Campaign to Protect Rural England
Standing up for your countryside

Back to the land: rethinking our approach to soil

FOOD & FARMING FORESIGHT – Paper 3

FOOD AND FARMING FORESIGHT

The soil never sleeps.
Never slips into ideology or nostalgia.
It is place and purpose,
The perfection of decay.
A story that shifts
From mouth to mouth.
A crucible for rebirth.
A rooftop on another world.

Adam Horovitz
From the poem *The soil never sleeps*

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Extract from *The soil never sleeps – Poetry from a year on four British farms* by Adam Horovitz. 2018. Reproduced by kind permission of the author.

Researched and written by Graeme Willis. The views expressed here are my own responsibility as are, of course, any errors which remain.

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Campaign to Protect Rural England
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Campaign to Protect Rural England: Food and Farming Foresight Series

The objective of the Campaign to Protect Rural England Food and Farming Foresight Series is to provide evidence-based research papers that support innovative policy solutions to critical food and farming issues.

The purpose of the series is not to set out CPRE's official policy position on the future shape of the food and farming system. Rather, it will explore a number of 'blue-sky' policy solutions with the aim of provoking wide ranging discussion over the future shape of food and farming.

The series examines different aspects of the food and farming system at a time, following the EU referendum decision, when there is the opportunity for major policy change.

With this in mind, we welcome comment on the policy recommendations within the Food and Farming Foresight Series.

Please email Graeme Willis:
graemew@cpre.org.uk

Food and Farming Foresight Series Papers to date:

1. New model farming:
   resilience through diversity

2. Uncertain harvest:
   does the loss of farms matter?

3. Back to the land:
   rethinking our approach to soil

FOOD AND FARMING FORESIGHT

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Note about data and geographies:
This report addresses soil issues primarily in England. Of necessity it relies on the public data that is available and the areas covered vary. Where possible English data is used. If not, the wider area referred to – for example, England and Wales or the UK – will be made clear in the text.

Restoring our soils to health

In the previous two papers in this Foresight series we have looked at how diversity – in all its aspects – is important to underpin a sustainable agriculture for this country. In this paper we look at what supports all our agriculture – soil – and how maintaining its health underpins our own.

Although the paper considers the broader context of soil, its main concern is with the land and the 70% of soils in England that are farmed, whether for arable crops, horticulture or grazed by livestock.

'The thin layer of soil covering the earth's surface represents the difference between survival and extinction for most terrestrial life.'
Doran and Parkin, 1994[1]

The paper explores why soils are important and their main functions. It looks at the key threats they face, from the way they are managed to their loss to farming when developed. It also analyses why soils must be better protected in the future, including to secure the domestic supply of food, reduce the risks of climate change, improve water quality and restore the health of the natural environment. It also considers why soils continue to be degraded and lost, including an analysis of the strengths and weaknesses of recent policy.

It comes at a time when soil is, for the first time in many years, starting to be given the political attention that it is due alongside other environment issues. The 25 Year Plan for the Environment recognises soil health as the foundation of productive farming and forestry; a new agricultural policy identifies soil and peat as public goods to be enhanced and protected; and we should soon see publication of an ambitious new strategy for restoration of peat.

KEY POLICY RECOMMENDATIONS

This paper leads to a set of recommendations, primarily for policy-makers in government. They are detailed more fully in section 6 but can be summarised as:

- Make protection of all soils from degradation a headline goal of the 25 Year Environment Plan and develop an action plan to achieve their sustainable management by 2030.
- Bring forward new measures to achieve net zero GHG emissions from agricultural land by 2050.
- Under the new agricultural policy design a new package of public investment and regulation to halt soil degradation and promote measures which protect and regenerate soils.
- Commit to developing and resourcing the comprehensive evidence base, metrics, indicators and monitoring processes needed to underpin sustainable management and effective protection of soils.
- Revise the NPPF and national planning guidance to fully recognise land and soils for their vital natural capital and ecosystem services and to minimise their avoidable degradation.

Yet there is a risk that the rising concern with soil will be overly focused on the agriculture soil can support for food production. This is not to diminish the fundamental importance of soil for a stable and secure supply of food, or the risks the most productive land faces from all forms of degradation. But the pivotal role soils play in supporting natural ecosystems and delivering multiple environmental services deserves wider recognition if they are to be fully valued and well-protected by public policy. Soil needs to be placed at the heart of the environmental agenda. Not least, this means recognising that soils can and must be part of the solution to the overwhelming threat facing the countryside and our current agricultural model: climate change.

As the Intergovernmental Panel on Climate Change (IPCC) in its Special Report so dramatically warned only a couple of months ago, we need to act considerably more quickly and more radically if we are to avoid global temperature rising 1.5°C above pre-industrial norms and the consequences. The IPCC also warns of the threat to food security if we go about trying to avoid the risks of 2°C warming in the wrong way, such as deforesting land for biofuels.

And last month the Committee on Climate Change called for new policy to deliver a transformation in the way land and soils are used and managed to respond to climate change as well as deliver on wider environmental objectives. They urge action now with a combination of measures including restoring peatlands, more trees and hedges and better management of soils and livestock to – they estimate – reduce the GHG emissions from agriculture and other land sectors by 35% to 80% by 2050.[2] Therefore, this paper explores some of the ways in which we can change how land is farmed and the methods used that can help store carbon and mitigate the risks of climate change, while benefiting the health of the wider countryside.

The way we use our land is crucial to our soil. Land use generally is explored more thoroughly in CPRE's 2017 publication *Landlines: why we need a more strategic approach to land*, but one important factor seldom discussed in relation to soil health and considered in this paper is building on previously undeveloped land, including agricultural land, and soil sealing – capping it with a hard surface – which undermines the processes that give soil value as natural capital. Sealing not only takes soil out of agriculture but deprives generations of the many natural services it can provide. The revised National Planning Policy Framework (NPPF), the rulebook for planning in this country, in effect regards greenfield land as 'awaiting development' rather than taking into account its natural capital and environmental services. The impact on what this means for our soils is disregarded as a consequence.

This paper is the result of many discussions (see acknowledgements) with those concerned for our soils, including of course those who deal with it every day: farmers, and in particular those who are farming in ways that will reduce degradation of their soils and regenerate them. The report proposes five new approaches that could make soils healthier and more resilient, and reduce the environmental impact when soils are degraded. The first four relate to farming practice and are explored further through four case studies of farms putting theory into action. The fifth is an approach to development of land to reduce the potential harm and, where unavoidable, reduce its impact on those wider services provided by soils.

We don't presume that these approaches will solve all the problems, or need to be used in isolation. Indeed, they can complement other valued approaches such as organic farming or integrated farm management. In particular, farming is, in its interactions with ecological and biological systems, extremely complex so no one system or approach is likely to have all the answers. However, to be sustainable, farming will need to become more efficient in its use of resources, find ways to replace unsustainable inputs with renewable resources and, ultimately, create a new low carbon model for farming in this country. The approaches proposed here combine something of all of these.

All about soil

Soil is a mixture of physical, chemical and biological elements: minerals from rocks, organic matter from dead plants and animals, living organisms, air and water.

The soils that we find are the result of five main factors: 'parent material (rocks), climate, organisms, topography and time'.[3] For example, different parent rocks form soils with very different physical properties: granites can form sandy soils and basalts clay ones. Climate affects how and how fast rocks break down from heat or rain or ice. Topography – or slope – can alter soil depth. Chemical processes break down underlying rocks which supply minerals like calcium and magnesium vital for plant growth and health.[4] Lastly, soil needs biology. Organic matter improves soil structure, allowing particles to clump together and helping water to be absorbed. Living organisms from bacteria to beetles[5] break down organic matter to recycle and release locked-up nutrients, making them available to plants.[6] It is this complex web of life, much of it microscopic, which contributes so extensively to healthy soils that support agriculture.

1.1 Why soils are important

Healthy soils depend on the interaction of these physical, chemical and biological properties. Soils support plants that provide food, fibre, fuel and much besides. They retain and release excess water, clean and filter it – removing pollutants and pathogens – to recharge underground stocks. They emit carbon dioxide and absorb it from the atmosphere. The web of organisms in soil are a primary food source for wildlife above. Most fundamentally, soil is the ultimate digestive system, decomposing all that lived and recycling it to enable new life.[7]

Varied land uses but especially farming have shaped the countryside but the underlying soils are fundamental to landscape and the habitats and ecosystems it supports. Soil is also a resource for industry – as a stable platform for buildings and infrastructure and for raw materials such as clay for bricks. It is a vast genetic repository, hosting billions of microscopic organisms in every handful, as well as being a natural laboratory with potential for new generations of life-saving medicines.[8] And it is vital to the nutritional quality of the food we produce. Plants derive nutrients from the soil which are eaten by us directly or in animal products.[9 10]

1.2 Why soils need care

Our ignorance about soil biology is profound. Soils have been abused and squandered throughout history. In our era (since the 19th century), the use of agricultural chemistry and the steel plough have become conventional in farming, allied to a focus on intensive management to raise yields and overall output. This system ignores soil's biological complexity and fails to nurture other important functions. Soils have been regarded as a resource that can last forever.

Fortunately, nature is resilient and we can, with care and skill, protect, regenerate and restore soils to health. There is an urgent need to do so. Farming and food production face immense challenges as does much of nature which coexists with it. Now is a critical time to protect the stock of high quality and high carbon soils that remain and to transform farming practices to rebuild our soil resource. We rely for almost all of our food – 95% according to the United Nations' Food and Agriculture Organisation (FAO) – on rainfall falling on a thin layer of soil, often only a few centimetres thick.[11] This living planetary skin is proportionally 10,000 times thinner than our own.[12] We need to continually remind ourselves how fragile that skin is and how much we rely on our soil as a resource – and care for it accordingly.

SOIL FOCUS

- **A gram of soil – about a quarter of a teaspoon – can contain one billion bacteria cells.[14]**
- **UK soils store around 10 billion tonnes of carbon or the equivalent of 70 years of annual UK greenhouse gas (GHG) emissions.[15]**
- **Over half of peat is organic carbon and England's peatland areas store some 584 million tonnes of carbon – or 2.14 billion tonnes of CO_2.[16]**
- **There are around 11 million species of soil organisms but fewer than 2% have been named and properly classified.[17]**

Figure 1. SOIL FUNCTIONS[13]

Nature and categories of ecosystem services and functions provided by soil systems and land use

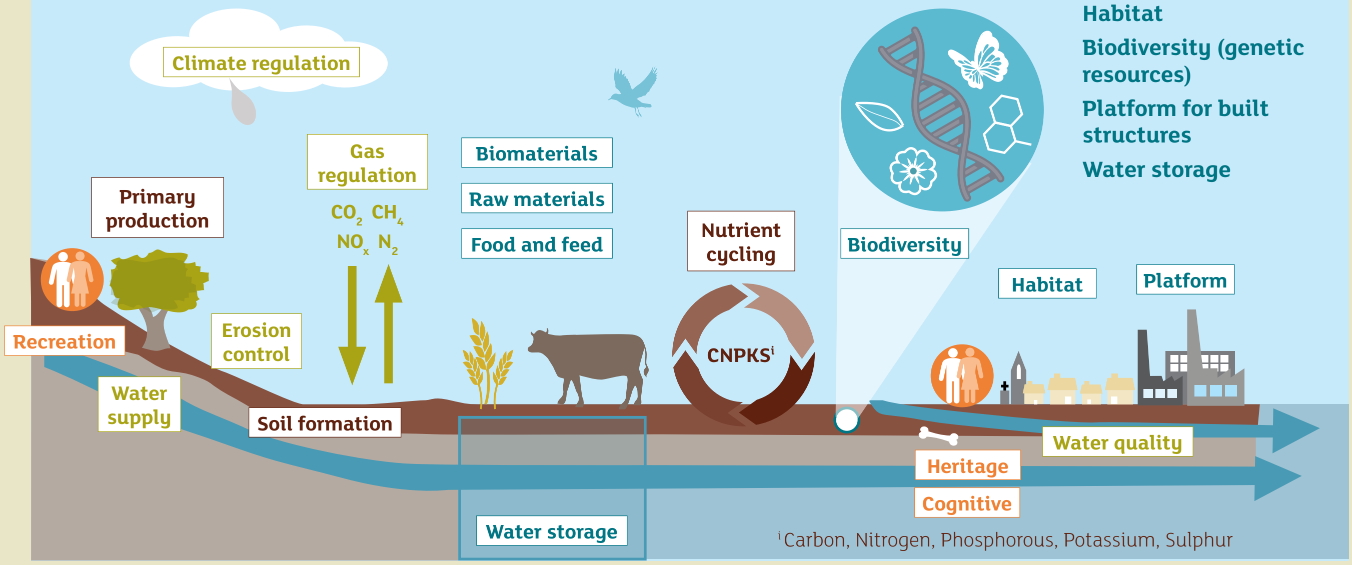
Roles that soil and land-use play: Supporting Provisioning Regulating Cultural

SUPPORTING
Supporting vegetation
Soil formation
Nutrient cycling

CULTURAL
Recreation
Heritage
Cognitive (education, inspiration and aesthetics)

REGULATING
Climate
Water flow and quality
Erosion control
Atmospheric gas

PROVISIONING
Biomaterials (timber, fibre, fuel)
Raw materials (soil, minerals, aggregates)
Food and feed
Habitat
Biodiversity (genetic resources)
Platform for built structures
Water storage



[i] Carbon, Nitrogen, Phosphorous, Potassium, Sulphur

1.3 Why land use matters

Wise use of land is critical to soil protection and restoration. For the 70% of England that is farmed landowners and land managers decide how and for what the land should be used. They are influenced by land and soil factors like slope and geology but also by market forces and public policy with a range of regulations and financial incentives. Another critical area of public policy influence on land use is town and country planning which places controls on the conversion of land from agriculture to other, especially built, uses.

The way that land is used is currently subject to intense debate. Brexit has provided the opportunity to develop new agricultural policy and new priorities for how farmland is used. Also, whether planning policy – as it stands – genuinely protects the environment while delivering the homes people need is questionable.

The broader context for these debates is that, in England – a relatively small and densely populated country – there is increasing pressure on land to provide more homes, to grow biofuels, to improve food security, to improve wildlife protection, to manage water better and to increase woodland cover.[18] And this is all set in the context of the overarching threat to our countryside – the need to adapt to and reduce the risks of climate change.

The need to deliver on so many objectives with a finite amount of land raises serious questions about the adequacy of the tools we have at present to decide what land is best used for and in what locations.[19] As Mace and Bateman point out, 'the simple distinction between agriculture, built infrastructure and nature conservation areas is no longer adequate'.[20] Decisions which focus on one primary use are ignoring the potential to deliver other important benefits – for example, green infrastructure in an urban areas or carbon storage in croplands. We need a more sophisticated way of valuing land and its capabilities – in terms of the wide range of services it can provide – and new tools and processes to establish how land can be used optimally and most efficiently. This report argues for a re-evaluation of land and its soil as a resource and for new strategic thinking about how the country's land area can deliver certain key national objectives such as producing sufficient food, storing carbon, reducing flood risk and delivering new homes.

WHAT IS NATURAL CAPITAL?

Natural capital is defined as 'the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions'. The term 'capital' here refers to living or non-living assets as the basis for production of goods and services – ecosystem services – defined as: 'functions and products from nature that can be turned into benefits with varying degrees of human input'. These include provision of food and wood, clean air and water and regulating the climate. So land, soil, species in the soil and its ecological communities as well as minerals and other resources below it are all forms of natural capital. All other forms of capital – manufactured, financial, human or social – derive from natural capital.[21]

The threats to soil

This section looks at six main threats to soils. They are often interrelated because of the complex relationships between soil elements.

2.1 Erosion

Soil formation and erosion are natural processes and, cataclysmic events apart, rates of erosion are generally balanced by rates of formation.[22] Good husbandry can sustain productive soils for centuries. If managed well, soil can be regenerated, too.

But removal of vegetation and disturbing the soil exposes it to the eroding agents of wind and rain. Typically, where plants are removed the roots that help bind the soil are also destroyed. On a bare slope, soil can erode up to 100 to 1,000 times faster than on a vegetated one. In UK cultivation, practices such as inversion ploughing to establish arable crops, and failure to plough along the contour line, cause serious problems. Other causes of soil erosion include overstocking of animals, leading to overgrazing, and heather burning for game.

2.2 Compaction

The physical structure of soil affects its quality and health. Soil is generally porous, having voids filled with air and water that provide a habitat for soil organisms and for plant roots to penetrate and spread. When soils are 'mechanically stressed' – put under physical pressure – they can become compressed, reducing the volume of pores. This is usually due to excess traffic particularly machinery and livestock especially on wet clay soils. The expanding size, power and weight of farm machinery has increased the risk.[23] Harvesting of maize with heavy vehicles in wet conditions also causes deep rutting of soil. This has worsened as the area of maize grown has increased vastly since the 1990s.[24] Also, expected wetter winters and more erratic weather will make predicting when land will be dry enough to be worked harder.[25]

2.3 Loss of soil organic matter

Formed from once living animal and plant matter, soil organic matter (SOM) is found in all soils and is an indicator of soil quality and health. It is vital for a range of key functions: absorbing, cleaning and storing water, storing carbon, supporting levels of

micro-organisms, providing key plant nutrients – such as nitrogen and phosphorus plus other trace elements – and contributing to soil structure. Without humus from SOM, soils lose the cohesive glue that protects smaller particles from erosion.

Land use and management affect levels of SOM. A key element in depleting it is soil disturbance: inverting the soil through ploughing exposes the organic carbon in upper layers to the air, releasing CO_2. So changes in land use, such as ploughing up permanent pasture for arable crops or to 'improve' it usually reduces SOM.[26] If soil health is to be maintained, it needs to be replenished.[27]

2.4 Changes to soil biodiversity

Healthy soil hosts an incredible diversity of life from tiny, single-celled organisms such as bacteria and protozoa to fungi, insects and invertebrates and animals such as moles. The abundance and variety of its microbial life are closely linked to important biological processes such as storing carbon, breaking down organic matter, dealing with toxins and pathogens and recycling nutrients; as yet too little is known of these relationships between soil biology and soil functions.[28 29 30] Plant roots work with microrganisms to extract nutrients bound up in soils or fix nitrogen from the air.[31]

Land management that changes the physical and chemical properties of the soil as well as vegetation, organic matter and nutrient levels will have an impact on soil biodiversity and these functions.[32] In farming the most damaging activities are:

- repeated disturbance by cultivation
- compaction reducing mobility of soil organisms
- adding ammonia and nitrate which acidify soil[33]
- use of toxic agrichemicals, particularly fungicides.

