The Royal Society of Edinburgh

Life in soil: does it matter?

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Executive Summary
This event completed a trilogy of discussion forums hosted by the Royal Society of Edinburgh (RSE) relating to biodiversity. Soils are one of the most diverse and important ecosystems on the planet. They contain an abundance of species which deliver a wide range of ecosystem services, playing a critically important role to human life and society. Professor Michael Usher, OBE FRSE, welcomed the speakers. The speakers provided an overview of soils and their importance at both a local and global scale. Professor Richard Bardgett, FRSNZ, discussed the role soil organisms play and the many different functions that soils perform and how they help in building resilience to environmental change. Professor Colin Campbell focused on Scottish soil diversity and demonstrated the importance of the range of strategic research which had been undertaken within Scotland to enhance opportunities and respond to challenges in the management and custodianship of soils. Professor Julie Fitzpatrick, OBE FRSE, explained the role that soil has within livestock farming, using Scotland, East Africa and Australia as examples, and discussed the relationships between livestock, pathogens and soils. Susan Davies, FRSB FRSA, Acting Chief Executive, Scottish Natural Heritage, chaired a panel discussion between the panel and the audience; the questions reflecting both the local and global perspective on soils and raising issues on their economic, environmental, biosecurity and societal–cultural roles. The event was concluded by Professor Lorna Dawson, FRSA, Environmental Change Programme Advisor, Strategic Research Programme, who presented an overview of the event, re-emphasised the importance of understanding soil biodiversity and announced the results of the vote for the audience's favourite soil organism.

Overview and welcome
Professor Michael Usher welcomed the audience and remarked that this was probably the first RSE meeting since its foundation 233 years ago devoted to life in soils, completing a trilogy of RSE Discussion Forums related to biodiversity: *Lost at Sea? The Atlantic Salmon's Ocean Odyssey*, and *Invasive Species – Friends or Foes?* It also concluded Scotland's participation in the 2015 United Nation's International Year of Soils, during which Scotland had demonstrated its international reputation in soil research and how this knowledge and expertise can be applied in policy and practice.

Professor Richard Bardgett
Professor Richard Bardgett remarked that a healthy soil is a living soil. He discussed research on identifying which organisms are found in soil, what these organisms do and why this matters for the different functions that soils perform (e.g., nutrient cycling, plant health, water purification, etc.) and how future environmental change may threaten life in soils.

What organisms are found in the soil?
Although soil physics and chemistry are important for understanding soil fertility, Professor Bardgett's research has mostly focused on the diversity of life in soils. A handful of soil taken from a local park can contain billions of different organisms and thousands of species. These include microbes (e.g., fungi and bacteria), but also a whole array of soil animals. Much research has been carried out to understand the ecology of these organisms and how this soil life is distributed. One recent study conducted across Central Park in New York found 122,081 bacterial and 43,429 eukaryotic species over an area of only 3.4 km^2. Also, the soils of Central Park were found to harbour nearly as many different soil species as would be found if sampled across the world, suggesting that they are mostly cosmopolitan. One of Professor Bardgett's early studies focused on measuring the abundance of soil animals as part of the NERC Soil Biodiversity Thematic Programme at Sourhope, in the Scottish Borders. Although the study site is unproductive acidic upland grassland, there is still a remarkable diversity of organisms in this soil. In another study, which involved sampling soils across the world, it was found that while the number of soil species does not vary in an obvious way with latitude, the make-up of the soil communities is very different at each site, suggesting that most soil animals are restricted to that location. The number of soil animal species might be similar across sites, but the composition of these communities is very different.

What do these organisms do?
While earlier studies have demonstrated the importance of soil diversity for improving soil functions, recent research has shown how the composition of soil diversity impacts on these processes. A recent controlled experiment demonstrated that as the life in a soil decreases so too does the soil's ability to perform these vital functions. This clearly shows that life in soils does matter with regard to how soils function. Professor Bardgett, along with a consortium of researchers, carried out field sampling and analysed soils from multiple sites from a variety of habitats located across Europe. This information will help to predict the impacts that changes to the abundance of different organisms can have on different soil functions across Europe. Results from both controlled experiments and field studies suggest that soil diversity does matter.

