Environmental Audit Committee

Soil health inquiry - publications

Inquiry status: **open - accepting written submissions**

Deadline for submissions extended to **5pm Thursday 28 January 2016**

Written evidence

67 items

View less

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Mr Ian Carr - written evidence | PDF version (53 KB)	SHI0001	09 December 2015
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Newcastle University Student And Staff Soil Science Society - written evidence | PDF version (89 KB)	SHI0031	20 January 2016
Dr Franciska de Vries - written evidence | PDF version (124 KB)	SHI0032	20 January 2016
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Dr Neil Humphries - written evidence | PDF version (73 KB)	SHI0034	20 January 2016
The Wildlife Trust For Lancashire, Manchester & North Merseyside - written evidence | PDF version (1.12 MB)	SHI0035	20 January 2016
British Geological Survey - written evidence | PDF version (86 KB)	SHI0036	20 January 2016
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Microbiology Society - written evidence | PDF version (120 KB)	SHI0074	03 February 2016
Agriculture and Horticulture Development Board - written evidence | PDF version (93 KB)	SHI0075	03 February 2016
Dr. Arwyn Jones - written evidence | PDF version (67 KB)	SHI0076	03 February 2016
Soil Research Centre, University of Reading - written evidence | PDF version (37 KB)	SHI0077	03 February 2016
Sustainable Food Trust - written evidence | PDF version (152 KB)	SHI0078	03 February 2016

Written evidence submitted by Mr I. Carr

I would like to raise the issue of the ploughing up of river meadows on the Marches , in particular Herefordshire. Most of the river meadows are now in an arable rotation, with considerable slt movement in times of flooding. The affects the water quality and the aquatic environment as a result of silt deposition. The matter should be looked into. I would hesitate to recommend what action to take.

December 2015

Written evidence submitted by Mr S. Norris

1. I am writing in response to your inquiry into soil health. By way of introduction, I am a PhD student that has just submitted my Thesis; I have been working/studying soil heath and ecology for 10 years. This response is the view of myself only and does not reflect the view of any organisation that I have been affiliated with. As this is a personal response to your inquiry I will attempt to keep my response short, however if you would like to further discuss my view I will be more than happy to assist in any way possible.

- **How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?**

2. Soil health should be measured through the organic matter content of soil, soil invertebrate biodiversity (Springtails and mites) and soil microbiology (fungi and bacterial) these test should be made mandatory for land managers, land owners and stakeholder in UK. These tests should be carryout every 5 years to ensure our soils are in good condition to enabling them to provide good quality food and aid with carbon sequestration. Investment should be made into find rapid and repeatable measures for these properties as there are only costly methods available.

- **What are the benefits that healthy soils can provide to society?**

3. The benefits that health soil can provide to society are often not immediate or obvious. Soil health is a long term investment that will pay dividends in the future. Improved soil heath can help improve crop yield, increase carbon sequestration, increase carbon storage potential and reduce the quantity of inorganic fertiliser required to grow crops. There are also benefits for supporting improved soil heath resulting in supporting the wider bio-economy.

- **What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?**

4. Ultimate disaster, the American dust bowl is a classic example of poor soil management and has been part of the UK national curriculum for a number of years. The environment will ultimately be damaged through increase soil losses, run-off, and nutrient loss leading to sedimentation of river bed and increase pollution, not to mention that due to a rapidly increase degradation of soils would lead to farmers applying more fertiliser which would feedback into being washed off into water-courses exacerbating the problems. In regards to public health, increased pollution would lead to greater severity in incidences of public health incidents. For example increased sediment loss from fields through poor soil management would lead to an increase risk of rivers being block from sediment loss. These risks will also be exacerbated in the future with greater rainfall intensity and frequency being predicted. The above factors combine to increases the risk of flooding, which is a public health risks. In regards to food security not managing soil heath appropriately would lead to reduced yields and increased application rates of organic and/or inorganic fertiliser just to maintain current yield, ultimately increasing the cost of production and increasing pollution as well as reducing the economic benefits from food production.

- **What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?**

5. The recommendations from the soil protection review should be implemented in to statutory polices. Although I am aware this will be considered a controversial view, I would like to see strict penalties for land owners that mismanage their soil, including confiscation of land. I hold this view because soil, although not a finite resource, takes many thousands of years to form and the disruption of this process impacts humans and nature for generations to come.

- **What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?**

6. A key role, it is the part of our ecosystem that supports our agriculture, wildlife, and culture. If we have poor unproductive contaminated soil there will be a dramatic reduction in our living stands. Land owners must be encouraged to manage their soil for their benefit and for the coming generations. Further research should be aimed at mitigating damaging anthropogenic effects on soil health, especially in the form of research that was conducted by defra before dramatic cuts rendered them useless.

December 2015

Written evidence submitted by Professor Mark Hodson, Head of Environment Department, University of York

I have been working on soil related issues for 20 years, all of which in broad terms cover Soil Health

I address each of the enquiry questions in turn

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

To define soil health you need to define what services you wish soil to deliver. Measurements are best done in the field on a regular basis - maybe once every 5 years to give things a chance to change, but at similar times of year and preferably after similar weather. Things to measure would include organic matter content, soil density, water holding capacity, rate of water infitration, fertility via a simple plant growth bioassay, soil biodiversity - I guess using genomics for microbial diversity, but also assessing soil invertebrate diversity, e.g. annelids - need to do this at an appropriate season, i.e. not the summer, some measure of erodability - perhaps soil aggregate distribution. To develop a strategy for tracking soil health the gov. just needs to decide on how frequently samples will be taken and determine a suite of regular sites for sampling - sounds a bit like the country side survey to me!

2. What are the benefits that healthy soils can provide to society?

These are well rehearsed in the ecosystem services literature - food provision, water storage and filtration, reservoir of natural antibiotics, carbon storage, amenity value etc.

3. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

These follow form the above - diminishing food production, increased flooding, decreased water quality, increased C in the atmosphere, loss of amenity and consequently physical and mental well being, loss of possible source of new antibiotics

4. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

I don't know about this.

5. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil is fundamental and should be at the heart of any measures to protect the natural environment. If you can't mine it you have to grow it. Plus see above in terms of consequences of failing to protect soil health.

December 2015

Written evidence submitted by Mr Glyn Mitchell, Promessa Soil

1 I am writing in response to your inquiry into soil health. I am a Living Soil Consultant, Bee keeper and a grower who assays soils through accepted scientific methods and makes microbial diverse Compost to treat soil stripped of life. I also work for a recognised Soil Food Web Laboratory based in Jersey Channel Islands. Our mentor is Dr. Elaine Ingham.

Executive Summery

2 The application of high rates of N.P.K in agricultural systems has had many unintended negative consequences for soil function and environmental health. Data from N. America's longest running field experiment on the impacts of farm production methods on soil quality have revealed that high inputs deplete soil carbon, impair soil water-holding capacity and ironically, also deplete soil N (Khan et al.2007, Larson 2007)

How Natural systems can replace synthetic application given a chance.

3 On a global scale, biological nitrogen fixation accounts for around 65% of nitrogen used by crops and pastures. There is scope for considerable increase. The supply of nitrogenous inexhaustible, as dinitrogen (N2) comprises almost 80% of the earth's atmosphere. The key is to transform inert nitrogen gas to a biologically active form. Fortunately - thanks to some 'enzymatic magic' - atmospheric nitrogen can be transformed to ammonia by a wide variety of nitrogen- fixing bacteria and archaea - for free.

4 As managers of plant growing systems, people just need to do two things: (1) stop killing beneficial organisms (all pesticides affect more than just the organisms listed on the label) and (2) manage the diversity of beneficial organisms so the plant can take care of itself. The plant will adjust nutrient cycling, i.e., control the forms of nutrients it needs, if it is given a chance to set up the biological system it needs. People need to "set the stage" and then let the plant do what it has been doing successfully for the last billion years.

Maximise productivity.

5 Typical ranges of bacteria, fungi, protozoa and nematodes, along with maximum diversity of all groups, for different plant species are known. There is no single food web structure or no one set of organisms that is right for all conditions, all plants, all chemicals, all soil types and so on. Select for grapevines by balancing bacteria and fungi on the strongly fungal end; for carrots the balance needs to be more bacterial; and for dandelions the soil needs to be much more bacterial than fungal. Few protozoa and nematodes occur in soils where weeds thrive. System productivity increases as protozoa, nematodes and micro arthropod biomass increases up to maximum levels in the most productive systems we know about.

6 There is increasing recognition of the fundamental importance of soil microbial communities to plant productivity. Unfortunately, many biological functions are compromised by commonly used agricultural practices.
Redesign of farming practice is not difficult. The first step is recognition of the importance of the year-round
presence of green plants and the microbial populations they support. Redesign has the potential to significantly reduce the impact of many 'problems' associated with chemical farming, including loss of soil C, reduced soil N, soil compaction, declining pH, low nutrient availability, herbicide resistance and impaired water-holding capacity.

7 Biological nitrogen fixation is the key driver of the nitrogen and carbon cycles in all natural ecosystems, both on land and in water. When managed appropriately, biological nitrogen fixation can also be the major determinant of the productivity of agricultural land.
Many farmers around the world are discovering first-hand how the change from bare fallows to biodiverse year-long green, coupled with appropriate livestock management and reduced applications of inorganic nitrogen, can restore natural topsoil fertility. Improving soil function delivers benefits both on-farm and to the wider environment.

Suggestion

8 Life in the Soil labs are available to which the general public can send their samples to have experts assess the biology in their samples and provide mechanisms to naturally provide for their crops requirements.

Making a statuary requirement that alongside chemistry tests, biological testing should become a condition of interests receiving public funding.

Conclusion

9 Man is not very good at growing plants, plants grow in soil, man should put more concentration into growing microbial diverse soil to meet their crops needs. Old forest systems the most productive systems, don’t require N.P.K to be the most productive systems on planet Earth.