2.5 Loss of peatland soils

Around 11% England is peatland. Just under half is classified as deep peaty soils (over 40cm deep) split into blanket bog and mires in the uplands, fens and reedbeds in lowlands and raised bogs in both.[34] Peat forms when land is waterlogged and vegetation breaks down more slowly so accumulates.[35] Over half of peat is carbon from organic matter deposited over centuries, if not millennia. Drainage reverses the process: peat shrinks and compacts as water flows out and, its carbon is oxidised when exposed to air. As upper layers dry they are more prone to wind or water erosion.[36]

Peatland areas have often been under-appreciated despite their cultural significance and their unique wildlife. Many were 'improved' for agriculture or other economic activity – cultivation, grazing, burning for game management or excavation – leading to their degradation. Moorland drains or 'grips' channel water causing erosion and large gullies. Burning heather exposes the peat to air and vigorous heather growth dries it further while the fire damages fragile habitats and species such as Sphagnum mosses that absorb rainfall. Peat for horticulture or for energy in the UK is removed at up to 100 times faster than it can form.[37]

2.6 Soil damage and loss from built development

Soil is a living system. Covering it with an impermeable surface such as concrete or tarmac – known as 'soil sealing' – prevents it functioning naturally. Sealing reduces multiple functions of non-developed land and soil mainly to one: as an inert platform for built development. This severely restricts the land's value as natural capital for the multiple services it can deliver. In fact, the damage to the soil goes well beyond the footprint of a building, extending to accompanying pavements, car parks and open space. Unless designed to be porous, they also seal the soil. Without great care even existing or planned areas of green space may be damaged. Topsoil may be removed and added back but deeper soils left unremediated. Soil once removed may be sold and used elsewhere or landfilled.

SOIL THREATS

- Between 42-78 billion tonnes of carbon have been lost from soils globally over the past century due to degradation, mostly emitted into the atmosphere as carbon dioxide (CO_2) and other greenhouse gases.[38]
- One third of UK soils are thought to be degraded, with 1 million hectares – 36% of all arable land – at risk of erosion.[39]
- Up to 2.9 million tonnes of topsoil are estimated to be lost to wind and water erosion annually in the UK.[40]
- Of over 1.4 million hectares of peatland in England, less than 1% remains undamaged.[41]
- In England and Wales the total estimated organic carbon loss from the soil each year is 5.3 million tonnes, or on average 0.6% of the existing soil carbon content.[42]
- In the UK in 2014, 21.69 million tonnes of soil were sent to landfill sites – representing 45% of all buried 'waste'.[43 44]
- The use of undeveloped land for building in England has more than tripled from 4,500ha a year in the 2000s to 15,800ha (2013-2017).[45]
- At current rates over 1% of England's land will be converted to built development each decade – an area larger than Greater London.

Why protecting soil matters

This section considers the wider issues that make protecting soils in this country urgent and important.

3.1 Securing our food supply

It should be self-evident that the UK needs to have a secure supply of food. It is also self-evident that for national strategic reasons a secure supply requires a strong domestic base. Currently around 55% of the food consumed in the UK is produced here with the remainder imported mainly from the EU.[46]

Food security is not achieved solely by self-sufficiency. Imports bring diversity of supply, flexibility and resilience as well as supplying foodstuffs we want but which we can't produce. However, relying on imports for a stable and affordable supply of food appears increasingly risky in the current climate, both political and literal.[47] Production elsewhere can be shut down by catastrophe such as drought or flooding or wildfires. Countries can impose export bans on foodstuffs over which we have little or no control. In addition, in an increasingly interconnected world, the price of commodities produced in the UK such as wheat can be influenced by global demand and supply. The UK is also directly affected by these factors. Its population is set to rise, meaning more mouths to feed.[48] Yet food production at current levels has relied on cheap polluting energy and depleting natural systems to increase yields. Climate change is also making weather less predictable and putting strains on production whether from drought in 2018 or intense rainfall and flooding.

These pressures mean that change is essential and urgent. We will need to work harder than ever merely to stand still in terms of producing food. So better management and use of the land and soils that are farmed for food will be vital. Soil health and soil quality lie at the heart of this approach. Healthy soils are more resilient to extreme weather, aid plant nutrition and can maintain or increase yields with lower inputs. Soil quality expresses the 'total properties of a soil and its fitness for purpose' such as its fertility, drainage and water holding capacity and ease of cultivation.[49] The areas of land with soil that is highly suitable for crop production continue to be lost to urbanisation. These stocks of high quality agricultural soils – particularly grades 1 and 2 – are finite and relatively limited yet are being depleted. We need to decide at a national level and for strategic reasons to maintain them to ensure continued levels of food production.

In a more turbulent world the need to ensure a stable domestic supply of food is greater than ever. This should make us value our own land assets and natural resources all the more, especially soil.

3.2 Mitigating climate change

Not long ago climate change was seen as a threat to future generations. Now, increasingly, it is a danger to those alive today. The urgent need for action to reduce greenhouse gases (GHG) entering the atmosphere is now recognised by international agreement. It is starkly set out in the recent report from the Intergovernmental Panel on Climate Change (IPCC). Capping the rise in average global temperatures to 1.5°C. is essential; otherwise even a 2°C rise increases the risk of triggering dangerous feedback mechanisms, such as release of methane from melting arctic tundra, and causing runaway climate change.[50] Global warming is accelerating as GHG accumulate, meaning action now to prevent further emissions remains imperative.

The natural environment acts as a regulator of climate with oceans, forests and soils acting as critical carbon sinks. But land use changes, particularly agriculture, have undermined this over a long period of time.[51] Cultivation of rich organic forest and grassland soils to feed people and livestock continues to cause GHG emissions through various forms of soil degradation. On one estimate, most arable soils have already lost 40-60% of their organic carbon.[52]

Reducing the impact of farming on climate change means: prioritising cutting emissions of carbon from SOM; reversing and rebuilding losses of carbon from soils so they act as a net sink; and reducing widespread use of synthetic fertilisers.[53] The bulk of UK agriculture emissions are nitrous oxide mainly from nitrogen fertilisers used to sustain high yields of wheat and other crops. They are energy intensive to produce and use fossil gas as a primary material. Nitrous oxide is particularly potent with a global warming potential 300 times that of CO_2.[54] Emissions from intensive wheat can be 400kg of CO_2 per ha.[55] Cereals produced with nitrates are fed to animals so underpin particularly the meat and dairy products that we eat. Methane produced from fermentation in the guts of cattle and sheep is also a major source of agricultural GHG emissions.[56]

The difficulty of making the necessary changes to food production is evident in the relative failure of farming to cut emissions in line with UK targets or the cuts made by other business sectors. The 2008 Climate Change Act established a target for 2050 of cutting GHG emissions by 80% from 1990 levels.[57] Farming GHG emissions have been cut by 16% from 1990 levels – an average fall of 0.6% or 0.34 $MtCO_2e$ a year – but have not fallen since 2012.[58] Unless this rate changes farming would only deliver a 37% cut in emissions by 2050 against an 80% national target (against 1990 levels).[59]

Farming must cut its GHG emissions and do so quickly. As mentioned in section 2, poor soil management can increase emissions. Conversely, there are many ways soils can be differently and better managed to reduce direct losses of carbon and cut emissions of GHGs related to use of synthetic fertilisers. These range from land use changes, such as converting arable land back to permanent pasture or rewetting peat soils, to changes in approach or techniques such as:

- additions of animal manures and certified composts to restore organic matter and reduce synthetic fertiliser use
- keeping plant residues on the soil or returning straw used as bedding to increase SOM
- no tillage to cut loss of SOM and reduce bare soils
- use of cover crops to prevent bare soils, capture nutrients and add organic matter
- more complex rotations, including fallow periods or herbal leys grazed by livestock
- use of nitrogen fixing plants such as peas, beans and lucerne to cut fertiliser use.

Lastly, appropriate land use and good soil management can also play a critical role in addressing adaptation to climate change by building soil health so that soils are more resilient to more volatile and extreme weather.

IPCC REPORT ON GLOBAL WARMING OF 1.5°C[60]

The latest special report of the IPCC[61] was published in October 2018. It concludes that, to avoid overshooting the 1.5°C maximum rise in global warming agreed in Paris in December 2015 – and to avoid the need for large-scale capture and removal of carbon dioxide – then total global GHG emissions (human generated) will need to fall well before 2030. This means cuts of around 45% from 2010 levels by 2030 and achieving net zero emissions by around 2050. To deliver these would require 'rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems' with 'deep emissions reductions in all sectors' and a wide range of mitigation options including sustainable intensification of land use, restoring ecosystems and dietary change. Some of the far-reaching implications are conversion globally of up to 17 million hectares of cropland and pasturelands to produce energy crops, ending deforestation, and increasing forest cover by 100 million hectares.[62]

3.3 Avoiding economic costs to society

Society derives huge benefits from soil. A fundamental argument for its protection is to maintain those benefits. But placing an economic value on such benefits is extremely complex. A slightly different approach is to assess the costs of soil degradation to ecosystem services – rather than the value of the benefits themselves – including agricultural production, flooding and climate regulation.

Cranfield University researchers produced an analysis of the annual costs of soil degradation for the Department for Environment, Food and Rural Affairs (Defra) in 2010.[63] The total cost for England and Wales was estimated at between £0.9 and £1.4 billion, with a mid-estimate of £1.2 billion a year. Of this 80% – or around £980 million – relates to impacts 'off-site', imposed on society beyond farming: principally flood damage, poor water quality and increased GHG emissions.[64] The remaining 20%, or £240 million, affects farmers themselves in the form of lost production (or £1,660 average per holding).[65]

These costs are enough to show the value of acting to better protect soils. However, for many reasons these costs are an under-estimate:

- The costs assessed are 2010 figures and need to be amended for inflation
- Lack of evidence meant that the cost to significant elements of soil services could not be quantified:

diffuse contamination, soil biota loss and soil sealing. Meanwhile a low figure of £2 million is given for the annual loss of SOM but this reflects only the replacement cost of organic additions, not the lost value of services such as flood abatement, soil health, plant nutrition and resilience to drought. The annual costs of floods and water treatment are estimated to be over £2.3 billion annually.[66]

- The effect of degradation on cultural ecosystem services is omitted because of lack of information. This includes important aspects of public enjoyment of the countryside such as landscape, biodiversity, recreation and heritage.

- Cranfield used a £51 per tonne carbon abatement cost to estimate the annual cost of GHG emissions from soil degradation as £570 million. But replacing it with a social cost of carbon, calculated recently by Stanford University researchers as £173 per tonne, would give an annual cost of £1.92 billion for GHG emissions alone.[67] A case could also be made to add the GHG impact of synthetic nitrate use that could be reduced with better soil management.

Our analysis above suggests the economic case for action on soils is stronger than first appears. Further support comes from examining the total income from farming (TIFF) compared to this level of costs. In 2017 this was £4.35 billion (provisional) and some £2,407 million of this came from public funding (for England and Wales).[68] In addition, overall costs should be considered when government allocates resources to soils research. The resource needed to develop of the evidence base and monitoring tools to drive better soil management is likely to be minimal in comparison.

3.4 Improving the viability of farming

Land use which degrades soils undermines their healthy functioning and can generate significant additional costs as farmers try to make amends. Below we analyse how the different threats to the soil, outlined briefly in section 2, also hamper farmers' ability to turn a profit.

- **Erosion**. Topsoil, which is the richest in organic matter and most fertile layer, is usually the first to be lost. Its loss can weaken root development but also increases the risk of soil drying out or being saturated. Irrigation and nutrients may be needed to compensate and maintain yields.

- **Compaction**. Less porous soils are harder for plant roots to penetrate and can waterlog more easily. Waterlogging creates 'dead zones' with lower soil microbial activity; this in turn restricts the recycling and availability of nutrients. Compacted soils may need twice the nitrogen fertiliser or more to maintain yields.[69] They are also harder to work, needing more fuel and labour, and cause wear on machinery. Aberdeen University estimated cutting farmers' costs in fuel and fertiliser by avoiding compaction could increase gross margins per hectare by £70-£120.[70]

- **Loss of SOM**. The accompanying loss of soil structure, nutrients and water storage affect soil functions and reduce resilience to extreme weather. It also makes soils more susceptible to capping and run-off in heavy downpours, already predicted to occur more frequently.

- **Loss of biodiversity**. This affects soil structure, nutrient availability for plants and levels of pests and pathogens. Ploughing kills off large numbers of earthworms which burrow and, in burrowing, continually aerate the soil and add nutrient rich casts. Micro-organisms produce humus which helps glue soil particles together and reduces erosion. Their loss also reduces the availability of nitrogen and other nutrients – when abundant and diverse they can out-compete any pathogens and pests.

Farming operates under tight margins which can drive short-termism. That it has much to gain from better soil management should be obvious but, as Graves et al point out: 'On-site' users of soils may not be aware of the long-term effects of degradation on the benefits they themselves obtain from land and its soils.'[71] Currently, farmers may be persuaded that managing their soils sustainably may mean they will lose out financially. Future agricultural support must be linked to valuing soil as natural capital as well as the income that can be derived from it. In so doing it must discourage exploitative use and make sustainable management of land and soils make financial sense.

3.5 Losing a finite resource

Some forms of land use are effectively destroying soils for ever. When this occurs, natural capital is lost and the value of the services or 'income' it produces. The land and soils which remain are put under greater pressure as are the natural systems they support. Unless we understand the true cost of what is degraded by a new land use, it is difficult to properly assess how efficiently we are using land and soils as a resource.

In this respect the land take for built development is an ongoing concern. The soil sealing that occurs is often irreversible and rarely reversed. The impact on farmland is our main focus but other land provides environmental services whose loss may ultimately affect farmland. These issues are of heightened importance since the conversion of non-developed land (typically farmland, forest, open and recreation land) to built development is currently occurring at its fastest rate for over 70 years.[72]

Agricultural land take is a major part of this trend and equates to 1% of commercial farmland being lost every decade.[73] This is exacerbated by the continued loss of what is described in planning terms as 'best and most versatile land' or 'the land which is most flexible, productive and efficient in response to inputs and which can best deliver future crops for food and non-food uses such as for energy, fibres and pharmaceuticals'.[74] Research for Defra in 2011 showed that this land continues to be developed despite limited areas of higher grades 1 and 2. Nor is the quantity converted tracked by government. So planning policy is failing to protect this resource despite repeated commitments to do so.[75]

A further complication is that the government's land use change statistics for England refer to change of use to built development based on the footprint of buildings so under-report soil sealed by other hard surfaces for car parks or public space. In addition, soil is also removed from development sites and disposed of. In 2014 over 41 million tonnes of soil excavated during construction work were removed from sites. And a large amount of soil is simply wasted. In 2014 this amounted to 21.69 million tonnes or 45% of all 'waste' buried in landfill.[76]

We are also seeing severe degradation – and sometimes destruction – of deep peat soils. Rich peat soils, particularly in East Anglia, were drained some 3-400 years ago to create some of the most productive, highest grade land in the country. Unsustainable forms of cultivation have shrunk the peat by around 1-2cm a year, amounting to the annual loss of 380,000 tonnes of soil carbon. As a result, 84% of East Anglian peat has been lost since the mid-19th century.[77] At these rates of loss shallow peat soils may disappear entirely within 15-40 years leaving underlying mineral soils which will need organic matter to be productive. Peat shrinkage has also lowered land levels, exposing much of the highest grade land to risk of riverine and coastal flooding which could damage crop production.[78] Added to this, peat is unsustainably extracted both in the UK and EU for horticulture use in England. Sales of peat-free compost remain relatively small – only around 9% of retail sales – with little increase this decade.[79]

3.6 'Slow and clean' water

Soil interacts with water in complex ways and soil degradation alters these relationships. Soil health and quality affect how water infiltrates the surface, is retained in the soil and flows down to the rock layers below. Soil organic matter can act like a sponge – 1% SOM can absorb 225,000 litres per hectare – so holding back and reducing the volume of peak flows, which decreases flood risk downstream.[80] In areas of water stress the ability of soils to hold water may sustain crops and yields at times of drought. By contrast, compaction and soil sealing prevent water soaking through to deeper layers to recharge groundwater and rock aquifers. Greater run-off means higher peak flows in streams and rivers, increasing the risk they will overflow their banks.

Degraded soils with low organic matter and poor structure are more prone to erosion, even on gentle slopes. The impact spreads well beyond the farm. Soil, which should be a valued asset, is deposited somewhere else where it becomes a nuisance. Silt and fine clay particles can be blown or washed off surface soils or via land drains and end up on roads, in ditches, streams and rivers, and ultimately in the sea. Three quarters of sediment pollution comes from farming.[81] In south-west England, on one estimate, up to half of river sediment comes from maize fields alone.[82] Silting of rivers with eroded soil also increases flood risk and dredging costs. It directly affects fisheries by clouding water and clogging gravel beds, so compromising fish spawning and other aquatic life.[83]

In addition the soil particles that are carried away can take other elements with them such as pesticides, nutrients, pathogens and pollutants like heavy metals. Nutrients affect the chemistry and biology of water by feeding algal blooms which starve other aquatic life of oxygen. Carried by the eroded soil, agrichemicals damage the ecology as well as the water quality for consumers and removal or dilution can be costly.[84]

Despite lower applications in recent decades, 50% of nitrate and 25% of phosphate pollution in UK waters still comes from farming.[85] This contributes to the poor status of many visible stretches of water.[86] In England only 16% of these areas are in good overall condition compared to 39% in Wales or 62% in Scotland. There has been no improvement in the past decade.[87]

How soil has been degraded

This section identifies a range of factors influencing how soils have been managed and protected. It covers broader contextual factors related to the economics and practice of farming as well as policy issues.

4.1 The economics and practice of farming

Conventional farming has long been reliant on the steel plough and considerable disturbance of soils to establish crops. While this is known to disrupt soil biology and, over time, reduce organic matter, farming has depended on synthetic fertilisers to mask these effects to improve crop yields. Along with pesticides, artificial fertilisers have simplified the way land is farmed, allowing shorter rotations, often of wheat and oil seed rape. For many farmers there has been little pressure or incentive or willingness to move away from this kind of farming for several reasons:

- The UK implementation of the Common Agricultural Policy (CAP) was production-focused from its inception until the early 2000s and the high-yield approach it favoured is deeply embedded.

- Farmers in most sectors receive direct payments, which can be used to underwrite some of their core costs, so there is less pressure on them to cut inefficient use of expensive resources such as fertilisers and pesticides.