How will environmental change impact soil diversity?
Many of the world's soils are under significant threat. It is estimated that 33% of the world's soils are currently degraded. The drivers of this are complex, but the two main causes are the intensification of land use and extreme climatic events. Increasing the intensity of land management practices has been shown to cause a decrease in soil diversity. Soils with higher diversity are better able to recover from drought. In addition, Professor Bardgett showed the importance of soil organisms in the recovery from flooding or drought. Although this research has demonstrated that soils are very resilient, further research is required to advise on how best to manage land in the future.

Professor Bardgett concluded by emphasising future research priorities. Greater awareness of the importance of biodiversity of soils in food production, resilience to climate extremes, and human health is required. We should develop, reshape and enhance soil biodiversity and functioning to build improved soil health.

Professor Colin Campbell
Professor Colin Campbell discussed whether Scottish soil diversity is different from that of the rest of the world and whether this should encourage greater local consideration. He highlighted Scottish research and how it has enhanced our understanding of soil diversity. Lastly, he discussed some of the future challenges.

Are Scotland's soils different?
Professor Campbell explained that soils are very different at the local, regional and global scales. Scotland's unique composition of vegetation, geology and climate means that some of our soils are rare in relation to the rest of the UK. For example, machair soils are sandy, alkaline soils which support a high diversity of plant life; while our serpentine soils have naturally high nickel levels. Scotland's agricultural soils have higher levels of organic matter, are more acidic, and contain less nutrients relative to the rest of the UK. Scotland's peaty podzols and highly organic soils are not that different from the rest of the peaty soils in the UK. They cover almost 50% of Scotland and 40% of the northern Polar region and have global significance.

What soil diversity research has been carried out in Scotland?
Professor Campbell discussed the rich heritage of Scottish soil research, particularly the work on soil pathogens dating back to the 1940s. More recently, the Scottish Government-funded Strategic Research Programme is exploring the links between soil diversity and its multiple functions. This research has led to the discovery of new species and genera, and the development of new surveillance techniques to detect pathogens, and is improving our understanding of how changes to climate and management will impact on our soils. The advancement of monitoring techniques has enabled researchers to conduct national assessments which have led to the creation of an asset register of our soil diversity. An example is the National Soils Inventory of Scotland (NSIS), where molecular techniques have been used to complement the chemical and physical data available, which is freely available for anyone to use.

What are the future challenges?
Professor Campbell explained how future challenges may harm Scottish soil diversity. One study involved monitoring soil transects across Scotland to investigate how Scots Pine forests are influenced by increasing temperature and rainfall levels and a decreasing capacity to take up nitrogen from the atmosphere (i.e., nitrogen deposition) by mycorrhizal fungi. Habitat growth was found to be influenced more by change in temperature and rainfall than by nitrogen deposition. This demonstrates that one of Scotland's iconic habitats could be under threat unless appropriate action is taken.

Another area of concern is the increasing levels of contamination from heavy metals caused by the repeated spreading of sewage sludge, often of human origin. Professor Campbell looked at how this practice impacts on the abundance of rhizobium bacteria in the soils of pastures. Rhizobium forms a symbiotic relationship with leguminous plants (e.g., clover, beans, etc.). Professor Campbell found that sewage sludge can cause the numbers of rhizobium to decrease, thus affecting the ability of the soil to fix nitrogen.

A major health challenge is the increased bacterial resistance to antibiotics. The majority of antibiotics in use today originally came from the soil. Therefore, exploring the DNA of soils provides a fantastic opportunity to discover new antibiotics.

Professor Campbell concluded by saying that through exploration of the life in soils, we can find many new potential applications in the future. For example, soil fungal networks can warn plants of potential pests and influence their response. Fungal diversity will interact with different strawberry cultivars to influence their flavour. He said that he would never have guessed 25 years ago that these mechanisms were there.

Professor Julie Fitzpatrick

Professor Fitzpatrick explained the different types of interactions between soil and livestock, using East Africa, Australia and Scotland as examples.

Global examples of soil–livestock interactions

Livestock are important in developing countries, as pastoralists produce around 10% of the global meat supply in some of the most remote and vulnerable communities. In East Africa, approximately 75% of meat comes from smallholder farmers. In Tanzania, smallholder dairy farmers tend to cut grass daily and deliver this to their livestock kept in pens; thus the feed quality depends on healthy and non-degraded soils. Soil degradation across much of Africa causes poor productivity levels and often leads to more land being converted to agriculture; a trend that should be halted. Maintaining the life in soils is, therefore, an important economic and environmental priority to many.

