEH) used samples from a vast soil archive in Lancaster to investigate how soil stability is affected by plants, humans, and the environment. They found that as the carbon content of the soil increased, so did the stability. More intensive land management practices tend to reduce the amount of organic matter in the soil, indirectly reducing soil stability.

**What's underneath the hedgerow?**

There are approximately half a million kilometres of hedgerow in the UK, but we know relatively little about this very British ecosystem. Leake and colleagues found that hedgerows had unique soil properties and harboured a distinctive community of microorganisms. Hedgerow soil is very high in organic matter, but tends to be dry – presumably because it is shielded from the rain. This means that hedgerow soil has a huge capacity to absorb water during heavy rainfall - far greater than grassy field margins.




Intensive and extensive soils harbour different soil communities. Opportunistic microbes dominate in intensively managed systems.




Characteristics of arable, intensively managed and extensively managed grasslands in the UK. Less intensive land management tends to increase soil stability and organic matter content, and boost populations of soil invertebrates (mesofauna) and beneficial fungi (mycorrhiza).

**Profiling the microbiome**

The soil is teeming with life, from soil invertebrates like beetles, earthworms, springtails and nematodes, to soil microbes like bacteria and fungi. As invertebrates move through the soil they create pores through which water and nutrients can move. Many plants also harbour mutualistic microbes, for example fungi called mycorrhiza grow in or on roots and extend thin filaments or 'hyphae' out into the soil.
Different soils harbour a very different soil community – even neighbouring soils in different environments can have different characteristics and biodiversity. For example, hedgerows and field margins (see Box 1) are distinct from the farmlands they surround.

**Microbiome Management**

The intensity of land management influences the diversity and activity of the soil microbiome. Richard Bardgett, an ecologist at the University of Manchester and his team have found that less intensively managed soils tend to have more diverse microbial communities. *"Human intervention tends to reduce the diversity and complexity of soil communities but also shift them to be more bacterial"*, he said. Intensive management increased the proportion of opportunistic soil microbes, with boom-bust lifecycles that tend to make them less stable.

Intensively managed soils tend to be particularly low in mycorrhizal fungi, because they are very sensitive to physical disturbance such as ploughing and because some varieties of crops do not create a supportive underground environment for these beneficial fungi.

*"Communities of mycorrhizal fungi … [and] earthworm populations have been depleted by arable management"*, said Jonathan Leake, a soil scientist at the University of Sheffield. These organisms are important for aggregating soil particles together giving the soil structure that allows it to absorb more water, reducing flood risk.

**Securing natural services**

The effect of intensive management on the microbiome is also likely to have knock-on effects for the ecosystem services soil provides us, such as nutrient cycling and carbon absorption. A team of researchers led by microbial ecologist Rob Griffiths at CEH conducted a UK-wide survey of microbial communities and natural soil services under different land management types. For a given soil type, they found that less intensively managed soils with a higher carbon content tended to have higher levels of activity of microbial enzymes involved in key ecosystem services.

## Managing soil health

Minimising the disturbance of soil is the most effective way to enhance soil organic content and biodiversity – two key measures of soil health (see Box 2). Recent research has highlighted a number of simple changes that can make a major difference to soil health.

**1. Plant leys to boost beneficial soil microbes**

Planting arable fields with short-term fields or 'leys' of grasses and legumes can allow soils a chance to recover, physically and chemically. Leake and colleagues tested small strips of ley on degraded farmland in Yorkshire. The leys resulted in *"a progressive improvement in really important soil functional properties which had been degraded by long-term farming practices"*, said Leake. At the end of the 3-year study, there were more earthworms and fungi in the soil under the leys than in the surrounding field. The soil also had higher levels of organic matter and a more complex internal structure, increasing the amount of carbon and water it was able to hold.

**2. Minimise soil disturbance**

Reducing disturbance by using less intensive land management practices can make soils more productive and promote more active soil communities that are better able to resist environmental changes. Leake and his team found that direct drilling wheat into their clover ley gave a yield of 8 tonnes per hectare – roughly the UK national average – but using only 35kg of nitrogen fertiliser compared to the usual 200kg.

**3. Reduce compaction**

Land management strategies that reduce compaction could improve the water-holding capacity of the soil and reduce flood risk. Recent work by Pattison and his colleagues used ground-penetrating radar to profile soil compaction and found that even within a single field, there is a lot of variation, which hasn't traditionally been included in computer models of flood risk.



## Promoting soil resilience

The erosion and degradation of the UK's top soil poses a significant threat to farmers' livelihoods, but is likely to be exacerbated by increasingly frequent extreme weather events driven by climate change. Extreme weather events, such as flood and droughts, are already becoming more common and are expected to continue to increase in their frequency and severity as the climate changes.

Drought has the potential to severely affect the UK's crops and food security. Here parched soils in Devon following an extended two month drought.

## Flooded soils

In 2012 Gary Bending, an agricultural scientist at the Univerity of Warwick, and his team were halfway through a studying soil fungi on farmland in Lincoln when prolonged heavy rainfall waterlogged the land for 8-weeks. Those summer floods had a profound impact on soil microbes, particularly fungi. *"All the evidence pointed to the extreme weather event affecting this [fungal] community"*, said Bending.

