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Global Food Security
Sustainable, healthy food for all

insight

The importance of soils for ensuring food security

Overview

- Soils provide a basic medium for plant growth, underpinning the production of crops and fodder and facilitate a range of ecosystem services, including nutrient cycling, water regulation and supporting biodiversity.
- Production from UK soils is worth £5.3 billion and soil degradation costs between £0.9 and £1.4 billion per year in England and Wales.
- The fertility of soil is sustained by high nutrient availability from organic and mineral soil components, good soil structure, high available water content, and microbial or animal communities which facilitate good root and shoot growth.
- Threats to soils include soil organic matter (SOM) decline, acidification, erosion and compaction; all accelerated by intensive cultivation. SOM makes a particularly important contribution to soil nutrient content, good soil structure and carbon storage.
- In the UK, a number of techniques can be employed to reduce soil degradation and improve soil quality, such as using bulky organic manures, applying inputs (fertilisers and agrochemicals), employing crop rotations, controlling farm traffic on fields, conservation tillage and taking a systems approach to farming.
- Global soil nutrient supply is variable; nutrient management approaches, suitable for different regions need to address this imbalance. Planting perennials and intercropping can be used to improve soil quality and increase a crop yields.

Global Food Security (GFS) is a multi-agency programme bringing together the main UK funders of research and training related to food. The GFS Insight series provides balanced analysis of food related research, for use by policy-makers and practitioners.

Image: John Innes Centre photography

Why are soils important?

Soils are vital for the production of crops and fodder. In the UK, total income from soil is worth £5.3 billion[1], but if soils become degraded, crop yields may decline. The cost of soil degradation in England and Wales has been estimated as being between £0.9 billion and £1.4 billion per year.[2] A number of different techniques are required to manage soils sustainably and ensure high yields in the UK, because production occurs on a wide range of soils, which have different properties.

Soil qualities which affect crop yield

Soils provide crops and fodder with an environment for seed germination, root growth, anchorage and the absorption of water and nutrients. Yields can be improved by identifying any soil factors which are constraining production and then making improvements by adding inputs, or changing management practices, although some soils will have natural limitations. Soils with good fertility have a combination of the following:

- High **nutrient** availability from organic matter and mineral soil (e.g. availability of nitrogen (N), phosphorus (P), potassium (K) and micronutrients).
- An appropriate **soil structure**.
- High available **water content**.
- Appropriate **soil microbial** and **animal communities** (e.g. earthworms).

Images: Frank Havemann

What are the current threats to soils in the UK?

Over the last 200 years, soil quality has been detrimentally affected by intensive farming, contamination and urban sprawl. Recently, soil condition has also been affected by climate change and an increase in the prevalence of severe weather events (i.e. drought and flooding).[3] There is, therefore, a need for innovative farming solutions to improve soil health so that food production resilience may be ensured. The following have been identified as the main threats to soils in the Soil Strategy for England[4], Scottish Soil Framework[5] and/or the European Soil Thematic Strategy[6]:

- **Soil organic matter decline** reduces soil quality, affecting fertility, structure, water retention capacity, soil biodiversity and carbon storage.
- **Soil erosion** can be accelerated by soil cultivation, leading to the loss of soil due to the action of water, tillage or wind.
- **Compaction** by farm machinery leads to a decline in a soil's capacity to retain water and supply oxygen to roots. This can lead to soil erosion, increased water runoff and GHG emissions; compaction affects 11% of Europe's soils.[7]
- **Soil sealing** is where soil is permanently covered by concrete or tarmac etc. It is caused by urban and industrial sprawl, leading to a long-term loss of fertile soils.[8]
- **Biodiversity decline** (e.g. soil microbes and soil animals) is affected by all of the above and also climate change. Soil microbes benefit crop production because they decompose organic matter, release nutrients in a plant available form (e.g. nitrogen mineralisation), stabilise soil structure and can control soil-borne pests and diseases.
- **Salinisation** is the build-up of salt in the soil due to irrigation from ground water sources. It affects 3.8 million ha in Europe (mainly in Italy, Spain and Hungary and is not presently an issue for UK soils[6]) and can lead to a decrease in soil fertility.
- **Soil contamination** with chemicals or pests and pathogens, results when hazardous substances are either spilled or buried directly in the soil, or migrate to the soil from elsewhere. Soil borne plant pathogens (e.g. Potato Cyst Nematode[9]) are an increasing threat in the UK and are already affecting land use and policy decisions.