- The ag-chem industry has a vested interest in promoting and selling 'out of the bag' approaches to improve yields and deal with pests; agronomists who advise farmers on their crop management are often tied to the industry and its preferred remedies and approach. Since privatisation of ADAS in the 1980s, apart from bodies such as FWAG or AHDB, farmers lack an independent national advice service to help them consider other low-cost and low-input options.

- The impact of poor soil management linked to maximising yield such as wind erosion and loss of carbon to air and water are not as visible as other phenomena like erosion by water.

- Yields can plateau but fertile, deep soils of high quality can remain very responsive to high doses of fertiliser so soil problems may not become evident for a long time.

- Tight economic margins in farming and low returns mean investing in new approaches and techniques such as direct drilling may appear too risky when returns cannot be guaranteed in the short to medium term.

- Farmers may be more risk averse due to the rising average age in the sector or short-term tenancies or year on year variability in returns of new approaches. Agricultural colleges offer few soils courses so there is a lack of teaching about soil science and management, particularly the physical, chemical and biological properties of healthy soils and their roles and functions.[88]

The continuing pressure to specialise to reduce costs and the chemical fix to soil fertility used over the past half century or so have gone hand in hand with many farms moving away from mixed farming where longer more complex rotations use livestock to add organic manures to the land to rebuild soil fertility and structure. The skills and infrastructure that once supported livestock as part of arable farming have not been needed in some areas over several generations. Moving back to a more integrated mixed model of farming would mean a significant transition for many farmers, with the need for new machinery, different ways of working (that is, business models) and new markets.

Farming has restructured over the post-war period with a higher proportion of larger farms and fewer smaller ones. This means individual farmers manage much larger areas of land and this adds further pressure to simplify the management systems. Applying chemicals is one way to obtain relatively predictable results. Other structural changes have led to more land being managed under contract or under shorter term, Farm Business Tenancies. In these cases, there is less incentive to invest time and money in managing soils today when someone else may reap the benefits sometime in the future. This short-termism also precludes farmers from developing the deep knowledge of land parcels that promotes good husbandry.

As climate change kicks in, farmers are facing new conditions for which the traditional methods may no longer work. Cultivation and harvesting will be more difficult as weather becomes more erratic – hotter, drier summers and warmer, wetter winters are predicted.[89] Safe working windows which avoid soil damage will be harder to identify. In this new context, harvesting winter vegetables on a specific date which retailers demand to fill shelves, or taking maize off land in late autumn can be highly damaging.

4.2 Research and data on soils

Sound policy-making requires evidence from up-to-date research and monitoring of change in soil properties. Despite an excellent science base, further research is urgently needed to fill gaps in our understanding of soils and what they do for us.[90] If soil degradation has not been tackled until now with the urgency and seriousness required, then addressing these gaps should support better policymaking and delivery as well as more efficient land use.

So what are these gaps? First, we lack recent, extensive sampling of soils to assess their current state. The National Soil Inventory took 6,500 samples in the early 1980s and 600 in the late 1990s. The Countryside Survey also sampled soils in 1997 and 2007. Neither have been repeated recently. Scotland and the EU published state of soils reports in 2011 and 2012 but England's dates back to 2004. The EU report recognises the lack of statistical data in many Member States and the need to 'establish harmonised monitoring networks with adequate updating intervals'.[91]

The UK also needs to harmonise soil sampling for different purposes. Sampling does take place to assess land for development planning or for geological surveys or on farm soil mapping. It would make sense to collate and join up this data, to cut costs and make it more widely available. An accompanying challenge is to agree a set of workable meaningful indicators of soil health and, critically, how these change over time.

This information could be used nationally to assess the state of and change in soils as natural capital under the 25 Year Environment Plan. Also, soil monitoring could support farmers' agronomic decisions leading to better soil management – to be rewarded under a new agriculture policy.

Strategic land use planning uses soil maps based on the Agricultural Land Classification (ALC) system including the current 1:250,000 maps of agricultural soils for England. Greater resolution maps are available for some areas. The ALC system dates back to 1966 and sampling to develop these maps took place from the 1950s to 1970s. The maps show the capability of land based on understanding of soils and climate but with a focus primarily on production of arable crops, especially for food. Also, because of their age, they rely on 1940s meteorological data, which doesn't reflect climate change; so the maps can't account well for what extreme weather events mean in terms of access to land.

Lastly, soils face multiple threats but are also expected to deliver a wide range of vital services. But little is known of how their delivery is affected by changes in soil properties and what the thresholds or tipping points might be for a breakdown in those services altogether. We also currently have little information about soils' ability to fulfil different, multiple functions and the win-wins or win-losses of different land uses. Early work was done in 2005 looking at the functional capacity of Hampshire's soils, mapping the pressures and threats they faced. The authors recommended further trialling this framework regionally but this has, seemingly, yet to happen.[92]

4.3 EU and international policy

EU Environmental Directives

The EU implemented important environmental policies on issues including habitats, water, air and noise but not for soils.[93] The Water Framework Directive brought together legislation from across the spectrum of water protection, illustrating the extent of policy development. The European Commission (EC) developed a Soil Thematic Strategy in 2006 and then an EU-wide draft Soil Framework Directive but a minority of key states, including the UK, blocked its implementation. After repeated attempts, the EC finally shelved the initiative in 2014.[94] This means that a range of standards and rules in other Directives apply to soil-derived pollution and its impact on water or air, for example, but not to soil health or protection in their own right. The EU Withdrawal Bill will translate these provisions into UK law but they could be revised thereafter.

The Common Agricultural Policy (CAP)

Soil protection on most agricultural lands has hitherto largely fallen to the CAP, incorporating cross compliance (CC) introduced in 2005, and greening measures in 2013. Agri-environment schemes have also been effective.[95]

CC is an EU-established principle whereby direct CAP payments to farmers depend on adherence to basic legal requirements and additional standards to maintain land in Good Agricultural and Environmental Condition (or GAECs). Payment penalties apply if farms fail inspections. Implementation has been criticised for being too onerous on farmers, in terms of paperwork and inspection procedures, and at the same time ineffective with insufficiently targeted inspections and penalties for the worst offenders.[96] The GAECs include three aimed at protecting soils – GAECs 4, 5 and 6.[97] The main issue here is their scope. For example, GAEC 4 seeks to minimise soil erosion yet permits maize stubbles which provide poor soil cover against water flowing overland. GAEC 6 refers to maintaining soil organic matter but only tackles the burning of crop residues, grass or heather.

A set of CAP 'greening measures' protect both permanent grassland and require some diversity in cropping for arable areas of more than 10ha, keeping 5% of land as ecological focus areas (EFAs).[98] EFAs can include hedgerows, fallow or resting land, legumes, catch crops and cover crops. But while helpful to soil protection and health, the area of farms covered apart from grassland is small. Agri-environment schemes have also rewarded measures that support soil management. Defra estimated that options such as buffer strips at field edges had cut GHG emissions from agriculture by 11% pa by increasing soil carbon in land taken out of cultivation.[99] The current Countryside Stewardship scheme includes similar measures but is targeted largely towards improving biodiversity and water quality.

The 2015 Paris Conference of the United Nations Framework Convention on Climate Change (UNFCCC)

Though successful, formal negotiations in Paris omitted agricultural soils despite the huge quantities of carbon they lock up globally – 1,500 billion tonnes – and the enormous potential for greater storage of carbon in soils to offset GHG emissions. A voluntary '4 per 1000' French initiative was also launched to drive actions to increase the store of carbon in farmland soils at a rate of four parts per 1,000 annually, which, if achieved globally would stop growth of CO_2 from human sources in the atmosphere. The feasibility of this is now debated.[100] Japan, Australia, the UK and other EU nations supported the initiative and it has now also been adopted by the UNFCCC as part of the Global Climate Action Plan. This aspiration has yet to be translated into UK policy.[101]

The UN Sustainable Development Goals (SDGs)

Building on the Millennium Development Goals in 2016 governments across the globe adopted the 17 SDGs under the 2030 Agenda for Sustainable Development. These goals aim to drive actions in an interconnected way to address a host of global challenges including poverty, inequality, climate, environmental degradation, prosperity, peace and justice. The SDGs and underlying targets are meant to be achieved by 2030. Governments have committed to delivering them and to be accountable for doing so.[102]

It could be argued that healthy soils underpin many of the SDGs, but the most soil-related are:

– SDG 15 Life on land[103] includes the goal to halt and reverse land degradation with a sub-target (15.3) to restore degraded land and soil by 2030 and to 'achieve a land-degradation neutral world'.

– SDG 11 Sustainable cities and communities includes target 11.3 refers to 'sustainable urbanisation' with an indicator (11.3.1) of 'Ratio of land consumption rate to population growth rate'.

The UK government believes the best way to meet its commitment to the SDGs is through relevant departments' plans. [104] Defra's plan outlines two actions to address soil degradation:

- restore vulnerable peatlands and work with the industry to end peat use in horticultural products

- design a new environmental land management scheme to deliver outcomes from the 25 Year Environment Plan.[105]

Peatland restoration is vital but, despite an anticipated 'ambitious' new framework for restoration in its peat strategy, the government's 25 year plan limits what may be done for lowland peat soils. It says restoration may not be 'appropriate' so these peatlands will be sustainably managed to extend the life of the soil. How 'appropriate' and 'sustainable management' should be interpreted isn't clear. For degradation of other soils reliance is placed on the Environmental Land Management scheme (ELM) but again it is unclear how degradation could be reversed outside the ELM – if, for instance, farmers or land managers opt out – or what applies for soils not being farmed at all.

There is no reference to soil sealing (built development) as a form of degradation or how to address SDG11 and sustainable land consumption. In fact, the Ministry of Housing, Communities and Local Government's plan refers to communities that are socially and economically stronger but omits the environmental dimension of sustainable communities altogether.[106] This reinforces the view that the government has failed to integrate the SDGs fully into its plans, policies or monitoring programmes. This in turn suggests their interconnected nature is not being reflected in separate departmental plans.

4.4 Policy in England

A number of domestic statements and policies have supported soil protection and management in England in the recent past, but most prominently in 2018.[107]

Policy pre-2018

Action to address soil degradation has been limited in the past decade despite a wide-ranging state of soil report in 2004[108] and the Soil Strategy for England in 2009.[109] In agriculture the UK has relied on CAP measures, principally cross-compliance and agri-environment schemes, to protect agricultural land. Yet cross-compliance measures have lacked the scope and enforcement to effectively protect soils specifically.[110] Agri-environment schemes have been valuable, particularly for biodiversity and habitat protection, but their coverage is partial and funding too small to arrest a pattern of overall species decline. Soil has been protected indirectly by measures targeting water quality driven by the Water Framework Directive. But soil health was not the primary goal.

Other than important initiatives to restore peatlands, soil carbon has also largely been ignored – despite early ambitions in the Defra Soil Strategy to cut losses. The Climate Change Act 2008 has been a critical piece of legislation for setting targets and driving action on CO_2 reduction but this has not been evenly shared across the economy. Farming has been slow to address the issue, not least in cutting soil emissions from cultivated peat. Ending peat use in horticulture has been a policy goal since at least 2009 but one not carried through. The 2011 Natural Environment White Paper (NEWP) *The Natural Choice: securing the value of nature* relied on voluntary initiatives, which broadly failed, instead of action as might be expected.

In addition there has been no political will to protect soils from sealing through built development. The NEWP did not acknowledge the threat despite research for Defra in 2011 showing planning policy failed to protect so-called 'best and most versatile' land, the highest graded for its productivity and flexibility of use. The new National Planning Policy Framework (NPPF) in 2012 also failed to bolster protection for these soils. In fact, the test for using other land in preference was weakened.[111] The NPPF also established a new 'presumption in favour of sustainable development' which has, ironically, undermined planning authority powers to stem unsustainable speculative development. So, high quality soils continue to be allocated for development in local plans. Average rates of building on agricultural land have tripled since 2013 compared to the 2000s.[112]

2018 policy

In 2018 three major policy documents emerged, each significant for soil management and protection. A fourth, an English National Peat Strategy, is awaited. From these it is clear that soil is much less of a Cinderella policy issue than before and the overall progress is encouraging. Yet important weaknesses remain.

The self-avowedly ambitious 25 Year Environment Plan reaffirms earlier goals to manage all soils sustainably by 2030, to end horticultural peat use and to develop tools and metrics to better understand soil health and assess progress under the plan. However, the plan delivers no plan of action that covers all soils nor does it explain what to 'sustainably manage' them would mean on the ground. Soil health is not of itself a major policy goal like clear air or water. The plan appears equivocal as to whether soil is a natural capital asset to be protected or a depletable resource so the threat of soil sealing from built development is not mentioned nor urban soils generally addressed. The metrics being developed to assess plan progress

will be critical to ensuring soils are given the prominence due to them for sustaining multiple ecosystem services/benefits.

The infrastructure and funding to deliver 25 year plan goals for farming are set out in the new agriculture policy set out in the Agriculture Bill, an accompanying policy statement, and developed via the Future of Food and Farming consultation. The new policy contains an overarching principle of public goods for public money and aligns environmental enhancement with productive farming. For this reason ensuring improved soil health emerges strongly as a policy objective. Soil and peat are named as candidates for public goods payments under the new system and a new Environmental Land Management Scheme (ELM) will reward farmers for environmental improvements. Examples in the consultation of actions to support soil health suggest what may be supported such as cover crops, grass leys, planting shelter belts and peat rewetting. Reading across the 25 year plan and the new agriculture policy there are important omissions: the difference between soil health and soil quality is blurred; the role of soil biology in soil health and nutrient cycling is missing, as is the potential to increase carbon storage and cycling in arable and grassland areas.

The third key document, the first major revision of the NPPF, was published in July 2018. The main focus of this policy is to manage the delivery of housing development, but it also addresses land use change and the need for sustainable development. There are improvements here on the earlier version, including recognition of the benefits of natural capital on undeveloped land, stronger tests to protect designated areas from major development and guidance on the efficiency and optimising of land use, reuse of buildings or their extension and more focus on brownfield land.

There is much good guidance for – but not a requirement on – local authorities in plan and decision-making which is intended to protect natural resources, including cherished landscapes, 'best and most versatile' (BMV) land and important geological soils and enhance biodiversity. In contrast, the NPPF places key constraints on councils to deliver development through the market such as by requiring a five-year land supply and delivery of homes, despite authorities' inability to control build out rates. This tips the balance in favour of market-led growth, not sustainability proper. There is indeed no overall planning purpose to manage land sustainably. This conflicts oddly with the 25 year plan which seeks to enhance natural capital, use resources efficiently and manage land sustainably. Also, underlying the NPPF is an assumption that undeveloped land is 'open for development' to deliver maximum economic benefit whereas shortage of land is seen as a local issue, not an overarching environmental constraint. This has consequences for the amount of soil sealing, loss of land and its soils for productive agriculture and other environmental services as well as potentially for inefficient use of a scarce, finite resource.

Finally, the development impact on broader ecosystem services is not well addressed. While the principle of avoid, mitigate or compensate for is applied to biodiversity loss, it is not applied to other services such as regulating water (to reduce flooding), storing carbon or food production. There is potential for these to be better protected on site and compensated in ways that could increase the efficiency – and indeed economic benefits – of a given development on a given site.

Overall policy in this area and over the past decade suggests much good intent but too little effective change, given the relationship of soil health to the wider environment, the challenges soils face and the urgency of action on carbon. 2018 has seen very important progress, but it is too early to say whether broad commitments such as the 25 year plan will have the funding, regulatory powers and legislative backing to be delivered by specific actions.

Changing our approach to soil

This section proposes five innovative ways to help achieve the goal of 'sustainably managing' the nation's soils. These are intended to be practical solutions to reduce the degradation of soils and, where possible, regenerate them. Each subsection sets out the concept, indicates how it works and explores its benefits and opportunities as well as the potential barriers to uptake.

5.1 Conservation agriculture (CA)[113]

Conservation agriculture (CA) aims to restore soil health by building up organic matter, biodiversity and fertility. It is a set of management techniques that combine three principles:

Minimum mechanical soil disturbance

This means minimal or no tillage of the soil. It is a critical shift from traditional inversion ploughing to burying surface weeds and seeds and creating a clean, fine seedbed for sowing. This involves no ploughing to invert the soil, but shallow scratching of the soil surface with discs, tines or blades to plant seeds, often followed by a roller to 'bed in' the seed. Seeds are planted directly into the soil with existing crops or crop residues, using a 'direct drill'.

Maintaining organic soil cover

Typically this involves preventing bare soil by keeping it covered with vegetation, either in the form of plant residues – such as stubbles after harvest or mulches like straw – or planting a new green cover or main crop. Undersowing existing crops like maize with companion crops such as ryegrass is also possible. A range of species are used as cover together with companion crops such as oats, mustard, radish, vetch, lupin and clover.

Diversification of crop species[114]

This can be done in several ways: switching from a simple rotation such as wheat-wheat-oil seed rape to a longer rotation to include more plant types in order to cut disease and pests and build fertility; introducing mixed species into the rotation by intercropping and companion cropping; or mixing perennial and annual species where layering can provide multiple benefits in terms of capturing sunlight for longer through the season and nutrients at different soil depths.

What are the benefits?

CA has many benefits for the farmer and wider society. There are overlaps between the techniques and, though each can be used separately, combining them, as CA does, increases the benefits and synergies between them. For example, when combined with cover crops 'no till' can bring erosion rates much closer to natural levels but this does not happen when used in isolation.[115]

Soil health and other benefits to productive farming

Ploughing can be destructive to soil health. Typically, it erodes soils 10 to 100 times faster than soils form. As a result it causes continuous loss of both topsoil and organic matter when exposed to the air. Numerous studies show the benefits of leaving the soil alone. [116] It can largely stem the loss of organic matter from inversion ploughing – one researcher saw carbon emissions from ploughing cut from 35.3kg per ha to 5.8kg per ha.[117] Similarly, not cultivating soils intensively allows natural systems to rebuild soil health. Fungal threads and earthworms are also more likely to be kept intact in minimal or no tillage systems than in plough-based ones.