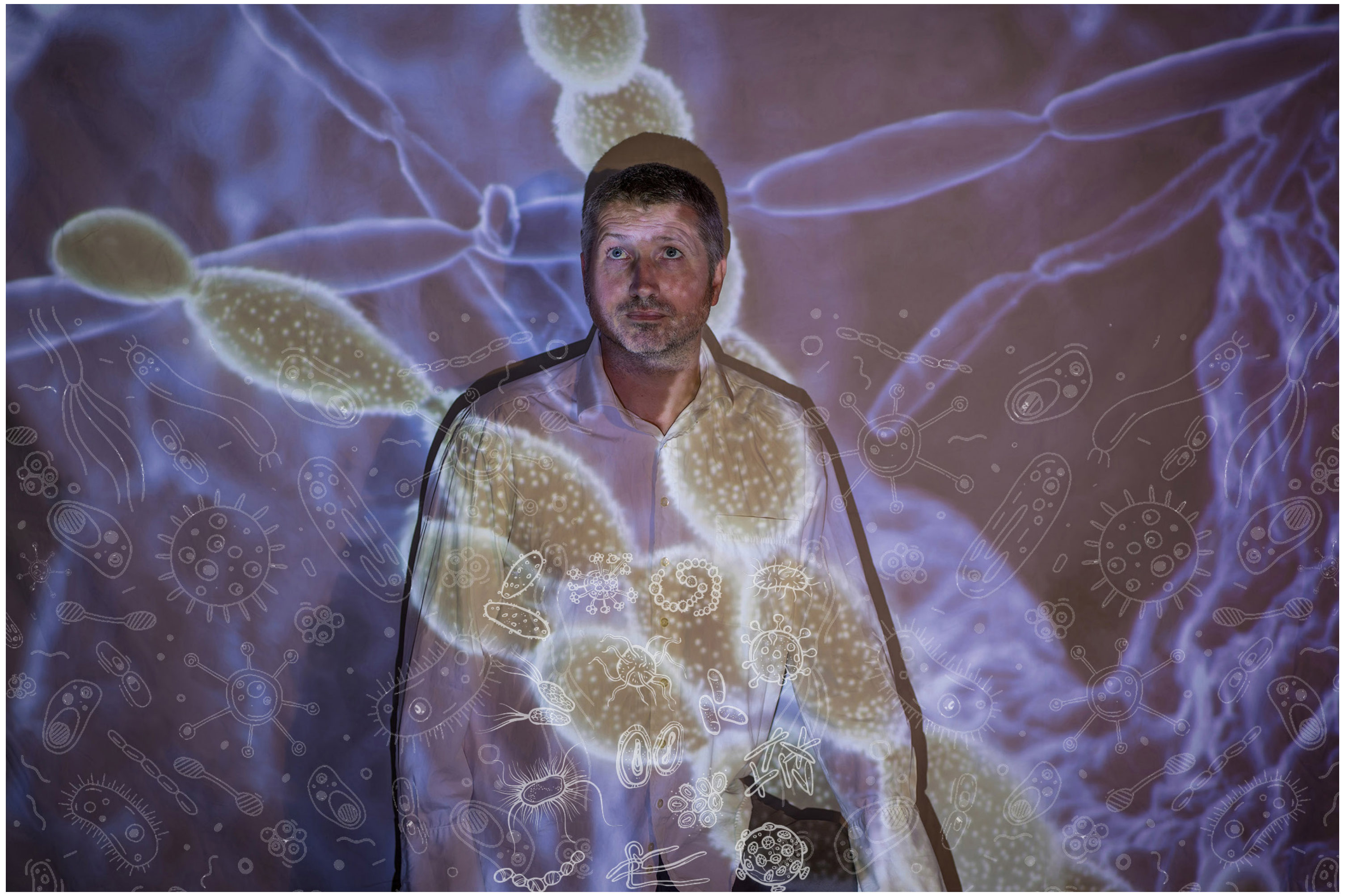
To confirm their theory, Bending and his team simulated flood conditions by water-logging blocks of turf and seeing what happened to the soil microbes. They found that summer floods have a big impact on soil microbes, because this is the season when they are normally very active, whereas winter floods, when microbes lie relatively dormant, had a far smaller impact. Longer floods had a greater and longer-lasting impact on soil fungi.

**Healthy soils can reduce flood risk**

Current estimates suggest that over 2.4 million UK properties are at risk of flooding, but whether or not a river floods during a period of heavy rain is influenced by the capacity of soils to take up excess water, which depends on the structure of the soil.

Simple management interventions can rebuild and preserve soil structure and could help make farmland more resilient. Leake have found that that soil from leys was more resilient in laboratory simulations of moderate droughts and flooding, and stored more water than permanent arable soil.. Recharging this natural service could be particularly beneficial for high-risk flood areas.

Rob Griffiths and colleagues tested different soil types across the UK to find reliable and responsive indicators of soil health. Photo: CareyMarks.co.uk



**Parched soils**

Another consequence of climate change is increasingly frequent and severe droughts. Drought has the potential to severely affect the UK's crops and food security and so there is an urgent need to understand what soil characteristics make soil more or less able to withstand and recover from drought conditions. Bardgett and colleagues found that drought reduces the amount of carbon that plants release from their roots, and which can be used by microbes and invertebrates in the soil.