Soil Organic Matter

Soil organic matter (SOM) is material in the soil which has originated from living things and has subsequently been broken down by decomposing micro-organisms. When SOM is broken down, carbon dioxide (CO2) is released into the atmosphere. Nearly 50% of European soils contain very low levels of SOM (0-2%), which has been caused by agricultural intensification.[10] However, many studies across Europe, including the countryside survey in the UK suggest that SOC levels are currently in a stable state.[11]

Globally, twice as much carbon is stored in soils as is present in the atmosphere. This is both a threat and an opportunity.[12] The threat arises because changes in land use could result in an increase of the conversion of soil organic carbon as CO2 to the atmosphere, while the opportunity arises from managing soils in such a way as to sequester additional carbon from the atmosphere.[13] Modelling results have suggested that soil carbon is projected to increase with climate change and increased production, because carbon inputs to the soil will increase faster than decomposition.[14,15]

Protecting soils used for agriculture

How soils are important to society

When soils are in good condition, they have the potential to provide society with a range of 'ecosystem services'; resources or processes provided by the natural environment, that benefit people.[16,17] The Ecosystem Services provided by soils are:[17,19]

- **Supporting services,** e.g. nutrient cycling, water release / retention, soil formation, habitat for biodiversity (of microbes and soil animals), exchange of greenhouse gases with the atmosphere, degradation of complex materials.
- **Regulating services,** e.g. the regulation of flooding, the retention of pathogens, contaminants and agrochemicals and the storage of carbon and other greenhouse gases.
- **Provisioning services,** e.g. providing a basis for food and fibre production and for recharging water supplies.
- **Cultural services,** e.g. soils support habitats, recreational pursuits and protect archaeological remains.

The UK and devolved governments have undertaken a significant amount of research to explore how degradation can affect the ability of soils to support key ecosystem services. Soil research has been a key part of the Scottish Government's Strategic Research Programmes for many years[20,21], outputs of which include a National Soils Database for Scotland[22]. Defra is funding research covering the themes Safeguarding agricultural soils, Peat (protecting and restoring peat and reducing horticultural use of peat) and Remediation of contaminated land. In June 2013, the Global Food Security Programme launched 'Soil and Rhizosphere Interactions for Sustainable Agri-ecosystems' (SARISA); a jointly funded BBSRC – NERC call for research proposals, worth £4.5M, into soil ecosystems and their impact on agriculture and food production.

How can soil fertility be improved?

To improve the fertility of soil, a number of interventions are often made (e.g. the use of fertilisers and tillage [ploughing of the land]), which can also affect soil properties such as nutrient status, pH, organic matter content and physical properties. Such interventions (typically applied to soils to improve crop production) can, however, be detrimental to other ecosystem services, leading to conflicting management options for agricultural soils.[12]

The following practices can be adopted by farmers to improve agricultural soils, (e.g. the organic matter content, climate change mitigation potential, physical properties and water holding capacity of soil):

- **Inputting organic material** to help preserve the structural integrity of soils, e.g. crop residues, animal manures and the targeted use of legumes.
- **Reduced tillage** practices (where soil is no longer turned over before sowing) can benefit soil structure, fertility, rates of root growth, water infiltration, reduce rates of erosion and possibly reduce GHG emissions.
- **Precision agriculture** to deliver targeted nutrient and herbicide applications, based upon variability within the field.
- **Intercropping** where at least two or more crop species are grown on the same plot of land. The species use nutrients, water and light differently, so that they do not compete. Intercropping with legumes (plants that accumulate nitrogen [N] from the atmosphere) can introduce N into the soil, whilst deep-rooted plants can make nutrients in the subsoil available.
- **Contour ploughing** across a slope following elevation contour lines, forms a natural barrier to water flow down the slope, reducing run-off. Contour ploughing can become dangerous if the slope is too steep.
- **Diversification of production types** including perennial food crops, nuts and fruit, using whole-system oriented approaches, such as those found in crop rotations and permaculture.

