Soils: Environment, Health and Society

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Introduction

The soils of Scotland provide a wide range of environmental, economic and societal benefits. Soils carry out a range of services including underpinning the provision of food, forestry and fibre production; regulation of environmental flows of water and compounds and elements; a source and sink of environmental carbon; provision of habitats for sustaining biodiversity; preservation of cultural and archaeological heritage and provision of a platform for buildings and roads. While Scotland's soils are generally in good health, threats including environmental change and loss of organic matter are significant and have profound effects on the ability of soils to function and provide ecosystem services. In addition, sealing of soils by construction, loss of biodiversity and deposition of acidifying and nutrient enriching air pollutants also represent significant threats to soils in Scotland. Accordingly, there is a significant body of policy in place relevant to soils, providing some direct or indirect protection of this vital resource.

In this booklet we present a range of research highlights, regarding soil, which have developed through the research performed in the RESAS Programme of work 2011-2016. We present summaries in four main subject areas: 1) Soils and Food Security; 2) Soils and Environmental Security; 3) Soils and Human Health and 4) Soils and Society. This breadth of subjects and impacts demonstrates the importance of soils to future productivity, sustainability and development of societies across the world, but specifically in Scotland.

In the first section we discuss the impact of how selecting the appropriate microbial community associated with plant roots (Chapter 1) and the appropriate seed traits (Chapter 2) will enhance our ability to effectively manage cropping systems to improve the productivity and environmental sustainability of agricultural practices. We present highlights of work on the production of a smartphone app which allows the user to gain instantaneous information on their soil wherever they are in Scotland (Chapter 3). We also demonstrate that better understanding of soil distribution and characteristics is allowing more effective management of forestry for multiple benefits (Chapter 4). Novel techniques for measurement of soil bulk density and the impacts of this on the ability of soils to act as a sink for atmospheric carbon are also presented (Chapter 5).

Soils have many impacts on human health. For example, urban allotment soils can be a source of contaminants, while also being a valuable source of recreation (Chapter 7) and essential dietary elements (Chapter 6). Finally, we show how important soils are in society by demonstrating their key role in forensic investigations of criminal activity (Chapter 8) and as a potential engineering solution to landslide impacts on transportation networks (Chapter 9). Society also has the opportunity to interact with this wealth of information on soils through the soils website whose development is also presented (Chapter 10).

The work introduced here addresses many of the key challenges to, and opportunities provided by, soils and highlights important future directions to progress this field.

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CHAPTER 1

Soils provide grounds for an Evergreen Revolution

Background

The "Green Revolution" since the 1950's led to an increase of crop yield at least three times greater than in the previous century, via the introduction of fertilizers, pesticides, and new crop varieties. However, while most crop yields are no longer increasing, the world population is. The sustainability of our current "toolbox" of fertilizers and pesticides is also declining, partly due to the many negative impacts of chemicals in our environment. Shifting plant breeding targets to promote the beneficial use of soil microbes combined with reduced agricultural inputs could be a key contribution to an "*Ever*green Revolution". Soils can partially replace many common agricultural inputs and improve nutrient availability, and reduce disease incidence and pest pressures, but only if we facilitate healthy soil for microbes which in turn help crop plants to grow. **Our research aims to find new ways of increasing crop yield and creating an "Evergreen Revolution"; here we demonstrate that management of soil is key to this aim.**

Approach

Most of our crops have been bred under optimal conventional agricultural conditions — tilled soil, high fertilizer and pesticide inputs, and monocultures with few weeds — and therefore when compared to wild relatives, they have fewer traits allowing them to benefit from interactions

Fig. 1: Plant root inoculated with vesicular arbuscular mycorrhizal fungi forming a symbiotic relationship which provides the fungus with energy and the plant with nutrients and water

with soil microbes. Research highlighted here has been targeted at understanding how to maintain a healthy soil community to provide an alternative for some agricultural inputs and reduce negative environmental impacts of food production such as greenhouse gas emission. We have performed experiments which look at the impacts of soil management such as tillage, chemical inputs and monocultures and plant management such as genotypic variation have on soil microbial community structure and function.

Results

- Tillage impacts the community structure of mycorrhizal fungi in soil, further impacting phosphorus availability to plants.
- There is genotypic variation in potatoes for the ability to form symbiotic relationships with arbuscular mycorrhizal fungi (Fig. 1).
- There is genotypic variation in cereals for the microbial community structure of organisms which contain nitrogen functional genes, which means we are able to select genotypes which specifically impact soil nitrification and denitrification.

Conclusion

To achieve a healthier soil community there are a number of important steps to be taken. We need to change how we grow crops to avoid the loss of important microbes, and some agricultural practices (e.g. minimum tillage and the use of alternative fertilisers such as composts) are being tested and used on farms. But we still need to improve our understanding of how soil works so that we can design better management systems for greater nutrient availability and faster and stronger plant defence responses when challenged by pests and diseases. We are now well placed to try and tailor our crop plants to select a beneficial community of microbes to 'replace' some chemical inputs.

