



# Soil

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## Editorial

### Healthy soils for a healthy planet

Healthy soils are vital in a world challenged by climate change. We need to decide how best to use land to provide food for a growing population and how it can be used to mitigate the effects of manmade emissions. The quality of soil must be maintained or restored if it is to provide its essential services: cycling nutrients, water and air, supporting biodiversity and acting as a substantial store for carbon. This thematic issue outlines key research in these areas.

About 70 billion tonnes of organic carbon are stored in Europe's soils alone. A changing climate could see the release of carbon from some soils. The article 'Alpine soils may release carbon following climate change' suggests that carbon, bound in soil for 17,000 years, could be released under rising temperatures.

Land use has a major impact on soils. This in turn affects soil's contribution to combating climate change. Ongoing research into future land use change is explored in 'The effects of future land use change on EU soil carbon stocks'.

Europe's population is increasingly living in towns and cities, which is having a profound impact on soils. The right information about soils will help planners develop more sustainable cities. 'Urban soil: how can we preserve its carbon and nitrogen sink?' reviews our current state of understanding of urbanisation and soil health.

Improved management of agricultural land can increase soil's carbon sink, while boosting productivity. Farmers who practice crop rotations with cycles of returning the land to pasture do not experience a drop in profits, according to 'Soil management: changes to crop rotations reduce carbon emissions'.

Farmers are entrusted with conserving farmland biodiversity through sustainable practices. For example, more conservative farming techniques, such as shallow ploughing, can enhance earthworm populations and improve soil functioning. See: 'Deep ploughing reduces diversity and number of earthworms'. Similarly, farmers who maintain grassy margins at the edges of fields provide important habitats for soil dwelling creatures. See: 'Grassy margins enhance soil biodiversity'.

The research highlighted in this issue represents only a fraction of efforts to protect our planet's soils. Soil is a vital, non-renewable resource providing essential support to human life, society and ecosystem services. We must continuously monitor soil quality in order to detect changes early on.

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## Alpine soils may release carbon following climate change

Climate change is expected to cause warmer climate zones to extend, not only further north, but also higher up into mountainous regions. High mountain regions may be particularly sensitive to environmental change. A recent study reveals that a warmer climate may cause carbon stored in Alpine soils to be released.

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Themes: Climate change and energy, Soil

“Warmer conditions encourage greater microbial activity in soil. Microbes help organic matter decay, releasing carbon.”

Soil was recognised as a significant carbon reservoir by the Kyoto protocol<sup>1</sup> and the proposed EU Soil Directive<sup>2</sup> would seek to enforce sustainable management practices. The soil carbon cycle is controlled by its chemistry, mineralogy and climatic environment. Warmer conditions encourage greater microbial activity in soil. Microbes help organic matter decay, releasing carbon. However, with the right soil chemistry, this carbon can remain locked in the soil. The findings of this study suggest that the composition of some Alpine soils do not favour carbon storage under a warmer climate.

The scientists analysed typical soils from eight sites (four south-facing and four north-facing) at 2100m high in two Italian Alpine valleys. The climate in each valley is cold (mean temperature below 8°C) and dry, with less than 90 wet days per year. Weathering rates and movement of minerals are high. Organic carbon content of the soil varies widely, depending on the plot, ranging between around 2 - 195g per kg. It is high in many cases.

Around half of the soil organic carbon was shown to be bound up with the dense mineral content of the soil. These ‘organo-mineral complexes’ protect the organic carbon from decay, so it can be stored stably in the soil for a long time. This was demonstrated by radio-carbon measurements, with ages of up to 17,000 years recorded, the oldest being found at the north-facing sites.

Total carbon content of north-facing soils was also higher, because they supported large amounts of weakly-degraded organic carbon which was not in mineral complexes. In south facing sites, this material decayed more rapidly. However, the north-facing soils did not support as much microbial activity, responsible for decay. This was mostly because the soils were acidic, but also because they received less sunlight.

The combination of soil acidity and high organic content also meant that north-facing valley soils were subject to greater ‘podzolisation’. This is where partly decayed organic matter binds to iron and aluminium ions which are washed downward in the soil (along with clays) leaving an increasingly acid, nutrient-poor and quartz-dominated soil at the surface.

As a result of these environmental conditions, the soils studied currently act as a carbon sink, but many climate change models predict warming of the sub-alpine region in which they are found. These findings suggest that microbial activity, and hence the rate of decay of organic carbon, will increase during the transition to warmer conditions in the valleys. These soils will become a source of carbon during this time, rather than a sink.