**Healthier soils emit less carbon**

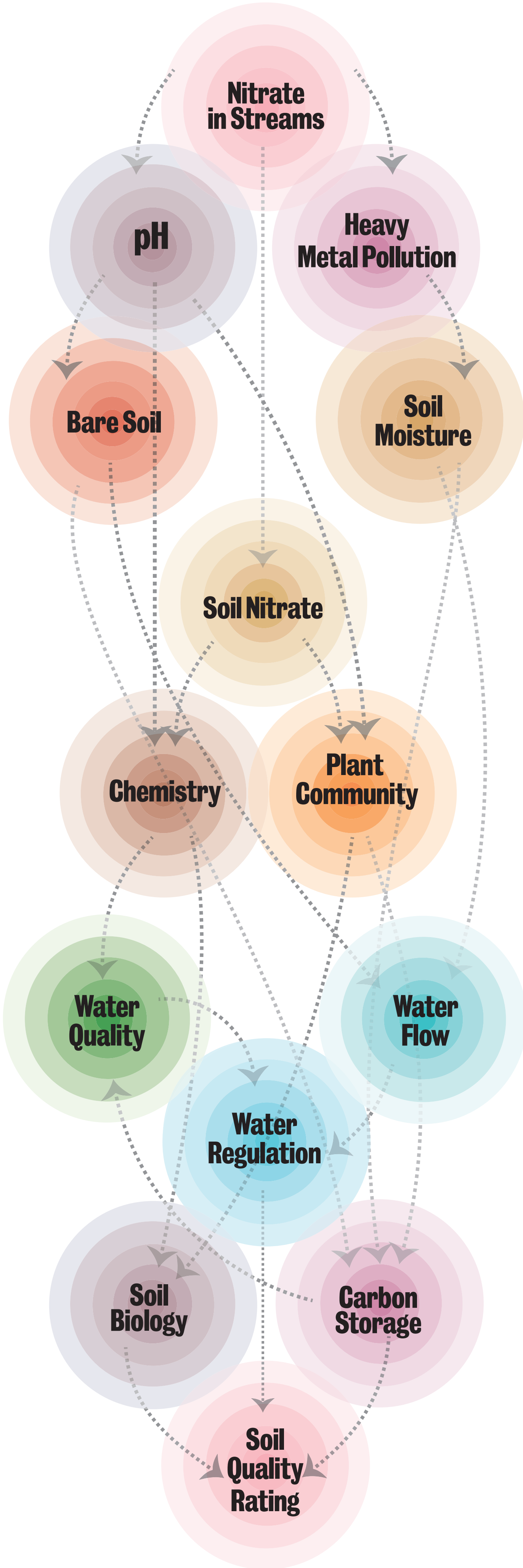
Bending's research revealed a feedback loop that threatens to exacerbate climate change. Flooded soils showed higher emissions of methane and nitrous oxide, both potent greenhouse gases. However, waterlogged soils that have been less intensively managed showed smaller increases in emissions, suggesting that careful land management could limit this feedback loop from driving run-away climate change.

Reducing the intensity of land management could launch a three-pronged attack against soil degradation – Improving soil structure, reducing compaction and boosting soil microbes – which will ensure our soils are resilient against whatever the climate has to throw at them.

# IMPLICATIONS & RECOMMENDATIONS

- Soil health is a somewhat abstract concept, but key traits to focus on for evaluating and monitoring soil health include organic matter content, density, acidity and the efficiency of microbial processes.
- More intensively managed soils have less organic matter, lower stability, and are more acidic, so switching to reduced intensity cultivation approaches could help restore degraded soils.
- Certain regions of the UK – particularly where the land is most intensively managed at the moment – have greater potential to improve soil health, so targeting land management interventions in these will have a large impact.
- Microbial communities in intensively managed soils are smaller and less active and tend to include more opportunistic, 'boom-bust' microbial species, so changing how the land is managed could enhance soil services like carbon sequestration and flood prevention, and make the microbiome more stable.
- Grass-clover leys can rebuild soil structure and promote earthworms and beneficial fungi, which result in higher water absorption and holding capacity. These simple management interventions can make farmland more resilient against flooding, particularly in high-risk areas.
- Prolonged flooding has a severe impact on the soil microbiome, but microbial communities in less intensively managed soils tend to be more adaptable, so reducing cultivation intensity can make them more able to resist extreme weather.

Flooding has a significant and lasting affect on soils. Bacterial communities in the most intensively managed soils showed the greatest change during prolonged flooding. photo: Bryan Eastham




Left: **What is soil health?**

Anyone who works with soil will probably have an instinctive sense of what healthy soil means, but putting that into a precise definition of the term 'soil health', is a bit trickier. Definitions of soil health tend to include both quantifiable soil properties, such as amount of organic matter or water-holding capacity, but we could also include more subjective characteristics that could only be assessed by an expert.

To address this, Andy Whitmore, a modeller at Rothamsted Research in Hertfordshire and his group developed a system for classifying soil health that can combine physical measurement of the soil with expert opinions. They found that the percentage of organic matter, soil density, and the efficiency of microbial processes are important factors when evaluating the health of soil.

Acidity was an important factor in rating the health of unmanaged soils, where historic acid rain has changed the pH, but carried less weight when assessing agricultural soils because farmers apply lime to neutralise the acidity.

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# THE ROOT OF THE PROBLEM

## Developing healthier relationships between plants and soil

*The thin layer between the root and the soil could prove key to making agriculture more sustainable*

By Claire Asher

**Introduction**
The delicate interactions between plants, soil and microbes could be the key to developing more sustainable agricultural practises and warding off climate change, according to research conducted as part of the UK Soil Security Programme.