The link between the Great Barrier Reef and the northern beef rangelands demonstrates how livestock grazing impacts upon water quality. Heavy livestock grazing has altered the soil structure and increased sediment flow into the Barrier Reef. These greater levels of sediment subsequently block oxygen and light, both being necessary for corals within the Reef. Livestock farmers in these regions are addressing the issue through innovative, precision-farming processes. Some of the soils in Scotland and the UK are deficient in copper, cobalt and selenium and can lead to some interesting and well-recognised animal diseases such as ‘swayback’, ‘pine’ and ‘white muscle disease’.

Animal-gut infections

Johne's disease is caused by *Mycobacterium aviam paratuberculosis* (MAP), which infects the intestines of ruminant species (e.g., cattle, sheep, etc.). This disease has potential implications for human health, due to its possible link with Crohn’s Disease. In Australia, scientists have found positive associations between MAP bacteria and sheep grazed on pastures with a number of different soil properties, including organic carbon, clay and iron content. These properties help the MAP bacteria remain in the upper soil horizons and make it more accessible for the grazing sheep. Recent studies have shown that a common protozoa found in soil, Acanthamoeba, can act like a Trojan horse by taking up the MAP bacteria into an intracellular position within the amoeba, thus allowing it to survive in the soil for longer. *Cryptosporidiosis* (*Crypto*) is a water-borne disease that can be transmitted to humans through contaminated water reservoirs. Studies in the Cairngorms have shown a higher than expected prevalence of *Crypto* in certain ruminant species. Toxoplasmosis is a parasitic disease caused by the protozoan *Toxoplasma gondii*. Cats are the definitive host which produce the infective stage, and humans are susceptible to infection via a number of routes. *Toxoplasma gondii* oocysts can remain present for up to 24 months in soils and 26% of human infections are attributed to contact with soils.

Non-gut animal infections

Ovine footrot is caused by *Dichelobacter nododus, a* bacterium which causes lameness in sheep. Advice on pasture management recommends only re-introducing non-infected sheep to contaminated pastures after 14 days. However, recent laboratory studies have suggested that this bacterium may survive for up to 40 days in soils. Professor Fitzpatrick remarked that perhaps it is time to revisit footrot control programmes in light of this work, and to re-consider the 14-day rest period. One important food-borne pathogen is *E.coli* 0157, which is a bacteria predominantly produced by livestock and spread in their faeces. Studies have shown that diverse soil microorganisms can reduce the prevalence of *E.coli* in soils. This is important in arable ecosystems, as *E.coli* can be taken up through plant roots, posing a risk to humans via consumption of vegetables.

Soil-associated infections
Professor Fitzpatrick discussed a range of soil-associated infections and their multiple trophic interactions: *Tuberculosis (TB),* which impacts cattle and badgers; livestock worms which use soils to protect their larvae; and sheep, liver fluke, snails and natterjack toads which all demonstrate the complex link between farming and biodiversity. During the Second World War, scientists released anthrax on Gruinard Island, off the North Coast of mainland Scotland, to look at the potential effects of biological warfare, and demonstrated that spores formed are able to survive for a long time within soils.

Anti-microbial drugs
Anti-microbials are known to impact soils via urine and faeces from livestock species. Professor Fitzpatrick said that anti-microbial drugs are used in our food-producing animal species, although EU regulations are careful to enforce adequate withdrawal periods so that these drugs do not enter the human food chain. However, antibiotic resistance genes are common in soils and in manure, with a recent study showing multi-drug-resistant soil bacteria with very similar genetic components to human pathogens.

Professor Fitzpatrick concluded that soil diversity matters for livestock keepers, as microbial diversity drives ecosystems. Better farming practices are possible through improved knowledge exchange and international efforts. From a livestock perspective, it is about focusing on health, reducing disease and using microbial drugs more responsibly. A better understanding of the interactions of organisms from livestock both above and below the ground is fundamental to this goal.

Panel Discussion
Susan Davies chaired the panel discussion, welcoming the greater prominence being given to soils as the foundation of healthy and productive ecosystems able to be resilient to change.

Asked about the lessons of managing livestock and treating sewage sludge, Professor Campbell said there are very strict regulations in place to prevent the spreading of contaminated waste. More long-term studies are required to monitor different types of human and organic wastes, to be confident that there are no negative effects on soil diversity and human health. Commenting from a livestock perspective, Professor Fitzpatrick believes there should also be less reliance on antibiotics and promotion of disease prevention through good husbandry and vaccination.