December 2015

Written evidence submitted by Dr Oliver Knox

- How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

One of the first challenges to be consider within the context of the first part of this question is the definition of soil health itself. Many exist, which cover a range of potential considerations, depth of required investigatory prowess and relevance to topic. Once you've established a definition then you have at least decided to some extent on the focus of your activities in this regard. And why is a definition so important? The first reason for this is soil itself is easily recognised as highly variable at every range of scale, from one aggregate to the next, sample to sample within a field, field to field on a farm, farm to farm and land use to land use. The second reason is that health itself is a subjective term. We recognise ourselves as unhealthy when we visually or physically express the symptoms of a pathogen being either at work or having delivered some impact on our immune system. The presence of the pathogen itself might not simply be enough to consider ourselves as unhealthy as for much of our lives we may well carry that pathogen with little effect from it. Similarly, some illnesses, such as slow progression cancers, we might associate with a health concern, but can go both unnoticed and unobvious for years. If we apply this same subjective and emotive concept of health to soil then what are we actually implying? For years I have used the term soil health as a teaching and engagement tool for students, the public and farmers, but given the degree of responses from audiences as to what they inferred from this term I have refrained from using it in my research. After 20 years of soils research I still feel that the term has merit as an engagement tool, but has to be clearly defined.

So once you define it, what do you measure? The following is an excerpt from the background I provide to students conducting a review of soil health indicators as part of their 4th or 5th year of university study.

Indicators are used in all sorts of industries and processes to gauge how well something is performing or to try and target areas where improvement can be made. To do this an indicator should be:

- Responsive, repeatable
- Adequate sensitivity (space, time)
- Ecologically meaningful
- Interpretive framework
- Widely accepted and understood
- Linked to management response
- Widely applicable
- Cost effective
- Archive/historical data
- Easily used by at least one user group

Indicators for our soils are needed because threats to our soils are increasing, our soils are increasingly recognised as a resource worth preserving (through legal frameworks), to allow us to assess aspects of soil quality quantitatively and to allow us to build long-term databases of values for soil quality parameters, which will allow us to monitor changes over time.

So what do we measure and what would we expect to be the general trend in data we are analysing in soils? To help us out on this we might consider setting threshold values for indicators. That's all very well, but obviously the way in which we would expect our values to go could go up or down, couldn't it? For example, in some cases we might decide that more is better (no adverse effects if the amount is increased, e.g. topsoil depth, organic matter), whilst in other situations less is clearly better (no adverse effects from lower amounts, e.g. contaminants), but in some situations there may be a case where an optimum range exists as both excessively low and high amounts have adverse effects (e.g. nutrient and lime requirements for crop production).

So thresholds can work well, but how do we establish what these are? There are several ways to do this of which the most common are; comparison against population averages and quartiles, comparison with known values in relation to agricultural production and forestry, comparison with known values in relation to environmental risk, expert panel opinion and, of course, a combination of all of the aforementioned.

Soil, being the wonderful heterogeneous matrix that it is, falls fowl of both biotic and abiotic components in determining is value or support of ecosystem functions or associated ecology. We can sometime use the previously mentioned schemes to offer up good possibilities for the abiotic components of a soil. For example, physical indicators might be identified from; texture, depth of soil, topsoil and rooting, infiltration and topsoil bulk density, water holding capacity, water-filled pore space, aggregate stability, resistance to compaction, subsoil permeability and strength, and soil structure. Chemical indicators of soil quality might be based on; total soil organic matter (SOM), particulate SOM, total soil N, pH, soil acidity, base saturation, cation exchange capacity, electrical conductivity, extractable macronutrients (N, P, K, Ca, Mg, S), heavy metals/PTE's (As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, Zn), and organic pollutants (dioxins, PCBs/PAHs, oils/hydrocarbons, pesticides, other). In most cases we should be able to reach a fairly good consensus on what would be desirable parameters for any of these potential measurements for a 'healthy' soil to function adequately, but how easy is it to do the same for the soil biology?

The good news is people have tried. Suggested soil biological indicators have been proposed such as; biomass production, microbial biomass C, potentially mineralisable N, presence of key organism groups (flora, macrofauna, microorganisms), biodiversity (flora, macrofauna, microorganisms), and microbial processes (methane oxidation, carbon sequestration, soil respiration). As can be seen, this is a much less prescriptive list and it would be harder, but perhaps not impossible, to estimate likely expected returns, not that this has stopped some from doing so.

Examples of where soil indicators have been pushed include the Landcare research, Soil Indicators (http://sindi.landcareresearch.co.nz/), which only uses one of the above biological functions as an indicator in its guide to soil quality. Another is the Soil Foodweb Institute (http://www.soilfoodweb.com.au/) who for a small fee will assess your soil and give you a health report based on various organism counts and functional activity measurements. There are limitations and clear flaws in both, but they are offering a system that might have adaptive potential.

We then ask the students to pick a proposed soil biological indicator, to review literature on it and from that undertake a subjective score against the indicator functions listed. The outcome to date, after three iterations of this exercise is that most currently considered biological indicators score between 5.2 and 7.8 out of 10. Yield, as a comparison, interestingly scores 8.4, but has obvious limitations. Perhaps there is something to be said for a test that incorporates both physical, chemical and biological approaches to soil health? If this is the case then there are again several options and one that is gaining greatest favour, at least in the USA, is the USDA Enhanced Soil Test. I am still not convinced that it would fit every situation, but perhaps it is a move in the right direction.

So how does a government develop a strategy? I'd set a definition and targets and I would do this through consultation with the soil science societies, the few remaining government soil scientists and end users groups (famers, foresters, land managers and members of the public). What governments also need to do is actually produce strategies with real powers. The Soil Strategy for Scotland was hailed as a land mark document, but it needed to go further. It needed to make it illegal to develop for housing or infrastructure any class 1, 2 or 3 land. This is what we will have to live off over the coming years and you can't do that if you have put it under tarmac and brick!

- What are the benefits that healthy soils can provide to society?

Any argument for soil loss being reduced, stopped or even reversed has to be seen as a positive in the face of ever growing population pressure on a shrinking land mass. Pick any of the five or six easily identified funcitons of soils and, with the exception of being a support for building and other infrastructure, it is a relatively easy exercise to convince the average joe of their importance for the future.

- What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The old quote of Theodore Roosevelt about the 'nation that destroys its soil destroys iteself' might seem a little dated, but look instead at erosion maps of Europe. Overlay these with volcanic activity maps and then look to see which countries either have or are near to financial ruin within Europe. The health of our soils is clearly critical even in this day to supporting our cultural and country based economies. Another argument is to look at how the stock markets decoupled from agricultural productivity as a primary benchmark in favour of banking systems and company perceived values and the change from stability to volatile markets, which subsequently crashed globably following the issues with prime loans. Soils were and remain central to our way of life, it's just that most have grown up at too great a distance from ever experiencing this. Perhaps actually embedding soil science or some form of soil based production units within the educational system is needed. It's just a shame that in the UK with most crops ready in summer the schools are off when the fruit of such activities is most evident.

- What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

As a member of the British Society of Soil Science I have been involved in promotional activity and the society remains very active in this area. This is where I got the link to this call from. The Soil Association may have an agenda regarding organics, but they are passionate about their soils. Forest Research has been developing improved soils management strategies for years. There are numerous trusts and land owners who also foster a desire to prolong the life of their soils and estates. I believe there is a passion out there for our soils and not just within the academic community. You simply need to ask the right people for help and you'll be surprised as to what there is.

- What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

The functions of soil are key to life on this planet. It represents the most important non-renewable resource we have and as the population continues to grow its value will increase. However, it remains under threat from all sides. If you don't make soil the central pin in any natural environmental (and by that I consider that about 45 % of the natural environment of the UK to be managed and most of that as farm land, whilst the rest either has or continues to experience the pressures of anthropogenic activity) plan then you have missed the point.

December 2015

Written evidence submitted by Professor Rod Blackshaw

I retired in 2014 with 40 years' experience as a soil ecologist, having worked in a range of roles encompassing research, extension and teaching in the Civil Service and the university sector. I also farmed for eight years on sandy soils in a flood plain, which provides some practical insight into the challenges of soil management.

My responses are focused on the questions asked in the terms of reference. However, I have only provided brief comments for questions 2 and 3 since these are pretty much a given for anyone working with soils. I would suggest that the question that should have been there is 'how will climate change affect the services provided by soils?'

1. How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

There have been a number of proposals emanating from the academic community as to how to measure soil health which pretty much relate to the discipline of the protagonist, and herein lies the problem. Soil is a complex and spatially variable environment that consists of a physical matrix within which biological and chemical interactions occur. At present there is no single sampling method that can be used to encompass all these aspects; no silver bullet.

The spatial scale of changes is also an issue. Agricultural decisions, for example, tend to be made field by field (give or take precision input technology) but socio-economic outcomes may be best adjudged at landscape, regional or national scales. So a national soil health monitoring system might be different to one used for evaluating the health of a soil that is actively managed.

The priorities at the 'land management decision scale' should be firstly to ensure that no reduction in soil quality occurs and secondly to bring about improvement if possible. Key indicators – appropriate to the timescale involved – might include soil bulk density and latent biological activity. Recognition needs to be given to the soil type/geography and results interpreted within this context. SBD is relatively straightforward but biological activity needs better definition. The obvious route for this is to use high throughput sequence analysis to determine both microbial, and faunal, diversity and quantity. This, however, is not yet fully deliverable and so identifies itself as a research need.

At national scale, tracking soil health needs to consider longer timescales and factors that indicate greater sustainability of our soils. Given the proposed 25 year life of the plan for the natural environment, soil organic matter content would be useful to track through periodic, spatially explicit, national surveys. For agricultural/horticultural land it would also be informative to track fertiliser use, on the principle that healthier soils require less to produce the same crop yield. However, it would probably be necessary to develop an econometric model in order to robustly interpret the data – another research need?

Although outside my personal expertise, I wonder if it is possible to monitor changes in soluble pollutants and sediment flow (a possible measure of erosion) using the existing Environment Agency aquatic health sampling, and data from water companies?

It would be appropriate to set SMART objectives in any plan.

2. What are the benefits that healthy soils can provide to society?

The direct answer to this question is readily available from the literature and our knowledge base – plant products, flood management, carbon sequestration and storage, biogeochemical cycling, biodiversity etc.

Philosophically though, the focus on soils being productive for human use leads to this being the wrong question. We accept that a clean river system is a healthy one and that is sufficient justification for policies that seek to deliver this. Similarly for the marine environment. For soils, however, they have to deliver something; the soil ecosystem deserves equal standing with soil health being good in its own right.

3. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

These are the obverse of the benefits. The general consequences are ones of increased costs and vulnerabilities.

4. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

The family of stewardship schemes promotes soil health though recommendations tend to be prescriptive when soils vary considerably. In the absence of a functioning public advisory service for land managers it is worth considering whether there are lessons to be learnt from the pesticide sector where the BASIS scheme helps ensure that malpractice is minimised and best practice promoted. A parallel scheme for those who implement soil interventions might yield similar benefits

The socio-political environment in England tends towards Government engaging with industry to put in place voluntary schemes to mitigate problems. The one area that I think should be considered for legal redress is soil erosion where this causes costs to other bodies, applying the principle of the polluter pays.

5. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil is central to the geographical character of the country and so its health needs be at the centre of any natural environment plan. Research in this area is fragmented and driven by sub-disciplines which hampers the development of an integrated soil management (biological/chemical/physical/socio-economic) approach. Government policy should be designed to promote ISM. Furthermore, although £5m seems substantial funding for research it only amounts to about 80 person-years of activity in real cost terms. This is inadequate given the scale of the challenge to find the means to restore soil health.

January 2016

Written evidence submitted by Mrs S. Atkinson, farmer

1. When considering the importance of soil health and why it is now a matter of major concern it is necessary to start by looking at soil itself in order to understand the subject. It is only the thin layer of soil that we call topsoil which is capable of providing the adequate support of plant life and in most cases this topsoil extends downwards for only about six inches. This has led to the expression that the world is only six inches from starvation. Soil develops slowly from minerals and organic matter and the process is so slow that it requires from 500-1000 years to produce an inch (2.5) centimetres of soil, yet that soil can be stripped very easily from the land by wind or water. While it may appear to be inert to the naked eye, it is teeming with life. It has been estimated that one square metre of soil may contain as many as 1,000,000,000 organisms, ranging in size from bacteria to earthworms and it is said that 95% of the life forms on Earth are actually beneath our feet. It is these life forms that are necessary for transferring nutrients into the growing crops and, as like all life forms they are oxygen breathers, the ideal soil composition is 50% soil and minerals, 25% water and 25% air. Many soil scientists consider soils to be non-renewable resources due to the length of time they take to form and the richness of life in them
2. Only about 10% of the world's land area is available for the growing of food. About 50% of the total land area is grassland or desert, while about one third is forest. Quite obviously the planet needs healthy soils if life on it is to survive. Farming is the interface between the eco-system and the rest of our society and it is farming that has allowed the human race to develop from hunter gatherers to a settled existence. At first farms could only support one family (about 4 or 5 people) but when output was improved so that each farm could support two families (8-10 people) villages were able to develop and some people were able to develop other skills and industries such as carpenters and smiths. Then farms became able to each support three or four families (18-20 people) and market towns started to develop. Cities were few in number until about 500 years ago. For thousands of years farms were mixed units and the manure from the livestock (plus night soil from humans) was all used to fertilise the growing crops. The development of artificial fertilisers and the drive to increase production and ever cheaper food meant that farms have mostly specialised into livestock or arable and while some livestock units struggle to dispose of manure, the main arable areas in the east of the UK have soils that now contain little organic matter.
3. At the same time, the development of artificial fertilisers plus herbicides, fungicides and pesticides led to the erroneous belief that traditional crop rotations, which had been practised for centuries, were no longer necessary and could be shortened or even disposed of altogether. Some farms grew only wheat, one crop after another in each field while others grew oilseed rape alternately with wheat and so on. The drive to cut costs or spread them over ever larger areas combined with the drive to ever more "efficiency" and the belief that only larger units could be efficient led to the "get bigger or get out" message being incessantly promoted. Farmers used to aim to leave their soil in better condition at the end of their farming careers than when they started, but that aim was superseded by the belief that technology would solve every problem. Livestock units have mostly remained relatively small, though now usual run as one man operations without hired help when previously practically every farm had at least one worker but arable units got ever larger and relied on ever bigger machinery to do the work. Low ground pressure tyres meant that the soil surface was protected from the worst effects of their weight but compaction damage caused by them got deeper and deeper as the years went on. Subsoiling was done regularly but as that really meant one large machine trying to remove the damage caused by other large machines, it was not a long term solution. Whereas fields would be regularly left fallow In rotation so that the soils could recuperate, this too became regarded as totally unnecessary, again to the detriment of the soils

4. Soil health has been ignored for decades as it was not considered important, but it is now apparent that serious problems have developed. Last year a report stated that the UK had only 100 harvests left in its soils while this year another report gave the soils in the east of the UK only about 25 years before they become ruined due to the over reliance on artificial fertilisers etc. that they have endured in recent decades. Scientists at the University of Sheffield have concluded that the world has lost a third of its arable land in the past 40 years due to erosion or pollution, with synthetic fertilisers and ploughing degrading soils so that they are being eroded 100 times faster than they can form. However, it is no coincidence that these reports about poor soil health have come when around the world farming is regarded as synonymous with poverty and destitution and it has been estimated that the world could run out of farmers in 20-30 years. UK farming is in dire straits and all that British farmers are producing is now being sold at less than the costs of production. If farming is not profitable there is no money to invest in anything, including soils. Soils are a national asset and the costs of protecting them cannot be dumped on a small section of our society, namely farmers, when they are the responsibility of all, directly or indirectly.
5. Farmers that are in the Assured Combinable Crops Scheme regularly monitor their soils by having soils samples for some arable fields tested in rotation so that every field is tested every few years. The soils of permanent pastures rarely need testing except after some adverse event such as serious flooding. These soils tests are done by qualified people and it would be relatively easy for them to do a report of their overall results to be monitored by soil scientists without breaching privacy laws.
6. Healthy soils provide multiple benefits to society and these are well documented. The first benefit is food security and without healthy soils the country would be totally dependent on imported food to feed itself. Farmers work to get the seed sown into the best seedbed possible so that the crops establish good root systems and healthy soils are needed for this. No crop with a poor root system ever produces good yields at harvest. Healthy soils capture carbon and so are important in climate change adaption and mitigation and soils also provide essential eco-system services. Healthy soils also absorb large quantities of water in times of heavy rainfall, which slows the amount reaching rivers and helps prevent flooding – a very topical issue at the time of writing. Ban Ki- moon is on record as stating that sustainable soil management is fundamental to achieving the sustainable development goals. However, soil does not achieve these benefits on its own but only when properly managed and that is where agriculture comes into the equation. The UK's landscape has been shaped by farming over many centuries and now 70% of it is farmed, with 70% of that farmed area being grassland. The topography of the UK etc. means that most of the livestock farming is in the west and most of the arable farming in the east of the country. Every gardener knows that if they do not attend to their gardens they soon become a mass of weeds and nothing else and so it is with farmland. Arable land will not grow food without careful management to keep weeds and pests at bay while the constant grazing of grassland prevents the more vigorous plants from swamping the more delicate ones and thus keeps the bio-diversity. Under-grazing is just as damaging as over-grazing. The grazing of the uplands by sheep stops them reverting to seas of bracken, heather or scrubby forest (the Cumbrian fells quickly reverted to bracken when the sheep were killed in 2001) and thus gives the scenery that attracts tourists and hill walkers to such areas. Yet how much longer can sheep be kept on the hills if they have to be sold at a loss more often than they make a profit?
7. Every farmer considers soil health to be important and the farmers in each area of the country are aware of how the area has been traditionally farmed for centuries but that knowledge is all too often ignored by other agencies and that in turn has led to soils being damaged. The most obvious example is that of the Somerset Levels, an area that has been farmed successfully since Roman times, if not before, though it has its challenges. The

practice of dredging stretches of river regularly and in succession had meant that floods, though a regular problem, were mostly confined to the fields and the villages were built on safer areas. Unfortunately, erroneous rules to protect the "environment" came into being and the terrible floods of 2014 occurred. The land would have flooded but not as extensively and many of the properties may have escaped being flooded if the rivers had been dredged. The lack of dredging was to protect water voles and improve water quality (ostensibly) as well as saving money but it is doubtful every vole swam to safety, rare plants were lost and barn owl populations plummeted due to their food chain being destroyed. Now Cumbria, followed by much of northern England and Scotland, has been flooded for the third time in ten years and farmers there are on record that they have been warning about this for many years. Again lack of dredging of the rivers has been blamed for increasing the severity of the flooding. If the flood defences there had held the farmland would still have been flooded as flood defences merely divert the water elsewhere at the expense of farmland. What is the point of a farmer trying to improve the health of his soil if the land is flooded at regular intervals in order to protect other people's houses? Are rural dwellers second class citizens? It is not just water that floods the fields but often sluices are opened to protect towns and villages being flooded and the water is contaminated. Why should farmers have to clean up their land without any compensation for these actions? Water is heavy and the weight of it not only drowns the soil but causes severe compaction as well. Surely it is time that a proper scheme was put in place to identify land that can be flooded and compensation paid?

8. Soil should be included in any plan for the environment but the environment cannot be treated as if it is divorced from agriculture. As it is, DEFRA is putting together a plan for farming that is intended to "grow more, sell more and export more food" (though there is no mention of farmers making a profit from what they sell) which obviously still regards soil as something that is merely a production machine rather than the important resource that it is. This country is now only 60% self –sufficient in food and no-one believes that transporting food around the globe unnecessarily is doing anything other than increase greenhouse gas emissions. It is time that emissions from shipping and aircraft were quantified and published regularly instead of pretending they do not exist. The world has had two record harvests in succession with the result that the UK is awash with wheat that cannot find buyers and yet the farmers that produced it are selling it far below the costs of production! If next year's harvest is as good the prices will be even lower and farmers will not be able to afford d to put another crop in the ground so why are we tied to rules that insist arable farmer grow at least three crops instead of letting the land be fallow until prices improve?
9. Whatever the long term outcome of the Paris Summit, the world is already an average of one degree warmer than a century ago and it remains to be seen if any future rise can be limited to a further one degree. The UK's climate is already altered due to the loss of Arctic ice resulting in the Jet Stream to meander around the Northern hemisphere instead of flowing west to east – a result that the scientists did not anticipate as they did not realise it was the temperature gradient between the Equator and the Arctic that kept the Jet Stream in position. On top of that, the flow of water from the ice cap has cooled and slowed the Gulf Stream, which in turn has led to strong winds being a feature of the UK's weather throughout the year and also the succession of storms that has hit the country in recent months. The winds may affect soils, particularly the light sandy soils and also damage the life forms in all soils, as can periods of being flooded or baked dry by periods of extreme heat.
10. Soil scientists I have spoken to have stated that they believe farms will have to become smaller again as the climate alters as soil health will suffer even further if otherwise. This is because the weather windows that farmers need to harvest crops in the best conditions for

both the crop and the soil are become shorter and more unpredictable. As we have our own old, small combine, my husband is able to wait for the best conditions so he can harvest the crops dry (wheat should ideally be less than 15% moisture when harvested or it needs drying) and when the soils are also dry. The drive for “efficiency” and ever cheaper food meant that many farmers have very large combines or no longer have their own combine and rely on contractors to harvest their crops. This means that many crops in recent years have been harvested when they have been very wet, even nearly 30% moisture while the fields have had their soil damaged in the process. In 2012 in particular many combines got stuck in the muddy fields and had to be dragged out by very large tractors, causing more damage. Also, the smaller farmers are being left to the back of the queue by contractors and they have seen the quality of their crops ruined by unsettled weather while they wait for the combine to arrive, leading to more financial loss.