'No till' is usually a single field operation with a direct drill or something similar. This drastically cuts tractor traffic and so reduces compaction. Ploughing, especially on heavy clay soils, can be demanding on tractor power and time. A single pass with a direct drill disturbs the soil much less. Over time soil structure improves, making drilling easier. Less tractor power, labour and fuel use and reduced tillage (min till or no till) can bring dramatic savings. Studies show a 73% fall in fuel use and labour savings of 52 minutes per hectare in no till compared to conventional ploughing.[118]

Ground cover and cover crops

A central reason for covering the ground is to protect soil from rain and wind and so reduce erosion. Surface cover also prevents weeds germinating. Cover crops draw in and store nutrients which heavy winter rain can wash away. These nutrients are then released slowly for the next crop as the cover crop breaks

CASE STUDY

CONSERVATION AGRICULTURE; NO TILL; COVER CROPPING; HERBAL LEYS; MOB-GRAZING[i]

Weston Park Farms, Weston, near Stevenage, Hertfordshire

Brothers John and Paul Cherry have managed the farm at Weston for over 30 years. It is a family-owned mixed farm with 800 hectares of arable, mainly combinable crops – wheat, barley, oats, oil seed rape, beans and peas – on boulder clay soils along with beef shorthorn cattle in a 140-strong suckler herd. The cattle graze 160ha of permanent grassland and 40ha down to four-year herbal leys as part of the arable rotation.

In the 1970s and 80s they, like many, were enthusiastic about chasing high yields with maximum ploughing to create the finest seed bed and using plenty of fertilisers, chemicals and other additions. But over time this took its toll on their arable soils, especially when compared to the permanent pasture. At a loss as to what to do John visited two no till farms – Simon Cowell's in Essex and Tony Reynolds' in Lincolnshire, both working heavy clay soils – and had a revelation. Giving up cultivating suddenly made sense. The farm experimented with minimum till but John concluded that cultivating down even 5-10cm was still disastrous for the 90% of soil life that sits in the topsoil and organic matter lost to the atmosphere. The farm moved to a full no till system from 2010.

The farm follows the three main principles of CA – no cultivation, using cover crops where possible and diversity in the rotation. John explains that not ploughing avoids disrupting the micro-organisms, including the fungal threads that drive the biological life of the soil. Diversity in the rotation and particularly breaks with herbal leys – with mixtures of shallower and deeper rooting grasses and broadleaf plants such as clovers, trefoils, sainfoin, plantain and chicory – suppresses grass weeds like blackgrass. The brothers are also experimenting with intercropping and undersowing cereals with clover to fix nitrogen. The leys are mob-grazed and all the cattle are fed on pasture or silage and straw. The cattle are so healthy on this diet that they do well without supplements. The vet is rarely needed. The herd comes in for the harshest winter months and onto straw which is then composted – 'to get more soil life into it' – and added back to the land.

The transition to no till has not been without problems and John and Paul have learned from mistakes along the way. Weeds and slugs have been a challenge. They have sometimes silaged weedy crops when they had to but the leys, fallows and spring cropping have helped. Weed seeds also stay on the soil surface where they can be eaten more easily or germinate and die. Slugs were tackled with pellets in the early years but the problem is easing as soils become healthier and support more beneficial predator species. Finding a good break crop for the cereals is also an issue, especially legumes that can fix nitrogen.

The benefits have been significant. With no till the brothers need fewer tractors so machinery costs are well down, including capital outlay, fuel and depreciation. Staff get to go home at 4.30pm while neighbouring farmers are working their fields day and night. They use far less fertiliser and chemicals but add some urea and use some glyphosate to kill off cover before drilling. Yields are down and can vary but costs are down more. The farm has other income streams which help buffer the business and enable them to experiment but John adds: 'The farm has to pay a rent and make money; it's not a charity. But the farm as a whole is making more money than it was before so financially and ecologically it's better off. The soil is getting better every year and so our capital base is growing every year.'

John's passion and enthusiasm for what he does is inspirational. He is excited about the year-on-year increase in wildlife that is 'feasting on all things living in soil or things living on things in soil' – including flocks of wagtails, skylarks, red kites, crickets and grasshoppers in abundance. He's also excited about the potential of farmland to help reverse climate change and shift carbon out of the atmosphere and into the soil where 'it could do so much good'. He cares deeply about the soil and can see its potential to improve. But the brothers' greatest achievement to date is to have successfully launched the first dedicated no till show and conference in the UK – Groundswell. Hosted on the farm each June this brings together engaged and innovative farmers and scientists from across the globe to learn from each other about soils and how farming can contribute to one of the most urgent issues of our time.

[i] In mob grazing fields are grazed for a short period then pasture is left to rest for long periods to build leaf and root structure before animals return.

down. Depending on the species selected, nitrogen and phosphorus levels can be increased as can plant residues in the soil.[119] This improves structure, organic matter levels and biological activity, including earthworm numbers. Lastly, greater biodiversity and deep root development can also lead to storage of more carbon.

Crop rotation and diversity

Alternating different crops benefits soils in several ways. They can rebuild fertility after soil-exhausting crops such as cereals or root vegetables; control weeds and pests such as blackgrass (a major issue for arable farmers) which copes less well in a grass mix; build soil biodiversity, and provide fodder to bring livestock into the rotation. Ongoing research testing mixes of cereals and legumes show these do better in combination than cropped singly in monocultures, tapping into what has been called the 'Darwin effect' – that is, when selected plants are grown together they 'overyield' by up to 50%.[120 121] This suggests plants work in synergy rather than competing for space, in similar ways to mixes of perennial and annual crops in agroforestry or permaculture. The diversity created by cover crops and undersowing helps pollinators and other wildlife. This can mean more pests but also species that prey on pests.

Wider system benefits

The wider benefits associated with conservation agriculture include:

- reduced erosion, loss of nutrients and soil to watercourses, leading to cleaner, healthier water bodies
- lower use of synthetic fertilisers and pesticides thanks to healthier soils with fewer pathogens
- less fuel use, so cutting energy demand and direct GHG emissions
- more in-field and between-fields diversity, creating richer habitat for wildlife
- more resilient soils enabling farming to do better in challenging conditions – for example, drought and extreme rainfall – so supporting food supply security
- more carbon locked up in soils, so helping reduce atmospheric carbon which contributes to climate change.

What are the barriers?

Conservation Agriculture (CA) is already widespread in the Americas because of its water retention properties in drought-prone and hot areas. Globally over 150 million hectares of cropland is managed this way with 42% of cropland in South America and 34% in the USA and Canada.[122] The estimated take-up of CA in the UK covered only 8% of arable land in 2016.[123] There must be scope to increase its adoption in this country but scaling-up will depend on CA being seen to work in differing conditions and over a number of years. This will include overcoming some of the barriers suggested below.

Soil type is a key limitation to CA effectiveness. Reduced tillage works better on sandy or loamy soils. On clay soils CA may do less well because of higher moisture in winter soils or lower spring temperatures. Issues can also arise with removing plant residues or 'trash'. Weed competition can be a problem in earlier years as can an increase in slugs. The Allerton Project at Loddington, Leicestershire is currently trialling CA on heavier clay soils but examples already exist of farmers successfully using CA on clay soils over the long term (see case study on page 21).

Cost is a further significant issue with most expense incurred before farmers see the benefits. Specialist seed drills are needed which cost around £100,000 or more. Farmers may initially find it more cost-effective to employ contractors with the right equipment than investing large amounts in a new technique. Specialist seeds for cover crops are an additional cost, though savings can be made by using a baseload of seed from a previous crop such as oats and adding bought-in seeds to boost cover crop diversity. In addition, yields may fall for the first two to four years of CA though they are likely to improve thereafter.[124]

Falls in output and other costs can be offset by much lower input costs for fuel, labour, tractor horsepower and fertilisers. However, chasing yield has long been the rational choice for farmers as they produce more to gain economies of scale given that returns on crops are often low. Concentrating on net profit, not yield, through reducing inputs as CA requires may mean farmers have to take a different perspective.

A study investigating what influences CA uptake found the main challenge in England was the uncertainty of results and profitability.[125] This uncertainty reflects the lack of adequate information and research. Research projects are often too short – around three years – to show CA's benefits over the longer term. Most research has been conducted abroad, where different growing conditions make the studies less relevant for UK farmers.

The bulk of information available on CA is farmer-driven, which can be very useful and practical but is not necessarily backed up with empirical data.[126] This may also be compounded by the planning needed to implement it. Brewin argues it needs to be well managed and part of a wider management plan for the farm that is adapted to local context and conditions.[127]

5.2 Agroforestry

Agroforestry brings together arable crops or pasture with trees that are harvested for timber, fuel and fruit to harness the benefits of farming and forestry and the synergies between them.[128] There are several forms:

- forest farming – planting crops in layers or multiple storeys under the tree canopy
- tree belts planted as windbreaks or to stabilise riverbanks (riparian strips)
- silvopastoral – adding trees to a grazing system, or, less commonly, pasture added to forestry
- silvoarable – combining arable/horticultural crops with trees.

Agroforestry is widely recognised in continental Europe and the USA. The EU 27 countries host around 15.4 million hectares of agroforestry, with over a million hectares each in Spain, France, Italy and Portugal.[129]

In the UK the practice of agroforestry is limited, but this is changing. As the concept becomes more familiar it may force us to re-evaluate many familiar aspects of the English countryside which could properly be described as agroforestry: grazed forests and orchards, wood pasture and parklands, shelterbelts and managed and relic hedgerows.[130] If we interpret it as the combination of perennial bushes and trees with annual crops such as grass then the UK may already have over 550,000ha of agroforestry plus some 500,000km of hedgerows.[131]

What are the benefits?

Agroforestry provides a range of goods and services of benefit to farmers, the land and soil, the countryside and society.

Soil health and other benefits to productive farming

Trees protect soils from erosion in three main ways. First, they provide shelter from wind, sun and rain. Trees in rows, belts or blocks offer wind protection up to a distance of 10 times their own height. At the 9,000ha Elveden estate near Thetford, Norfolk, extensive belts of mature Scots pine provide vital shelter for the light sandy soils of the Breckland.[132] In many areas hedgerows do the same. An added benefit for protection from drought is that tree shelter reduces water loss from the soil and the crop. French research shows reduced wind speeds cut evapotranspiration in crops by 30%, so reducing irrigation demands.[133] Tree shelter can also create a more moderated microclimate which helps protect seed beds and growing crops from the elements, particularly wind, heavy rainfall and sun. Indeed, extreme rain can lift and wash away young plants.

Second, they add valuable organic matter to the soil through leaf litter which is drawn down and decomposed by soil organisms. This improves soil structure. The role of tree roots and leaf litter can go further. Tree roots can penetrate more deeply and into different soil layers than most annual crops or grasses. This means they can draw up water and minerals from underlying rocks and soils and capture leached nutrients to return them in leaf litter to the upper layers of the soil. As a result, research shows, nitrogen losses in agroforestry can be up to 50% lower compared to conventional cropping.[134] Some tree species such as alder and robinia also fix nitrogen, which then feeds crops via leaf litter.

Where tree leaves and roots combine with annual crops and grasses in agroforestry systems, the perennial layer adds productive capacity to a given land area over space and time. Combining trees and/or bushes with crops or grasses maximises the sunlight captured by plants on any given plot. The perennial layers add leaf area which captures sunlight for more of the season, especially post-harvest.

And third, tree roots help stabilise soils and improve infiltration of water. Rows of trees, planted across the slope, along the contour line, or as buffers at field edges and next to water courses, can slow and capture run-off, so reducing soil and nutrient losses to water courses. Introducing trees to arable areas has been shown to reduce soil erosion by nearly two thirds.[135]

Another signal benefit from integrating trees with crops and livestock is that they harbour a greater mix of wildlife such as birds, insects and invertebrates that are predators of crop pests like ground beetles, parasitic wasps and ladybirds. This means lower pesticide use, costs and load on soils. Trees also provide valuable shelter for livestock. In exposed areas, particularly uplands, protection from the elements is important and can cut mortality and improve growth rates. Tree protection can extend the grass growing season, enabling animals to stay longer outdoors and cutting costs significantly for bedding, fodder and slurry management. Poultry also lay better quality eggs when they can range in woodland with 20% tree cover.[136] Some farmers are also planting trees with nutritional and medicinal properties for livestock foraging to improve and diversify diets and so aid digestion, cut parasites and reduce ailments.[137]

As productive crops, trees also benefit from silvoarable and pastoral systems. Wider spacing means less competition from other trees which increases capture of sunlight and growth in tree widths. Experimental plantations have shown increases in tree diameter growth of over 80% in six years.[138] Planting fewer trees also offers potential cost savings with little need to thin or clear undergrowth and some nutrient gained from associated cropping and livestock. Breaks

CASE STUDY — AGROFORESTRY; COMMUNITY AND CONSERVATION FARMING; EDIBLE WOODLAND

Home Farm, Screveton, near Nottingham

David Rose farms 200 hectares at Screveton on land his grandfather farmed in the 1930s. David originally built up the family business, forming a large-scale co-operative with three other farmers which managed 2,400 hectares of mainly arable crops. Yet, despite the scale, the economics were marginal and dependent on CAP payments. With input costs rising, fluctuations especially in land area could threaten the finances of the business, making it a high pressure way of working. In 2012 David left the partnership to find a more rewarding way to farm.

A root and branch review of the farm's future led the family to focus on the family business, on the environment and engaging younger people in the farm. David had long felt that direct payments to farmers couldn't last and that if support for the environment is the future, then greater public access is a must. As he explains: 'People need to understand the value of their food and see what the costs of producing it are as well as the costs of managing the environment and creating a countryside to live in and enjoy.' A first step was to bring in a young, local farming family keen to take on extra land and they are developing the arable business under a share farming agreement. The farm returned to being mixed with arable and 200 ewes now graze grass as part of the crop rotation.

Adding more trees was a logical step. They already featured on less productive land planted up as game cover for the local shoot. But a key influence was a Nuffield conference where David heard and was inspired by agroforestry pioneers Stephen Briggs and Tim Downes. He realised how bringing trees into the farming system could protect the soil, improve crop yields, attract and encourage wildlife, including pollinators, provide shelter and shade to animals and create new streams of income. They could also make the landscape more attractive to the people he wanted to bring onto the farm. With advice and support from the Woodland Trust, 11,000 trees have now been planted over six years: in shelter belts, connective corridors and lines of fruit trees in crop fields. A 6ha 'edible woodland' has also been planted with a host of fruit and nut species such as walnut, almond, medlar, apple, pear and cherry.

David expects the trees to put life into the soil and for tree roots to help with compaction. The farm is the subject of a 20-year study by Elm Farm Research Centre looking at many aspects of the system, including soil structure, acidity, biodiversity, insect populations, airflow and yields. There are some challenges. Weeds have started migrating from the tree strips into the crops, pushing up some costs, but David is trialling different crops and techniques such as putting the land into grass as part of a five-year rotation.

And what of the future? David feels there needs to be extra income from the market, perhaps through accreditation schemes like LEAF Marque and Red Tractor, to reward sound environmental management coupled with food production. He sees greater public access as key to getting the support farmers need and he walks the walk. He has set up an energy efficient eco-education centre with a vegetable garden, livestock paddocks and nature trail, which hosts regular visits from school children, as well as a farm shop and café. In 2018 a huge get-together attracted over 600 people from all backgrounds and cultures. And the next step is to offer local people shares in the edible woodland as part of a community benefit society which will give them a real stake in the farm's future as a community farm for conservation farming.

in tree lines can cut the risk of spreading pests and diseases such as in apple orchards where pesticide use conventionally tends to be high. It can also cut fire risk, an increasing issue as our climate heats up. Finally, alley cropping could encourage production of high value timber trees that forestry rarely produces such as walnut, pear, wild cherry and maple.

Wider system benefits

The wider benefits associated with agroforestry include:

- Tackling climate change – hedgerows, rows of trees and shelterbelts can all be harvested for timber and renewable fuel, cycling carbon from the air but also increasing carbon locked up in root systems. Agroforestry reduces competition between trees compared to forestry plantations. This means root systems of trees are nearly a third larger than in plantations and this increases the overall carbon stored by the system – reaching 41 tonnes per hectare, according to French research, and producing 50% more SOM than in single arable crops.[139]

- Water and flood management – trees capture rain in leaf cover and aid infiltration of water, which can lower flood risk. Research at Pontbren in mid-Wales shows predicted peak water flows reduce by 20% in shelterbelts and by 60% with full tree cover.[140]

- Increasing biodiversity both in trees themselves and their understorey – agroforestry can cover just 5% of a land area but represent over 50% of the biodiversity supporting birds and insects.[141]

- Diversity in outputs and markets – agroforestry reduces the risk producers face of exposure to single commodity markets and creates a more diverse, financially more resilient land-based rural economy. This has benefits for jobs in forestry and processing of products such as timber, orchard and soft fruits, nuts and juices and ciders.[142] Value can be added by marketing products for their environmental and welfare credentials. [143]

- More varied landscapes – it creates variety in areas dominated by monocultures such as wheat and oilseed rape.

What are the barriers?

There was little government support for agroforestry in England until as recently as 2017. So there are policy, as well as financial and practical, barriers to broadening its uptake. Some of these have been set out by the Soil Association and Woodland Trust:

- Separation of forestry and agriculture in English policy leaves agroforestry stuck between the two in a policy void.

- Existing CAP/rural development funds echo the policy confusion, so tree densities in agroforestry are too high for the land to qualify for direct payments (BPS) yet not high enough for woodland creation grants.

- Existing farming/forestry advice networks offer little information or guidance.

- Existing short-term tenancy structures hinder long-term capital investment in trees.

- There is a lack of processing capacity to support development of innovative products from agroforestry systems.[144]

We can add other issues. Undoubtedly some farmers have an aversion to trees because their shade reduces daylight hours, temperatures and soil moisture, so will see them as incompatible with producing good arable or grass crops. There are solutions though. Planting on a north-south axis in rows spaced at 10m to 14m maximises available light to the crops and enables machinery to cultivate and harvest the alleys. Trees can be pollarded, coppiced, cropped or pruned to reduce shade effects.[145] Disseminating information on the benefits, costs and solutions to problems is key to wider adoption and part of changing attitudes and mindsets of land managers. Another significant challenge is the capital cost of tree planting, including equipment, guards, fencing and treatment to suppress weeds. Investment may yield no return for timber for decades and several years for fruit and nut harvests. Lastly, a different set of skills is needed by farmers/foresters crossing over to manage agroforestry systems. These skills may also alter over time as the trees grow and the system itself develops.

5.3 Pasture-based livestock farming (PBLF)

The UK climate and soil is ideal for producing grass. Pasture-fed systems can work on lowlands to uplands. They rely on ruminants – typically sheep and cattle – that can thrive on grass and species of wildflowers and herbs to produce high quality meat and milk. [146] The animals feed on pasture or grass-based forage (hay, haylage, silage)[147] as winter feed or supplement for the whole of their lives up to slaughter. Pasture-based farming can work with a range of other systems, conventional or organic. There are different types of pasture, including herbal leys, temporary or permanent pasture, and unimproved grassland such as meadows and moorland. PBLF can be used with set stocking systems – where animals stay in the same area for much of the grazing season[148] – or with forms of 'mob' or rotational grazing where livestock are moved onto fresh pasture at regular and short intervals. The main restriction of PBLF is that grain or other supplements and concentrates cannot be used if products are to be certified by the Pasture Fed Livestock Association (PFLA).[149] For this reason the system is not to be confused with 'grass-fed' where, according to Defra, only 51% of the animals' diet has to be grass or grass forage.