<sup>1</sup> See: [http://ec.europa.eu/environment/soil/three\\_en.htm](http://ec.europa.eu/environment/soil/three_en.htm)

<sup>2</sup> <http://ec.europa.eu/environment/climat/kyoto.htm>

Source: Egli, M., Sartori, G., Mirabella, A., Favilli, F., *et al.* (2009). Effects of north and south exposure on organic matter in high Alpine soils. *Geoderma* 149: 124-136.



## The effects of future land use change on EU soil carbon stocks

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Theme(s): Agriculture, Soil, Sustainable development and policy analysis

“Under the Kyoto Protocol, governments must report soil organic content (SOC) changes due to land use change. However, there remain uncertainties in estimating these changes.”

Policy, demographics and globalisation are expected to cause large changes in EU land use in coming decades. A new study models four scenarios of future land use change (LUC) to estimate the effects on carbon stored in soil and vegetation.

Soil is an important carbon sink and LUC the main driver of carbon transfer between land and atmosphere. Under the Kyoto Protocol, governments must report soil organic content (SOC) changes due to LUC. However, there remain uncertainties in estimating these changes. Therefore, the impact of future LUC on levels of sequestered carbon is also uncertain.

The study<sup>1</sup> aims to assess how LUC between 2000 and 2030 would influence carbon sequestration in soil and vegetation in the EU. The model accounted for spatial and temporal dynamics of LUC. For example, it used country specific data on emissions and sequestration for different types of land use.

Four scenarios were modelled (based on the four IPCC SRES scenarios). Each encompasses a different range of political conditions, with different repercussions for land use. They were:

1. **Global Economy:** lean government and strong globalisation. These conditions are thought to increase production and global trade of agricultural products. Agricultural set-aside policies are abolished.
2. **Continental Markets:** lean government and regional development. This scenario assumes high pressure on land resources (croplands and urban areas) due to high economic growth.
3. **Global Co-operation:** governmental intervention and strong globalisation. Under this scenario, agricultural subsidies are abolished after 2010. Set-aside policy is abandoned from 2020 onwards.
4. **Regional Communities:** governmental intervention and regional development. Agricultural subsidies remain largely unchanged. Population numbers decrease and crop productivity increases.

Carbon sequestration rates for soil and vegetation were combined to give a total figure. If the level of LUC remains the same, carbon sequestration rates are expected to fall by 4 per cent in 2030 relative to 2000. Scenario 2 was the only situation that demonstrated a decrease in sequestration, by a further 2 per cent. It was the only scenario with no decrease in cropland. The other three scenarios demonstrated an increase in sequestration rates by 9-16 per cent in 2030 relative to 2000. All three experienced a decrease in cropland. In scenarios 3 and 4, cropland is converted to forest while in scenario 1 it is converted to urban land. The highest sequestration rate was in scenario 4 (15 million tonnes of carbon per year) where agricultural subsidies remain largely unchanged and development occurs regionally.

Total carbon sequestration is mainly determined by high sequestration in forests, emissions from cropland and deforestation. As cropland emissions depend on SOC content and forest sequestration depends on age, location of LUC is important. For example, removing old forests leads to larger carbon losses than removing young forests. Although the authors admit to high uncertainty, the results indicate that LUC is a strong driver of carbon sequestration.

Source: Schulp, C.J.E., Nabuurs, G., Verburg, P.H. (2008). Future carbon sequestration in Europe – Effects of land use change. *Agriculture, Ecosystems and Environment*. 127: 251-264.

<sup>1</sup> This study partly builds on material from the EU-funded CarboEurope IP project. See: [www.carboeurope.org](http://www.carboeurope.org)



## Urban soils: how can we preserve their carbon and nitrogen sink?

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Themes: Climate change and energy, Soil, Urban environment

Globally, the population and size of urban areas is expected to rapidly increase in the next 30 years. Soils are important carbon sinks, and the effects of rapid urbanisation on this valuable service are unclear. A recent analysis reviews our present understanding of the impacts of urbanisation on soil, with particular emphasis on its role in carbon and nitrogen cycling.

“Healthy soil will help to sequester nitrogen and carbon in the ground, and, with improved knowledge, the authors suggest urban soils could be managed to mitigate climate change.”