11. It is impossible to be concerned about the nation’s soils while not being concerned about the physical, mental and financial health of the nation’s farmers. Farmers are at the top or near the top of all groups for suicide, stress, mental illness and marital and relationship breakdowns The very low farm prices in all commodities have been well reported this year while the BPS fiasco caused even more financial strain on many farmers. The subsidies farmers receive were supposed to help counter balance the inevitable price swings that occur year to year in farming due to variations in crop yields and prices etc. Instead they are all the profit a farm makes (and some may be used to help cover losses) while farmers are on benefits and visiting food banks. Farmers cannot invest in soils or the measures needed to help combat climate change in these circumstances. What is needed is money for flood defences, livestock protection and so on. This year saw Scottish farmers having to re-house livestock in August due to bad weather which also ruined crops, even if other parts of the country had record harvests. Why should farmer invest in breeding better livestock just to see them swept away by floods? They need to be able to put in measures to re-house or otherwise protect livestock whenever necessary. Arable farmers need to be able to buy smaller, more basic machinery that can be easily mended when it breaks down and got going quickly so weather windows are not missed, as opposed to large expensive machinery that has elaborate computer controlled features that mean long lay-offs and very expensive repairs whenever something goes wrong.
12. One size fits all policies are not going to solve these problems. Every area needs to be looked at with the involvement of all interested parties and a consensus obtained about what each area and soil type needs, with plans being adjusted whenever necessary as our climate changes.

January 2016

SHI0009

Written evidence submitted by Dr T. Harrod, soil scientist

1] Measuring and monitoring soil health.

What might be understood by soil health? Soils have many functions: economical, environmental, ecological and cultural. A healthy soil performs whichever of those is required of it at close to an optimal level. However, there may be conflicts of interest. A wet pasture may only be brought to full "health" for the farmer only after drainage, an action which an ecologist interested in the pasture's flora would see as detrimental.

Having been "out of the loop" for some years, I will leave answers on techniques of measuring and monitoring to others, but with the following qualifications.

A strategy for tracking soil health will have to fully recognise the diversity and range of the country's soil properties. There is an array of contrasting soils in this country. Considering the topic is one of health, the variety of soils means that a valid analogy is with the diversity of potential veterinary subjects, rather than medical patients. A strategy should also take into account the value of soil scientists and decision makers having real experience of the range of soils "in anger" in the field.

Regarding soils' chalks and cheeses, the ranges in their environmental, hydrological, ecological and economic /productive properties are diverse. While these are broadly covered by publications of the former Soil Surveys of England and Wales and Scotland, followed by the work at Cranfield's NSRI and the James Hutton Institute, detailed mapping and characterisation of the soils over the bigger part of the country is still awaited. The 1: ¼ million scale maps, published in the 1980s, which cover the whole of the country, although excellent for what they are, are only broad brush for the bigger part of their cover. In England and Wales at least much of the detailed soil mapping at 1:25,000 scale was on sample areas selected to represent major soil and land-use landscapes. With a few exceptions, in the past much soil research and monitoring has not taken advantage of this approach to best extrapolate findings. A future strategy should avoid perpetuating this shortcoming.

While I find the present generation of scientists studying soils and related subjects outstanding as scientists and users of a gamut of technological devices, it is sad that their grounding in the field differs from that of soil workers of my and earlier generations. Whereas many of us had long and full experience of the subject in the field, sometimes for many years, currently that is not possible. This means most lack the almost instinctive, visceral feel for soil and land-use problems that my generation enjoyed, and the immediate empathy with farmers and land-users that went with it. Professor Ian Mercer's comment about *"ecological expertise coupled with agricultural naivety",* with respect to Defra and other institutional workers' dealings with Dartmoor farmers, makes the point. A strategy concerned with soil health should address this shortcoming in the background of current and future generations of soil workers.

The treasure trove of soil information, already mentioned and acquired at public expense by the English and Welsh Soil Survey has copyright held by Cranfield University. The university needs to charge full economic cost for use of the maps and data by outside agencies. Sadly this is a serious deterrent on use of the data and maps by people who really should be drawing on the resource as a matter of routine. There is a Gordian knot here to for the strategy to cut, to get this basic information better used, without prejudicing Cranfield's team of experts managing and developing the resource.

A further obstacle on the routine use of much of the Soil Survey information lies in it having been published before the revolution in digital technology and publishing. There is a wealth of descriptive and interpretive material in the paper maps and explanatory publications, which clearly is being missed in electronic literature searches. Putting this right would be another part of constructing a robust strategy for oversight of soil health.

2**] Benefits of healthy soil:** With healthy soils our tiny, many would say overcrowded, country will benefit economically, environmentally, ecologically and culturally. Without soils in the best of heart any and all of these aspects of our national life will suffer. A brief list will outline the advantages of soils functioning at their optimal level:

- more efficient, profitable and sustainable food , biomass and timber production
- better water management, protection of ground and surface water resources and supplies, less flooding, less pollution from chemicals, sediment and organic wastes
- beneficial effects on wildlife habitats and biodiversity
- improved carbon sequestration and storage, which in turn improves the soils' adsorption and neutralisation of many pollutants
- enhanced management of the impacts of any climate change
- better preservation of our archaeological and cultural heritage

3] What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

A] *The environment.* The consequences are numerous. Perhaps an example will be representative, one which I was exercised about some 20-30 years ago in work for MAFF, NRA, EA, OECD and USDA, and which I still observe to be as serious as ever.

The naturally freely draining soils that occur over some of the country's major aquifers, when in pristine condition, accept rainfall at rates of centimetres an hour. This means that not only are the aquifers recharged at optimal rates, protecting groundwater resources, but also that there is no runoff, so no pollution by sediment, slurry or chemicals and no flooding. Soil pits often show such soils having many large earthworm burrows, natural drainage channels, penetrating to a metre or more below the surface. However, arable land on these soils represents sites for much of the water erosion of soil seen on British farmland. Why this apparent contradiction?

As well as free draining, these are among the country's most easily worked ground, often colloquially regarded as "boys' land". So they have been long favoured for tillage. One consequence is that organic matter content has been depleted by this long arable use, so that stability of aggregates, or tilth, is compromised. Sand and silt grains are then easily detached by rain drop impact and quickly block any pores, forming a cap across the surface. Often only a millimetre or so thick, the cap effectively seals the soil and runoff commonly starts with rainfall of less than a millimetre an hour, very little actually soaking in. As a farmer friend remarked, *"rain not worth putting my coat on for!"* Such rainfall will not in itself produce drastic erosion but it does persist for many tens, even hundreds, of hours per year. The less frequent falls of maybe five or ten mm an hour can cause serious erosion, flooding, pollution and nuisance with sediment, all because of soil caps. While these effects are very much "in your face", it should not be overlooked that all the water running off the surface is lost to aquifer recharge, in the long-term compromising water resources.

One of the areas where I studied this aspect of the degradation and loss of health of freely draining soils for MAFF was in the Parrett basin of south Somerset. Years later only a matter of weeks before the disastrous long-term flooding downstream of there, Palmer [a former Soil Survey colleague] and Smith [EA] published, almost presciently, a paper in Soil Use and Management drawing attention to the extent of soil degradation in that and adjacent areas of the Southwest. To his credit, Smith has been one of the very few EA staff who has properly appreciated the role of soils in meeting the challenges faced by the EA, for the better part of 25 years much of his message falling on deaf ears.

B] *Food security*. Damage to soil health by its degradation, whether loss of organic matter, capping, erosion or compaction, inevitably reduces plant growth below its full potential. If this goes uncorrected, the yields after all the technical advances with plant breeding, fertilisers and pesticides that agriculture and horticulture achieve, come despite the handicap of soil degradation. A few percentage loss on yield may be the difference between profit and loss on the crop, risking us becoming that much more dependent on imported produce, with otherwise attendant, unnecessary air or shipping miles.

C] *Ecological and amenity effects.* Again an example, which covers both; it should not be overlooked that amenity and leisure have real economic value in their own right. The country sport that this example impinges on is certainly a case of that.

Over the centuries the salmonid population of British rivers and streams have declined drastically, in places to the point of extinction. It is hard to believe but there is strong historical evidence, for example from the Domesday Book, that most rivers in England had salmon runs not dissimilar to those often shown in wild life films on British Columbia and Alaska. The decline must have complex causes, centuries of pollution from urbanisation and industry, over fishing, diseases and landuse changes are all widely quoted. Work by the USDA has shown that salmonid spawning success is seriously undermined when fine sediment enters the streams and rivers. This accumulates in the pores in the river bed gravels where the fish have laid their eggs in redds, the build-up reduces the flow of water and consequently the oxygen supply, suffocating the eggs. In the UK much of the fine sediment found in spawning gravels has been shown to derive from land use practices which compromise good soil health.

4] What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Regarding what measures are in place for the promotion of good soil health, again I do not feel that, in retirement, I am fully au fait with the current situation. Save it to say that I feel from observation, whatever measures are in place, they are far from totally successful, or in the case of cross compliance in the context of single farm, now basic payments received by farmers, seldom enforced. One sees practices routinely followed which are detrimental to soil health and to the wider environment. An obvious and widespread example is the way maize stubble is left over winter without any effort to abate runoff across the soil compacted during harvesting. Rough ploughing following the maize harvest obviates runoff risks, but is scarcely ever carried out. The motivation is that leaving the ground as it is facilitates spreading of farm yard manure and slurry ahead of the next crop, which is frequently a return of maize, on many farms repeated year after year. This spreading, sometimes at excessive rates, often is primarily a waste disposal exercise rather than one of measured organic fertiliser application. I see such fields that I monitored in the 1990s, when they already had ADAS phosphorus indeces at levels likely to pollute water, still receiving the same cropping and the same generous FYM and slurry applications.

The comments in the previous paragraph should not be read as and advocacy of wide-scale punitive action over cross compliance. Education of the users of soils has a strong role to play. One looks at the present patchwork, sometimes mare's nest, of advice, scatter gunned rather than targeted, directed at farmers in particular, whether from a range of nature conservancy interests, from the Environment Agency, from fishery interests and from other bodies, and wonders could this not be done better, more uniformly?