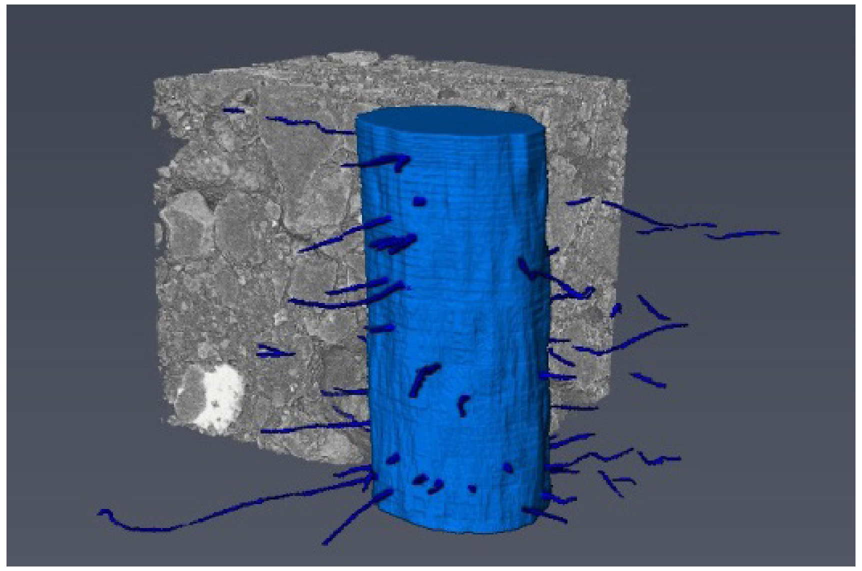
Far from being the inert and homogenous substance conjured up by the word 'dirt', soil is a highly structured yet dynamic environment that is home to millions of microbes and invertebrates. Top soil – the first 30cm or so below our feet – forms foundation for the entire food chain. But our soils are degrading, largely due to intensive farming practises.

According to a recent special report by the Intergovernmental Panel on Climate Change (IPCC), conventionally managed agricultural fields worldwide are eroding 100 times faster than the top soil can be replenished. The long-term security of our food supply is totally dependent on the fertility of this soil, so restoring and maintaining it is fast becoming a top priority for governments globally.

**Entering the rhizosphere**
To understand how we can develop a healthier relationship between crops and the soil they depend on, scientists are looking to the site where they interact most intimately. The thin zone of soil in direct contact with plant roots – known as the rhizosphere – is the most biologically active part of the soil. In the rhizosphere, carbon and other chemicals are exchanged and recycled, and plants obtain all the water and nutrients they need to survive and grow.

*"The rhizosphere is the zone of soil influenced by the root"*, explained Gary Bending, an agricultural scientist at the University of Warwick. It is where chemical reactions occur, where carbon is exchanged and recycled, and it is through the rhizosphere that plants must obtain all the water and nutrients they need to survive and grow.

Poplar tree *(Populus)* roots with root hairs and mycorrhizal fungi visible. Mycorrhizae live inside roots and extend their network of hyphae out in the soil.



The 3D structure of the rhizosphere, photographed using the Diamond Light source, the highest resolution X-ray CT scanner in the UK. Roots engineer the soil around them, affecting water storage, nutrient cycling and greenhouse gas emissions.

**Plants are soil engineers**
Plant roots are covered in tiny root hairs that penetrate deep into the soil to find water and nutrients. Research by Paul Hallett, a soil physicist at the University of Aberdeen and his colleagues have shown that these hairs physically alter the structure of the soil, drawing soil particles together into crumbs and creating air gaps called pores.

The team used a state-of-the-art imaging technique known as X-ray CT to visualise this interaction in intricate detail. With these methods, *"you can see through the soil"*, said Hallett. They found that root hairs actively change the physical structure, chemistry, and biology of the rhizosphere soil.

Root hairs also release a chemical cocktail designed to create better conditions for root growth and nutrient absorption. Hallett and his group analysed the composition of these secretions and found they contain two main types of compound – acids that break down soil particles, and polysaccharides that have a gelling effect on the soil, both of which help create pores that pave the way for new roots and root hairs to grow.

The plant even has an influence over the microbial community that lives in the rhizosphere. Although they are small and seemingly insignificant, soil microbes are incredibly numerous – a single gram contains billions of bacteria, fungi, and other microbes, which are responsible for many of the ecosystem services the soil provides.

But Gary Bending and his team have found that the rhizosphere is home to just a small subset of all the species present in the soil, and this rhizosphere community is remarkably similar across different soil types and climatic conditions. *"The plant is selecting a defined [microbial] community from that really complex community"* present in the rest of the soil, explained Bending.

Many plants also house mutualistic microbes inside their roots. A particularly important group of root-dwelling microbes are known as mycorrhizal fungi, which help plants take up nutrients in exchange for food and protection. These beneficial fungi live in or on roots and extend thin filaments or 'hyphae' out into the soil, thereby extending the rhizosphere and helping the plant take up nutrients over a wider area.

**The hairier the better**
When Hallett's team compared the rhizosphere structure surrounding hairless plant roots with those of short- and long-haired roots, they found that hairier roots produced large pores where the soil has been compressed by the growing root. It is not known whether modern plant breeding has made roots more hairy or bald, but selecting for hairier roots could help improve soil structure.

Soil pores are essential because they create spaces for living organisms to live, feed and move about, and for allowing water and nutrients to move through the soil. Computer modelling by Wilfred Otten, a biophysicist at Cranfield University, and his colleagues has shown that the structure of connections between pores in the soil plays a vital role in determining the biological and chemical processes that occur beneath the ground. The soil pores are *"where all the process happen"* said Otten. *"that's where water flows through, that's where animals move and find each other and find their food sources"*.

Soils with a greater number of better-connected pores have a greater capacity to absorb and store water and carbon, making them more resilient to floods and more effective in mitigating climate change. In laboratory experiments Hallett and colleagues found that larger pores created by longer root hairs increased the soil's water storage capacity and made it more stable against extreme weather conditions.