Populations are expected to continue migrating to large urban areas. The fastest growing urban populations are in tropical regions. Urban areas are estimated to be responsible for 78 per cent of global carbon emissions, and the ‘heat island’ effect affects the local climate. Fuel combustion, pet wastes and garden fertilisers are major sources of nitrogen compounds in the urban environment. The authors report that a better understanding of the impacts of urban life on soil can help us manage urban soil’s functions and help mitigate climate change.

Nitrogen and carbon are naturally cycled between soil, water, vegetation and air. Urbanisation alters this cycling process in many ways. For example, the unusual composition of many urban soils may alter the way they store and release nitrogen and carbon. Many are dominated by material from human activity. They may be constructed from industrial wastes, perhaps containing a higher percentage of coarse material, oil, plastics, building materials or sewage sludge than rural soil. Different combinations may be very acidic or alkaline. Additionally, the soil may be compacted, or deeply mixed, covered (e.g. by tarmac) or uncovered. These disturbances also alter the cycling process. Healthy soil will help to sequester nitrogen and carbon in the ground, and, with improved knowledge, the authors suggest urban soils could be managed to mitigate climate change.

Domestic gardening, using water and fertilisers, and urban woodland promote productivity and carbon cycling, but often replace natural vegetation. Mowed grass, for example, is a greater source of carbon than the natural cover it replaces. Also, cutting and clipping of plants and removing plant litter extracts nutrients from the system. Soil erosion is accelerated by factors including deliberate topsoil removal (in landforming), irrigation or vehicles. Disturbance by atmospheric and stormwater pollutants also increase in urban areas.

The variety of soil properties, climate and land use combinations in urban areas suggests that many urban planning strategies need to consider soil function. Based on what is currently known, several measures are recommended, including:

- design urban soils to enhance ecological functions, such as retention of nutrients and hazardous compounds, and carbon sequestration
- confine future construction within cities to unproductive soils and retain more productive areas for vegetation
- minimise soil disturbance during construction
- plant trees
- reduce urban sprawl

As little is currently known about the biogeochemical processes within urban soils, the authors recommend a substantial programme of research to help planners manage cities more sustainably and enhance the role of urban areas in mitigating climate change.

Source: Lorenz, K. and Lal, R. (2009). Biogeochemical C and N cycles in urban soils. *Environment International*. 35:1-8.



## Soil management: longer crop rotations reduce carbon emissions

Changing the way farmland is used could help increase the amount of organic carbon retained in soils. According to recent research, studies of different crop rotation patterns will help decision makers design policies which help reduce carbon emissions.

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Themes: Agriculture, Climate change and energy, Soil

“Encouraging land owners to increase soil carbon content through longer crop rotations could contribute towards carbon emissions targets, while also increase agricultural productivity.”

Farming and forestry practices aimed at maximising the amount of carbon at land level are broadly referred to as ‘LULUCF’ – land use, land use change and forestry. Although carbon sequestered through LULUCF does not count towards Kyoto Protocol targets, these practices are nonetheless considered an important way of decreasing atmospheric carbon concentrations in national greenhouse gas inventories<sup>1</sup>.

The researchers studied the effects of different land management practices on soil concentrations of carbon in order to help decision makers design appropriate policies to increase concentrations. Computer modelling was used to reveal how the various practices may affect soil quality and carbon content in the long term. They conclude that encouraging land owners to increase soil carbon content through longer crop rotations could contribute towards carbon emissions targets, while also increase agricultural productivity.

The study focuses on the effects of different management practices on farmland soils in the La Higuera region of Central Spain. Most farmland here is used for winter cereals. Traditionally, cereals are cultivated here in three year cycles – wheat is grown the first year, then the land is planted with legumes and turned into pasture. It is then left to rest (fallow) in the third year. Soil samples from different field locations revealed that carbon levels were lower in soils used for growing cereal crops compared to levels in soils from pasture land.

Results from previous long term soil studies in the same region were used to validate a computer model. The effects of different management were then projected over 25- and 100-year periods. According to the model, management strategies play an important role in determining carbon content. Land which has been used to cultivate cereal and then turned into continuous pasture would contain the most carbon. After 25 years, it is projected to contain 1.7-1.8 times more carbon than land which continues to undergo traditional 3-year crop rotations.

However, there is an alternative strategy, which allows the farmer to continue growing crops while increasing soil carbon levels, although to a lesser degree than the continuous pasture scenario. Five year crop rotations – where the land is turned into pasture for five-year periods between five year wheat-fallow rotations – increases carbon levels by 1.3 times after 25 years.