What are the benefits?

There are growing concerns about the environmental impact of eating meat, particularly beef, because of its carbon footprint. If we choose to continue to eat ruminant meat – but less and of a higher quality – then it seems evident we need to find the optimal way to produce it. Below we look at the range of benefits offered by PBLF, which suggest it is a desirable replacement for more intensively reared livestock systems as part of a transition to lower-impact farming.

Soil health and other benefits to productive farming

Pasture covers and protects the soil. Animal manures and plant roots enable soil fertility and organic matter to build. PBLF makes best use of permanent pasture but also, by reducing demand for cereals, could bring back pasture into rotations. This could help to rebuild soil fertility and carbon that have been depleted by arable cropping. PBLF can amplify these benefits by emphasising mixed species pastures to deliver the quality of forage that is needed to support robust animal growth and health. Instead of the typical rye monoculture, PBLF uses a rich mixture of diverse grasses and broad-leaved plants. This includes legumes such as clovers and vetches that fix atmospheric nitrogen in the soils through their root nodules.

With appropriate management, mixed pastures can build up soil fertility for subsequent crops without the need for inorganic nitrogen which can leach into, and pollute, water systems. Species diverse pastures are also a richer habitat for soil life – microbes, insects and invertebrates – that build soil health and underpin the food chain of insects, birds and mammals above ground. This extends to wildflowers that feed insect pollinators. Sward diversity [150] means a range of species have different rooting depths. Deeper-rooted species like chicory or sainfoin take up nutrients at lower levels, open up the soil structure to water and air and are more drought resistant than a shallower-rooted rye pasture. Deep roots also store soil carbon at lower levels where it is less likely to be disturbed. Mob-grazing systems are very promising in this respect. They can foster stronger root systems by leaving more leaf area on plants which prevents root growth being retarded.[151] Carbon is added to the soil too as animals trample plant material into the ground. Recent research from the USA has shown average carbon sequestration of 3.59 tonnes of carbon per hectare per year in mob-grazed pastures.[152]

Raising sheep and cattle on upland and lowland livestock and mixed farms is an economic challenge and many producers currently rely on public funding to carry on their business. But research from the PFLA shows pasture-based farms can achieve similar or better profit margins than some of the best conventional producers.[153] Relying on forage alone can mean reducing livestock numbers and total output. However, cutting inputs such as concentrated feeds can bring costs down dramatically and so improve profits. Net margins – after costs – compare well to top producers. [154] Gross margins can be very healthy – particularly for breeding ewes and finishing beef cattle to slaughter. Figures are boosted by the premium price that PFLA-certified meat can attract.[155] Certification costs relatively little. Animals grazing on herb-rich grassland also have a more diverse diet which can give better natural protection from disease and pests and therefore cuts the need for pesticides, antibiotics and veterinary care.[156]

Wider system benefits

Feeding animals on pasture rather than cereals brings other environmental benefits. A large proportion of cereals are grown for feeding livestock – City University estimated this accounted for around 43% of such land in the UK or 1,347,000ha in 2014.[157] Conventional beef production uses some 1.25m tonnes per year of grain – or 10% of UK production from 150,000ha of land – with grain fed to sheep requiring another 16,000ha.[158] Replacing cereals with pasture avoids the harms of conventional arable production. Removing reliance on ploughing and synthetic chemicals cuts the inputs of fuel, fertiliser and pesticides required and the heavy environmental load in GHG emissions and damage to soils, water and wildlife. It removes risks from cultivation, including compaction, erosion, loss of organic matter and soil biodiversity.[159]

Well-managed hedgerows also have an important part to play in pasture-based systems. They provide shelter and shade to animals but also soil and water protection and wildlife habitat, hosting predators that can prey on crop and other pests. Hedgerows also add to the patchwork character and intimacy of many cherished landscapes and grazing livestock provide incentives for farmers to manage hedgerows well.

Raising animals on pasture produces a high quality product. A successful pasture-based system relies on choosing the right breeds with the right genetics and 'good grassland management'. For beef, traditional breeds such as Hereford, Longhorn, Red Polls and Highland cattle thrive on pasture alone but their meat is also some of the tastiest. This also translates into quality of nutrition – there is good evidence to show that pasture-fed meat has higher levels of omega 3s and 'conjugated linoleic acids': that is, the healthy fats needed in our diet and in the right proportions to omega 6. It also has a lower overall fat content.

What are the barriers?

A recent interim report by the PFLA considers the benefits of pasture-based livestock farming but highlights several barriers to wider adoption:[160]

- There is no legal definition in the market for terms such as 'grass-fed', 'pasture-fed' and 'grain-fed' in the UK. This means consumers have no certainty about how ruminant animals were fed or raised apart from the PFLA's own and organic certification.[161]
- Beef and sheep meat are marketed in ways that focus not on how they are produced but on things such as breed, country (for instance, Scotch beef, Welsh lamb), how meat is matured and basic assurance such as Red Tractor labelling.
- The environmental impact of grain-fed livestock production is external to the farmer and hidden. It includes the inefficiencies of nitrate (N) and phosphate (P) fertiliser use to produce grain to feed livestock – only a quarter of the N and P in feed ends up in the human diet.[162]
- There are complicated issues around how to assess the environmental impact of meat production – particularly beef – especially in relation to the carbon cycle and climate change.[163]
- There are other complexities in the pasture-based system which requires good grassland management and where inefficiency cannot be masked by feeding with grain.

CASE STUDY PASTURE-FED LIVESTOCK WITH MOB GRAZING; OUTSTANDING LANDSCAPE; HERITAGE FARM BUILDINGS; WILDFLOWER RICH MEADOWS

Romshed Farm, Underriver, near Sevenoaks, Kent

Romshed is a 70-hectare historic farmstead sitting within the High Weald Area of Outstanding Natural Beauty. Listed buildings include a 15th century tiled Kent barn and now rare Victorian pigsties. Most of the land is down to grass with 10ha of cereals, 10ha of woodland and a further 20ha rented as late summer conservation grazing. The farm sits within a typical Wealden landscape of small, well-hedged fields, woodland strips and wildflower meadows.

The farm was run down and buildings derelict when Fidelity Weston (below) and her husband Martin bought it in 1984. They set about renovating and managing it with conservation and wildlife firmly in mind. It was a rational choice to run it as a low input farm and to convert to organic when grants became available in 2000. The main livestock are sheep – 150 Lleyn ewes with 200 lambs – and a herd of 60 Hereford cattle with a resident bull. All are reared on pasture and wildflower-rich forage and spend as much of their lives outdoors as conditions allow. Organic conversion meant the farm stopped using nitrate fertiliser and initially this reduced the quantity of fodder produced. But after two years clovers, vetch and trefoil built up nitrogen levels, adding bulk, and the swards became as productive as ever but progressively more diverse. Without added nitrate ryegrass became less dominant and allowed dormant seeds to germinate, leaving swards with ever greater levels of diversity. Around 40% of the land now has 15-40 species per square metre, a level usually only seen in unimproved grassland.

Fidelity was keen to raise the profile of her grass-fed animals for her direct sales of organic meat to customers and this led her to the Pasture Fed Livestock Association (PFLA). The meat produced is now PFLA-certified and 100% grass-fed. This adds value to the product and she sees more people interested in buying her local meat for its quality, high animal welfare and the connection it offers to a local farm. Customers can visit and take a walk around to see its benefits for themselves.

Fidelity values the PFLA as a community for sharing knowledge. Visits to two PFLA farms in Kent inspired her to trial mob grazing at Romshed from autumn 2017. Cattle are now moved regularly every one to four days from paddock to paddock to fresh grass and managed with a lightweight electric fence. The principle behind the mob-grazing system is to allow animals to eat one third of the grass and trample one third into the ground – eventually building soil carbon – while a final third is left to capture sunlight and regrow. If overgrazed the plant will deplete its roots to build new shoots, leaving shallower roots. If properly gauged and grazed, the plant recovers more rapidly and roots more deeply with advantages for plant and animal nutrition, soil carbon and resilience. Fidelity is learning to assess grass levels by eye and judge when to move cattle on. The hope is that improved pastures will enable livestock to stay out for longer and cut overwintering costs for bedding, fodder and labour. Eventually the mob grazing may allow the farm to increase its stocking rates.

Romshed Farm produces high quality food sustainably for a good price – and it has cut its costs. It is supporting good soils, rich conservation pastures and beautiful landscape. These should all stand the farm in good stead for the changes in farming policy and funding ahead. But the ideal for Fidelity would be a market which recognises pasture-fed and rewards farmers for doing what is good for the land, the livestock and the people who are fed by them.

To these we would add a few other challenges:

- It will be difficult to counter a well-established and now conventional approach – feeding grain to beef started in the 1960s to make use of surplus barley – and to resist pressure from the feed industry wanting to sell concentrates and supplements.
- The dominant focus is on high output/high yield production which has developed over decades during the CAP and in response to increasingly low margins from the market.
- There are few incentives to take risks and change systems in the livestock sector of farming, which generally struggles to make a net profit and is highly dependent on public funding.
- Farmers will need to develop the skills of managing grassland and understanding the genetics of breeds best suited to pasture-based production.
- The mass meat market needs to be reshaped so that it supports nutritionally high quality meat, production method and provenance. Much beef is eaten as mince in burgers so it's difficult to secure a premium price.
- Direct and local sales and supporting infrastructure – abattoirs and butchers' shops – could support market differentiation for pasture-based meat but remain relatively niche and lack policy support.
- There are confusing public narratives around the health and environmental effects of meat production and consumption linked to a rise in veganism and flexitarian eating.

5.4 Paludiculture

Peatlands need to be managed sustainably for their ecosystems, carbon stores and productivity in farming. Yet current peatland use is unsustainable – whether because of conventional arable farming, game management practices or peat extraction. It is possible to return peat areas back to nature – as in the Great Fen project in Cambridgeshire, which aims to restore 3,700ha of fenland around two remaining wild fens, Holme and Woodwalton.[164] However, peat soils are some of our richest and we rely on them for important crops. In practical terms, we need a range of options, including ones which can restore peat, lock up carbon and provide an economic return. One potential approach is paludiculture.[165]

Paludiculture – from the Latin *palus* for swamp – is the productive use of wetland areas in ways that preserve their peat.[166] In simple terms this involves rewetting peat that has been drained, stopping peat extraction, avoiding or minimising drainage, using plants that can tolerate wet soils and cultivating marketable crops which do not require peat disturbance or nitrogen fertilisers. As a result the peat is not oxidised through exposure to the air or through nitrification. Such forms of production already exist and are being trialled and developed across Europe. They include:

- maintaining wet meadows as pasture and for haymaking, providing fodder especially for cattle and potentially for water buffalo for beef and mozzarella cheese-making[167]
- growing reed or reed canary grass as biomass and turned into pellets or briquettes for renewable heat production; also sedges and cattails species[168]
- reed cultivation for building materials, typically for thatch roofs but also conversion into insulation and fire-resistant board and plasters
- production of black alder for timber
- sphagnum farming for turning into horticultural media
- 'pharming' – for instance, growing sundews to extract active ingredients for medical use.[169]

As a form of land management paludiculture is in the early stages of development. Of Europe's 28.5 million hectares of degraded peatlands, just 194,000ha – or less than 1% – have been rewetted, with paludiculture covering only a fraction of this area.[170] However, there is now an urgent need to restore and sustainably manage our peatlands and this should be a catalyst for a rapid expansion.

What are the benefits?

Soil health and benefits to productive farming

Paludiculture will reduce carbon losses from oxidation of the peat when it is exposed to the air through ploughing or erosion caused by wind blow of drained peat soils. Current practice means lowland peat-based soils may eventually degrade down to mineral soils with serious damage to their quality and what can be grown in them. Paludiculture could help retain such soils in long-term productive use as well as protecting deeper remaining layers of peat.

Paludiculture also has the potential to reduce the degradation of soil quality associated with salt water ingress or salinisation from peat subsidence, particularly in the Fens. It could also help address increasing pumping costs as land levels fall. At Holme Fen the land level has fallen by around 4m since the late 19th century. Much of the lowland peat

CASE STUDY

PROFITABLE FARMING; LOW INTENSITY GRAZING; BLANKET BOG RESTORATION; BALANCING FOOD; FARMING AND NATURE

Nethergill Farm, Oughtershaw, North Yorkshire

Chris and Fiona Clark farm around 180 hectares in Upper Wharfedale in the Yorkshire Dales National Park. The land rises from 1,200 feet to nearly 1,900 feet with a mix of soils, mostly acidic and poorly draining peat. Over 120ha is 'Oughtershaw moss' – mainly blanket bog – with a few hectares of in-bye land with hay meadow and pasture, together with areas of mature broadleaved woodland and Scot's Pine. The Clarks bought the farm with a mortgage in 2005 intending to make a living raising sheep and cattle. They started with 250 ewes and followers rising to 300 ewes but they soon realised that the more livestock they had, the less profitable the farm became. An economies of scale approach was not the answer to a profitable business and they settled on finding a better balance between the needs of food, farming and nature – something they feel is vital for the future of the uplands and their communities.

The emphasis now is to match stock levels to the quality and quantity of natural grass available. So over time the farm has moved to a much lower intensity of grazing, with fewer sheep. Chris has also introduced hardy native cattle, Whitebred Shorthorns, that can cope with the rough grasses and harsher environment in the uplands. They are a very friendly, docile breed that calve on their own and can live outside all winter if there's enough grass, so cause minimal work. There are no costs for fertiliser to 'improve' the grass or concentrated feed for the livestock. Chris sold all the remaining sheep in 2017. He now brings his neighbour's sheep onto the farm at low levels to get the right mix of grazing and browsing. With financial support from the Yorkshire Peat Partnership, drainage channels or grips in the peat have been stopped up – grip blocking – to restore the natural drainage patterns that favour blanket bog. The Clarks have also built leaky dams and planted 28,000 native trees.

The impact on the health of the land and its biodiversity is impressive. As Chris notes, the stocking rate, type of animal and breed all affect the kind of habitats that the land supports. Combining sheep and cattle, which graze differently, at low levels is now creating a mosaic of habitats. The sweeter limestone-type grass is being eaten off first and then the animals radiate out to other attractive areas and, as stocking levels are low, they leave boggy areas and coarser grasses alone. Sphagnum hummocks are not being trampled and so are increasing. The farm now has the most species of sphagnum in North Yorkshire, with two particularly rare ones for the area. Species-poor mire is transforming into species-rich and important priority habitat. More curlew are appearing and black grouse have started nesting for the first time. Meanwhile the grip-blocking is helping to reduce run-off from the moss – it acts like a sponge, so the water is not flowing off in vast quantities when the gills are in spate as before.

The Clarks know that for an upland farm like theirs the future does not lie with large intensively-managed flocks of sheep. Instead, Nethergill has a portfolio of revenue streams which includes income from pedigree livestock, direct area-based (BPS) and environmental payments, and some off-farm income. The farm has also diversified into holiday cottage lets and adds value to the beef by selling ready meals to visitors, friends and family. Chris believes this is a model upland farms will have to emulate. His consultancy work with similar upland farms shows they need to find their natural, sustainable stocking rate: 'Once a hill farmer uses up all their natural grass, no amount of other inputs such as fertilisers or purchased feed can make that farm any more profitable.' The 'win-win' is that by switching to a lower intensity of livestock, costs will fall and farmers will be able to tap into new environmental payments based on carbon sequestration and clean water as the peatland habitat and biodiversity improve. Chris believes individual farmers need support for marketing their meat and adding value. The opportunities are there in the public's appetite for ready meals – a market already worth over £2 billion a year. He believes National Parks and other bodies could be the catalysts for creating new umbrella brands to market this kind of upland meat, its provenance and its environmental credentials. The future could be Yorkshire Dales beef or Lake District lamb.

area (representing around 60% of all grade 1 land in England) is less than 5m above sea level so is at increasing risk from tidal surges as sea levels rise due to climate change.

Wider system benefits

Once drainage has ended and a higher water table has been restored, peatland areas can begin to function in the way wetlands are supposed to. They can support landscape restoration and nature reserves which sustain water levels in adjoining wetland nature reserves as in the Great Fen area. They can safely absorb excess water without damaging their productive function so act as a buffer for extreme weather and high run-off and floodwater from urban areas and other farmland. Reedbeds can filter and extract excess nutrients and cut damage to aquatic life. If large areas were rewetted and laid down to wetland crops then margins and headlands could remain uncropped and left to rewild with native wetland species. This could build new links across the landscape, providing routes for animals and plants to travel and joining up existing wetland reserves.

In upland areas, peatlands have been drained and degraded by grazing and burning for game shoots. Food output is relatively low so it should be possible to reduce grazing pressure or burning to rewet and restore upland bogs with their ecosystems and wildlife. If a sphagnum-rich surface layer is present, new peat can form, adding to carbon storage as well as safeguarding existing stores of deep peat from fire risk.

Paludiculture could diversify farming and so add resilience to the economy of peatland areas. Wetland plants have long been used as fuel or for building but demand for green building materials and renewable fuels will rise as industries decarbonise. This would create new, sustainable and productive work with mechanisation of harvesting possible. Peat extraction mainly takes place outside England but could be replaced by some sustainable production of sphagnum moss for horticultural mixes, given that peat extraction is due to end by 2030. Lastly, rewetted and restored peatlands would contribute to more diverse patchwork landscapes with reed beds, mosses, woodland and pasture. These could provide richer opportunities for recreation for a rising urban population – perhaps ecotourism, angling and wildfowling – in areas of East Anglia that are currently intensively cropped.

What are the barriers?

As a novel form of land management, paludiculture faces a number of obstacles. Not least of these is its current niche status: it is largely unknown in the UK, though more widely developed in other parts of Europe. Much more research and development is needed to establish its ultimate potential and to support product development to build economies of scale in the UK.

Novelty alone means land managers may be unwilling to trial it unless they have seen it done successfully. There is currently no UK demonstration farm that we know of. This will be compounded by the financial risks of moving away from profitable arable and horticultural crops with a ready market to new markets with relatively unproven crops. This isn't entirely the case as thatch is well-established as a roofing material and we currently produce less than needed so have to import it. Potential for biomass production for renewable heat is growing although, as with all biomass, there is a need to show the net carbon benefits through robust life-cycle analysis. Markets in these areas already exist and could be expanded.