**A carbon sink**
Soil pores are also where organic matter is broken down into carbon. What happens to that carbon next depends on the processes occurring inside soil pores, Otten and his team's modelling shows. The distribution of organic matter in the soil and its accessibility to microbes living in the pores are crucial determinants of how much carbon is stored in or emitted from the soil.

The role of soils in global greenhouse gas emissions has put them high on the climate agenda, and the IPCC's 2019 special report highlighted the need to restore degraded soils in order to mitigate and reduce emissions. Otten's research *"goes towards rethinking how we understand or model our soil carbon dynamics in climate change models"*, he said.

### Repairing the rhizosphere

Improving the health of the rhizosphere could be a relatively quick, low-cost way to restore degraded soils, boost crop yields, and limit carbon emissions. For example, fungi are very sensitive to soil disturbance because it breaks their delicate hyphae, so land management practises that minimise disturbance could help their populations recover. Research led by Jonathan Leake, a soil scientist at the University of Sheffield, has shown that zero-tillage management - where crops are planted directly into the soil without ploughing - can boost the activity of beneficial fungi in the rhizosphere.

Conversely, harmful microbes may be at the root of an agricultural phenomenon known as 'yield decline', in which each successive harvest of the same crop produces lower yield than the last. Oilseed rape, for example, shows an average decline in yield of 25% in the second year of growth.

The researchers at Warwick found a distinctive signature of yield decline in the genes expressed by bacteria and fungi in the rhizosphere. An altered microbiome and a large loss in yield were associated with a higher prevalence of harmful bacteria and fungi. Conversely, beneficial root-dwelling fungi such as Tetracladium were associated with higher yield. Rotating a larger variety of crops and including cover crops that support the microbiome in the cycle could help minimise yield decline.

### Selecting for a healthier rhizosphere

In the longer term, selecting for crop varieties that support a healthy rhizosphere could maintain soil health whilst offering farmers the freedom to grow whatever crop they want. There are several possible targets for plant breeders to improve the health of the rhizosphere – root hairs, root secretions, and the root's relationship with microbial communities. Designing crops with root traits that will help them efficiently extract nutrients whilst also fostering the soil microbes that are needed to replenish those supplies, could make our crops and soils more resilient into the future.

*"Through breeding or through agronomy … we can enhance this rhizosphere and then enhance soil properties"*, said Hallett. For example, root hair traits could help improve soil structure and health, boosting ecosystem services like nutrient cycling and carbon sequestration.

Hairy or not? Roots with longer hairs create a more complex soil structure, boosting soil health and promoting ecosystem services.



A ploughed field in Hampshire. Ploughing the soil breaks down soil structure and damages fungal networks. Photo credit: Neil Alderney

But it won't be enough just to restore degraded soils – to reduce greenhouse gas emissions and ensure a stable supply of food we will also need to ensure the rhizosphere's health is resilient against future climate change. How soils respond to climate warming and extreme weather will depend on the complex interactions of physical, chemical and biological characteristics of the soil, but a rhizosphere with better soil structure and healthier microbial communities will be the best placed to cope.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## IMPLICATIONS & RECOMMENDATIONS

- Hairier roots create larger soil pores, building soil structure and boosting water-storage capacity, so plant-breeders should focus on root hair traits when selecting for new crop varieties
- Plant roots exude acids and gelling compounds that help transport phosphorous and other nutrients, so these root traits should be selected to improve crop absorption of key nutrients, allowing farmers to use fewer fertilisers
- The internal structure of soil influences the accessibility of carbon to decomposing microbes and determines how much carbon dioxide is released back into the atmosphere. This improved understanding of carbon dynamics in the soil can help us design land management strategies to promote soil health and minimise greenhouse gas emissions.
- Repeated harvests of the same crop tend to harm the soil microbiome, promoting harmful bacteria and fungi and leading to a phenomenon known as 'yield decline', so rotating a larger variety of crops and selecting those that support a healthy rhizosphere will have substantial benefits for yield.
- Rotations of grass-clover leys improve soil health and increase yield, but these benefits are likely to be lost when the soil is ploughed. Reducing disturbance by direct drilling can improve crop productivity and promote soil communities that are better able to resist environmental changes.

# FOR PEAT'S SAKE

## Preserving Britain's biggest carbon store

*To meet climate commitments, the UK must protect its peatlands*

By Claire Asher

The squelchy bogs of Scotland and East Anglia must be carefully managed, protected, and monitored if the UK is to meet its obligations to curb tclimate change, according to research as part of the UK Soil Security Programme.

They might not look very special at first glance, but peatlands provide some of the most fertile agricultural land in the UK, and they store huge amounts of carbon and water, reducing greenhouse gas emissions and flood risk. But these natural services are lost as peat soils degrade due to drainage and erosion.

**The UK's biggest carbon store**

Peatlands are formed in waterlogged soils, where the lack of oxygen prevents microbes from decomposing dead plants and animals. This makes the soils incredibly rich in organic matter, meaning peat bogs are packed full of carbon. Peat holds one third of all the carbon stored in soils – a quantity roughly equivalent to all the carbon dioxide ($CO_2$) currently present in the atmosphere. Keeping that carbon in the soil will be crucial for mitigating climate change.

Peat bogs come in two main types – lowland 'fens' bogs and upland 'blanket' bogs. Fens dominate the East Anglian countryside but are also found in Scotland, northeast England and Northern Ireland. Blanket bogs cover around 2.25 million hectares in the UK and are found predominantly in Scotland and northwest England.