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CHAPTER 2

Utilising seed-soil interactions

Background

The seed coat, or testa, protects the plant embryo until germination and they can be highly variable in their structure. *Myxospermous* seeds are those with a layer of dried mucilage on the surface of the testa, which, on contact with moisture, expands rapidly to surround the seed. Myxospermous seeds occur in species spanning genetically distinct plant families, indicating an ancient adaptation. The trait is common in plant species which inhabit arid and low-nutrient environments, and it influences the way the seed responds to soil conditions such as drought, and in turn may also affects the soil properties. **Understanding mxyospermy may help improve how we perceive and manage seed-soil interactions.**

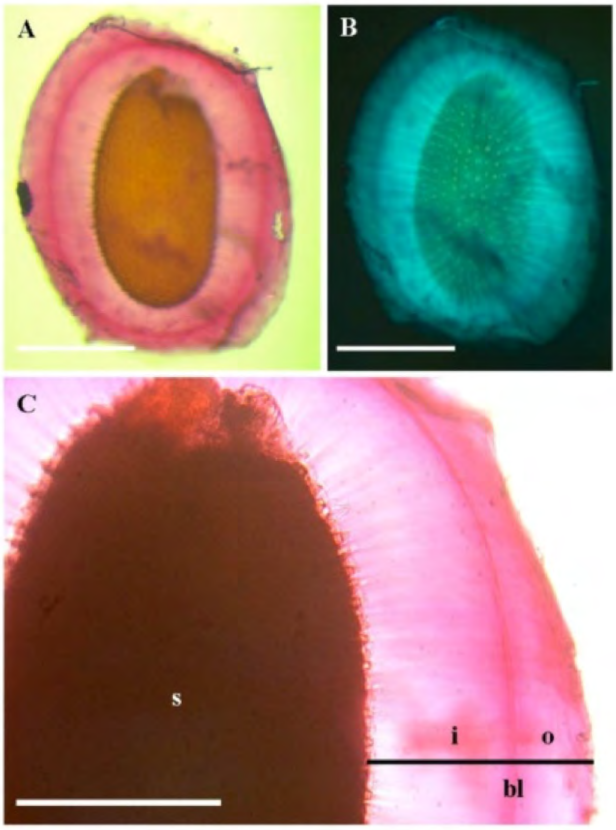

Fig. 1: Shepherd's purse seed imbibed in a dual-stain. In A and C, the seed is illuminated with white-light showing pectin (using ruthenium red). The expanded mucilage appears as a bi-layer structure with an inner (i), outer (o) and boundary (bl) layer. C shows the seed under UV illumination to reveal cellulose (calcofluor), with denser staining in the inner-most layer. Scale bars are 500, 500 and 250 µm, respectively

Approach

Myxospermous seeds of the plant genetic model species *Capsella bursa-pastoris* L. Medik. (shepherd's purse) were assessed in a multi-disciplinary and international collaborative project. A wide variety of methods were employed, including those for soil physical attributes plus light- and confocal-microscopy (Fig. 1).

Results

- The dry mucilage represents a large biological investment, at 25% of the dry seed weight. On hydration the mucilage expands in 5 seconds and its volume increases 75-fold. This increases seed volume 6-fold and seed mass 2.5-fold with 16 g water absorbed per gram of dry mucilage.
- The mucilage is more viscous than those of other plant parts. Almost all (85%) of the mucilage is held at the testa surface, bound by a network of cellulose fibres.
- Added to a sandy-loam soil the myxospermous seeds: increase soil water retention, reduce soil hydraulic conductivity (speed of water flow), and improve soil-strength, especially as soil dries.
- Sandy-soil containing myxospermous seed can also sustain seedling growth with five times less water.

Conclusions

Our findings provided the first evidence that the seeds of wild plants can significantly affect soil physical properties. This has direct relevance to seed- and soil-conditioning treatments to help maintain plant performance in conditions which would normally be stressful. Such treatments may help improve crop production efficiency and/or mitigate the impacts of climate change. Future research will test the capacity of a myxospermous seed to maintain crop growth and production under conditions of limited soil moisture content; and its ability to influence the diversity of beneficial soil microbes.

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CHAPTER 3

Monitoring soils with smartphones

Background

The use of smartphones for estimating soil characteristics can provide us with information on several important indicators of soil health and fertility, including carbon content, pH, clay and elements such as magnesium. These characteristics and others provide broad information about the capacity of the soil to provide nutrients, water and physical support to crops. They also provide information about erosion and compaction risk.