How UK agricultural soils are currently regulated

Soils in the UK or devolved administrations are not currently protected by a single piece of overarching legislation; instead a number of regulations and guidelines exist, which impact upon soil management (see page 5). At a European level, the EU Thematic Strategy for Soil Protection was launched in 2002.[6] From this strategy, a draft Soil Framework Directive was proposed in 2006, with the aim of integrating and raising the level of soil protection across the EU.

A series of negotiations were held between 2007 and 2010, but political agreement could not be reached (UK, France, Germany, Austria and Netherlands were against the directive) and negotiations have since stalled.[23] Defra takes the view that whilst it strongly supports the protection of Europe's soils, robust domestic policies are already in place for soil protection.[23] It is not opposed to the Soil Framework Directive in principle, but thinks the current proposal would represent a considerable administrative and regulatory burden, with little additional benefit, at a time when the government is looking to reduce regulatory burdens.[24]

There is some evidence to suggest that overarching soil legislation at a European level might benefit soil health in central and eastern Europe, where there are significant problems with salinization, erosion and covering over with tarmac (sealing).[25]

Improving the soil nutrient supply

Global soil nutrient supply has been described as being from "feast to famine"[26], because some parts of the world (e.g. Africa) struggle to supply soils with the nitrogen (N) and phosphorus (P) needed for crop production[27], whilst others are applying fertiliser at an excessive level, with no added benefit to the soil e.g. The North China Plain[12]. Nutrient planning and management approaches, suitable for different regions need to be developed to address this imbalance (e.g. nutrient budget approaches, recommendation tables, simple computer based decision support systems and sensors for measuring the nutrient status of soil or crops).[12] To increase the use of fertilisers in developing countries, it has been suggested that fertiliser packages should be made available in smaller sizes, affordable for smallholder farmers.[12]

Image: John Innes Centre photography

Current soil regulatory mechanisms

In the UK and devolved administrations, little specific statutory protection for soil exists, although soils are indirectly protected by other legislation, e.g. prevention of pollution, contamination and land use planning. Non-regulatory mechanisms which exist to protect soils include produce assurance schemes, such as Red Tractor, LEAF (Linking Environment and Farming), Soil Association organic certification and clauses in contracts signed by farmers, to encourage sustainable soil management. Regulatory mechanisms which encourage UK farmers to manage their soils sustainably include:[4]

- **Single Farm Payment**, farmers must meet the standards of Good Agricultural and Environmental Condition (GAEC).
- **CAP cross compliance**, which requires farmers to assess their soil and take actions to address identified problems.
- **Environmental Stewardship**, which includes options that reduce soil erosion from wind and water.
- **Water Framework Directive measures**, which include measures to prevent soil erosion.
- **Nitrate Vulnerable zones** are areas of land that drain into waters polluted by nitrates and mandatory rules are required to tackle nitrate loss from agriculture.[28]
- **Biosolid application rate controls** aim to limit any build-up of soil contaminants.