By replacing 3-year rotations with 5-year rotations, farmers would only lose three rotations over 100 years (30 versus 33), meaning that economic impact is likely to be small. Nonetheless, policies addressing land use change would need to consider how changes to crop rotations affect income and government subsidies. However, the study points out that humus (stable organic material) levels could also increase by 2-3 times under 5-year rotations. Humus is important to soil health and can increase crop productivity.

Source: Boellstorff, D.L. (2008). Estimated soil organic carbon change due to agricultural land management modifications in a semiarid cereal-growing region in Central Spain. *Journal of Arid Environments*. 73: 389-392.

<sup>1</sup> QICSIM, (2009), Technology Brief: Land Use, Land Change, and Forestry and the Kyoto Protocol, Queen's Interactive Crisis Simulation, [online], available from: [http://www.qicsim.com/Country%20Profiles/Land\\_Use\\_russia.pdf](http://www.qicsim.com/Country%20Profiles/Land_Use_russia.pdf)



## Deep ploughing reduces diversity and number of earthworms

Less invasive soil preparation methods in farming, such as harrowing, have a positive impact on the numbers, biomass, and species richness of earthworms, unlike conventional ploughing, according to new research. The long-term study compared the results of five different methods of soil preparation on agricultural land in Germany over a ten-year period.

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Theme(s): Agriculture, Biodiversity, Soil

“Loss of earthworm biodiversity has a negative effect on soil functioning in agricultural ecosystems, especially in areas of intensive farming.”

Earthworms play a major role in the functioning of soil ecosystems. They help keep soil healthy by enhancing the turnover of organic residues, increasing microbial activity, and contributing to enhanced mineral take-up and nutrient availability in the soil. Their burrowing and feeding activities alter the soil structure and its ability to absorb water. These benefits improve crop productivity.

The five soil preparation methods compared in the study were:

- conventional ploughing to a depth of 25 cm
- non-invasive loosening of soil to 15 cm, using a wide-bladed grubber (a tilling tool)
- slight loosening of soil to 15 cm with a disc harrow (also a tilling tool)
- sowing seeds with a shallow grubber, which leaves a layer of mulch on the soil surface
- direct sowing without any soil tillage

After ten years, the numbers, size and community composition of earthworms were measured. They varied strongly depending on the type of soil tillage used. For example, the number of earthworms per square metre varied between 119 in ploughed land and 160 in land treated with the disc harrow.

Other key results include:

- Overall, total bulk size of earthworms was significantly higher with disc harrow treatment relative to ploughed land
- All less-invasive tillage treatments resulted in higher species richness – eight species were found in these soils, compared with six species in ploughed soils
- The density of larger (anecic) earthworms decreased in deep ploughed soils, probably a result of mechanical damage to their bodies and disturbance of their habitats
- The density of smaller (endogeic) earthworms increased in deep ploughed soils, probably a result of the lower bulk density of the soil and transport of organic matter to lower levels

The researchers believe that loss of earthworm biodiversity has a negative effect on soil functioning in agricultural ecosystems, especially in areas of intensive farming. They conclude that changing from conventional ploughing to reduced or conservation tillage methods changes the distribution of soil organic content in topsoil and has a positive effect on earthworm populations. These could be important ways of sustaining soil conservation and plant production in agro-ecosystems. However, potential negative effects of reduced tillage, such as possible increased herbicide use, were not discussed in this study and would need to be considered before implementing these practices.

Source: Ernst, G. and Emmerling, C. (2009). Impact of five different tillage systems on soil organic carbon content and the density, biomass and community composition of earthworms after a ten-year period. *European Journal of Soil Biology*. Doi:10.1016/j.ejsobi.2009.02.002.



## Grassy field margins enhance soil biodiversity

Grass strips at field margins are almost as valuable as hedgerows in encouraging diversity of soil creatures, according to new research. Six metre wide margin strips increase the number and variety of species such as earthworms, woodlice and beetles, and may act as corridors between isolated habitats.

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Theme(s): Agriculture, Biodiversity, Soil

“A diverse range of species that consume leaf litter, such as woodlice, naturally improve soil fertility. Predators found in these margins may also function as a natural form of pest control.”