We have been working to find out whether it is possible to use a smartphone camera to provide estimates of soil organic matter content. What we have found is that if we link the soil colour data from a smartphone camera image with information about the location where it was taken, then we can greatly improve our ability to estimate certain soil characteristics, including organic matter. **The aim of this research is to develop cheap and easy-to-use tools for land managers to get instant soils information in the field.**

Fig. 1: Example of image taken for the smartphone app. Shows soil with various light exposures and the colour correction card

Approach

To develop the underlying models, we have used the James Hutton Institute's database of Scottish soil samples that allows us to link soil data to colour and site descriptions. A number of factors can influence the colours in a digital photograph, including lighting conditions and camera design. Colour correction allows us to reduce these effects and get a more accurate representation of the soil colour. This is important because colour is such a strong indicator of several soil characteristics. The requirements for taking a photograph of soil in the field are not overly strict, as long as the colour correction card is visible in the shot (Fig. 1). The photograph can be taken from up to a metre away, and requires very little preparation of the soil (a 30-cm hole will do).

Results

- A mobile phone app (Android & Apple) has been produced that provides an estimate of topsoil organic matter rapidly and for free (Fig. 2).
- This app currently only works for Scottish soils, but we are working on expanding further.
- We are also working on models that can provide estimates of several other soil attributes.

Fig. 2: Example screen shots of output from the app

Conclusion

There are many soil attributes that can be estimated using this method, and we are aiming to produce a number of smartphone tools for rapid, low-cost soil monitoring. The next steps are to improve the image analysis and underlying models, to allow us to estimate more than just soil organic matter. Currently we are focussing on soil structure and texture, by looking at the information that can be extracted at different image scales. Links to the existing apps can be found at:
http://www.hutton.ac.uk/research/groups/information-and-computational-sciences/esmart

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CHAPTER 4

The vital role that detailed soil mapping plays in the sustainable management of Scotland's forests

Background

Site-specific knowledge of soil resources, notably derived by detailed soil mapping, plays a vital role in the inventory, planning, modelling and management of forest areas. This is particularly important in the UK where there is great variation of soils, due to the diversity of climate, geology, and terrain. Scotland's landscape has been radically changed by human influence, with forest cover reduced to 4% by the early 1900s and subsequently increased, due to policy intervention to approximately 18% now with a vision of around 25% for the late 21st Century. Expansion of native woodland is also under way to meet nature conservation and Habitat Action Plan targets and forests are now expected to deliver a wide range of objectives. However, only a proportion of the forest estate has soils mapped in any detail. **The aim of this research was to increase the coverage of soil mapping at 1:10,000 scale to facilitate the management of Scotland's forests for multiple benefits.**

Fig. 1: Digging soil inspection pits

Approach

A soil classification was devised by the Forestry Commission, focusing on the main soil groups, notably Brown Earths, Podzols, Iron-pan soils, Gleys, Rankers and Peatland soil types. Information was gathered in the field by digging small soil inspection pits (Fig 1.) approximately every hectare and by the use of soil augers, with the frequency of recording determined by the complexity of soil patterns. Field mapping was carried out on aerial images overlain with topographic data, with boundary lines drawn to show the extent of different soil types. The soils data were digitised and uploaded into 'Forester', the Forestry Commission GIS management decision support system.

Results

- The classification was used to map soils at 1:10,000 scale over 300 km2 of forest land and on new acquisitions between 2010 and 2015.
- Attributes recorded include soil type, drainage, subsoil texture, stoniness, lithology, impedance to tree rooting and ground vegetation. Such information contributes to the overall Ecological Site Classification, the choice of species on planting and future stand management.
- The semi-natural vegetation on areas of open hill presents vital clues as to the variability of underlying soil types, in contrast to areas already afforested or newly felled where patterns may be obscured.
- With developments in digital technology and modelling there is a greater awareness by forest managers that such data have a vital role to play in evidence-based management of the forest estate.

Conclusions

Forestry in the UK is now much more focused on delivering multiple benefits, notably related to human health and wellbeing, biodiversity, water protection and enhanced landscape quality, as well as timber production. Soil is a key determinant of how these aspirations might be achieved from our woodlands and the detailed mapping and interpretation of soil resources plays a vital role in the sustainable management of the nation's forests. This project goes some way to providing this vital information and will continue on into the future.