History and experience suggests indeed it could. When farming was seen as almost vital to national survival, an attitude which prevailed well into the 1970s, the industry benefited from a model extension service, NAAS, later ADAS. Staffed by people with sound agricultural backgrounds who spoke the farmers' language and had their confidence, something of a contrast with the situation alluded to by the quote above from Ian Mercer. NAAS and ADAS provided a mechanism for improvement and change often at an impressive scale and speed. As an example in the 1960s grassland farmers were changing from hay as their main winter fodder to grass silage. In the early stages many were directly cutting the grass with forage harvesters into trailers and ensiling it there and then. The unwilted grass made poor quality silage and produced heavy discharges of highly polluting effluent. Within a year or two grass was being cut, allowed to wilt for 24 hours and then ensiled, curtailing the water pollution and fish kills by the effluent, and, win-win, improving silage quality. Much of this was achieved thanks to the work of NAAS.

Come the change in the 1980s from an agenda of all out production from agriculture to a realisation of the industry's place in the environment, what happened? The organisation was emasculated and an exemplary means of easing farming, including soil management, into a new era, was squandered, just when farming need guidance and direction it could trust.

While it is too much to expect a resurrection of the structure and organisation of the agricultural advisory services at their peak, in them can be seen as a means of an effective way of guiding and educating farmers and other users of the land in protecting and improving soil health. Furthermore we could do worse than apply the model more widely to the whole natural environment.

5]What role should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soils are the bridge in the terrestrial environment between its living expression as biodiversity and its inanimate side provided by geology, geomorphology, hydrology and climate. Research at Exeter University in the 1990s demonstrated that soil type was one of the chief controls on the distribution of badger setts. Different soils have their various effects on the movement of water to both aquifers and to rivers and streams, as the CEH publication on Hydrology of Soil Types [HOST], clearly confirms, saying *"it is difficult to overstate the importance of soils in influencing hydrological phenomena at both the site and catchment scale".* The EA's groundwater vulnerability guidelines are similarly based on soil properties.

The place of soil in any plan for the natural environment is as vital as other elements, such as biodiversity or the control and abatement of pollution. The health, good or bad of soils, is critical to the multitude of functions and services that they provide across the natural environment and the way we use it.

January 2016

Written evidence submitted by R.C. Palmer, Soil Assessment Specialist

1 I have a background of 18 years as a surveyor with the Soil Survey of England and Wales (employed by the Lawes Agricultural Trust), working extensively in Midland England (1968-86) from a base in Wolverhampton. Following privatisation of SSEW in 1986, and its transfer to Cranfield University, I worked for 20 years (1986-2006) in charge of the York office of the Soil Survey and Land Research Centre, a Department of Cranfield University. Since 2006 I have been a self-employed soil scientist specialising in the field assessment of soils and worked widely on the effects of modern intensive farming on soil structural degradation for a range of clients.

2 Executive Summary

- Soil structure is the basic building block of soil and is mutually dependant on porosity. It describes the form of the solid part of the soil and porosity describes the spaces within and between the solid fragments. Therefore, an improvement in soil structure produces an improvement in porosity, whilst degrading structure will reduce porosity. The level of soil structural degradation that has been reported in the last 15 years is reducing porosity in soils and having a dramatic detrimental affect on a wide range of soil functions (Blum,1993 and Defra, 2004). Biomass production (food fibre and forestry), environmental interactions (filtering, buffering and transforming compounds) and biological habitat and gene reserve are all being degraded.
- Soils in good health (ie structurally undamaged) can be radically changed, very quickly, by compaction (structural degradation), which reduces temporary winter water storage capacity by up to 75% with a knock-on effect of increasing the risk of:-
  - flooding,
  - soil erosion,
  - surface water pollution,
  - and muddy floods, which occur in areas not normally prone to flooding and distant from river floodplains.
- Structural degradation inhibits root development and when severe can seal-off subsoils from root penetration, which reduces yield.
- Soil structural degradation is easy to identify and assess in the field by simple visual and tactile inspection of soils using a spade. There is no need for expensive laboratory work to identify degradation features.
- Farm advisers and farmers should be given guidance on undertaking field assessment of soils - to identify compaction; to diagnose the effects of surface capping, plough pans and dense structureless massive topsoils; and to develop remediation plans for damaged soils, as required, within on-going farm management plans.
- An annual soil structural health check should form an integral part of soil management plans especially where arable crops are grown, especially maize and other late harvested crops and winter cereals.
- Instruct a competent body to monitor the maintenance of physical soil health by field inspection of soil structure and review of soil management

plans with the aim of relating the level of the single farm payment to the state of physical health of soils across the farm. Field inspections of soil structure must be carried out from November through to March when soil compaction features are most easily seen and diagnosed.

3 Soil structure describes the size, shape degree of development and spatial arrangement of solid particles into structural units (peds) and the voids (pores and fissures) between and within these aggregates. In topsoils structures can be naturally formed aggregates (peds) or artificial aggregates formed by cultivation (fragments or clods). Peds are relatively permanent aggregates and persist through cycles of wetting and drying. Fragments, however, are less permanent and can be slaked or broken during wetting and drying cycles. Soil structure is determined by texture and soil water regime and influenced by vegetation.

4 These comments are based on field assessments made during detailed catchment surveys reviewing soil structural degradation under a wide range of crops/land use from permanent grass to ley grass, to winter cereals, to late harvested crops (including maize vegetables and potatoes), to upland rough grazing.

5 Over the last 15 years, soil structural conditions have been assessed in 26 river catchments mainly in SW England but also in East Anglia and Wales. The catchments range from the Tone and Parrett in Somerset, the Avon in Hampshire, the Wensum in Norfolk and the Clyst in Devon. In total soil structural degradation has been assessed at approximately 4,000 sites in these catchments.

6 Work has been carried out mainly for the Environment Agency but also projects have been funded by Farming and Wildlife Advisory Group (FWAG), Natural England, National Trust, BBSRC, Catchment Sensitive Farming Initiative (CSFI); and Farmcare. A detailed Report has been produced for each catchment survey including location and details of the assessment sites and where necessary recommendations were provided for soil structural improvement.

7 A simple methodology has been devised to assess the structural state of field soils, which is used to classify the degree of structural degradation found in the field into one of 4 defined classes.

Field evidence	**Degradation Class**	**Remediation?**
Pronounced structural damage with widespread erosion associated with Severe class	Severe and High	Immediate remediation required
Evidence of local surface runoff	Moderate	Remediation not yet needed; standard operations within rotation sufficient
No surface runoff	Low	Soils in good structural health

8 A review of results for the 24 catchments in SW England has been published (Palmer and Smith, 2013) in ‘Soil use and Management’, an international peer-reviewed journal. This scientific paper reviewed data collected from 3,243 sites, including 2,032 cultivated sites and 1,154 under permanent grass. Key findings were;

- 75% of late harvested crops (principally maize and potatoes) required immediate structural remediation
- Over 60% of winter cereal fields required immediate structural remediation
- 55% of all cultivated sites (including ley grassland) required immediate structural remediation.

9 Healthy soils with a vegetated cover readily absorb rainfall events that happen in the UK, in almost every situation. They also allow the recharge of our groundwater aquifers. Physically damaged soils (through compaction, capping, plough pans) can absorb up to 70% less of winter rainfall events resulting in a predominance of lateral surface-flow or lateral through-flow in the soil. This increased lateral flow results in: greatly increased flood risk; an increase in soil erosion and sediment removed to watercourses; an increase in water pollution by crop nutrients as topsoils wash into watercourses; and an increase in muddy floods as rain washes from fields into areas not normally prone to flooding and often some distance from river floodplains. The volume of water percolating to recharge groundwater aquifers is greatly reduced.

10 This practical research demonstrates that runoff from managed farmland has been increasing over recent years because of widespread and profound soil structural damage caused by increasingly intensive farming operations. This increase in the proportion of rainwater running off fields coupled with the increase in intensity of winter storms is having and will continue to have increasingly severe impacts on flood risk across England and Wales.

11 ‘Catchment Sensitive Farming’, a Natural England initiative to reduce agricultural water pollution is now available in priority selected catchments across England, and includes ‘soil condition’ as one of the training packages available to farmers in these areas. Specific training on how to recognise surface capping, plough pans and degraded topsoil structure, together with instruction on how to diagnose the effects these features will have on the farm business and wider environment should be incorporated into this training package. Then farmers would be competent to incorporate a remediation strategy for structurally damaged fields into their farms’ forward plans. If proof of concept for this type of training can be achieved within CSF, then it should be extended to all other catchments in England currently outside the scheme.

12 Soil health should play an extremely important role within the Government’s 25-year plan for the natural environment. Politicians have recently spoken about how flood risk needs to be looked at differently as the sole reliance on flood walls and barriers may no longer be sufficient. There is a need to incorporate better use of flood plains, better use of catchments for water retention, which

includes better retention of water in soils and slowing the movement of water from agricultural land to watercourses and soil health, through better soil structure should be part of this mixture of new ideas.

13 If soil structure is to be improved there needs to be a clear system of monitoring soil condition by the RPA and EA as part of cross compliance inspections. Where runoff causes water pollution and flooding recommended remedial works need to be undertaken in an efficient and timely manner otherwise a system of penalties should be invoked, which reduce the level of their single farm payment for those fields. Persistent offenders, in continuous breach of rules, especially where high risk crops are regularly grown on unsuitable soils causing repeated muddy floods or gross water pollution events should lose the whole of their single farm payment for that land. In some cases it may be more appropriate to change the use of high-risk farmland that is prone to soil degradation and runoff whereby farmers are compensated for loss of profit using agri-environment scheme monies e.g. land use change to woodland and low-input, low-intensity grassland.

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January 2016

Written evidence submitted by Professor Lindsay Stringer

I am a Professor in Environment and Development at the University of Leeds. I am making this submission in a personal capacity drawing on recent work I have been involved with, particularly through the Economics of Land Degradation initiative and an EUFP7 funded project (called RECARE: http://www.recare-project.eu/) which focuses on remedying soil threats in Europe. I am also a coordinating lead author for the Intergovernmental science-policy Platform on Biodiversity and Ecosystem services (IPBES) for the Africa Regional Assessment, and a lead author on the IPBES Land Degradation and Restoration Assessment. I comment not as a soil scientist but as an environmental social scientist – a disciplinary area that is vital to informing sustainable soil use and management, but which is often overlooked due to a dominance of input from the natural sciences. For transparency, I provide the academic references upon which my thinking is based at the end of my response.