People have drained these waterlogged soils to plant crops or graze sheep but doing so exposes the organic matter to microbes as well. Dormant microbes reawaken and start eating the peat from the inside out, releasing carbon back into the atmosphere. As a result, damaged peatlands account for 5.6% of global greenhouse gas emissions.

Restoring and maintaining these precious ecosystems will be crucial for the UK to meet its component of the EU commitment to the Paris Agreement. *"The peatlands are one of our most effective ways of storing carbon"*, said Nicholle Bell, a research fellow at the University of Edinburgh.

Blanket bog in Forsinard, Scotland. Damaged peatlands release greenhouse gases into the atmosphere and contribute to climate change.

Intensive and extensive grasslands harbour different soil communities. Opportunistic microbes dominate in intensively managed systems.

### Lowland Peatlands

Draining the carbon-rich lowland peatlands has provided us with extremely fertile agricultural land, particularly in East Anglia's fen peatlands. These super-productive fields provide the majority of our salad vegetables - an industry valued at £1.2 billion a year. But these prized soils are rapidly degrading – consumed by microbes and blown away by the wind.

People began using pumps to drain the fen peatlands in the 17th century. Since then 90% of the original area has been converted to cropland or grasslands, and estimates suggest that the soil is vanishing at a rate of 1–2 centimetres a year. *"I would say that it is the most unsustainable place in the whole of the UK in terms of agriculture"*, said Davey Jones, a soil scientist at Bangor University.

Jones and his team analysed soil samples from 13 fen peatbogs in the UK and found that the depth of the water table had a big influence on how much $CO_2$ and other greenhouse gases were being exchanged between the air and the soil. Experimenting on blocks of turf, they found that raising the winter water table to 50cm – 60cm below the surface reduced $CO_2$ emissions by more than two-thirds.

**Striking the right balance**

However, keeping the water table high throughout the year had a major impact on crop yield, so most farmers couldn't afford to do it year-round. Instead, the team suggest raising the water table in winter and lowering it again in the summer, which reduces $CO_2$ emissions without harming lettuce yield. To strike the perfect balance, farmers should raise the water table by 1m in winter. If this strategy were rolled out across all of the UK's peatlands, it would cut $CO_2$ emissions by 4.3 megatons a year, Jones says.

### Upland Peatlands

They superficially look quite similar, but peatlands in the uplands are a totally different animal. Known as 'blanket bogs', upland bogs aren't nutrient-rich like the lowland bogs in East Anglia, making them poor for agriculture. Instead, these bogs have been drained for sheep grazing and forestry. But whether you drain a bog for agriculture, forestry or livestock, the result is the same - the soil compacts, air and gases are squeezed out, and microbes begin breaking down the stored carbon.

**The rise and fall of bogs**

As spongy peat soils gain and lose water, gases or organic matter, the surface gradually rises and falls - like slow-motion waves on the ocean. While testing a novel technique for remotely monitoring peatlands (see Box 1), environmental scientist David Large, from the University of Nottingham, discovered an unexpected pattern in the height Scottish peat bogs that could help scientists monitor their health from a distance.

Large and his colleagues found the seasonal timing of the rises and falls depends on the type of vegetation present, which is known to be a good indicator of the health of a bog. Wet, healthy peatlands tend to be dominated by mosses, and reach their peak height in mid-winter, whereas drier peatlands tend to be covered in heather and peak in early spring. This discovery could help scientists diagnose peat soils remotely.

**Molecular soldiers defend soil carbon**

Mosses also seem to be crucial for protecting the peat. *"Carbon is stored within the peatlands because there are some soldier molecules … that prevent the decomposition of the peat bog by switching off all the microbial decay pathways"*, said Bell. The soldiers are thought to be phenolic compounds, produced by mosses such as Sphagnum to protect themselves against hungry herbivores. Phenols are bitter tasting, so animals don't like to eat them. But they also turn off microbial enzymes - known as hydrolases - that would otherwise break down organic matter. The antibacterial activity of phenols even made Sphagnum a popular as a disinfectant in the 19th century.

Microbes do have a defence against this onslaught – an enzyme called phenol oxidase – but it is disabled when oxygen levels are low. Draining the bog allows oxygen in and kills the moisture-loving mosses, so the supply of soldier molecules dries up too. But Bell and her colleagues discovered that an army of molecules is coming back after restoration that could protect peatland carbon. Chemical tests for these molecules could become a regular part of monitoring the recovery of degraded peatlands.

## Nurturing peatlands back to health

The importance of peat for the UK's greenhouse gas emissions has not gone unnoticed by the government, and peatlands feature prominently in the their 25-year Environment Plan. In 2018 the Department for Environment, Food and Rural Affairs (Defra) pledged £10 million to four projects that aim to restore over 6,500 hectares of peatlands in the north and west of England.

Scottish peat bogs in particular are poised to become a great restoration success story. Over the last 7 years the Scottish Government has invested over £400 million in peatland restoration through the Peatland Action programme. Amongst the recipients was a 21,000-hectare restoration site managed by the Royal Society for the Protection of Birds (RSPB) in Forsinard in Scotland's Flow Country.

### Monitoring bog recovery

But to know whether these ambitious restoration projects are proving effective, scientists need to be able to monitor the health of the peat. Traditionally, scientists would have looked for biological signs of a healthy bog, such as the return of mosses. But Bell and her colleagues believe looking at the soil chemistry could add the below ground perspective that is needed to comprehensively monitor peat restoration.

The researchers identified chemical differences between untouched, degraded and restored peatlands in Forsinard. *"We're starting to see some molecular indicators that it's still able to fight the battle effectively"*, she said. Restored peatlands do indeed show signs that carbon-digesting enzymes are being kept at bay, but the molecules protecting the carbon may not be the same as before the damage took place.