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CHAPTER 5

Using infrared spectroscopy to estimate bulk density and carbon stocks of Scottish soils

Background

Soil can play a major role in carbon sequestration for climate change mitigation. Measuring changes in soil carbon concentration and carbon stocks over time is an indicator of the carbon dynamics in response to environmental change. Since the late 1930s, the soils of Scotland have been sampled and stored in the National Soil Archive, and soil carbon concentrations have been measured. These are used to calculate carbon stocks by taking account of the carbon concentration in soil horizons, the horizon thickness and its bulk density. Unfortunately, bulk density was rarely measured routinely during the initial soil samplings. Resampling of soil archive samples between 2007 and 2009 gave an opportunity to measure the soil bulk density at resampled sites and calibrate novel methods for bulk density assessment to allow accurate estimates of carbon stocks in soils. **The aim of this research was to develop a novel approach to the estimation of soil bulk density through development of near infrared spectroscopy (NIRS) predictive calibrations.**

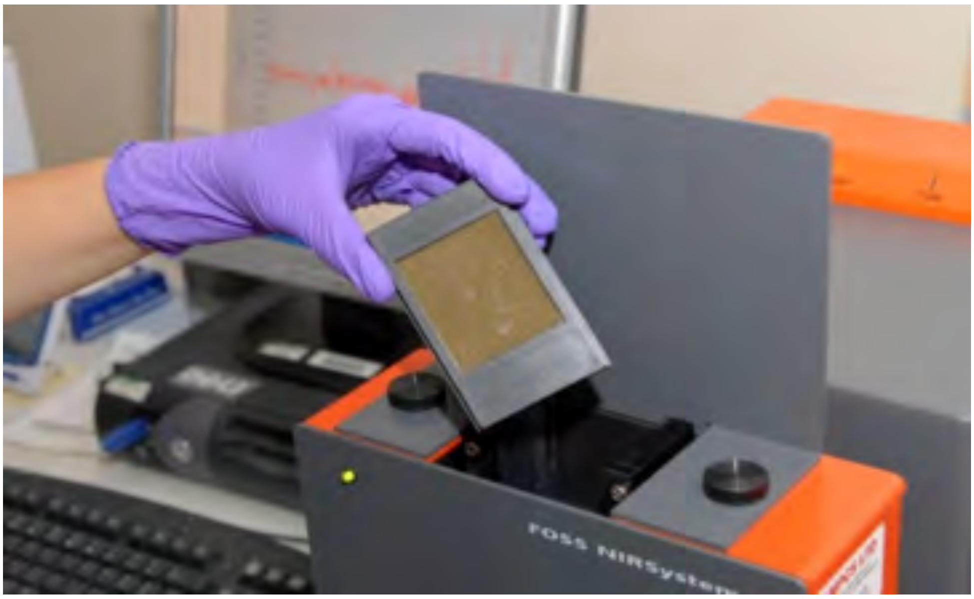

Fig. 1: Soil sample analysis using a NIR spectrophotometer

Approach

NIRS calibrations to predict bulk density were developed for the 2007-09 sampling of the National Soils Inventory of Scotland (NSIS; 701 horizons from 183 soil profiles). Calibrations allowed quantification of changes in carbon stocks for Scottish soils. Additionally, a set of soils from sites sampled between 1961 and 1988, that were subsequently planted with trees, were re-visited and sampled in 2013 (239 soil horizons in 39 profiles) to quantify changes in carbon stocks in response to afforestation. Calibrations from the 2007-09 NSIS samples were used to predict bulk density for this set and bulk density values measured during re-sampling were used to validate the accuracy of the calibrations. The samples selected for NIRS analysis (Fig. 1) were air dried (30°C), sieved (<2mm) and their NIR spectra were recorded, in reflectance mode, at 2 nm intervals in the range between 1100 and 2500 nm.

Results

- Best predictions of unknown soil bulk densities were achieved when the full NSIS dataset was used for horizons with less than 37% carbon but, for those with more than 37% carbon a subset of samples (>37% only) gave the best results.
- The calibration incorporating both the NSIS samples and the afforested soil samples gave the best results for calibrations that included the afforested soils.
- Calculations of carbon stocks based on predicted bulk density revealed that the only significant changes in carbon stocks occurred where litter layers had formed on the soil surface, which was associated with an annual increase of 0.56 t C ha^{-1}.

Conclusions

NIRS has proven to be a valid tool for fast, non-destructive and reliable estimation of bulk density from archived soil samples where the bulk density had not been previously measured. It has allowed the calculation of soil carbon stock changes that occurred over nearly four decades, the estimation of which would have been otherwise impossible.

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CHAPTER 6

Improving soils for human nutrition

Background

Humans need sufficient quantities of about two dozen mineral elements for their wellbeing. They obtain these largely from the foods they eat. It is thought that the diets of up to two thirds of the world's population lack one or more essential minerals. In many instances, this is because the crops they eat do not acquire enough minerals from the soil. The mineral elements most commonly lacking in human diets include iron, zinc (Fig. 1), calcium, magnesium, iodine and selenium. Inadequate intakes of any one of these can lead to serious nutritional diseases. The properties of the soil affect the ability of roots to acquire mineral elements and, therefore, the mineral nutrition of the plant, crop yields, and the nutritional quality of edible produce. Many of the soils of the world, including in Scotland, lack sufficient available iron and zinc for maximal crop production, despite there being large amounts of these elements in most agricultural soils. **This research aims to enhance the zinc concentration in the edible parts of crops taken from the soil by altering agronomic practice.**