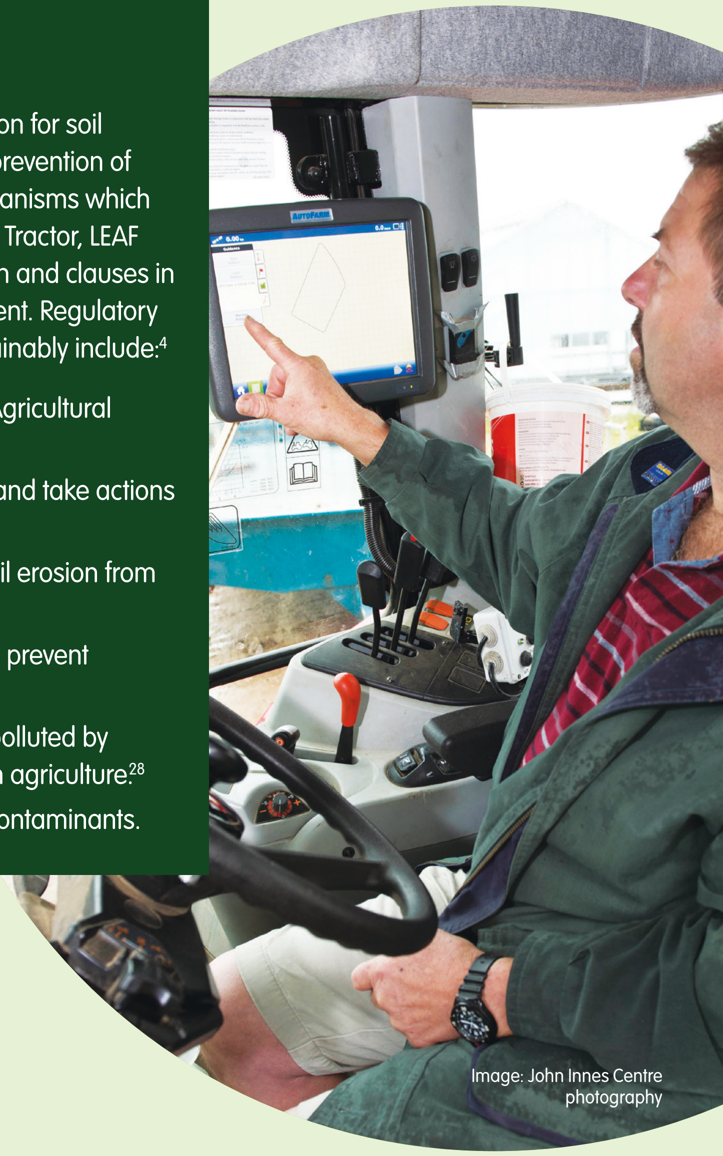

Image: John Innes Centre photography

Trends in soil management

What controls soil structure?

Roots grow best in crumbly soils, containing a range of pore sizes that supply water and air in appropriate quantities. If the soil is too wet, there will be insufficient oxygen available and roots will become hypoxic, if the soil is too dry, roots will suffer from water stress and the soil will become too hard to permit growth.[29] Making sure that good soil structure is maintained is therefore important so that roots can grow.[30] Growth can be impeded if sufficient cracks and pores, across a wide range of size scales are not available for root growth before soil dries.[31]

There has recently been a global increase in severe weather events[3] (e.g. droughts and flooding) which has led to reductions in crop yield. To ensure resilience in food production, new approaches to managing soils are important, such as increasing the organic matter content of soil, increasing root and biological activity in the soil and decreasing compaction from farm machinery.

Conservation tillage

In minimum tillage systems, the soil is kept covered and seed and fertiliser are placed with minimal soil disturbance. Studies have shown that minimum tillage can increase water infiltration, moisture storage and reduce soil erosion by 10 to 100 fold.[32] However, recent studies have indicated that the net accumulation of C under reduced tillage is less than previously thought and is really a redistribution with more at the surface (9-10cm) and less below.[33] Weed species diversity has also been found to be greater in no-till systems.[34] At the Allerton project, a number of improvements have been associated with minimum tillage.

Reducing damage to the soil from farm traffic

Farm traffic on agricultural land can result in soil damage over significant areas of the field. Controlled traffic farming systems (CTF) concentrate wheel tracks to about 25% of the field, rather than the 90% of the field, as found in "conventional" random traffic farms.[35] In a study of potatoes in the UK, yields were 19.4% greater under zero traffic conditions, compared to conventional traffic conditions.[36] The Allerton project noted a number of improvements associated with tramline management.

Not all areas within a field are the same. Precision agriculture technologies gather information about the temporal and spatial variability of a field and then use this to farm areas of the field optimally. The Institution of Agricultural Engineers (IAgrE)[37] has highlighted the following precision farming techniques as methods in which soil compaction can be reduced[35].

- **Automatic steering** uses satellites (global positioning systems) to guide the machine. The method reduces soil compaction because there are fewer tracks, a reduction of underlaps and overlaps and savings can be made in fuel, time and costs. Depending upon the system, accuracies within 1 cm can be achieved.[35]
- **Rubber tracked machinery** spreads the machine load over a greater soil surface area and can improve traction. The method helps to minimise soil compaction.