1. How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

Ii0I focus my response to this point on the second part of the question, regarding how the Government could develop a strategy for tracking soil health. Multi-stakeholder engagement will be key to the development of such a strategy, as indicators will vary in their appropriateness in different parts of the country and for soils under different land uses. (See approaches to developing soil and land sustainability indicators from overseas in Reed et al., 2011, which could usefully be adapted and followed).

Stakeholder engagement from the very start of strategy development would likely increase the buy-in from land managers in assessing their own soils, and could deliver a more cost-effective and joined up approach overall. It would also promote learning and reduce potential conflicts between stakeholders (see e.g. Dyer et al., 2014; Reed et al., 2014). Further, given the growing body of research highlighting the need for policy coherence, and in light of international commitments under e.g. the UNFCCC and the Sustainable Development Goals, it is vital to ensure that any strategy to track soil health supports reporting obligations under wider, related policy frames. Multi-stakeholder approaches can again underpin this.

Engaging the private sector in strategy development and monitoring will also be key to ensuring soil health. With this comment I highlight the need to look beyond the agriculture sector to also involve businesses operating within the forestry, mining, energy, water, tourism and transport sectors. These industries impact upon soil and often have a large land footprint, as well as facing threats to their profitability through soil degradation (Barkemeyer et al., 2015).

2. What are the benefits that healthy soils can provide to society?

Aside from the obvious benefits linked to the delivery of different types of ecosystem services, which requires healthy soils, I draw on the recent ELD report "The Value of Land" (see http://eld-initiative.org/) to highlight their economic benefits. Taking action in preventing top soil loss to increase crop productivity can have benefits worth nearly a trillion USD over the next 15 years in Africa alone. Similarly, the cost of inaction on this issue is anticipated to be almost two trillion USD over the same period. Agriculture only captures a small percentage of global GDP, but lost ecosystem service values are between 10–17% (USD 63 trillion). Agricultural lands provide a significant output of ecosystem services not accounted for if only dollar values of agricultural products are included (roughly USD 1.7 trillion/yr, or 2.8% of the global annual GDP). This suggests that beyond ecosystem services and the maintenance of cultural and social values (see Kenter et al., 2015), ensuring sustainable use and management of soils can benefit the UK tax payer over the long term.

3. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

Linked to my response to the question above, and again, drawing on information in the ELD Value of Land report, loss of ecosystem services through land and soil degradation costs USD 43,400–72,000 per square km globally, every year. Ecosystem service loss from land degradation costs USD 870–1,450 per person/yr. Accumulated, this exceeds the GDP of 15 countries. Globally, 50 million people are expected to face displacement in the next 50 years as a result of desertification, land and soil degradation. That many migrants assembled would constitute the world's 28th largest country by population and research shows that vulnerability under conditions of resource scarcity can act as an amplifier of conflict (Okpara et al., 2015). In relation to the latter point, soil degradation is clearly a globally relevant issue. Any efforts undertaken in the UK could provide useful lessons for other countries to also protect their soils, ultimately reducing soil degradation overseas and reducing risks of displacement driven by a failure to protect soil health. Obviously the situation is highly nuanced and complex – more so than in the example I have provided. However, these wider linkages are often ill-considered in sector-based policy and strategy development, and so I would like to highlight the importance of joined-up thinking and its wider implications.

4. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

My expertise is primarily grounded in sustainable land management activities overseas and at a supra-national level. I regularly engage with UN institutions such as the UNCCD, FAO, UNEP and UNDP on soil health related issues. The UK Government is currently rather inactive in its engagement with international soil- and land-related frameworks such as the UNCCD and I am not aware of UK Government activities to support initiatives such as the 2015 International Year of Soils beyond those of the Scottish Government.

As already highlighted above, the UK has considerable expertise that could play an important role in guiding good practices overseas through these frameworks. Similarly, by strengthening engagement in these kinds of fora and related initiatives linked to e.g. SDG 15.3 on land degradation neutrality, it affords the opportunity to harness wider benefits. It is also worth explicitly noting the UK's declining self-sufficiency ratio and consequently, its increasing reliance on food imports from elsewhere. Our food system is highly globalised so it is vital that the strategies used to monitor and improve soil health are similarly global, while simultaneously addressing the UK's needs in a nested approach.

5. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil is fundamental to our very existence. It has long been sidelined and undervalued in policy, yet it plays a key role in our food production, in regulating our climate and fresh water (and thus in our efforts to mitigate climate change) and in supporting the planet's biodiversity. As such, ensuring soil health should be a keystone priority in the Government's upcoming 25 year plan for the natural environment.

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January 2016

Written evidence submitted by Professor Mark Kibblewhite

Background

I welcome the opportunity to contribute to the Committee's inquiry in to soil health. I am an independent soil scientist based in Dorset and the proprietor and director of MK Soil Science Ltd, which provides technical support to public bodies, including recently the European Commission, the European Environment Agency and the United Nations. I am an Emeritus Professor at Cranfield University, an Emeritus Research Associate of Landcare Research New Zealand and the current President of the Institution of Agricultural Engineers. Former roles include Director, National Soil Resources Institute; Chair, European Soil Bureau Network; Head of Land Quality, the Environment Agency. I am making this submission as an individual citizen.

Key points

- Soil is a living system. Some soil types are of higher quality than others for specific uses e.g. agriculture, but the health of all types is important.

- A meaningful indicator of soil health is the level of organic carbon in a soil, relative to a characteristic range for the soil type.

- Existing soil monitoring networks can be used to assess soil health at the national level. The National Soil Inventory has not been re-sampled for a decade but could be re-established with relatively modest investment.

- There is no Government strategy for soil protection (that adopted by the last Labour administration was not endorsed by the Coalition Government).

- The requirements for soil management under the Basic Payment Scheme are minimal and inadequate considering the costs to the economy of soil degradation (estimated at £1.2 billion annually for England and Wales). This suggests greater Government emphasis on minimising regulation than securing soil protection.

- Key areas for incentives to maintain soil health are: (1) against land use and management causing permanent damage to soil i.e. restrictions on certain land uses and management practices; (2) support for better utilisation of manures and organic materials to improve soil health.

- Soil underpins the terrestrial environment and should be a centre plank of the Government's 25 year plan for the natural environment.

Question	Response
How could soil health best be measured and monitored?	A definition of soil health[1] is needed before explaining its measurement and monitoring. Soil is a living system. Its physical and chemical properties define the habitat for micro-organisms that use carbon from plant residues to support soil functions. This ecosystem can be likened to a 'biological engine' fuelled by carbon and working to support plant growth and terrestrial life, including humans. Different soils provide different physical and chemical conditions that support microbial and plant ecosystems differently. Consequently, the potential of soils to support services varies between soil types. Some soils are high 'quality' for e.g. agricultural production, water storage and management, while others are of lower quality. The health of a soil of a given quality can vary and with this so will its actual delivery of services. A parallel with human athletes helps with understanding soil health. One athlete may be of higher quality than another because they have key attributes such as height, but the other may actually perform better because they are fitter i.e. healthier. There is also a parallel between the way in which the health of athletes and soils can be assessed. Athletes use carbon from different sources e.g. carbohydrate or fat, to provide energy. As the net energy delivered from different sources varies, the human body uses them sequentially. Simple sugars cost less to use than carbohydrates and these cost less than fats and in turn these less than protein. A healthy athlete can access good reserves of higher energy yielding carbon. By contrast, a starving human in poor health will eventually consume poor energy sources e.g. structural protein (muscle tissue). Similarly, soils that have an abundant supply of easily processed and higher energy yielding carbon, e.g. in polysaccharides, are healthier than those that do not. And where soils have been driven too hard and soil organic carbon levels have been lowered excessively, the 'biological engine' in soil struggles to fuel itself, does less work and, at the extreme, will consume structural organic matter that holds the soil together in aggregates. Therefore the organic carbon content of soil is a meaningful measure of soil health. Moreover, measurement of total soil organic carbon in soil is well understood, robust and routine[2]. The critical issue is then to define which levels of soil organic carbon represent a healthy soil. It turns

[1] Kibblewhite et al. (2008) Soil health in agricultural systems. *Philosophical Transactions Royal Society B: Biological Sciences* **363**(1492), 685-701.
[2] Kibblewhite et al. (2008) Environmental Assessment of Soil for Monitoring: Volume VI Soil Monitoring System for Europe. Office for Official Publications of the European Communities, Luxembourg.

	out that there is a relationship between the clay content of soil and its 'normal range' of soil organic carbon. The clay content defines the minimum soil organic carbon level that a particular soil may reach[3] and it can also be used to define an upper limit to its 'normal' range[4]. The level observed within this range is an indicator of the soil health i.e. the soil is less healthy if it is close to the bottom of the range. Useful thresholds can be defined e.g. soil health is 'good' where the soil organic content exceeds half of the normal range.
How could the Government develop a strategy for tracking soil health?	The minimum requirements to implement soil organic carbon content as a national indicator of soil health are: 1. A well-constructed national network sampled at appropriate intervals. 2. Data on clay contents for different soil types interpreted to provide their 'normal range' of organic carbon contents. Unfortunately, an existing national scheme (the National Soil Inventory or NSI) has not been maintained via Defra funding. This can provided soil measurements across England and Wales but was last sampled more than a decade ago. Previous data reported in 1995[5] indicated an overall loss of soil organic carbon. The causes for this apparent loss have been debated but are probably mainly a result of historic land use and management changes[6]. Importantly, the changes reported for arable soils were small, probably because many have fallen to the bottom of their normal range i.e. their health as indicated by soil organic carbon contents is at a low ebb. Restoring the NSI as an operational monitoring scheme would not be complicated, with costs for re-sampling, testing and interpreting the NSI for England and Wales likely be relatively modest because extensive design costs have already been incurred. Note. There are several existing networks. The NSI provides national unbiased coverage of top soils under different land uses with sampling at nodes on a 5km grid. In Scotland, a parallel network is established and has been sampled more recently[7] than that in England and Wales. The Countryside Survey samples soil under different land cover using stratified sampling[8]. The European Commission's LUCAS network includes soil carbon measurement for a