### Ensuring long-term resilience of peat

But the long-term future is uncertain for blanket bogs, which face new challenges as the climate changes. Their unique characteristics mean peatlands are particularly affected by drought, which can lower the water level, killing mosses and allowing peat to degrade.

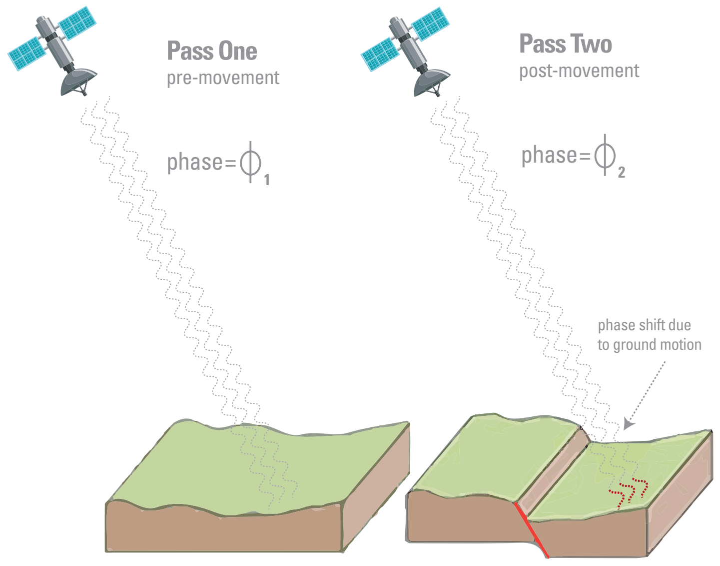
Restoring vegetation on degraded peatlands and protecting it from grazing could protect the soil from erosion, and Richard Bardgett, an ecologist at the University of Manchester, says it could also make them more resilient to climate change by buffering soil microbial communities against droughts. Bardgett and his colleagues have found that droughts leave a mark on the microbes living in the soil, especially fungi, which suffered greater declines during drought. However, the presence of vegetation helped to buffer the fungal communities against the harmful effects of drought.

At the landscape scale, the impact of droughts on peatlands can be surprising. Bogs tend to have a domed shaped, with deeper, wetter soils in the centre. But satellite monitoring by Large and colleagues showed that droughts in 2018 flattened this domed shaped, because the centre dried more rapidly than the edges – damage that could take decades to regrow he warned.

Nicholle Bell's team compared the chemistry of peat soils at different states of degradation and restoration to track the return of compounds like phenols as the soil recovers.

### A toolbox for monitoring peatland recovery

Scientists are now equipped with a whole toolbox of methods to insure that investments in peatland restoration are being used effectively - from new chemical tests, all the way to satellite monitoring of whole landscapes. This will prove essential as the UK's peatlands, and the 584 million tonnes of carbon they hold, start to become a top priority for governments in search of practical ways to tackle the climate emergency.




**Tracking the success of peatland restoration schemes using radar.** Government agencies may have invested hundreds of millions in restoring peatlands but they face challenges in monitoring the success of these schemes over the enormous areas involved. Large and his team trialled a new satellite-based monitoring technique for land managers and policy-makers that could allow them to *"cost-effectively validate the success of their investments,"* said Large.

The satellite-mounted radar system known as 'interferometric synthetic aperture radar' (InSAR) is able to visualise the motion of the peatlands allowing scientists to remotely monitor their health – a task that was once laborious and extremely expensive. Satellite-borne monitoring techniques like InSAR are *"giving us a whole new scientific view of the peatland and peatland processes"*, said Large.

Just like radar navigation devices, InSAR works by bouncing microwaves off the surface of the ground and calculating the distance. The team found the technique was 78% accurate to measurements on the ground. Its only downfall was when soils moved up or down very dramatically, such as in 2018 when severe droughts caused the peat to drop 3cm in just 6 days, exceeding the technical limitations of the equipment.

## IMPLICATIONS & RECOMMENDATIONS

- Bare peat soils are vulnerable to erosion but vegetation can protect top soil and rebuild nutrients, so planting cover crops on cultivated peatlands could help protect them against natural erosion and extreme weather events.
- Carbon dioxide emissions from peatland soils are affected by the depth of the water table, so raising the water table in cultivated peatlands over the winter can reduce emissions without negatively affecting crops.
- Prolonged droughts disrupt microbial communities in upland peat soils, and climate warming makes these communities more vulnerable. Shrubs can help buffer soil fungi against these extreme weather events, so minimising grazing pressure could make peatland microbes more resilient.
- Sphagnum mosses are found on healthy peatlands and release compounds into the soil that protect carbon from being consumed by hungry microbes, and these protective compounds can be measured slowly returning to recovering peat soils, so monitoring chemical changes could help evaluate peatland restoration programmes.

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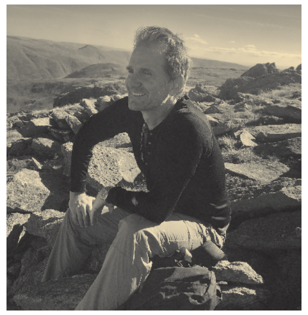
# RESEARCHER BIOGRAPHIES



**Richard Bardgett** is Professor of Ecology at The University of Manchester, United Kingdom. His research seeks to develop a mechanistic and conceptual understanding of how interactions between plants and soil biological communities regulate biogeochemical cycles and plant community dynamics, and their response to global change.
He has written several books on this topic, including *The Biology or Soil* (2005), *Aboveground-Belowground Interactions* (2010) and *Earth Matters: How Soil Underpins Civilization* (2016), and is routinely recognised as a Highly Cited Researcher in ecology and environmental. He currently serves as President of the British Ecological Society and Senior Editor of Journal of Ecology.