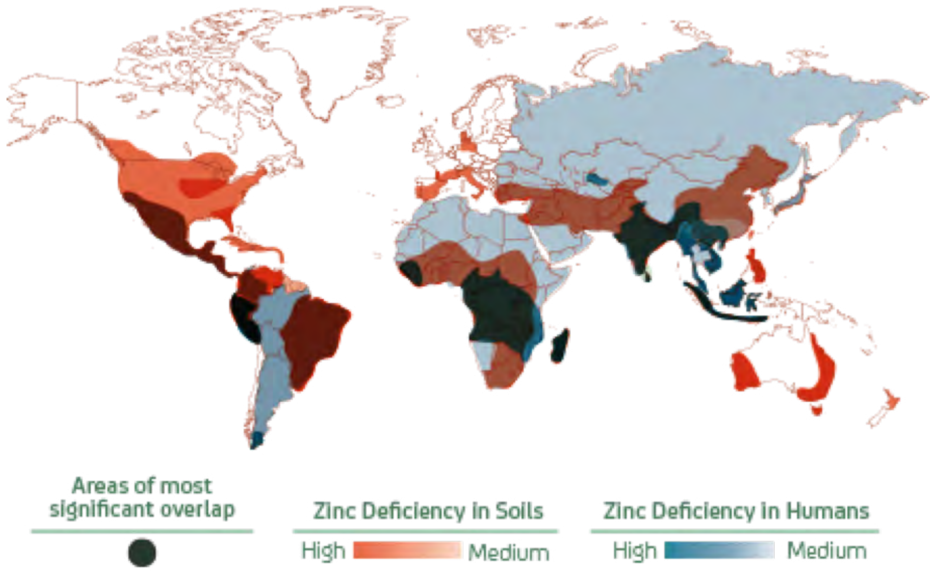

Fig. 1: Global distribution of zinc deficiency in soils and where these deficiencies coincide with largest human populations

Approach

The "biofortification" of edible crops is an agricultural strategy to increase the delivery of essential minerals to people susceptible to mineral deficiencies. It is particularly effective in regions where resources or infrastructures are not available for traditional interventions. It combines agronomic techniques that increase the availability of mineral elements to plants, such as soil husbandry and precision fertiliser applications, with the development of new crop varieties that acquire minerals better from the soil and accumulate more minerals in their edible tissues. Here we performed experiments which looked at the interaction between genotype selection and fertilisation of plants with zinc to enhance the zinc concentration of tubers of potatoes.

Results

- Zinc and iron deficiencies in humans occur predominantly in regions where crop production is limited by the availability of these elements in soils (Fig. 1).
- Foliar zinc fertilisers can increase zinc concentrations in both flesh and skin of potatoes.
- Zinc-biofortified potatoes contain up to 3.5-fold more zinc than non-biofortified potatoes after cooking.
- Zinc-biofortified potatoes can significantly increase dietary zinc intakes of people in Scotland.

Conclusions

The simplest way to increase concentrations of minerals in crops growing on soils with low availability of mineral elements is to apply them in fertilisers, either to the soil or to the leaves. This strategy has improved the health of people in various countries. Our research demonstrates that it is possible to increase the concentrations of essential mineral elements in Scottish crops. This work focuses on biofortifying our staple crops, wheat and potatoes, and common vegetables, such as brassicas, with mineral elements essential for human nutrition. It is hoped that, one day, this work will help eliminate mineral malnutrition of humans both at home and abroad.

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CHAPTER 7

How soils keep us healthy: gardening in urban areas

Background

Most land use regulations associated with public health are almost exclusively focussed on the potential negative impacts of contaminants in soil. Such pollutants may be in the form of heavy metals, organic compounds such as pesticides, or physical contaminants such as asbestos. Protection of public health against these contaminants is of obvious importance, and as such various guidance, soil quality standards, and statutory instruments for contaminated land risk assessment have been developed. If contaminated soil is sealed over with buildings there will be no pathway for soil contaminants to reach the public. However, where land is used for gardens or allotments, there is a much greater risk of exposure to contamination through contact with the soil and through consumption of any produce. This approach precipitates the perception that soils are dangerous and can cause harm, especially in urban areas where people are growing and consuming fresh produce. However, there are a range of health benefits provided by soils and by activities involving soil (e.g. gardening, consumption of fresh food); and it could be argued that only by combining the risks and benefits can we see a true picture of the impact of soil on public health. **This project developed an approach to evaluating the combined benefits and risks of urban gardening.**

Fig. 1: Dissemination of information at allotment shed event

Approach

Existing databases on plant uptake of contaminants were used to develop risk assessment models. Allotment holders and gardeners were interviewed using an established short form health questionnaire plus questions about produce consumption and physical activity to estimate benefits. In addition samples of soil and produce were taken from allotments for chemical analyses. A systems modelling approach was developed to explore how risks and benefits could be combined.