[3] Loveland and Webb (2002) Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. *Soil and Tillage Research* **70**, 1-18.
[4] Verheijen et al. (2005) Organic carbon ranges in arable soils of England and Wales. Soil Use and Management **21**, 2-9.
[5] Bellamy et al. (2005) Carbon losses from all soils across England and Wales 1978–2003. *Nature* **437**, 245-248.
[6] Barraclough et al. (2015) Is there an impact of climate change on soil carbon contents in England and Wales? *European Journal of Soil Science* **66**, 451- 462.
[7] Chapman et al (2013) Comparison of soil carbon stocks in Scottish soils between 1978 and 2009. *European Journal of Soil Science* **64**, 455–465
[8] Reynolds et al. (2013) Countryside Survey: National "Soil Change" 1978–2007 for Topsoils in Great Britain—Acidity, Carbon, and Total Nitrogen Status. *Vadose Zone Journal* **12** (2).

	sub-sample of its sites[9]. The BioSoil[10] network samples soil where there is forest cover. Other European countries have initiated and are maintaining national soil monitoring networks e.g. a powerful scheme covering all of France was established successfully a decade ago[11].
What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?	Soil is a form of natural capital underpinning many provisioning, regulating and supporting services and goods delivered by natural resources. It is an important part of the national infrastructure e.g. for water and waste management as well as food security. Where soil is degraded the future provision of goods and services and / or the costs of their delivery are compromised leading to a less efficient economy. It is probably not possible to quantify the natural capital value of national soil resources. They are many in type and in their uses and the unique contribution of soil to delivery of services and goods is not easily extractable from that provided by other resources, such as water and above-ground biodiversity. Moreover, some of the services e.g. cultural ones are not readily monetised. However, it is feasible to estimate the costs of degradation to the wider economy. A recent study[12] estimated that for England and Wales the damage costs arising from the management of agricultural and semi-natural land likely amount to £1.2 billion per annum, with 80 percent of these costs being external to the land user. The committee's question focuses specifically on soil health. Strictly, this puts aside the impact of degradation of soil quality and quantity. Whereas soil health is in principle recoverable (by increasing inputs of organic matter), this is less straightforward for losses in soil quality (i.e. the maximum outputs available when the soil is healthy) or in soil quantity (e.g. by extension of the built environment). Some types of soil degradation and their consequences for soil health, quality and quantity are summarised briefly below. **Erosion by water and / or wind** reduces soil depth and permanently lowers the capacity of the soil to e.g. support agriculture or regulate water flows. It lowers soil quality. **Decline in soil organic matter** lowers soil organic carbon levels and leads to a loss of soil health. In principle, this loss can be recovered by increasing the supply of organic carbon to the soil.

[9] Tóth et al (2013) The LUCAS topsoil database and derived information on the regional variability of cropland topsoil properties in the European Union. *Environmental Monitoring and Assessment*. **185**, 7409-7425.
[10] Vanguelova et al (2013) A new evaluation of carbon stocks in British forest soils. *Soil Use and Management* **29**, 169-181.
[11] Arrouays et al. (2003) A new projection in France: a multi-institutional soil quality monitoring network. *Comptes rendus de l'Académie de agriculture de France*. **88**.
[12] Graves et al. (2015) The Total Costs of Soil Degradation in England and Wales. *Ecological Economics* **119**, 399-413.

	Compaction alters the physical properties of soil and compromises its capacity to e.g. support plant growth and to absorb and moderate water flows. It reduces soil quality rather than soil health. This loss is short-lived for topsoil cultivated annually but may be longer-term in grassland and in subsoils. **Contamination** of soil alters its chemical properties and remediation is not economic at least for arable and other greenfield sites. It reduces soil quality. The most serious degradation of soil is where soil functions are effectively terminated by **extension of the built environment**, via excavation and sealing. The issue here is the loss of the soil as a functioning natural asset i.e. a loss of soil quantity.
What measures are currently in place to ensure that good soil health is promoted?	The UK is party to the European Thematic Strategy for Soil Protection as agreed by the Council of Ministers[13], however there is no existing formal operational strategy to promote soil health or to protect soil resources in England. The Coalition Government chose not to endorse the strategy agreed by the previous Labour Government[14] and the current Conservative Government has no new one. Some soil protection measures are a requirement of the Common Agriculture Policy (CAP) and therefore unavoidable for the UK if it is to make Pillar One payments. At least for England, their design and implementation indicate that the Government priority is to apply a minimalist approach to achieve compliance with least regulation, rather than to implement a strategy aimed at soil protection. Cross-compliance measures applied within the Basic Payment Scheme have been revised for 2015[15]. There is now no requirement for farm Soil Protection Reviews. Instead, there are specific requirements for minimum soil cover (GAEC 4), site specific conditions to limit soil erosion (GAEC 5) and for maintenance of soil organic matter (GAEC 6). These are weak measures considering that damage costs exceed £1 billion[16]. GAEC 6 is particularly weak; it banns in-field burning of crop residues (e.g. stubble) which is a very long-established legal requirement in the UK. As such, it achieves no new improvement to inputs of organic matter to soil – it could be described as a 'non-policy, policy measure'. The overall position in England is of an ineffective 'light touch'. This view is reinforced further by the fact that not all agricultural land falls under the Basic Payment Scheme and so is not covered by the GAEC rules anyway. And 'Without inspection, things tend to deteriorate' and there have to be serious doubts about the effectiveness of Defra's inspection regime, bearing

[13] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - Thematic Strategy for Soil Protection [SEC(2006)620] [SEC(2006)1165]
[14] Defra (2009) Safeguarding our soils – a strategy for England. 42pp.
[15] Defra (2015). The guide to cross compliance in England. 77pp.
[16] Graves et al. ibid.

	in mind the large number of farms relative to inspectors and the impact of cuts to Defra's resources.
And what further measures should the Government and other organisations consider in order to secure soil health?	Two priorities to help secure soil health are: 1. Restrictions on damaging land use and land management 2. More effective recovery of manures and organic wastes to land. Soil is damaged when land is exploited inappropriately e.g.: forage maize production on erodible soils, where late harvesting in wet conditions causes soil compaction and the soil surface is left bare during winter rainfall, leading to soil erosion; potato and other root crop production on alluvial and lowland peat soils leading to declining soil organic matter, loss of soil structure and a risk of erosion during flood events; over stocking of fields with animals that are not winter-housed, causing compaction and a loss of soil structure; continuous arable production on soils formed on chalk, leading eventually to an almost complete loss of soil organic matter. All of these and other damaging scenarios are well-known and widely communicated but remain common. They continue because they bring short-term economic advantage to farmers. Moreover, while the on-farm damage costs are significant (estimated at £200 million per annum for England and Wales), they are only about a fifth of the total costs[17], with the remaining four fifths or as much as £1 billion of costs being borne by the wider community, via e.g. increased flood risk and atmospheric carbon emissions. In this context, there is a clear rationale for stronger policy intervention. To improve soil health, net inputs of organic matter to soil need to be increased. The first priority is to maximise the production of organic matter by crops and ensure that a high proportion of this is retained in soil via strong root growth and incorporation of above-ground crop residues. Productive agricultural systems are the key to achieving this priority, ideally enhanced by the inclusion of cover crops in arable systems. However, there is an urgent need to utilise manures and other organic wastes better, as these represent a valuable and generally under used resource in conventional agriculture. The problem is that intensive livestock production and centralised food processing create more organic wastes than can be used on land that is within economic and logistical reach, because of transport costs and as the timing of organic materials' production and when it can be usefully applied to land are not coincident. Possible solutions include: the collection and industrial-scale processing of animal and food residues to produce a dry product that can be stored, more easily transported and marketed over a wide geographical area; the formation of local / regional farm collectives within which sources and spreading opportunities for wastes can be shared better. These are not new ideas but their effective and wider implementation

[17] Graves et al. ibid.

	requires incentives to disrupt current practice, for which the mind set often remains one of disposal, via spreading to 'sacrificial' land or transfer to energy from waste facilities, rather than recovery of a valuable resource.
What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?	Soil resources are foundational to the terrestrial environment and underpin the delivery of land-based services and goods. They are critical for food production and security. They are at the heart of catchment management for reduced flood risk, ensuring safe water supplies and conserving aquatic biodiversity. They are the biological engine at the base of the food chain supporting above as well as below-ground biodiversity. Therefore soil resources should be central to the plan for the natural environment and their health must be a strategic objective and the Government should develop and apply a new soil strategy. This should include proper monitoring of soil health (via soil organic carbon content); a legal framework for soil management that incentivises good practices effectively; and, conservation within the planning regime of the best and most versatile soils for agriculture and biodiversity.

January 2016

Written Evidence to submitted by the Permaculture Association Britain

Summary of recommendations

- The Permaculture Association recommends a national soil monitoring campaign built on citizen science.
- The Permaculture Association believes that healthy soil is the basis of modern society.
- The Permaculture Association recommends agricultural extension services that focus on raising farmers' engagement with the health of their own soil.
- The Permaculture Association recommends that building healthy soils should be a government priority.

About permaculture and the Permaculture Association Britain

"Permaculture is an approach to meeting human needs while increasing ecosystem health." *Rafter Sass Ferguson*. Devised in the mid-1970s by two Australian ecologists, permaculture combines ethics, ecological principles and design strategies to create healthy, productive and non-polluting sustainable settlements. Permaculture offers a practical route towards a society living in harmony with nature, where we take responsibility for ourselves, each other and future generations.

Since 1983 the Permaculture Association Britain, a registered charity and company limited by guarantee, has been supporting the development of permaculture in Britain. It's vision is 'an abundant world in which we care for the earth, each other and future generations, whilst living within nature's limits', and its mission is 'to empower people to design thriving communities across Britain, and to contribute to permaculture worldwide'.

The Association's primary activities are focussed on supporting ecological design and sustainable living through a wide range of education, research and networking activities and events. Specifically, offering the Diploma In Applied Permaculture Design, organising the LAND demonstration network, helping people to collaborate, share resources and engage in practical solutions, providing a key point of contact for the UK and an international hub, and maintaining a popular website, e-bulletin, newsletter, and social media communications. There are 10 paid staff (5 FTE), 120 volunteers, 1400 members and 7000 e-bulletin subscribers. In September 2015, we hosted the 12th International Permaculture Conference in London, attended by over 600 delegates from 70 countries.

Detailed response to the Inquiry

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

The Permaculture Association recommends a national soil monitoring campaign built on citizen science.