The study analysed the presence of invertebrates of three main feeding types – soil ingesters such as earthworms, litter consumers such as woodlice and millipedes and predators like centipedes. Using soil samples, the numbers of rare and common creatures in fields with and without grass margin strips were compared with levels in other habitats on the same farm including winter-wheat fields, woodland, hedgerow, pasture and set-aside land. Rare species included the millipede *Polydesmus coriaceus* and the rove beetle *Lamprinodes saginatus*.

Establishing grassy strips at the edge of arable fields is popular in European agriculture. For example, around 33,000 hectares of grassy strips were in place by 2004 in England under the Countryside Stewardship Scheme<sup>1</sup>. These semi-natural habitats have a recognised value for species such as birds, bees, butterflies, small mammals and beetles, but less is known about the biodiversity of soil-dwelling creatures, which play an important role in soil ecosystems. A diverse range of species that consume leaf litter, such as woodlice, means organic matter is broken down more quickly, naturally improving soil fertility. Predators found in these margins may also function as a natural form of pest control.

The impact of grass strips on biodiversity on a 2630 hectare mixed arable farm in Southern England, was evaluated to find:

- The number of species unique to the grassy strip habitat
- The amount of species turnover (beta diversity) between the grass strips and the other habitats
- The distinctiveness of species assemblages in the grass strip habitat

The most diverse habitats were found to be hedgerows with 69 species, followed by grass strips with 59 species. Of the 59 species found in grass strips, 13 – or ten per cent of the total soil-dwelling species list for the farm – were found only in these field margins. These habitats are therefore an important source of biodiversity within the farm.

Additionally, of these 59 species, 26 were represented by a single individual. Grass margins may therefore benefit rare species, or enhance species dispersal by acting as corridors between isolated habitats.

Although environmental conditions in the grass strips were similar to other cultivated habitats, in terms of soil pH and soil temperature, for example, their value to soil biodiversity approaches that of hedgerows. The findings support the inclusion of grassy margins in agri-environment schemes.

Source: Smith, J., Potts, S. and Eggleton, P. (2008). The value of sown grass margins for enhancing soil macrofaunal biodiversity in arable systems. *Agriculture, Ecosystems & Environment*. 127(1-2):119-125.

<sup>1</sup>. See, for example: <http://www.naturalengland.org.uk/ourwork/farming/funding/closedchemes/css/default.aspx>



## A selection of articles on Soil from the *Science for Environment Policy* News Alert

### **Tropical soil carbon sink under threat (9/3/09)**

There are strong concerns that the conversion of tropical forests into land for agriculture or plantations has negative effects on the carbon budget. A new study conducted in South-East Asia reveals that moderate or heavy disturbance of tropical forests can damage fine root structures, which in turn reduce carbon transfer to the soil.

### **Protecting valuable urban soil (18/12/08)**

Soil provides multiple services, ranging from food production, water-filtering and carbon capture, to green park areas in towns and cities, important for human well-being. However, increased urbanisation is leading to a loss of soil resources. Researchers have developed an online evaluation method that can be used as an aid to urban planning to avoid the loss of precious areas of good quality soil.

### **Evaluating risks from contaminated soil: a standardised approach (4/12/08)**

Soil plays an important role, as a habitat capable of recycling water, carbon and nutrients and a provider of food and raw materials. Research investigating the risk assessment procedures adopted in different EU member states, suggests that there needs to be greater standardisation in the methods of assessing risks from contaminated soils.

### **Drying peatlands will exacerbate climate change (27/11/08)**

Peatlands hold vast stores of carbon, preventing it from being released into the atmosphere. However, a new study suggests global warming could cause much of this carbon to be released, thus exacerbating climate change and causing further temperature rises.

### **Plant diversity: the secret to more nitrogen and carbon in soil (19/6/08)**

Plants play a key role in soil carbon (C) and nitrogen (N) accumulation. New research suggests that plant diversity may have an important role to play in stimulating C and N storage in some soils. The findings suggest ways to improve carbon sequestration in grasslands and increase biomass production, for example for biofuel crops on nitrogen limited soils.

### **Researchers study how soil breathes to understand carbon-cycling (5/6/08)**

Soil respiration (SR) plays a major role in moving carbon from the ecosystem to the atmosphere. Converting land for agricultural use accelerates CO<sub>2</sub> emissions via SR. Planting trees (afforestation) has been heralded as a potential climate change mitigation approach. However, new research suggests that the effects of agricultural practices on peatland remains for decades and can continue to influence CO<sub>2</sub> emissions even 30 years after afforestation.

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