



# Soil Degradation:

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A Major Threat to Humanity



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Effects of soil erosion on farmland in Shottisham near Woodbridge Suffolk, UK, 2007.

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## Summary

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- Soil degradation needs to be recognised alongside climate change as one of the most pressing problems facing humanity and solutions need to be developed and introduced which address both issues simultaneously.
- Research by the Economics of Land Degradation Initiative in 2015 calculated that soil degradation is costing, between \$6.3 and 10.6 trillion dollars per year globally, but these costs could be reduced by enhancing soil carbon stocks and adopting more sustainable farming methods.
- In the UK, a research group at Cranfield University estimated that about 50% of the value of soil degradation in England and Wales is related to loss of soil organic carbon (SOC), and that intensity of farming is a major cause of soil carbon loss.
- Land use change can significantly reduce soil organic pool and increase carbon dioxide (CO<sub>2</sub>), nitrous dioxide (NO<sub>2</sub>) and methane (CH<sub>4</sub>) emissions. Changing land use from pasture to cropland results in the greatest loss of SOC and GHGs emissions.
- Farming practices can be employed to improve soil quality and increase soil carbon, including optimal fertilisation, crop-grassland rotation, hedgerows planting and animal manure application. The effects of other practices to SOC stock, like no-till and green manure, are highly debated: recent studies show that their contribution is often limited, and in some regions no-till may even lead to yield declines compared to conventional tillage systems.
- In arid and semi-arid regions, salt-induced soil degradation is one of the most widespread soil degradation processes. It has been estimated that over the last 20 years, 2,000 hectares of agricultural land per day has been lost due to salinization, an area the size of France, equivalent to a global economic loss of around \$27.3 billion per year. Efficient water management, along with better fertilisers use and improved crop varieties could significantly reduce the negative effects of salt-induced soil degradation.
- Given the technological advances that have been made in recent years and the greater scientific understanding of the issues today, all types of soil degradation are potentially reversible, given wide public support and understanding, and political will.

# 1. Introduction

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Soil is a vital resource for the future of humanity. It needs to be protected and enhanced. Instead, however, more than half (52%) of all fertile, food-producing soils globally are now classified as degraded, many of them severely degraded, (UNCCD 2015). Throughout human history, at least twelve past civilisations have flowered on fertile soils and made huge advances, such as the development of written language, mathematics and financial systems, only to disappear over time, as their soils progressively degraded and could no longer feed their populations.

These civilisations occupied, or depended on, defined geographical regions: the Sumerians in Mesopotamia, the Roman Empire's exploitation of the once highly fertile soils of north Africa, parts of ancient Greece, China, Central America, India and elsewhere. The damage done to soils in these regions is still present today, but new civilisations were able to spring up elsewhere, converting forests and native grasslands to agriculture and thrive on the fertility that had built up over thousands of years in the soil. Today, however, due to the global trade in food, the global adoption of exploitative farming methods and the extent to which forests and natural grasslands have already been converted to crop production, it is the entire global civilisation that is threatened by progressive soil degradation.

Soil degradation is a critical and growing global problem, with implications for a number of key policy areas, including food security, climate change, flood risk management, drought tolerance, drinking water quality, agricultural resilience in the face of new crop diseases, biodiversity and future genetic resources.

Discussions around climate change seldom refer to soil, even though the soils globally, down to one metre in depth, contain 1,500 billions of tonnes of organic carbon, over three times as much carbon as the atmosphere. Soil degradation adds carbon (C) and reactive nitrogen (N) to the atmosphere, increasing global warming, which in turn accelerates degradation processes (Lal 2004). Moreover, soil contains over 98% of the genetic diversity in terrestrial ecosystems (Fierer et al. 2007). Soil biodiversity, however, is not mentioned in the Global Biodiversity Outlook from the UN Convention on Biological Diversity (CBD), it is not referred to in the International Union for Conservation of Nature Red List of Threatened Species, and it has not been considered by the UK Natural Capital Committee.

Agriculture and the food we eat depend on soil. Under appropriate management soils are an infinitely renewal resource, while under inappropriate management they are effectively a very finite resource. Under natural condition it can take 500-1,000 years to form an inch of soil from parent rock.

Recent estimates indicate that every year:

- Soil degradation affects 1.9 billion hectares,
- 12 million hectares (23 hectares a minute) of land is lost to food production
- 24 billion tonnes of fertile soil is irretrievably washed or blown away (3.4 tonnes for every human on the planet).