It may be more difficult to alter attitudes towards halting and then reversing drainage of land. Drainage of deep peaty soils has created some of the best farmland in England and the concept of rewetting this might appear heresy to some. From a narrow, short-term economic perspective, continuing to crop such land, even when it is degrading, may appear rational especially when we are less than self-sufficient in food such as vegetables and salad crops that this land can grow well.

There are other economic barriers. One is the potential impact on employment in rural areas where horticulture is labour intensive. Paludiculture may be easier to mechanise and could lead to job losses, though those that remain will be more sustainable. In addition, specialised machinery that can work on wet and easily-damaged soils will require considerable investment. Ending peat extraction would also entail visible economic loss but will be unavoidable as carbon budgets tighten and the 2030 policy deadline looms. Renewable sphagnum production might usefully supplement the production of horticultural and peat-free growing media.

Finally, there is some question about the emissions of greenhouse gases caused by rewetting, notably methane and nitrous oxide. Lindsay argues strongly that peat bog restoration can sequester very high levels of carbon and offset such emissions, which may be short-lived in any case.[171] Loss of peat over centuries has contributed to atmospheric carbon and so should be reversed but the risk of increasing emissions of methane and nitrous oxide – both with high global warming potential – has to be taken seriously. More research is needed into the positive and negative impacts of peatland restoration on GHG emissions.

5.5 Soils and built development

Building on undeveloped land usually involves changes to the soil as well as a fundamental change of land use. Construction uses the soil as a foundation in a way that radically alters its natural functioning and productive potential. Built development disrupts key environmental services and, when the built use ends, it is often difficult and expensive to restore land to productive use. To minimise environmental damage, land needs to be used wisely for built development and care taken to maintain the services it provides.

Built development that is sensitive to soils should recognise a number key principles:

- the need to protect undeveloped land and its soils as a finite, precious resource
- that undeveloped land delivers a number of key environmental functions and that healthy soils play a key role in many of them
- that, as far as possible, development should start by avoiding the use of undeveloped land
- the need to assess the impact of development of undeveloped land on delivery of ecosystem/ environmental services
- where development is needed which caps soils then, where possible, its land footprint should be minimised
- that built development can remediate and restore previously developed land and, with care, retain important soil functions and services
- development should aim to avoid environmental damage, or, if this is not possible, to mitigate the harm and, failing that, to compensate for it. In other words, it should aim to retain or replicate the existing ecosystem services on site, but if that proves impossible then follow a proximity principle and do so as closely as possible.

The sections below suggest how these principles and three key elements – avoid, mitigate, compensate for environmental damage – might be applied.

Avoiding undeveloped land take

The term 'undeveloped land' is used as a broad term even in national policy and inferred to mean land not built on such as land used for agriculture, recreation, forest and open land.[172] It is the loss of agricultural land through development that is our main concern here.

With land, as in all things over the long run, we need to move away from a linear economy to a circular economy. This means reducing, reusing, then recycling precious resources such as land and existing buildings. Better use of existing buildings should precede better use of land since buildings represent embodied energy and materials that can be lost if recycled. Where buildings cannot be re-used then their removal means the land can also be reused or recycled. So 'avoiding undeveloped land take' should be taken to mean not using open, undeveloped land where other options exist.

What this means in practice is firstly, making greater use of existing buildings. This presents many opportunities:

- reducing the number of empty homes or the under-use of existing homes by, for instance, removing tax barriers such as stamp duty to people downsizing, or offering greater tax breaks for letting rooms or floors and increasing tax charges for 'buy-to-leave' properties
- making better use of spaces in other buildings such as creating homes above shops or in redundant buildings and retail units in struggling town centres
- more imaginative urbanism by making smarter use of already developed land such as building homes over car parks or roads
- prioritising recycling of previously developed or brownfield land if derelict or when current land use ends, and if buildings on site are unfit for reuse. As uses and needs change brownfield land can be a form of renewable resource.[173]

Reducing damage to soils and environmental services

Sites should be tested to select those that have the lowest environmental value so, if used, will cause the least environmental damage. Ultimately that has to involve a rigorous assessment of the natural capital of a site and the services that flow from it. This means there will undoubtedly be trade-offs between different types of services – such as managing floods, producing food, habitat for wildlife and landscape. Establishing what these are, or valuing them against each other, is difficult.[174] It will need time and resources to develop the tools to do this well. But not to measure them is the best way to sacrifice them in site selection in the first place.

Once a site is selected then every effort must be made to reduce damage on site, to minimise the built footprint and spread of hard surfaces and to use porous or green surfaces. For housing this would mean avoiding space-hungry forms like bungalows and picking compact forms that deliver comfortable, spacious, naturally-lit and thermally-efficient homes. It should also involve retaining space on site for healthy soils to function. This means, through careful design, retaining land for private and public green space such as gardens, landscaping, pocket parks and allotments. A balance needs to be struck, however, between the benefits of including green space within developments in order to minimise sealing, but where soil may progressively be sealed over time, with more compact forms of development that encroach less into open land in the first place.

Lastly, soils need protection while the site is developed. Compaction by heavy plant can leave soil structure severely damaged. Adding back topsoil that was removed fails to restore the soil and its functions. There is extensive government guidance on soil management during construction,[175] but still some question about the extent of compliance, how compliance is monitored and whether damaged soils are made good when the guidance fails.

Compensation for loss of land, soils and environmental services

Currently, when land is developed many of its environmental functions cease. This need not be so if we accept the principle of compensation for losses. On-site compensation would mean designing new development differently in future to retain key natural functions or to replicate them where they are lost. In essence, a new urban multifunctionalism would replace the original multifunctionality of the land that is being developed.[176] Where this isn't achievable on site, then as a last resort there should be compensation off-site but as close by as possible. This should aspire to restore the services lost so they work for the area and the community that has lost them. This process must stem from understanding what land and soils do in the first place and using this to drive equivalent yet practical solutions. Some possibilities are explored below:

- All land harnesses sunlight, which drives natural cycles of plant and animal growth. Design should ensure the built structure of homes and other buildings maximises natural lighting and solar heat to cut energy demand. Solar cells for heat and electricity could compensate for loss of solar capture.

- The function of soils to enable water to infiltrate and recharge groundwater and aquifers and to be absorbed and stored to reduce flows to water courses needs to be replicated. This could be achieved by much wider use of green roofs, permeable pavements and other hard areas, supplemented by rainwater capture (for local business and domestic use), storage ponds and new wetlands.

- Stored carbon lost from soils and above ground biomass can be compensated for in carbon within the built fabric by using timber frames, walls and cladding, windows, floors and natural fibre insulation. Hemp can be added to store carbon in lime-based concrete.

Of course, some functions of undeveloped land and its soils cannot be replicated easily on site. Undeveloped land supports myriad forms of life below and above ground. It can contribute to distinctive landscapes and local countryside character and provides local amenity areas for people to unwind and exercise as well as protecting archaeological heritage. If environmental services lost on site – such as managing water – cannot be compensated for adequately on the built land then the last resort is to improve other land to do the task better. This should be as close to the original site as feasible – in the catchment for flood management, for example. This could involve remediation of contaminated land, wetland creation, peat restoration, improving the landscape and green spaces in urban edge areas and creating new natural habitats, including woodland and wildflower meadows. In extremis new land could be created elsewhere, not least to avoid landfilling millions of tonnes of soil. One recent example is the new saltmarsh created from spoil from Crossrail 1 tunnels.

What are the benefits?

These measures would prevent almost irreversible change to undeveloped and semi-natural areas. They also offer important wider system benefits which would strengthen the social and economic case for their take-up. These include:

- promoting urban regeneration through reuse of wasteland and removing the blight of derelict land and buildings which can drag down a locality, hamper investment and lead to a cycle of decay, taking account of any environmental or heritage value inherent in such sites

- better use of existing infrastructure such as high streets, shops and services, transport hubs and links, utilities and local amenities, which can improve their viability but also cut costs of developing new infrastructure elsewhere, often met from public funds

- replacing run-down buildings and areas with high quality, thermally-efficient buildings, including homes with better private and public space and living standards

- removing car-blighted areas such as roads and car parks to make towns and cities more permeable and easier for cycling and walking

- better retention and protection of soils should cut soil sent to landfill; landfill tax is payable at £88 per tonne – and presumably drives up the cost of construction.[177]

What are the barriers?

Changing land use to built development is much more tightly regulated than agricultural land use. This is only right since construction can permanently alter the character of land. For this reason, weak or poorly enforced policy is a major barrier to soil and land protection. However, pressures on those who make policy and development decisions are also correspondingly higher, so the social, political and economic context plays a significant role in determining the nature of policy. In this section we explore policy and contextual barriers to forms of development that would better value land and its soils.

Planning policy

There are numerous ways in which planning policy does not adequately protect farmland and other undeveloped land from development:

- There has been a national failure to target development where it is most needed – in areas in urgent need of regeneration and revitalisation – and away from areas where market demand is greatest. Local authorities face pressure to make land available for development despite environmental and other policy constraints.

- Open land sites are continually targeted and selected for development when other suitable brownfield sites are available.

- The emphasis is on low density building and development of larger homes that are marketable rather than the affordable, starter and social homes that are needed.

- Undeveloped land is insufficiently valued within policy for its natural capital and environmental services and simply regarded as ‘awaiting development’.

- Policy is based on a presumption of sustainable development but the sustainability of development is not clearly articulated in terms of environmental constraints and limits.

Contextual factors

These policy failures arise from a variety of contextual issues:

- Large construction companies and landowners have a strong vested interest in land development because an uplift in value from development can generate vast wealth.

- Development business models with high profitability and shareholder value as primary goals rather than social value mean such businesses will seek to develop open land in highly marketable locations rather than previously developed urban sites that need economic regeneration.

- The economic or social costs of new development (for instance, congestion or lack of school places or medical centres) are externalised and often borne by public investment which provides infrastructure and services to new locations. So developers have few internal, economic incentives to select more sustainable sites and use them efficiently.

- The uplift in value that development consent delivers means developed land uses can, in simple, reductive economic terms, always trump the value of undeveloped uses. In these circumstances an economic case for developing land can always be made.

- Allied to this is a lack of adequate processes and tools to assess the natural capital value of land for the range of environmental services it provides. As a result we have an inadequate evidence base.

- Measures of economic growth continue to represent unsustainable use of scarce and depletable natural resources as part of growth. This supports the notion of a linear economy rather than a circular model of sustainable use, and reuse, of resources.

- Policy on food security places high reliance on trade and food imports and so implicitly undervalues retaining our capacity to grow food. It is assumed that production can be maintained or increased – sustainable intensification – despite a reducing land base and the need to find substitutes for widespread unsustainable practices, including use of fossil fuels, damage to nature and soils, and air and water pollution.

- Development which seeks to address market demand is functionally limitless. As economic growth makes us wealthier, expectations grow so people will want larger homes, garages, multiple homes and so on. Unless growth is decoupled from resource use, including land loss, then further damage to soils and the wider environment is unavoidable.

A call to action

The analysis in this report shows that soils are fragile and face significant pressures. It also suggests innovative approaches exist that can safeguard these natural assets while delivering the needs of society that so depend upon them.

This section makes a series of recommendations to government to support the scaling-up of these approaches and to strengthen the policies and tools that are being developed. We believe these will protect and restore the nation's soils.

1. Make protection of all soils from degradation a headline goal of the 25 Year Environment Plan and develop an action plan to achieve their sustainable management by 2030

The government should:

- make 'healthy soils' one of the headline goals of the 25 Year Environment Plan and include it as a headline indicator for assessing progress
- update the 25 Year Environment Plan at the first revision[178] to:
  - clarify the meaning of 'sustainably manage all soils in England' and set out an action plan to achieve it
  - recognise the need to halt land degradation and identify a sustainable land consumption rate for urbanisation to harmonise with the UN Sustainable Development Goals 11 and 15
  - clearly recognise land take for built development and soil sealing as pressures on undeveloped land and soils, and the environmental services they deliver
  - establish a new policy under 'Using and managing land sustainably' to reduce avoidable land take of undeveloped land for built development and associated harm to environmental services
  - Ensure well-enforced regulation is put in place to provide minimum standards of soil management across all sectors.

2. Bring forward new measures to achieve net zero GHG emissions from agricultural land and other land uses by 2050

The government should align the 25 Year Environment Plan and associated measures[179] and the new agriculture policy to:

- establish a new goal for transition to sustainable low carbon then net zero emissions agriculture by 2050[180]
- rapidly develop the proposed stronger domestic carbon offset mechanisms and markets for domestic carbon reduction[181] and extend these to peat and other agricultural soils
- set a timeline for banning burning of peat soils, including blanket bogs and peat moorland
- set interim phased targets to end the sale of extracted peat in England by 2030. If voluntary measures fail to meet interim targets, then introduce a compulsory levy on all peat-based horticultural media with a built-in escalator tied to targets
- ensure proposed measures to support woodland and afforestation – such as the new Woodland Grant Scheme or Forest Carbon Guarantee scheme – are fully adapted and funded to support agroforestry in its various forms[182]
- support development of innovative approaches like agroforestry and paludiculture through market-based mechanisms such as equity release schemes for timber and forward supply contracts for products.

3. Under the new agricultural policy design a new package of public investment and regulation to halt soil degradation and promote measures which protect and regenerate soils

The government should establish an Environmental Land Management scheme (ELM) which:

- is sufficiently well-resourced to fund a comprehensive universal offer to all farmers and land managers to address soil degradation across the countryside and more targeted measures such as higher-level agri-environment payments to restore soils such as peatlands for carbon storage and wider public benefits[183]
- ensures management plans at holding or landscape scale include good soil management as a core element in the plan

- specifically supports whole farm approaches to improve all soils on a holding and across landscapes
- builds on current Facilitation Fund success to support clusters of farms adopting innovative approaches – including CA, agroforestry, pasture-based livestock and paludiculture – through facilitation and external and farmer-to-farmer mentoring and advice
- offers a menu of simple options to improve soil health which can be locally tailored and developed by land managers such as no till, cover crops, mob-grazing and alley cropping
- fully recognises and rewards the multiple benefits of soils-based measures such as herbal leys which support pollinators, carbon storage and other biodiversity that cuts fertiliser use
- has the flexibility to reward management practices where results cannot be easily monitored in the short term such as carbon storage in soils or for land managed under short-term tenancies or contract
- rewards restoration of the hydrology of farmed upland and lowland peat soils and their sustainable management including through paludiculture
- defines land management eligible for the scheme in ways that include beneficial practices like agroforestry and paludiculture.

The government should introduce a set of strong baseline regulations on soil management which:

- discourage (and, for persistent offenders, penalise) bad soil management such as cropping or late harvesting on vulnerable soils on steep gradients
- address the degradation of soils and wider environmental damage – including GHG emissions and the effects on water and air quality
- must be complied with as a prerequisite for ELM scheme participation.

4. Commit to developing and resourcing the comprehensive evidence base, indicators, metrics and monitoring processes needed to underpin sustainable management and effective protection of soils

The government should commission research and development to:

- develop a comprehensive set of soil indicators and metrics to underpin the 25 year plan. This should include: supporting a healthy soils headline indicator with workable metrics of soil organic carbon and biodiversity; enabling farmers to benchmark their soil management against other farmers on similar soil types and use this as a baseline for their own progress
- develop and include asset indicators for soil sealing and efficiency of land take for built development; and monitoring and reporting on these regularly as part of assessing the plan's progress
- investigate carbon cycling and storage potential of varying English soil types under different forms of land management
- produce a gridded representative soil survey to assess and report on the state of England's soils and their properties[184]
- review the agricultural land classification system and update land quality maps, underpinned by up-to-date weather/climate data and projections
- map ecosystem service provision linked to soil type and context in order to assess land capability and appropriate land use for optimising delivery.

5. Revise the NPPF and national planning guidance to fully recognise land and soils for their vital natural capital and ecosystem services and to minimise their avoidable degradation

The government should revise national planning policy and guidance to give clear direction to local planning authorities to:

- include sustainable management of land as a core purpose of urban and rural land use planning
- minimise soil sealing and the increase in artificial surfaces covering soil[185]
- give great weight in planning to avoiding built development particularly on grades 1 and 2 agricultural land, recognising it as an essential and irreplaceable asset for long-term food production
- fully evaluate and take into account the natural capital value of all land and its environmental services, especially in plan development, decision-making and delivering net environmental gain
- select sites to avoid or, at the least mitigate, undeveloped land take or, as a last resort, compensate for unavoidable environmental damage and lost ecosystem services
- ensure compensation prioritises the replication of environmental services on site through careful use of design, the built fabric and non-sealed soils/green infrastructure.

Time for change

The damage and loss of soil is a much-overlooked tragedy of the modern age. It is also avoidable. Soil, literally beneath us, is easy to take for granted but it matters existentially.

If we fail to take care of it we undermine our life support systems and squander an irreplaceable and priceless natural resource. We also risk food shortage, even famine, flood, polluted waters, declining nature and greater costs, inefficiencies and waste. And we risk making climate change worse. Protecting the nation's soil resources from further degradation is essential but so are reversing the trends and managing soils in ways which regenerate them. Healthy soils can better support our needs in terms of food, clean water and other natural benefits. But action on soils is also action on the most pressing and urgent issue of climate change that is the overwhelming threat the countryside faces.

Threats to soils in the temperate UK may appear less severe compared to those in other global regions but their fates and ours are interwoven. The UK relies heavily on resources from abroad to feed us and our livestock. The stability of our food supply depends on productive agriculture here. In a period of unprecedented challenges it makes sense on many levels to prevent degradation of our natural resources, to use them wisely and to reduce risks by rebuilding the resilience of our natural environment to cope with change. Identifying the kinds of positive actions that can do this is important. This report presents a number of approaches, primarily led by farmers, which offer workable solutions to the problems soils face. They also address much wider issues, including keeping carbon in the soil where it can drive healthier soil ecosystems to produce food. These in turn offer farmers ways to harmonise managing their land to produce food with a rewarding living and vocation as well as sustaining nature.

This is a time of challenges and much uncertainty but also of significant policy change. Defra and government have shown impressive leadership in developing a policy framework that begins to tackle some of the fundamental soil issues and the relationship between farming, land use and the environment. The delivery of this wide-ranging agenda will be critical, as will the political will and resources to do so.

The political and policy context – not least with Brexit – is very dynamic. Nevertheless, the compelling messages in the IPCC Special Report remind us that nature is also very dynamic and will not wait on us. If anything it should increase the government's ambition to build rapidly on the progress already made. This report urges the government to put soils at the centre of its environmental policies, to halt their degradation and support their protection and restoration. This means integrating sustainable use of land across government, including optimising the use of land for all development of homes, infrastructure and industry. It also means setting farming on a path towards being sustainable and producing low and ultimately no net carbon emissions.