Results

- The systems model contained a contaminated land risk assessment module derived from the database mining and uptake modelling and a benefits module based on the questionnaire data.
- Different approaches to combining risks and benefits were trialled and compared including the use of a single metric (Disability Adjusted Life Years, DALY), expert opinion, and like for like comparisons.
- The analysis showed that risks associated with greater lead contamination in urban grown vegetables were outweighed by the physical and mental health benefits of producing and consuming the vegetables.
- This information was disseminated to allotments users (Fig. 1).

Conclusions

Findings from our study population suggest that, while many individuals were consuming produce grown on soils with elevated levels of some heavy metals (especially lead), these exposures were relatively small and tended to be outweighed by increased fruit and vegetable consumption, increased exercise and improved psychological health and well-being.

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CHAPTER 8

The use of soil in the criminal justice system

Background

Soils contain many physical, chemical and biological characteristics, including indicators such as diatoms, pollen grains and trace plant debris, all of potential use to the forensic investigative process. Soil is a complex and heterogeneous material which has contact with people, vehicles, tools and objects. That complexity can provide specificity to location. Field survey, Geographical Information Systems and an understanding of the landscape and the relationships between soil, hydrology, vegetation and geology are central to developing search strategies in the field. Such information can help both in the intelligence stage of an investigation, such as in the search for a missing person by excluding areas for search, and can also provide physical trace evidence. Each of these can ultimately be presented as evidence in court. **The aim of this research is to provide criminal investigators with tools based on soil which are useful in crime scene investigation.**

Approach

Soil mineralogy, elemental composition, organic characterisation, botanic fragments, diatom, fungal and nematode identification, plant and seed DNA analysis, and bacterial DNA profile characterisation are some of the characteristics that we have developed methods on for use of soil in case work. These use a wide range of state-of-the-art methods: X-ray diffraction, infra-red spectral analysis, Gas Chromatography, Scanning Electron Microscopy, elemental analysis, and light and

Fig. 1: Collecting soil evidence from vehicle wheels

heavy isotope analysis, all of which have been used to great effect in many cases. Geographic Information Systems have been developed to allow the mapping of evidence and the exclusion of areas of land in search operations, enabling police to fine-tune areas on the ground for missing persons or objects. We also use soil to provide information on biomarkers in soil, such as sterols and volatile organic compounds, which can indicate the presence of a human cadaver nearby or that a body had been present but subsequently relocated. Vehicles (Fig. 1), footwear, clothing, spades and tools, as well as trace amounts of material, e.g. found under a fingernail, or splashes on clothing, can also be examined, recovered and analysed, potentially turning round a sample analysis and interpretation in less than 24 hours helping in the critical search operations when a person goes missing.

Results

- Methods for the identification of inorganic and organic substances in soils have been developed and along with methods of identification of organisms and specific plant material are offered as a soil forensics service.
- Soil has been used as part of many high profile searches and as evidence in court: for example, in the Worlds End murders, Edinburgh, in the first ever double jeopardy case.

Conclusion

DNA from soil, along with soil mineral and organic characteristics, can provide vital clues about how death might have occurred or crimes been committed, or can help in crime reconstruction, ultimately helping to complete the investigative jigsaw of crime investigation.

Acknowledgments: The author would like to thank the Crown Office and many forensic agencies and police forces for collaboration in developing these tools.

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CHAPTER 9

Soil stabilisation: key factors for predicting mechanical reinforcement by plant roots

Background

Root systems of plants play a vital role in both stabilising soils and minimising soil loss and degradation from erosion and shallow landslides. The mechanisms by which they do this include extracting water and physically binding soil together with their tensile strength and production of sticky exudates. Understanding root stabilisation of soil is important for crop growth, to minimise the risk of plants lodging (falling over), and for the adoption of sustainable 'green' engineering techniques to stabilise soil, rather than more conventional hard-finishes that incorporate concrete and steel. Plants are incredibly diverse, both above and below ground. Decades-old root systems of trees may measure 20 cm at the trunk base, with some much thinner tree roots penetrating several metres into deep soils. In contrast, grasses have large numbers of highly ephemeral roots only a fraction of a millimetre in thickness, but often with more than a metre of these fine roots within a single teaspoon of topsoil. **This study aimed to understand the impacts of root age, root type and soil environment on root mechanical properties with respect to their impact on the stability of soils.**

Approach

Barley was used a model plant due to the known genetic diversity of its fibrous root system, and its importance within the Scottish economy as an important and widely grown crop. Plants were grown in soil with different environmental stresses limiting growth of the root system, including mechanical impedance and waterlogging. Root mechanical properties of strength and elasticity were measured in relation to root type and root age.