Image: John Innes Centre photography

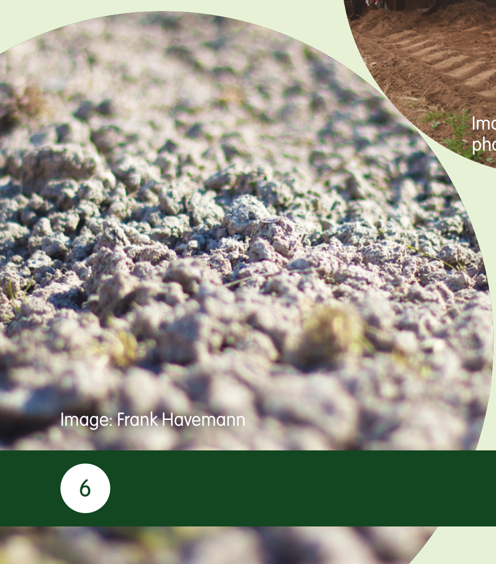
Image: Frank Havemann

Using soil to improve the nutritional value of food

Globally, two thirds of the world's population lack one or more of the essential nutrients required by humans, with over 60% being iron deficient, over 30% being zinc deficient, nearly 30% iodine deficient and about 15% selenium deficient.[32] The reason for this deficiency is either because of the low availability of these essential mineral elements in the soil, or because the crops that people consume have inherently low tissue concentrations of certain mineral elements.[40]

One way of enhancing the nutritional value of crops or fodder is to increase the nutrient content of plants (biofortification), by adding mineral fertilisers to soils. Other methods include carrying out conventional breeding or genetic modification.[41]

Perennial crops and intercropping

Perennial plants live for two or more years and often have deeper roots than annuals, a longer growing season and produce more biomass above and below-ground[11,41]– qualities which are good for reducing soil erosion and increasing the amount of C stored in soil. Soil fertility can be improved and yields increased by integrating perennial plants with food crops[42], although mixed crops may not be appropriate in developed countries with conventional cropping systems, because they are not easy to harvest and sell.

Beneficial traits from perennials can be integrated into existing arable crops (perenniation) and breeding programs have been initiated in wheat, sorghum, sunflower, intermediate wheatgrass and other plant species.[43] A further expanding research area in the UK, is plant breeding to optimise root structure for soil nutrient uptake.[44]

Intercropping can also be used as a technique to improve the utilisation of resources by crops[41] because intercropped plants can use nutrients, water and light better, due to the spatial and temporal differences in their growth and response to environmental stress[41]. Intercropping is common in developing countries such as China, India, Southeast Asia, Latin America and Africa. In the UK, sowing mixtures of varieties has shown similar benefits and also reduces the incidence of some diseases[45].

The Allerton Project

The Allerton Project[38] was established in 1992 by the Game and Wildlife Conservation Trust to test the effect of farming on wildlife and the environment. It has played a key role in influencing agricultural policy in the UK, through its farm business and research activities.

Tramline management

Research at the project found tramlines running up and down the slope to be responsible for 80% of surface run-off, despite occupying just 2-3% of the field surface area.[38] To improve infiltration and reduce run-off, different management methods have been tested at the project; these have included shallow sub-soiling with a tine (a prong), seeding down to the tramline, re-profiling to create a convex cross section, surface soil disruption, and the use of low ground pressure tyres. The latter two approaches were the most effective.

Reduced tillage

Over the past decade, tillage intensity at Allerton has been reduced so that a zero tillage policy could be adopted. Researchers found that the reduction in soil disturbance has resulted in an increase in earthworm numbers, higher microbial biomass and more soil fungi.[38] At Allerton, and also in other studies,[39] the increase in soil fauna, has led to improvements in soil structure and the capacity of the soil to absorb water during heavy rainfall.

The drawback of zero tillage farming was an initial decrease (~5%) in wheat yields, and an increase in grass herbicide costs (from £20 to £70 per hectare) in the early years of adoption. Overall, the net wheat crop margin increased over the plough based system, because crop establishment costs were typically 20% lower. Spring bean and oilseed rape yields demonstrated substantial increases, partly due to conserving soil moisture during the dry spring and autumn sowing periods by using a single pass crop establishment system.

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