It is also projected that this will lead to a 12% decline in global food production over the next 25 years, resulting in a 30% increase in world food prices (UNCCD 2015). This will occur during a period when more is demanded of soils than ever before, due to the growing global population and climate change.

The most likely reaction to this will be to encourage even greater intensification of food production (and this is already happening), but while this may bring some short term increases in productivity and delay the development of food shortages, all indications suggest it will only increase the rate of soil degradation, making the underlying problem even worse (UNCCD 2015). This will increase pressure for the last remaining areas of natural grassland and forest to be converted to food production, something that would have a devastating impact on the natural world and planetary systems. As such, the issue of soil degradation needs to be given a high priority now, before we reach a crisis point, and be considered alongside climate change as one of the greatest threats facing humanity. This is also important because some of the most actively promoted measures for mitigating climate change will actually increase soil degradation. It is therefore essential that these two global threats are considered together, so solutions can be developed which address them simultaneously.

## **2. Soil organic carbon (SOC) and its importance for soil quality**

Soil organic carbon is the major component (approximately 58%) of soil organic matter and plays a vital role in agricultural production and in a range of other soil functions. It is also recognised as the most useful single indicator of soil quality (Soil Carbon Initiative 2011). For many years it was assumed by many advocates of intensive farming that soil carbon was not a limiting factor in crop yields because studies failed to show otherwise, but more recent research has shown that once soil carbon falls too low, maximum crop yields cannot be achieved no matter how much fertiliser is used (Johnston et al 2009). Soil organic carbon (SOC) also improves the physical properties of soil that increase the extent to which it can absorb rainfall and hold water, making it available for later crop use.

Other important properties influenced by SOC include: the ability of soils to absorb minerals, including fertiliser nitrogen, without becoming more acidic, its role as a major source of

nutrients, ability to reduce leaching, and the extent to which it enhances microbial biomass activity and species diversity of soil fauna and flora. Crops grown in soils with a low organic carbon level are also more susceptible to disease (Barrios 2007; Stone et al. 2004; USDA 2004; Altieri and Nicholls 2003).

Depletion of organic carbon in agricultural soils is exacerbated by, and in turn exacerbates, soil degradation (UNCCD 2015). Between 42–78 billions of tonnes of carbon have been lost from soils over the last century due to degradation, mostly emitted to the atmosphere as carbon dioxide (CO<sub>2</sub>) and other greenhouse gases (GHGs) with negative implications for climate change and food production (Lal 2004). In England and Wales the total estimated organic carbon loss from the soil each year is 5.3 million tonnes, corresponding to a mean rate of 0.6% of the existing soil carbon content (Graves et al. 2015; Bellamy et al. 2005).

Soil microbial life only makes up 5% of soil organic matter, but it is nevertheless vitally important in relation to maintaining or enhancing SOC levels, because it is responsible for the decomposition of crop and livestock waste and any added organic material, which once fully decomposed constitutes the soil's stable organic matter. This will slowly increase or decrease over time according to farming methods, temperature, soil type and other factors, but undecomposed organic matter rapidly oxidises to carbon dioxide and is therefore of little value (Johnston et al. 2009).

### **3. Land use change and inappropriate land management practices - major causes of soil degradation, SOC reduction and GHGs emissions.**

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Because there is more than three times as much organic carbon in the soil as there is carbon in the atmosphere (Lal 2004), small changes in SOC levels can have a large impact on atmospheric carbon dioxide concentrations (Stockmann et al. 2013). Land use change from native forests and natural grasslands to agriculture contributes to GHGs emissions through the mineralisation of soil carbon and decomposition of vegetation. Land use change is estimated to have contributed 55-135 billion tons of carbon emission as CO<sub>2</sub> during the period 1850-1998 (Lal 2004).

While it might be assumed that the greatest losses of SOC result from conversion of forests to agriculture, and this is true when the biomass of the trees is included, a meta-analysis of 74 studies (Guo and Gifford 2002) found that in relation to SOC, grassland soils converted to crop production lost 59% of their carbon, while forest soils lost 42% of theirs. Reversing these land use changes leads over time to reversal in these trends, returning carbon from the atmosphere to the soil. In contrast, conversion of cropland to grassland leads to an

average 19% increase in SOC, but another surprising finding, one based on 170 separate observations, is that the conversion of native forest to grassland leads to an average 8% increase in SOC, (Guo and Gifford 2002, Stockmann et al. 2013).