**Davey Jones** holds a Professorial Chair in Soil and Environmental Science at Bangor University. A major focus of his research is on understanding below-ground processes with specific focus on nutrients and human pathogen behaviour in soil-plant-microbial systems. Current applications of his work include (1) the implementation of strategies for controlling viral pathogens in agricultural, freshwater and marine ecosystems, (2) promoting carbon sequestration in agricultural systems and understanding the factors regulating carbon cycling and greenhouse gas emissions, (3) developing ways to improve nutrient use efficiency in cropping systems with specific focus on nitrogen and phosphorus, (4) devising strategies for the effective reuse of wastes for land restoration and remediation, (5) modelling nutrients dynamics in the plant-soil-microbial and freshwater ecosystems, and (6) understanding the barriers to technology adoption by farmers.


**Professor Gary Bending** is an environmental scientist whose research focuses on the structure and ecosystem functions of microbial communities. He completed a BSc in Biological Sciences at Exeter University and a PhD on mycorrhizal ecology at Sheffield University. He was a research group leader at Horticulture Research International and successor organisations at Wellesbourne, before moving to the School of Life Sciences at Warwick University in 2010, where he is lead of the Environmental Science Research Theme. He is a member of the NERC Peer Review College, and between 2013 and 2019 a member of the UK Government Expert Committee on Pesticides.

**Aidan Keith** is an ecologist striving to measure soils, better understand their inner workings and unpack the black box, in an effort to shape more sustainable and resilient multi-functional landscapes. His research, spanning across different scales, aims to improve knowledge of land use and climate impacts, with emphasis on soil biodiversity, plant-soil interactions, biophysical properties and functioning, and changes in natural capital and ecosystem services. Recent projects have focused on extreme weather (flooding and drought) and the development of proximal sensing approaches for rapid soil assessment. He is keen to foster data visualisation approaches for better science communication and knowledge exchange in soil research.

**Jackie Stroud.** Jackie developed pro-active strategies to tackle misinformation in agriculture. She formed co-learning partnerships with farmers by leveraging the unique network properties of Twitter (@wormscience). Together they transformed an on-farm symbol of soil health into a global systematic field observation network using social media (#WorldWormWeek). Over 25,000 earthworms were studied by UK farmers, revealing soil biological pitfalls in no-tillage adoption. Doing Science Differently fostered better learning and community connections towards the common goal of sustainable agriculture. She has relocated to Australia to continue working in soil science following her fixed-term NERC Soil Security Programme fellowship based at Rothamsted



Dr Ian Pattison is an Associate Professor in Physical Geography at Heriot Watt University, Edinburgh. His research focusses on flood risk management, particularly "Working with Natural Processes" in catchments and cities, the concept of Natural Capital in Agricultural landscapes, and flood forecasting using Artificial Intelligence techniques. He completed his PhD in 2011 at Durham University on "The role of land management on catchment scale flood risk" where he developed methods to upscale Natural Flood Management and bring more strategy to the approach. He worked on a DEFRA funded project on the impact of sediment on fish spawning habitat at Southampton before becoming a lecturer at Loughborough University in 2012.

**John Hammond** is a Crop Scientist in the University of Reading's School of Agriculture, Policy and Development, where his research focuses on plant-soil interactions, in particular, how plants obtain nutrients from the soil and adapt to changes in their environment. He obtained his PhD in Crop and Plant Sciences from the University of Nottingham in 2004 and has conducted research on vegetable, fruit and arable crops working at Universities in the UK and Australia.

Dr David Large is an Associate Professor at the University of Nottingham where he lectures in Environmental Engineering. His background is in Earth Science and his primary research interest is the mechanical motion of peatland surfaces and the limits to peatland carbon accumulation. He has led the development of satellite measures of peatland surface motion to quantify peat condition and carbon emissions. In particular, he has demonstrated that Interferometric Synthetic Aperture Radar (InSAR) can detect changes in water storage and peat condition and has the potential to transform our understanding of peatland dynamics across whole landscapes and regions.

Rob Griffiths is a molecular microbial ecologist, with a key interest in understanding the ecology of diverse soil microorganisms. He uses cutting edge molecular biology and functional approaches to understand the broad scale drivers of microbial biodiversity, and learn more about the functional abilities of previously undiscovered microbes. A current main research focus is in determining land use impacts on soil biota and their functional resilience to further environmental change across a wide variety of different soil ecosystems.

Wilfred Otten joined Cranfield University in May 2016 as Professor of Soil Biophysics. He obtained a degree in Agricultural Engineering and a PhD degree in Horticultural Sciences, focusing on closed fertigation systems (Wageningen University, The Netherlands). His research focuses on biological invasions into heterogeneous plant and soil environments, response of soil properties to change, and the application of emerging technologies in soil science in order to enhance our predictive ability of soil systems. He is an expert in the use of X-ray CT to characterise soil structure which he applied to understand the impact of land management on soil-root-microbe interactions.

Andy Whitmore is a chemist by training and a soil scientist and agricultural system modeller by profession. He leads the soils systems modelling group at Rothamsted and besides his project looking at soil quality and health funded by the Soil Security Programme, he has led projects recently on managing agriculture and the wider environment together in the landscape, understanding resilience and networking scientists working on the sustainable intensification of agriculture. He is a visiting Professor at Cranfield University