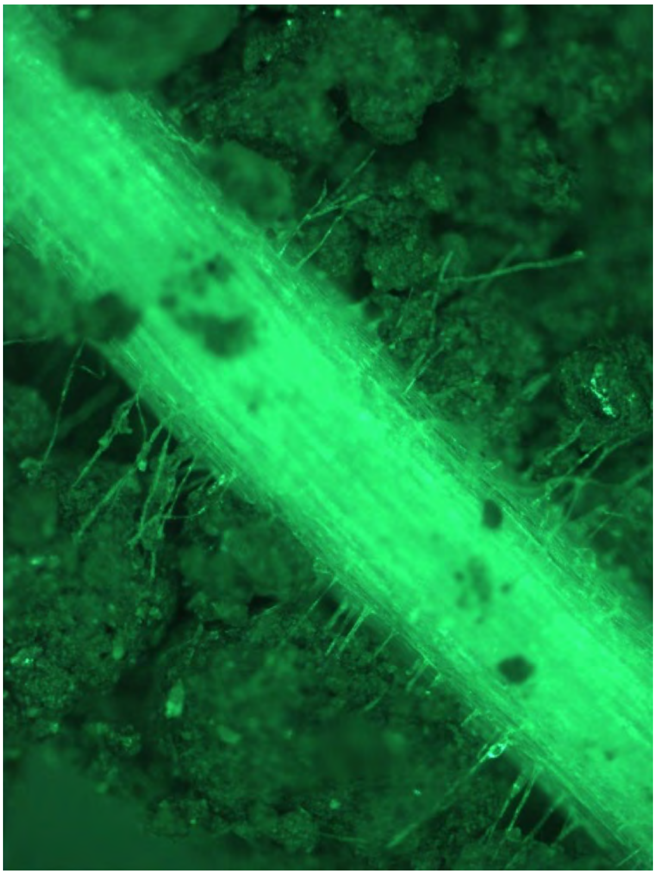

Fig. 1: Root growing through soil with evidence of root hairs reinforcing soil at a micro scale

Results

- Knowledge of root age, root type, and soil conditions increased how accurately we could predict root strength, root elasticity and, hence, soil reinforcement (Fig. 1).
- Older roots were stronger for a given root diameter.
- Thinner roots were generally stiffer and stronger than thicker roots.
- Main root axes were often many times stronger than branch roots.
- Waterlogging decreased root strength and eliminated the relationship between root diameter and root mechanical properties. This was probably related to changes in internal root anatomy and cell wall properties

Fig. 2: Landslide on the A83

Conclusion

The research has increased our ability to predict root reinforcement of soil, and its underlying mechanisms. Root mechanical properties were significantly impacted by both the soil environment and the age and type of the root tissue. Existing models used to predict soil stability have typically had a large scatter in their predictions, which may be due to uncertainty in root age, root architecture, and environmental stresses. We now need to understand how root reinforcement changes dynamically with time for root-reinforced soil. This requires us to develop methods of measuring root reinforcement rapidly *in-situ* to guide species choice and inform engineering approaches to managing vegetation (Fig. 2).

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CHAPTER 10

Scotland's Soils website

Background

Scotland has an excellent national coverage of soil maps which are supported by around 14,000 soil profile descriptions. Until recently, access to these data tended to be difficult and often limited to specialists and researchers. However, as soil is of interest to so many stakeholders (policy makers, environmental and conservation agencies, planners, farmers, foresters, NGOs, waste contractors etc.) the demand for soil information by a wider group became increasingly obvious. In 2012, the Scottish Government funded the development of Scotland's Soils website. **Our aim was to produce a Soils website that was comprehensive, user friendly and valued by a range of stakeholders.**

Approach

After an early prototype website was developed, a stakeholder workshop was held. Key findings from this workshop, which guided much of the website development were:

- Users wanted interpreted data, not raw data
- Different users required different scales of data
- Strong preference for maps
- A strong demand for data in the context of climate, food & flooding
- Range of functions requested - download, searching, etc.

An Editorial Group then drafted text describing Scottish soils and their functions and developed a logical page structure and links to create Scotland's Soils website (http://www.soils-scotland.gov.uk/) which was launched in December 2013.