In soils with a high clay fraction SOC carbon levels do not fall indefinitely, but instead fall to a lower equilibrium level. In contrast, light and sandy soils containing little clay are less able to resist soil carbon decline which can fall to extremely low levels where the soil is incapable of supporting livestock or growing crops (Johnston et al. 2009, Johnston 2011). This is a very important point, which applies in particular to many soils in Africa, which under inappropriate farming systems have the potential to degrade rapidly (FAO 1995, Elias and Fantaye 2000).

## **Land use change and soil nitrogen losses**

While it has received less attention than carbon, land use change also results in the loss of nitrogen from soils, and in contrast to carbon, which is lost annually over 50-100 years, nitrogen is lost very rapidly in the form of nitrous oxide, the most persistent and potent, in global warming terms, of all the major greenhouse gases. A study undertaken in the Netherlands found that taking nitrogen losses into account increased the net GHG impact of converting grassland to crop production by 50%, with an associated soil fertility decrease and disruption of nutrient cycles (Vellinga et al. 2004). In contrast to carbon also, which is both lost and sequestered principally as carbon dioxide, nitrogen is lost as reactive nitrous oxide but sequestered mostly from the unreactive di-nitrogen gas which makes up 80% of the air we breathe, suggesting that in global warming terms the loss of soil nitrogen is very much harder to reverse than the loss of soil carbon.

## **The soil methane sink**

Land use change can also reduce the soil methane sink - the capacity of certain types of soil bacteria (methanotrophs), which use methane as an energy source, to negate methane emissions from other soil microbes and also break down atmospheric methane to carbon dioxide and water (Tate 2015; Nazaries et al. 2013). The greatest damage to the soil methane sink occurs when forestland or established grasslands are converted to croplands and when ammonia-based nitrogen fertilisers are used (Acton and Baggs, 2011; Reay and Nedwell, 2004; Willison et al 1995).

Atmospheric methane levels are a serious global concern because concentrations are approximately 2.5 times higher than before the industrial revolution. Because of the huge scale of the methane problem, most studies have tended to ignore or underestimate the

significance of the soil methane sink, because it only breaks down 5% of global methane emissions (the rest mostly being broken down in the atmosphere over 10-12 years). But since global methane levels have been increasing by 0.1% per year over the last decade (Nazaries et al. 2013) it can be seen that even a small reduction in the soil methane sink could make a major contribution to overall methane increases over time.

## **Soil carbon sequestration**

Soil carbon sequestration is the reverse of SOC loss. It is the net removal of carbon from the atmosphere and its storage in soil. All plants take carbon dioxide from the atmosphere and combine it with water through photosynthesis to produce carbohydrates, the building blocks of plant growth. The difference between farming methods which result in a net loss of carbon and those which result in a net gain relates largely to the extent to which plant and animal residues are able to decompose and turn into humus, the soil's most stable carbon reserves, rather than rapidly turning back to carbon dioxide.

This is influenced by factors such as cropping patterns, method and extent of cultivation and livestock grazing density, compared with grassland productivity. Grassland soils under extensive management conditions are significant stores of carbon, with global carbon stocks estimated at 50% more than the amount stored in all forests (FAO 2010). All soils also have an equilibrium point (which depends on soil type and other factors) above which carbon levels cannot be increased, but the carbon sequestration potential of the world's grasslands has been estimated 10-300 millions of tonnes of carbon per year (Lal 2004).

## **4. The financial cost of soil degradation, globally and in the UK**

Determining the value of soil as natural capital would help to translate the greater understanding we have today of soil degradation, through advances in soil science, into policy for sustainable development. This requires a multidisciplinary approach engaging the fields of ecology and economics.

A recent study by the Economics of Land Degradation Initiative (ELD) calculated that global soil degradation costs us between US\$6.3 and US\$10.6 trillion (£4.4 to £7 trillion) per year. The ELD study also estimated that US\$480 billion (£317 billion) could be generated by enhancing carbon stocks in soils, and that by adopting more sustainable farming practices increased crop production worth an US\$1.4 trillion (£900 million) could be achieved (ELD 2015).