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3 As listed by Hans Jenny in 1941; cited in Montgomery, D.R. *Dirt – The erosion of civilisations*, 2012. p18.

4 With oxygen, carbon and hydrogen from the air, plants require 17 nutrients for healthy growth including nine macro-elements such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) and eight micro-nutrients including iron, zinc, boron and cobalt. Udall, D., Rayns, F. and Mansfield, T. *Living Soils – A Call to Action*. Centre for Agroecology, Water and Resilience, Coventry: Soil Association. 2015, Bristol. p5. The availability of N, P and K is usually the limiting factor for plant growth and ecosystem activity. Montgomery. 2012. (as above) p16.

5 These include bacteria, fungi, protozoa, nematodes, earthworms and various invertebrates including beetles, centipedes, springtails and molluscs (slugs and snails).

6 Earthworms are key soil organisms. They also churn soil, opening it up to air and water. Darwin estimated that worms can move from 10 to 20 tons of soil per acre annually. Montgomery.D.R. 2012. (as above) p11.

7 Montgomery. 2012. (as above) p16.

8 These include for example vital antibiotics like streptomycin used for tuberculosis, tetrocyline and neomycin and a range anti-tumour, anti-viral and cholesterol lowering drugs.

9 We could add here the cultural value of soil for example used in art, literature and cinema and their role in heritage as a store of archaeological remains.

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30 Of 11m species fewer than 2% have been properly classified. Turbé et al, cited in Natural England. 2015. (as above) p10.

31 Plants release solutions of amino acids and sugars or 'exudates' through their roots to feed soil organisms which are able to supply them with key minerals bound up in the soil such as phosphorus. The ability of legumes such as clover, peas and beans to fix atmospheric nitrogen in the soil depends on the presence of soil bacteria rhizobia.

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33 pH or potential Hydrogen is a measure of the acidity or alkalinity of a solution, based on a plant's ability to attract Hydrogen ions. Cereals tend to grow better in more acide soils and the addition of N, P and K fertilisers accentuate this but also make soil less suitable for microorganisms like bacteria, fungi and mycorrhiza.

34 Fen peatlands occur in wet lowland areas near springs, in hollows or near water edges, are very biodiverse and have diverse vegetation including reeds, sedges, mosses and plants. Upland blanket bog covers large areas of uplands (over 350,000 ha) in areas of high rainfall and cloud cover with mosses, cotton grass and heathers typical. Raised bogs occur where peat builds up, forming a dome dominated by mosses fed by rain. Natural England. 2010. (as above) p6.

35 Peat has been defined as 'the partially decomposed remains of plants and soil organisms which have accumulated at the surface of the soil profile'. Joint Nature Conservation Committee. (as above) p3.

36 The upper peat layer (acrotelm) holds living vegetation, often sphagnum species, and lays down peat so protects the lower layer (catotelm) which stores it. Lindsay, R. 2010. (as above) pii.

37 Peat accumulates naturally at a rate of less than 2mm per annum but peat of up to 2 metres depth is usually removed. Lindsay, R., Birnie,R. & Clough, J. Commercial peat extraction. *IUCN UK Committee Peatland Programme Briefing Note no 6*. 2014. p1. https://www.researchgate.net/publication/268220756_IUCN_UK_Peatland_Programme_Briefing_Note_No6_Commercial_peat_extraction

38 Lal 2004 cited in Young,R., Orsini,S. & Fitzpatrick,I. *Soil Degradation: A Major Threat to Humanity*. Sustainable Food Trust. 2015. p4. https://sustainablefoodtrust.org/articles/soil-degradation-as-big-a-threat-to-humanity-as-climate-change/

39 Defra. *The Future Farming and Environment Evidence Compendium*. February 2018. p61. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/683972/future-farming-environment-evidence.pdf

40 Defra. February 2018. (as above) p61.

41 Natural England. 2010. (as above) p2.

42 Graves et al. 2015; Bellamy et al. 2005, cited in Young,R. et al 2015. (as above) p4.

43 Defra. *Digest of Waste and Resource Statistics – 2015 Edition.* January 2015. p10, 17. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/482255/Digest_of_waste_England_-_finalv3.pdf

44 Defra. *UK statistics on waste.* 22 February 2018. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/683051/UK_Statisticson_Waste_statistical_notice_Feb_2018_FINAL.pdf

45 2013-2017 data from *LUCS 2016-17 Land use based change tables* Table p361. Comparable figures for earlier years (1989 to 2011) are 8,256ha pa (1989-2000) and 4560ha pa (2001 to 2011) come from *Tables p261 to p265: land use changes to developed uses (Table p261 for England 1989 to 2011)*. https://www.gov.uk/government/statistical-data-sets/live-tables-on-land-use-change-statistics

46 Defra et al. *Agriculture in the United Kingdom* 2017. 2018. Table 14.5 p106; chart 13.3 p97. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741062/AUK-2017-18sep18.pdf

47 Sir John Beddington described a 'perfect storm of factors' in *Foresight. The Future of Food and Farming. Final Project Report*. The Government Office for Science, London. 2011. These included population growth, a growing middle-class consuming more, depletion of natural resources and climate change. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/288329/11-546-future-of-food-and-farming-report.pdf

48 UK population itself is also predicted to rise from around 60 to over 73 million by 2035. ONS. *Summary: UK Population Projected to Reach 70 Million by Mid-2027*. 26 October 2011. https://webarchive.nationalarchives.gov.uk/20160105223720/http://www.ons.gov.uk/ons/rel/npp/national-population-projections/2010-based-projections/sum-2010-based-national-population-projections.html

49 The Royal Society. *Reaping the benefits: Science and the sustainable intensification of global agriculture.* October 2009. p13. https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2009/4294967719.pdf

50 Dunster, B. *Zed Life – How to build a low carbon society today*. RIBA. 2018. p7.

51 See Montgomery. D.R. *Growing a revolution: Bringing Our Soil Back to Life*. 2017.

52 Paustian, K. et al. Management Options for Reducing CO_2 Emissions from Agricultural Soils. *Biogeochemistry.* 2000. 48, 147–163; cited in Young, R. & Fitzpatrick, I. *The Hidden Cost of UK Food* 2017. p22-24.

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54 According to Reay, nitrous oxide emissions globally from fertilised soils, or nitrates lost to water and air, are equivalent to around 3 billion tonnes of CO_2 or the annual emissions from 1 billion cars. Reay, D. *Nitrogen and Climate Change – an explosive story*. 2015. p85.

55 Glendining et al. 2009. Cited in Royal Society. 2009. (as above) p15.

56 It has been argued that livestock methane emissions should be assessed against GHG emissions from fossil sources but also from land use change to arable cropping causing carbon losses from grassland soils; pasture can lock up carbon and livestock eating it also cycle nitrogen already in the system rather than adding it from fossil sources. For example Young. R. *Rebalancing the carbon cycle*. Presentation to Health and Harmony Conference, Llandovery, 10-11 July 2017.

57 This was set by The 5th Carbon budget and agreed by the government in 2016. https://www.gov.uk/guidance/carbon-budgets#setting-of-the-fifthcarbon-budget-2028-2032

58 Committee on Climate Change. *An independent assessment of the UK's Clean Growth Strategy: From ambition to action*. January 2018. p24. https://www.theccc.org.uk/wp-content/uploads/2018/01/CCC-Independent-Assessment-of-UKs-Clean-Growth-Strategy-2018.pdf

59 CPRE calculations based on BEIS/ National Statistics, 2016 UK GREENHOUSE GAS EMISSIONS, FINAL FIGURES, 6 February 2018. p27. Table 10. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/680473/2016_Final_Emissions_statistics.pdf

60 IPCC, Global Warming of 1.5°C: *an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, Special Report SR1.5, October 2018. http://ipcc.ch/report/sr15/

61 IPCC, Global Warming of 1.5°C. IPCC Special Report SR1.5, October 2018. The IPCC is the UNEP founded lead body for the assessment of climate change and its impacts. It brings together the work of thousands of experts to form an objective and comprehensive view that is policy-neutral.

http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

62 IPCC Special report 1.5 Summary for policymakers, October 2018. http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

63 Graves, A., Morris,J., Deeks, L., Rickson, J., Kibblewhite, M., Harris, J. and Fairwell, T. / Cranfield University The Total Costs of Soils Degradation in England and Wales. Research Project Final Report to Defra. June 2011. pp2-3.

64 The central estimate was £1,229 million with 80% calculated at £983.2 million pa. This work was subsequently published in Graves, A.R., Morris,J., Deeks, L.K., Rickson, R.J., Kibblewhite, M.G., Harris, J.A., Farewell, T.S., & Truckle, I. The total costs of soil degradation in England and Wales, *Ecological Economics*. 2015. 119:399-413 but without substantial change to final costs.

65 CPRE estimate. On a crude estimate of average cost per farm holding, this approximates to £1,660 (using £240m and 144,300 holdings per closest figures available in 2012. Defra at al, *Agriculture in the UK 2012*. 2013. Table 24. https://www.gov.uk/government/statistics/agriculture-in-the-united-kingdom-2012

66 Francis, A. et al. *New markets for land and nature: How Natural Infrastructure Schemes could pay for a better environment*. Green Alliance. 2016. p2, p9. The £2,373 million includes £1,065 million costs to water companies for the level of pollutants in water courses; £642 million costs of insurance payouts and costs to authorities to rebuild infrastructure and £526 million spent by the Environment Agency and others on flood defence infrastructure. According to government, the cost of flooding to the UK is £2.2 billion annually. Government Office for Science. *Foresight Future Flooding* report. 2004, cited in Moncrieff, C. & Draisey, Z. / WWF. *Saving the Earth – A sustainable future for soils and wate*r. 2018. p13. https://www.wwf.org.uk/updates/saving-earth-sustainable-future-soils-and-water

67 Young, R. and Fitzpatrick, I. *The Real Cost of Food.* Sustainable Food Trust. 2017. p22. The authors give an estimate for the UK of '£3.21 billion for soil carbon loss across the UK' but accept this is 'a rough estimate given the absence of precise data on soil carbon losses for each country in the UK'. Our estimate is for England and Wales only and was derived by taking Graves et al. 2011 figures and working back, using a mid-estimate cost of £566 million replacing £51/tonne with £173/tonne. This figure also does not reflect the cost of other GHG emissions linked to land use and soils from nitrous oxide and ammonia, for example. http://sustainablefoodtrust.org/wp-content/uploads/2013/04/HCOF-Report-online-version.pdf

68 See Defra et al. *Agriculture in the UK 2017*. 2018. p24 table 3.2. gives TIFF for England and Wales which have been added together here; note that this total income includes what are listed as 'subsidies on production (Basic Payment Scheme,environment schemes) whichfare given in table 10.3 p75 for 2017 as £2,116 million and £291 million for England and Wales respectively. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741062/AUK-2017-18sep18.pdf

69 Soane & Vanouwerkerk (1995) cited in Dobbie et al. 2011, (as above) p104 – see figure 8.3.

70 Cited in written evidence by Aberdeen University SHI0060 to Environmental Audit Committee Soil Health Inquiry. 'We argue that good soil health results in greater farm gate income as the requirement for inputs (fertilizer, fuel) decreases and yields can increase. In an economic study of soil compaction mitigation for Defra[1]. we found £70-£120/ha gross margin increases from compaction avoidance depending on soil type. When environmental costs are factored in, the economic benefits can be over 10 x greater.' [1] http://sciencesearch.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=17587 http://data.parliament.uk/WrittenEvidence/CommitteeEvidence.svc/EvidenceDocument/Environmental%20Audit/Soil%20Health/written/27448.html

71 Graves et al. 2011. (as above) p33.

72 See G. Sinclair. *The Lost Land: Land Use Change in England 1945-1990*. 1992.p61 table 9.1. Official figures given on total rural land loss since 1945 show the highest previous rates to be in 1950-1969, averaging 14,000ha a year.

73 Agricultural land converted to built development (2013 to 2017) was 38,706 ha or average 9677 pa per *Table 350: Land Use Change: Land changing to developed use by previous use*. Figure based on 9,176,000ha of land on commercial farm holdings in England – 2017 data from table 2.4 Defra et al. 2018. (as above) p16. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/595736/1516_Land_Use_Change_Statistics_Live_Tables_Feb_revision.xlsx

74 Natural England. 2012. (as above) p2.

75 Thurston, N. et al. / Defra. *Review of the weight that should be given to the protection of best and most versatile (BMV) land – Technical Report SP1501/TR*. Final Report. 2011. http://randd.defra.gov.uk/Document.aspx?Document=9905_SP1501finalreport.pdf

76 Defra. *Digest of Waste and Resource Statistics – 2015 Edition.* January 2015. p17, p10.; Defra. *UK statistics on waste.* 22 February 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/482255/Digest_of_waste_England_-_finalv3.pdf https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/683051/UK_Statisticson_Waste_statistical_notice_Feb_2018_FINAL.pdf

77 Udall et al. 2015. (as above) p3.

78 Based on Agricultural Land Classification grades figures of 2.7% of land being Grade 1 and 60% of this being below 5m AOD (Above Ordnance Datum – mean sea level). From national estimates of land of ALC grades 1,2,3a,3b,4 and 5 in ADAS. *Controlling soil erosion.* MAFF 1999. p13.

79 See tables 3 and 5 in Denny,D. & Waller, P. *Tracking peat usage in Growing Media production.* CP 100 Project Annual 2016 report. The report gives data from 2011 to 2015; pp5-6. https://horticulture.ahdb.org.uk/project/tracking-peat-usage-growing-media-production

80 1% SOM = an additional 20,000 to 25,000 gallons per acre, or at least 225,000 litres per hectare. 0.2-0.4% increase (20% increase on 1-2%) = 45000 to 90000 litres. Based on Byrant L. *Organic Matter Can Improve Your Soil's Water Holding Capacity*. 2015. *http://switchboard.nrdc.org/blogs/lbryant/organic_matter.html* cited Payton L. / Soil Association. *Seven Ways to Save Our Soils*. 2016. p4. https://www.soilassociation.org/media/4672/7-ways-to-save-our-soils-2016.pdf

81 Defra. February 2018. (as above) p60.

82 Jaafar, M. *Soil erosion, diffuse source pollution and sediment problems associated with maize cultivation in England*. 2010. University of Exeter, cited in POSTNOTE 502. *Securing UK Soil Health.* August 2015. p3. https://ore.exeter.ac.uk/repository/handle/10036/98234

83 Higher levels of sediment causes high levels of failure in fish larvae – 15% fine sediment on gravel beds causes 50% of eggs and larvae to die. See Environment Agency. *The state of soils in England and Wales.* March 2004. p6. http://www.adlib.ac.uk/resources/000/030/045/stateofsoils_775492.pdf

84 Some agrichemicals such as metaldehyde in slug pellets cannot be removed and must be diluted from cleaner water sources; nitrates can also persist in groundwater for decades until flushed out where they go on to affect water courses.

85 Defra. February 2018. (as above) p60.

86 'Surface water status is measured by both its ecological and chemical status. It is assessed against the scale of high, good, moderate, poor and bad.' See Priestley, S. & Barton, C. *Water quality*. House of Commons Library BRIEFING PAPER Number CBP 7246. 26 July 2018. p10. http://researchbriefings.files.parliament.uk/documents/CBP-7246/CBP-7246.pdf

87 There is some variation in the time periods and way figures are compiled for the three nations. See Priestley, S. & Barton, C. 2018. (as above) p14. researchbriefings.files.parliament.uk/documents/CBP-7246/CBP-7246.pdf

88 Lack of skills education has been highlighted in two reports: Kibblewhite, MG., Deeks, LD. & Clarke, MA. *Gap Analysis on the Future Requirements of Soil and Water Management in England*. Report commissioned by Royal Agricultural Society of England (RASE). 2010. Godwin, RJ. et al. *The Current Status of Soil and Water Management in England*. Report for the Practice with Science Group. RASE. 2008.

89 A recent Met Office report (2 November 2018) shows that for periods 1961 to 1990 and 2008-2017 averages show highest maximum temperatures had risen by 0.8C and rainfall from extremely wet days up from 64 to 75mm. https://www.bbc.co.uk/news/science-environment-46064266

90 The government acknowledges this: "We currently lack sufficient data to know just how badly our soil has been affected." HM Government. *A Green Future: Our 25 Year Plan to Improve the Environment*. 2018. But the accompanying actions are limited in ambition and resource: a weak pledge to ' investigate the potential for research and monitoring' and to invest 'at least £200,000 to help develop soil health metrics and test them'. https://www.gov.uk/government/publications/25-year-environment-plan

91 Jones,A. et al, *The State of Soil in Europe*, European Commission Joint Research Centre, 2012, p54. https://esdac.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/EUR25186.pdf

92 Thompson, T.R.E. and I.Truckell / National Soil Resources Institute (Cranfield University Silsoe), *Protecting Hampshire's Soils: Development of a soil function-based methodology*, A Report to Hampshire County Council and Defra, May 2005, p4.

93 These include: The EU Water Framework Directive 2000, the WFD-set targets for surface waters to achieve good chemical and ecological status by 2015. It also incorporates key environmental principles of 'the polluter pays' and 'no deterioration' – see Freeman, H. 'Water environment objectives and ambition under threat'. Blog for Wildlife and Countryside LINK. The 1991 Nitrates Directive which set up Nitrate Vulnerable Zones; the Ambient Air Quality Directive (2008) which set legally binding levels for pollutants harmful to health – mainly particulates PM_{10} and $PM_{2.5}$ and nitrogen dioxide https://uk-air.defra.gov.uk/air-pollution/uk-eu-policy-context HFreeman blog: https://www.wcl.org.uk/water-environment-objectives-and-ambition-under-threat.asp

94 http://ec.europa.eu/environment/soil/process_en.htm ; https://www.euractiv.com/section/climate-environment/news/eu-soil-protection-law-blocked-by-uk-france-and-germany/

95 https://ec.europa.eu/agriculture/direct-support/cross-compliance_en Greening measures have applied since the 2013 reforms.

96 See Moncrieff, C. & Draisey, Z. / WWF. 2018. (as above) pp30-33.

97 These are *GAEC 4 Providing minimum soil cover; 5 Minimising soil erosion and 6 Maintaining the level of organic matter in soil*; Defra. *Cross compliance in England: soil protection standards 2015.*

98 Defra Farming Advice Service. *Greening Update for 2018*. http:// http://farmingadviceservice.org.uk/events/assets/Uploads/Webinars/Greening-update-2018-Webinar.pdf

99 Defra. 2007. *Research into the current and potential climate change mitigation effects of Environmental stewardship*. BD2302. Cited in Natural England. *Summary of evidence: Soils.* Information Note: EIN012. p6.