Asked about what gardeners should be mindful of when spreading compost and manure, Professor Campbell said using compost is very positive, but contaminants have been found in green composts. Gardeners should be careful about what products they use. Professor Bardgett added that urban gardening and farming is more popular, but people do not know enough about contaminants. People need to use common sense (e.g., washing the soils off hands) to restrict the potential intake of contaminants.

Professor Campbell responded to a question about the effects that pesticides and veterinary medicines have on soil, saying that products applied to soils go through rigorous testing procedures. Soils are bioreactors which degrade most products applied to them, or transform them into less harmful forms. Soil biodiversity needs to be protected to maintain this function. Regulations can only protect soil from the things we know, so we need to be cautious about the things we do not know.

Asked about how farmers can maintain yields whilst increasing soil diversity, Professor Bardgett said that improving soil diversity may not necessarily improve yields**.** For him, one of the key issues for managing for soil diversity is to make soil functions sustainable.

Professor Campbell said you need to accept that soil is living and this requires growing your soil before you can grow your crop**.** In the future, biological controls will replace our current chemical ones, and we will have biological mechanisms which increase plant growth by adding specific organisms to crops.

Professor Bardgett was asked to clarify the statistical relationships between the amount of soil organisms and different processes in one of his studies. He responded by saying that it is always difficult to say with certainty that relationships are casual in the field, because many factors might explain variation. However, he also said that the patterns they saw in the field have been backed up by experiments which eliminate this extra variation; thereby providing more evidence of causation.

Professor Bardgett responded to a question about the duration of floods and how they impact on worms by saying that flood duration has a big impact and many soil organisms can die. However, soils are able to recover very quickly, so worry should be reserved for reoccurring floods and how changes in the way land is managed might hamper this ability to recover in future years.

Asked about the impact that fertilisers and tillage have on the abundance of soil microbes, Professor Campbell said that the use of fertiliser can increase soil microbe abundance, but adding too much can lead to changes in the microbial community composition. Tillage is important for weed and disease control, but it can break up mycorrhizal networks. There is no universal or single appropriate tillage strategy and it will be region- and soil-specific. Professor Bardgett added that studies have shown that certain groups are sensitive to the application of fertiliser, particularly fungi. Tillage is generally not beneficial for soil diversity and no-till agriculture is something which is being practised more widely.

Replying to a question about appropriate quantitative indicators for soil biodiversity, Professor Campbell said there are some really good biological indicators available, as well as surrogates, such as soil carbon which scientists and policymakers agree will bring multiple benefits if levels increase. Professor Bardgett said there is no single indicator but, instead, a suite of simple indictors is most appropriate. Professor Fitzpatrick mentioned that indicators for biological efficiency for land use could indirectly incentivise managing for soil diversity.

Asked about the effect of adding charcoal to soils to protect trees from Chalara (ash dieback), Professor Campbell said that charcoal can have a big impact on soil nutrient retention. Currently, the science is contentious on the benefits of using charcoal for different purposes. Susan Davies said that research into this is still in the early stages.

Professor Campbell responded to a question about the prevalence of flatworms, highlighting the research done by the James Hutton Institute in this area and the flat worm surveillance map which is available on their website. They are not as common in agricultural soils, but they do cause problems in urban soils.

Asked about what they would protect if they were designing a soil network, Professor Bardgett said that many soil types are becoming extinct in different parts of the world. One of the criteria could be the variety of soil types and their uniqueness. Professor Campbell would target Scotland’s mountain, machair and pine woodland soils, but added that all soils need protection. Professor Fitzpatrick would choose to protect the soils in East Africa, due to their importance for food production for the poorest of people.

Conclusion
The lively and searching debate reflected the high level of interest and engagement on the topic of life in soil; it really *does* matter.

Prior to the event, the audience members had been encouraged to choose their favourite soil organism from eight possible choices as part of an awareness-raising exercise. Professor Lorna Dawson announced the audience's favourite soil organism – the earthworm, followed by fungus and the mole.

The Vote of Thanks was given to the Royal Society of Edinburgh, the James Hutton Institute, the Rural and Environment Science and Analytical Services Strategic Research Programme, the Scottish Government, Scottish Natural Heritage and the Moredun Foundation.

To conclude, Professor Dawson reinforced the fundamental importance that soils play in our lives, and the need to protect them can be exemplified by the following quote by Franklin D. Roosevelt: "A nation that destroys its soils destroys itself."