## The cost of soil degradation in England and Wales

Some idea of the relative significance of soil degradation compared with the much more easily understood issue of soil erosion (which is just one manifestation of soil degradation) can be seen by comparing the costs of soil erosion in England, estimated at £45 million per year, which includes £9 million pounds in lost production (Defra, 2009) with the costs of soil degradation in England and Wales which has recently been calculated by a research group at Cranfield University. They estimate the value of quantifiable soil degradation in England and Wales to be approximately £1.33 billion per year (Graves et al. 2015). This value – which does not include the costs associated with loss of cultural services, soil biota or soil sealing – is mainly linked to: loss of organic content of soil (47% of total cost); compaction (39%); and erosion (12%). The estimated costs of soil degradation are positively correlated with the intensity of farming.

Other studies also show that soil degradation in Britain has often been linked with intensive agriculture and inappropriate land use practices. For example, as a consequence of the conversion of large areas of extensive grassland to intensive arable fields, the highest erosion rates ever recorded in the UK occurred in the South Downs of South East England (Boardman et al. 2003).

In the context of the UK Natural Environment White Paper (2011) and the EU Thematic Strategy for Soil Protection (2006), the evaluation exercise conducted by Cranfield University provides an economic argument to highlight the need to reduce soil compaction and erosion on intensively farmed soils and maintain the organic content of soils in general.

## 5. Salt-induced soil degradation

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Salinisation is one of the most widespread soil degradation processes, which commonly occurs in arid and semi-arid regions, where rainfall is too low to maintain adequate percolation of rainwater through the soil and irrigation is practiced without a natural or artificial drainage systems. Irrigation practices without appropriate drainage result in the accumulation of salts in the root zone, affecting several soil properties and crop productivity negatively.

Salinisation also occurs in these regions because evaporation rates are extremely high, meaning that with commonly used irrigation systems much of the water evaporates rapidly, leaving dissolved mineral salt in the top part of the soil profile, which build up progressively over time. It has been estimated this results in 2,000 hectares of once productive farmland every day for the last 20 years reaching the point where degradation becomes so severe that further crop production has to be abandoned (Qadir et al. 2014). Over the last two decades

an area the size of France, i.e. about 62 million hectares, has been lost in this way, with an estimated global economic loss of \$27.3 billion per year (Qadir et al. 2014). Improved water management, along with better fertilisers use and improved crop varieties have the potential to reduce the negative effects of salt-induced soil degradation considerably, but in some areas fundamental consideration needs to be given to whether the cultivation of crops requiring irrigation is the best and most reliable way to produce food or whether the land would better be returned to low intensity grazing using deep-rooting grasses and herbs, due to their greater drought resistance, before the point of no-return is reached.

## **6. Combatting soil degradation**

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Some agricultural practices are known to sequester SOC, reduce GHGs emissions and reverse soil degradation, while others are well known to reduce SOC and increase degradation. In between these come a number of techniques, some widely employed, where evidence of their sequestration potential is either disputed or has recently been called into question by new research. A detailed consideration of these is outside the scope of this paper, but in this section we will summarise some of the key issues and dilemmas.

A key point to note is that because soils vary so much between countries, regions, farms and even individual fields, no single solution fits all cases. Instead solutions need to be tailored to each situation. Reversing land degradation is also potentially much easier in some regions and with some farming systems than with others. As such there is a case for picking off the easier ones first. One of these might be intensive horticultural systems, such as those in parts of California, Spain and Southern England.

Given the political will, SOC could be increased rapidly in these systems through the use of carefully prepared compost derived from urban waste and the replacement of nitrogen fertiliser with compost and fertility building break crops, such as clover and other legumes. The relatively high profitability of these systems per hectare means that most producers could afford to introduce more diverse rotations if this were, for example a requirement of cross compliance and Good Agricultural and Environmental Conditions, which producers need to satisfy in order to received subsidy payments through the Basic Payments Scheme.

Soil degradation in temperate grain growing regions such as northern Europe, parts of Russia and the US as well as much of Asia could be reduced by improvements on existing systems and rotations but only reversed by the re-introduction of mixed farming systems. However, these regions have adequate rainfall and sufficiently moderate temperatures to make to make such changes possible. More difficult would be to address the degradation that has occurred in extensive grain growing regions, such as parts of Australia, the southern US, parts of the

former Soviet Union and parts of south America, drylands, such as those in Namibia, where precipitation is limited or erratic, or climate extremes, such as hard frosts limit options.

Hardest still is to reverse the degradation in sub-Saharan Africa, other desert regions, such as in the Middle East, in mountain soils and other areas where large populations are trying to survive in some of the most difficult conditions on the planet.