Results

- The website allows the user to view and download:
  - The 1:250,000 scale soil map with underpinning information on the soils that each map unit contains

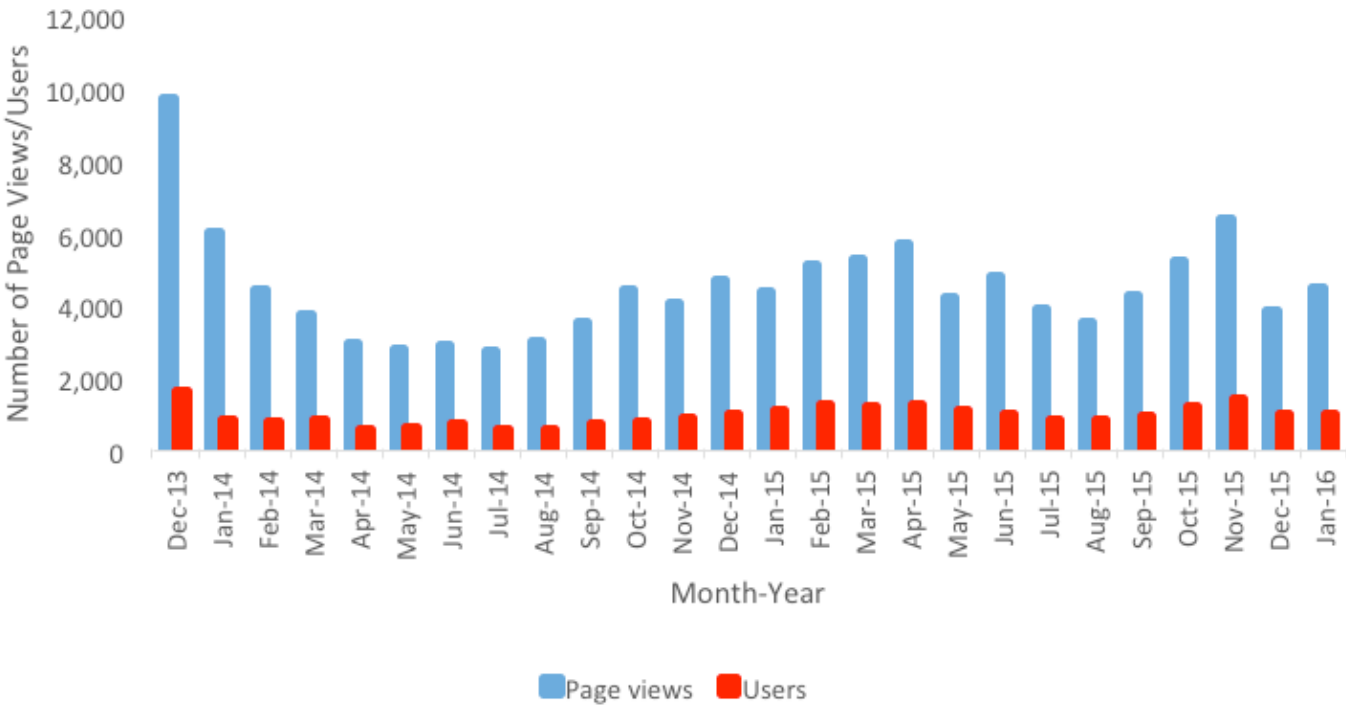

Fig. 1: Summary of number of users and pages viewed each month

- The National Soils Inventory (1978-88) dataset which contains over 100 attributes from over 700 sites across Scotland
- The 1:250,000 scale Land Capability for Agriculture (LCA) and Forestry maps

- Information is available on the properties of Scottish soils, the roles that they play in our landscape, their contribution to society and the pressures that they face
- Summary data on the chemical, physical and biological state of Scotland's soils can be accessed
- Additional datasets have since been added, notably the 1:25,000 scale soil data and the 1:50,000 scale LCA data
- The data are INSPIRE compliant and have extensive metadata and descriptions attached to them
- There have been around 1000 data downloads from the full suite of stakeholder types
- Although most visitors to the site are UK based, there have been visitors from around the world, notably the USA and Australia.

Conclusion

Scotland's Soils website, a daughter website of Sotland's Environment website (SE Web), has been popular since its launch and visitor numbers have been maintained (Fig. 1). Clearly, there is a demand for soil data and it is envisaged that this will continue into the future. It is difficult to gauge the impact that increased and easy availability of data has had on the perception and awareness of the importance of soils to society; the data pages have been the most frequently visited but it is hoped that the pages on Scottish soils and the extensive library have also had positive impacts. There are plans to refresh the site during 2016, including the upload of new datasets and updating the pages with contextual information.

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The research programme ran from 2011 to 2016 and involved researchers from:

- Biomathematics and Statistics Scotland
- Scotland's Rural College
- The James Hutton Institute

BioSS

SRUC

The James Hutton Institute

The research presented involved collaborations with:

- Forest Research
- Griffith University
- Ricardo AEA
- Royal Botanic Gardens Kew
- Southeast University
- University of Aberdeen

This booklet, and others in the same series, including Ecosystem Services, Grassland Biodiversity, Biodiversity and Upland Management, Woodland Biodiversity and Ecosystems, Peatlands and Exploiting Diversity for Sustainable Agriculture are available online at www.hutton.ac.uk

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