100 White, RE. et al. A critique of the paper 'Soil carbon 4 per mille' by Minasny et al. (2017). *Geoderma*, 2018. 309, pp.115–117.

101 https://www.iatp.org/blog/201512/what-to-make-of-the-soil-carbon-initiative-launched-in-paris; https://www.4p1000.org/

102 https://www.un.org/sustainabledevelopment/

103 The goal is defined as: 'Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss' https://www.un.org/sustainabledevelopment/biodiversity/

104 UK Government Corporate report. Implementing the Sustainable Development Goals – December 2017. (Updated 23 May 2018). https://www.gov.uk/government/publications/implementing-the-sustainable-development-goals/implementing-the-sustainable-development-goals

105 Department for Environment, Food and Rural Affairs single departmental plan. (Updated May 2018). https://www.gov.uk/government/publications/department-for-environment-food-and-rural-affairs-single-departmental-plan/department-for-environment-food-and-rural-affairs-single-departmental-plan-may-2018

106 Corporate report Ministry of Housing, Communities and Local Government single departmental plan. (Updated 23 May 2018). https://www.gov.uk/government/publications/department-for-communities-and-local-government-single-departmental-plan/ministry-of-housing-communities-and-local-government-single-departmental-plan

107 In fact, policy to protect farmland from development was, according to Sinclair: 'the most fundamental plank of countryside protection policy until 1987.' This was principally to support food production but Planning Policy Guidance Note 7 issued in 1992 clearly signalled a more relaxed approach to development other than on BMV land. Sinclair,G. 1992, p61.

108 Environment Agency. 2004, (as above).This considered multiple threats to soils including erosion, nutrient loss, air pollution, compaction, loss of grassland, peat drainage, contamination and built development.

109 Defra. *Safeguarding our Soils – A Strategy for England*. 2009.

110 Loss of permanent grassland was eventually controlled by the CAP following vast losses of lowland meadows in the 20th century: Environment Agency. 2004. (as above) p15 reports that the lowland grass area fell by 97% between 1934 and 1984.

111 Policy wording was changed from the earlier Planning Policy Statement 7 from 'where significant development of agricultural land is unavoidable' to where it 'is demonstrated to be necessary'. para. 113. Department for Communities and Local Government. *The National Planning Policy Framework*. March, 2012. https://www.gov.uk/government/publications/national-planning-policy-framework--2

112 See footnote 44 above.

113 Key Sources for this section: Roberts, A. *To plough or not to plough? An investigation into what influences farmer decision making regarding the adoption of conservation agriculture*. MSc theses. Lund University. May 2017. Brewin, J. *The Soil and Water Balance – The Science Behind Soil Friendly Farming*. Game and Wildlife Conservation Trust. 2018. pp68-73.

114 Friedrich et al. 2009, cited in Roberts, A. (as above) 2017.

115 Soils form at around 0.1mm/yr and ploughing erodes them at 1mm to 1cm/yr. See Montgomery, DR. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences*. 2007. *104*(33), 13268-13272.

116 See Brewin, J. 2018, (as above) cited in notes 49-52.

117 Lal. 2004, cited in Roberts, A. 2017. (as above).

118 Lal. 2004, cited in Roberts, A. 2017. (as above) Leake, A. & Lane, M. 2009, cited in Brewin, J. 2018. (as above) p71; Piggott I. reports diesel costs cut to less than £30/ha (presentation at LEAF Open Day at Elveden Estate 17 May 2018).

119 Legumes can fix nitrogen from the air with the aid of soil fungi; phacaelia and vetch can also mobilise phosphorous – see Brewin. 2018. (as above) p52-53.

120 Wilkinson, I., Lane, S. & Totterdell, P. *The Herbal ley farming System, Cotswolds Grass Seeds.*

121 James Hutton Institute DIVERSify initiative is testing legume and cereal mixes such as pea and barley or fava bean and wheat. The evidence so far indicates shows yield benefits for plants grown in mixtures but needs plant breeding to target the cooperative (or 'facilitative') traits shown, combination than if in a monoculture. https://www.hutton.ac.uk/news/crop-mixtures-and-evolution-can-improve-agricultural-productivity

122 Montogomery, D.R. 2017. (as above) p83; global data is for 2013.

123 According to Conservation Agriculture UK Association: "In the UK, CA area has increased from 150,000 hectares of arable land in 2011 to 362,000 hectares in 2016 (8% of UK's total arable land area)". http://www.conservation-agriculture.co.uk/our-story/why-conservation-agriculture/

124 Brewin. 2018. (as above) p46 cites a large European study (Van den Putte, A. et al 2010) which showed yields fell by 4.5% for reduced tillage and 8.5% for no-till (though not CA) for maize and winter crops but were on average more profitable for reduced tillage.

125 Roberts, A. 2017. (as above).

126 Roberts, A. S*ection 5.2. Quality, accessibility and relevance of conservation agriculture information.* 2017. (as above).

127 Brewin. 2018. (as above) p72-73

128 The United States Department of Agriculture (USDA) characterises it via four 'I's' : intentional, intensive, integrated and interactive. https://www.usda.gov/topics/forestry/agroforestry

129 These are Spain, 5.5 million hectares; France, 1.6 million hectares; Italy, 1.4 million hectares; and Portugal, 1.2 million hectares – den Herder et al. Current extent of stratification of agroforestry in the European Union. *Agriculture, Ecosystems & Environment*. 2017241:1. pp121-132.

130 '(G)razed forests and orchards, wood pasture and parklands, shelterbelts, hedgerows, wooded buffer strips, and isolated trees on grassland or cropland' are all forms of agroforestry according to Burgess. P. 'Agroforestry in the UK' in *Quarterly Journal of Forestry*. April 2017. Vol 111 No.2, 111- 116. p111. http://www.rfs.org.uk/about/publications/quarterly-journal-of-forestry/

131 Petit et al, 2003. cited by Burgess. P. (as above) p112.

132 The estate is 22,500 acres or around 9,100 hectares – http://www.elveden.com/farm-landabout-the-farm/about-the-farm/

133 Briggs S. *Agroforestry: a new approach to increasing farm production. Nuffield Farming Scholarships Trust report. June* 2012. 2012. p40. p43-44. Briggs cites French Institut National des Recherches Agricoles Montpellier (INRA) research which shows that trees draw water from deeper layers than annual crops but moisture exhaled overnight by trees is drawn in from the air by alley crops in a process called 'hydraulic lift'. http://www.nuffieldinternational.org/rep_pdf/1341272658Stephen-Briggs-2011-report.pdf

134 Research at University of Guelph, Canada cited by Briggs, S. 2012. (as above) p40.

135 Palma, J. et al. 2007; Pattanayak, S. and Mercer, DE. 1996, cited in Soil Association/Woodland Trust. *Agroforestry in England – Benefits, Barriers and Opportunities*. 2018. p4.

136 See CPRE. *Uncertain Harvest*. 2017.p22 and Soil Association / Woodland Trust. 2018. (as above) p3. https://www.cpre.org.uk/resources/farming-and-food/farming/item/4647-uncertain-harvest-does-the-loss-of-farms-matter

137 Shropshire dairy farmer Tim Downes has planted trial rows of trees, including sycamore, hornbeam, small leaf lime and elm, to increase the diversity of fodder and the digestion efficiency of nitrogen in the herd. Tannins in tree leaves may also reduce parasites, particularly nematode worms in cattle. Willows are also medicinal as sources of aspirin or salicylic acid, which could reduce inflammation in dairy cows suffering from mastitis (a bacterial disease of the udder), stomach upsets and lameness. See Trees provide fodder and boost production. Woodland Trust case study. October 2015. https://www.agricology.co.uk/resources/trees-provide-fodder-and-boost-production

138 What is agroforestry. INRA Montpellier http://www1.montpellier.inra.fr/safe/english/agroforestry.php

139 Cited in Briggs S. 2012. (as above) p40. The carbon figure relates to 'alley crops, tree timber above ground and roots below, leaves etc'.

140 Estimates based on research on tree planting in a 400ha sub-catchment at Pontbren by Wheater et al. 2012, cited by Burgess 2017.(as above). P114; see also Woodland Trust, *The Pontbren Project – a farmer-led approach to sustainable land management in the uplands*. Research report.February 2013. https://europeanlandowners.org/files/Awards/Soil/Soil%20award%20winner%202013-2014%20Pontbren.pdf

141 Agroforestry Research Trust. About Agroforestry. https://www.agroforestry.co.uk/about-agroforestry/

142 Production of food, fruit, fibre, furniture, fragrances, fun, fodder, fuel, fencing, firewood, flocculation, (f)armaceuticals. Per Jane Rickson (personal communication, 2 September 2018).

143 The environmental credentials and animal welfare potential are also significant for marketing. Woodland eggs are sold at a premium as free range and high animal welfare. Free range woodland chicken and pork is already available. See Burgess. 2017. (as above) p113.

144 Soil Association/Woodland Trust. 2018. (as above) p6.

145 See Briggs S. 2012. (as above) p33. Pollarding also cuts the cost of replacing trees.

146 Ruminants are animals which can predigest food in the rumen – a kind of stomach or foregut – which ferments plant material to break it down through microbial action https://en.wikipedia.org/wiki/Ruminant

147 Haylage is produced from grasses and other species as for hay but left to dry for a shorter period then wrapped after baling which helps it to ferment naturally which preserves it with higher moisture levels than hay http://www.smallbalehaylage.co.uk/what-is-haylage.html

148 See https://sites.google.com/site/thefoxsfarm/livestock/set-stocking

149 The Pasture Fed Livestock Association (PFLA) works to promote and certify pasture-based livestock and their products.

150 Sward comes from the Old English word sweard or skin of the earth. In farming terms it means the upper layer of soil, especially when covered in grass https://en.oxforddictionaries.com/definition/sward

151 For example see Jenkins, M. How mob grazing can be used to improve soil health. *Farmers Weekly*. 27 April 2018. pp36-37 shows no to minimal root growth retardation for up to 50% leaf removal.

152 Stanley, P. L. et al. Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. *Agricultural Systems*. 2018. 162. pp249-258. https://www.sciencedirect.com/science/article/pii/S0308521X17310338

153 See Pasture for Life. *It can be done – The farm business case for feeding ruminants just on pasture*. January 2016. The research compares data from 13 PBLF farms with data from 314 farms in the AHDB Stocktake, in both Severely Disadvantaged Areas (SDA) and non-SDAs for breeding ewes, suckler herds and beef finishing.

154 See, for example, Neil Heseltine case study in Pasture for Life. 2016. (as above) p13.

155 Pasture for Life. 2016. (as above) pp3-7. For breeding ewes PBLF compares well on gross and net margin with the top third producers; for beef finishing with higher market prices PBLF farms far exceed net and gross margins for average farms, which generally show a loss.

156 The essential oils in some herb species are known to have protective properties and diverse swards with mixed root depths are likely to be better at scavenging essential minerals from the soil that end up in forage.

157 See table 14 in Schoen, V. & Lang T. *Horticulture in the UK: potential for meeting dietary guideline demands*. Food Research Collaboration Policy Brief. 24 March 2016. p19. In 2016 an area of 3.1 million hectares was given over to cereals (1.8 million to wheat and 1.1 million to barley plus oats).Defra et al. *Agriculture in the UK.* June 2016. pp13-14.

158 PFLA. *The animal welfare and environmental benefits of Pasture for Life farming – interim findings.* August 2018. p5. https://www.pastureforlife.org/media/2018/08/the-animal-welfare-and-environmental-benefits-of-pasture-for-life-farming.pdf

159 Although this reports deals with England, the import of soya for concentrate feed into the UK is implicated in land use change in South America and continuing loss of rainforest and Panatal. Maize growing for livestock fodder has also increased in the UK with issues for soil damage.

160 PFLA. 2018. (as above).

161 According to PFLA pasture-based and organic 'require access to grazed or conserved pasture, 100% in the case of Pasture for Life and more than 60% in the case of organic (i.e. <40% of an organically raised animal's diet can be grain).' PFLA 2018. (as above) p4.

162 See PFLA. 2018. (as above) p11: 'Globally, the 80% of N and P in crop and grass harvests that feeds livestock ends up providing only around 20% (15-35%) of the N and P in human diet (Sutton et al. 2013).

163 See Easting Better Roundtable. *The Climate Impacts of Pasture Farming: Summary report*. 27 November 2017. Haupt, F., Streck, C., Bakhtary, H., Galt, H. (2017).*Taking a Bite Out of Climate Change: Why We Should Stop Harming the Planet and Ourselves by Eating Too Much Beef*. 2017. Working Paper prepared by Climate Focus. https://www.eating-better.org/uploads/Documents/2017/Eating_Better_Roundtable_Pasture_Farming_and_Climate.pdf https://climatefocus.com/publications/taking-bite-out-climate-change-why-we-should-stop-harming-planet-and-ourselves-eating

164 http://www.greatfen.org.uk/about/introduction

165 Research indicates forms of paludiculture can lock up carbon in biomass and in peat itself (above 1 tonne C per hectare pa) – see Beyer.C.and Höper.H., Greenhouse gas exchange of rewetted bog peat extraction sites and a Sphagnum cultivation site in northwest Germany, *Biogeosciences*, 12, 2101–2117, 2015; Schäfer & Joosten 2005 cited in Wichtmann, W., Schröder, C. and Joosten, H., *Paludiculture-productive use of wet peatlands*. 2016.

166 In European Union. *Paludiculture – Sustainable productive utilisation of rewetted peatlands*. November 2015. p6 it is defined as: 'the productive use of wet peatland in ways that preserve the peat body'.

167 Mozarella and burrata are already being produced in the UK at Laverstoke Park from buffalo milk – see https://www.laverstokepark.co.uk/produce/dairy/mozzarella/ and https://www.independent.co.uk/life-style/food-and-drink/features/burrata-britains-new-big-cheese-2229887.html

168 Reed is *Phragmites australis;* reed canary grass *Phalaris arundinacia;* sedges *Carex* species and cattails *Typha* species.

169 See European Union. 2015. (as above) pp14-19.

170 Tanneberger,F., Schröder C. & Wichtmann, W. *Paludiculture projects in Europe*. Presentation slides, Greifswald Mire centre. https://www.ramsar.org/sites/default/files/documents/library/7_tanneberger-_paludiculture_in_europe.pdf

171 Lindsay, 2010. (as above) Methane emerging from peat and vegetation as it is rewetted will be oxidised by micro-organisms within that vegetation. Keeping water tables below the surface is critical to this process. Also, carbon balances may vary each year, but on a long term scale paludiculture sites should remain carbon neutral or act as carbon sinks. Clough, J. (personal communication 8 November 2018).

172 The NPPF and 25 Year Environment Plan use the term 'undeveloped land' (for instance, NPPF. Para 118. p35). Confusingly, LUC statistics use the terms 'previously developed' and 'non-previously developed' more broadly. Undeveloped land is defined there as 'Grassed areas in urban areas, excluding residential gardens and verges, that are not otherwise classified'. DCLG, Land Use Change Statistics 2013/14 Methodology changes guidance. June 2015. p19. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/432348/DCLG_LUCS_New_Methodology_Guidance.pdf

173 CPRE research of published brownfield registers shows: "there are suitable brownfield sites available for over 1 million homes in England. If this figure is extrapolated to account for unpublished registers, there would be space for at least 1.1 million homes." CPRE. *State of Brownfield 2018: An analysis demonstrating the potential of brownfield land for housing*. 2018. https://www.gov.uk/government/publications/code-of-practice-for-the-sustainable-use-of-soils-on-construction-sites

174 Site selection would also need to consider the extent to which, for any given site, its loss could be mitigated or compensated for as a relevant factor.

175 Defra. *Construction Code of Practice for the Sustainable Use of Soils on Construction Sites*. 2009. https://www.gov.uk/government/publications/code-of-practice-for-the-sustainable-use-of-soils-on-construction-sites

176 The Natural Environment White paper 2011 proposes that local authorities should deliver multifunctional development to use land efficiently. The NPPF, July 2018, states in para. 118: 'Planning policies and decisions should: a) encourage multiple benefits from both urban and rural land, including through mixed use schemes and taking opportunities to achieve net environmental gains.'

177 We have not seen any reports of the cost of soil sent to landfill. Based on figures reported above for soil sent to landfill in 2015 – 21.69 million tonnes – this would represent a charge to construction of £1.9 billion (if replicated at the current landfill tax of approximately £88/tonne).

178 The government plans to update the 25 year plan every five years but may do so more frequently 'during the first five years... to capitalise on the opportunities of leaving the EU.' HM Government 2018, (as above) p136.

179 This could include: The Clean Growth Strategy, which states that "We will develop new ambitious plans for the sustainable management of our natural environment including capturing more carbon by our plants and soil."; though it sets no firm target or date to achieve this. HM Government. *The Clean Growth Strategy Leading the way to a low carbon future.* October 2017. p105.

180 The government is supporting low carbon sustainable agriculture in Brazil according to the Plan but there is no mention of it in reference to the UK. Defra 2018. (as above) p123.

181 Defra. 2018. p48.

182 This would include alley cropping, shelter belts, riparian strips, woodland pasture and hedgerows.

183 See Wildlife and Countryside LINK, *A Future Sustainable Farming and land Management Policy for England*. September 2017 https://www.wcl.org.uk/docs/WCL%20Sustainable%20FarmingFINAL%20spread.pdf

184 The NSI soil surveys were carried out on a gridded or 'randomised' basis at 5km intervals basis to assess soil properties; this gives them the flexibility to be interrogated to consider land/ soil for a different set of purposes depending on social/ political priorities in the future; they were initially done for agricultural production to underpin the Agricultural Land Classification mapping. See also Haygarth and Ritz. 2009. (as above) pp193-196.

185 The UN Food and Agriculture Organisation (UNFAO) gives the following definition: "Soil management is sustainable if the supporting, provisioning, regulating and cultural services are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity." Their guidelines on sustainable soil management include principle 11. "Soil sealing is minimized through responsible land use planning." They place particular emphasis on considering the total value of soils under land use planning, and 'protecting soils from land conversion for settlements an infrastructure' where they deliver significant ecosystem services eg carbon storage, high suitability for agriculture or high biodiversity. FAO, Voluntary Guidelines for Sustainable Soil Management. Rome 2017. p2 and p12. http://www.fao.org/3/a-bl813e.pdf

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