However, in all of these areas there are inspiring examples of what can be achieved with determination and imagination. What is needed is for greater public and political understanding of the issues, the extent to which our shopping choices contribute to the problems and an understanding of why the constant financial pressure pushing producers worldwide to intensify and increase the size of their holdings or leave the industry is not in the best interests of consumers.

Despite, the need for different approaches some general points can be made. Long term experiments in the UK at Rothamsted Experimental Station show that SOC declines steadily where grassland soil is ploughed and converted to continuous arable crop production, while it increases steadily where arable cropland is sown to grass (Johnston et al. 2009). These studies also show that rotations alternating between cropland and grassland have the potential to maintain or slowly increase SOC levels providing the correct balance is achieved between carbon building under grass and carbon exploitation under cropping.

There appears however to be very little mainstream research looking at SOC trends in traditional mixed farming systems in the UK, such as those used by many organic and biodynamic farmers, where in addition to rotations alternating land use between grass and crop production, animal manures combined with straw and other bedding material produce traditional farmyard manure which is then thoroughly composted before being applied to the land. However, a review of studies quantifying soil carbon levels in organic and equivalent intensively farms soils, by the Soil Association, found that on average organically farmed soils contained 28% more carbon (Azeez 2009).

In the UK, however, over the last decade there has been a continuing conversion of grassland to cropland, driven in large part by the low profitability in the grazing livestock sector with the overall number of grazing animals declining.

Amongst land management practices, several studies show that as an alternative to conventional tillage, no-till is beneficial to the functioning and quality of soil: it helps to increase resilience to weather variability and contributes to climate change adaptation in some situations (Garcia-Franco et al. 2015; Powlson et al. 2014; UNEP 2013; Lal 2012). However, a meta-analysis of the evidence undertaken in the UK by Powlson et al. (2014),

showed that mitigation potential of no-till through soil carbon sequestration is actually very limited and has been widely overstated, with any measurable increase in SOC in the top few inches of soil doing no more than compensating for SOC losses at greater depths. The studies conclude that in regions where no-till is appropriate and does not negatively impact crop yields it should be promoted for its beneficial effects to soil structure and resilience, but not on the basis of equivocal evidence for climate change mitigation. However, a review of 610 studies comparing no-till with conventional tillage undertaken by researchers at the University of California Davis found that while there are situations in which no-till can increase production, overall it reduced yields by 6-9%. Taken together these two studies call into question the value of no-till systems for increasing SOC and crop yields.

The use of green manures is increasingly advocated in conjunction with no-till. Evidence suggests that where such crops can be established after harvest, they have the potential to reduce nutrient leaching over winter and improve soil workability. However, the fact that such crops remain in the ground only for a few winter months during which they grow only a little suggests they have little potential to sequester SOC or reverse soil degradation in all arable production systems. According to research conducted at Rothamsted Experimental Station, the contribution of green manures to SOC stock is small and has been widely overstated (Johnston et al. 2009). Moreover, most of the experimental studies that focused on the impacts of green manure on SOC dynamics have been performed under extensive cereals and irrigated crops.

Other practices with the potential to increase SOC and reduce soil degradation including optimal fertilisation, careful calculation of appropriate grazing animal stocking density, the use of more productive and more nutritious grasses, deeper-rooting grasses, forage legumes, hedgerows and tree planting and carefully timed animal manure application (Lemaire et al. 2015; Soussana and Lemaire et al. 2014; Strassburg et al. 2014; Franzluebbers and Doraiswamy 2007).

## **7. Conclusions**

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Loss of soil organic carbon and nitrogen related to degradation reduces the ability of the agricultural sector to secure food and significantly contributes to climate change. It is becoming increasingly evident that allowing soil to degrade is expensive, both to producers and society in general, especially in the long-term, and the costs of investing in prevention are much lower than the costs of letting degradation continue and intensify (ELD 2015).

While many advances have recently been made, more studies are needed to understand

soil processes for different sites, land uses, management systems and scales. For instance, it is still disputed and arguably not entirely clear from the evidence how soil can be used to mitigate GHGs emissions and, at the same time, meet our needs for other ecosystem services, especially increased food production.

Determining the economic value of the natural capital of soil including all the ecosystem services it provides and the costs of degradation is crucial in order to implement effective policy instruments and stimulate public interest in reducing soil degradation.

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