The creation and maintenance of healthy soil is central to permaculture. Therefore, over the last three years the Permaculture Association Britain has directed considerable effort to the development of simple soil tests. Our view is that healthy soil has three elements of equal importance; chemistry, biology and physics (structure), but that agricultural soil science, and particular lab-based soil testing, has focussed too much on chemistry at the expense of the other two elements. We also believe that an understanding of healthy soil should not be limited to scientists but should be readily available to all growers. We have therefore developed a series of simple soil tests which can be done without specialist equipment and with no technical knowledge. These tests measure soil type, structure, pH, texture, bulk density, water penetration and depth, and use earthworms and slaking as proxies for soil organic life. These tests bring soil into the realm of 'citizen science', allowing a large body of growers to record the health of their soil, and changes to it over time, with minimum cost.

The Permaculture Association would therefore strongly encourage the UK government to develop soil testing as a citizen science activity. The benefits of this would be three-fold. Firstly, it would enable a variety of sites and a geographical range which would be beyond the reach of soil testing done by professional scientists. Secondly, it would be considerably cheaper than a national soil testing programme undertaken by professionals. Thirdly, being involved in such a programme would have considerable educational and awareness raising benefits to the participants themselves, the growers on whose actions soil health depends; in this way, growers become active participants in both the creation and analysis of healthy soil on their land in a new way.

What are the benefits that healthy soils can provide to society?
What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The Permaculture Association believes that healthy soil is the basis of modern society.
The development of agriculture was central to the development of human settlement, and in turn to the development of civilisation. For 8,000 years soil has supported agriculture, which in turn has supported an ever growing population of humans. There is no more precious natural resource than soil. Healthy soil is also a crucial resource for the non-human environment. Soil is itself a vastly complex eco-system supporting thousands of different forms of life. Soil in turn supports the whole ecosystem above ground, be it woodland, grassland or wetland. Soil forms the solid foundation of the food pyramid, being the basis of almost all primary production on land; while primary producers derive their energy from sunlight, for nutrients, water and stability they need soil. Complex, stable, healthy soil will almost inevitably produce complex, stable, healthy ecosystems. Conversely, the absence of healthy soil will be a major block to the development of any healthy ecosystem.

Though it is often forgotten today, without healthy soil agriculture will eventually fail and, even in our industrial age, so will the food supply. The desertification of once rich agricultural lands in North Africa and the Middle East serves as a warning of what can happen when fertile soils are not properly cared for. The number of humans who can survive by fishing, hunter gathering, or even on synthetic meat is likely to be tiny. The development of scientific agriculture over the last two centuries has freed the majority of humanity from back breaking agricultural toil, but without the maintenance of healthy soil this will not continue. There is plenty of evidence that a crisis of soil is beginning, with increasing soil erosion, falling fertility and, recently, the serious problems for soil posed by flooding. It has been estimated that under current management practices soil in the UK can support less than a hundred more harvests. These problems are likely to intensify under the pressures of climate change, as dry summers alternate with wet winters. There is also the problem of the over-reliance on soluble fertilisers and pesticides at the expense of soil biology, meaning that the natural fertility of much soil in the UK is now seriously compromised.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

The Permaculture Association recommends agricultural extension services that focus on raising farmers' engagement with the health of their own soil.
Anecdotal evidence suggests that many farmers, especially tenant farmers, have little awareness or understanding of the soil they work. Reliance on mechanisation, dependence on soluble fertilisers for soil fertility, and the time pressures of modern farming often remove farmers from a direct relationship with the health of their soil. This neglect of soil health can been seen during periods of wet weather where substantial areas of arable soil appear to have become waterlogged due to panning. Moreover, even a cursory examination of many farm soils reveals an apparent absence of organic life.

We do not believe that farmers need to adopt solely organic methods of farming to improve the health of their soil. However, they do need to direct their attention to a systematic, holistic design for soil health. This means a full review of their soil cultivation practices with the assistance of a trained professional. In particular it means the conscious design of a soil management regime that will promote rich soil biology. The scientific evidence for how to build healthy soil is clear, but in practice few farmers systematically follow these practices. Evidence suggests that many farmers, when given the tools and knowledge necessary to create healthy soil on their land, are keen to do so. We therefore suggest the government create a planned programme of agricultural extension aimed at actively engaging farmers in the process of creating healthy soil.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

The Permaculture Association recommends that building healthy soils should be a government priority.

The crisis of soil described above is by no means inevitable. Using permaculture, or other regenerative management techniques, it is possible to rebuild healthy soils relatively quickly, in as little as five years. The key factor is a conscious and holistic management approach, which sees soil health as a priority and implements systematic management practices that will build it. The scientific literature strongly supports the success of these techniques in building soil health and natural fertility. There are plenty of examples in the UK and elsewhere of the ability to do this. Adoption of full organic farming principles is not necessary in this process, but a change in soil cultivation and soil feeding is.

We believe that the UK government needs to take a lead in supporting farmers to build healthy soils. Increased use of the CAP and other environmental subsidies could be made to incentivise farmers to build their soil. Government could set targets for increasing soil organic matter content and decreasing run off across the UK. Targets and incentives could also be introduced to develop soil as a carbon sink. Flood protection measures could include building the water holding capacity of soil, especially in upland areas. A national programme of agricultural extension which focuses on soil building could be supported. Overall, a systematically designed plan for the creation of healthy soils needs to be developed by both government centrally, and by every farmer and land owner locally.

January 2016

Written evidence submitted by Professor John Quinton, Professor Philip Haygarth, Dr Jess Davies, Dr Alona Armstrong, Dr Carly Stevens, Professor Nick Ostle and Professor Kirk Semple on behalf of the Lancaster Environment Centre, Lancaster University

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

As with other major components of the environment (air and water) the UKs' soil capital needs to be monitored regularly to detect whether its health is improving or deteriorating, thus permitting adaptive soil management.

● **Design** - Soil health metrics should focus on vital soil properties that are critical to the provision of crucial ecosystem services (e.g. climate change mitigation, regulation of hydrology, nutrient dynamics, food security). Soils should be monitored at 5 year intervals in their entirety to the base of the soil, so that changes in biodiversity, chemistry, physical condition and stocks of macronutrients e.g. carbon and nitrogen, can be properly quantified. Monitoring needs to cover a full range of UK soils, landscapes and climates, including urban areas. For this any future scheme will need to be delivered as a partnership between government agencies, the UK scientific community, land owners-managers and the public.

● **Integration** - Previous monitoring schemes in the UK include the National Soil Inventory and Countryside Survey with new monitoring schemes establishing in Scotland and Wales. Any new monitoring scheme would ideally need to integrate with these activities to reduce costs and improve data availability.

● **Innovation** - We also consider that there is now potential to harness next generation portable technology for rapid field measurements e.g. x-ray fluorescence, near infra-red spectrometry, laser/hyperspectral probes that would reduce costs. Existing international soil monitoring frameworks demonstrate the opportunity to include citizen science approaches e.g. Cornell Soil health Monitoring, in a new UK soil health monitoring programme.

● **Data** - Importantly any new soil monitoring data sets should be placed in the public domain and accessible to all. For too long England and Wales's principle soil database (the National Soil Inventory) has been only accessible to those able to pay for it. This has had a negative impact on the generation of soil knowledge for England and Wales and affected the training of undergraduate and postgraduate students.

● **Knowledge** - Monitoring needs to be designed to improve understanding of the phenomena that influence soil health, function and response to change i.e. climatic, management, land use. Biological, chemical and physical characteristics of soils are known to be affected by these pressures with impacts on soil functions e.g.

Armstrong et al. 2015; Ward et al 2013. Predictions of future soil security and resilience will rely on this new knowledge.

What are the benefits that healthy soils can provide to society?

● **Ecosystem function -** Healthy soil is critical for food production and the provision of a range of other ecosystem functions that society needs, desires and expects. Soils lie at the heart of most terrestrial ecosystems and underpin crucial ecosystem services that support human life and affect public- private property e.g. food production, water quantity and quality control (flooding), air quality, carbon sequestration and the promotion of health and well-being (Powlson et al., 2011; . Haygarth and Ritz, 2009). Soils play a critical role as carbon stores and have the potential to mediate or amplify climate change. Several studies have shown the potential for this (Ostle et al. 2009; Ostle and Ward 2012). However, we need to scale theses effects and there is an urgent need for models at nation scale that predict future changes soil functioning.

● **Costs** The damage to these functions caused by soil degradation (erosion, organic matter loss and compaction) is estimated to cost the UK economy between £150M to £250M per year (HMG, 2011), globally it is estimated that to replace the nutrients lost due to erosion would cost US$ 33 to US$ 60 billion for N and 77 to US$ 140 billion for P.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The most pressing issues are associated with the role of soils in food production the regulation of water resources and management of greenhouse gases.

● **Food** - A predicted increase in global human population to 11.3 billion by 2100 (UN data) will exert unprecedented pressures on soil and food security and sustainability as climate change progresses. Un-constrained land conversions for food production have the potential to accelerate global soil degradation (Quinton et al 2010). It is estimated that this could reduce crop growth area by 15% by 2050. This is particularly important in developing countries where there is often an imbalance between nutrients being harvested from soils by crops and lost by erosion and/or leaching with that which is added to the soil in the form of inorganic or organic amendments. **The consequences of poor global soil health would be significant for food supply and cost with severe impacts on human nutrition and health/survival.**

It is thus in the UK public interest to both improve sustainable soil security globally (i.e. food imports from sustainable sources) and nationally (i.e. resource efficient sustainable soil management to increase crop production).

● **Water** - In the UK poor soil health results in losses of soil nutrients, chemicals and particles to waters are significant and constitute an important efficiency-economic cost as well as an environmental problem - eutrophication, contamination and sedimentation of surface waters - leading to higher treatment costs for water companies, changes in aquatic biodiversity and loss of amenity value (Deasy et al. 2009). Poor soil health also affects hydrological processes (e.g. retention, flow) that can exacerbate flooding impacts on people and property during severe weather events as seen in 2015. The frequency of extreme rainfall events is predicted to increase in the UK making this aspect of soil health a matter of high importance.

● **Carbon** - UK soils contain significant carbon stores in the form of organic matter that is important for a number of key functions. Organic matter is the base substrate for all of the biological growth and thus food security, at the same time providing resilience to drought and regulating water retention. Soil carbon sequestration is also important globally as a means to manage/mitigate/offset fossil fuel derived greenhouse gas emissions. The monitoring and management of this natural capital will be an important means to mitigate climate change impacts and feedbacks on soil security and health e.g. UK soil carbon sequestration (Ostle et al. 2010).

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

●**Disparate sources** - Currently sources of advice on the management of soil health are disparate. Defra and previously MAFF Codes of good agricultural practice did provide a reference point for land managers and regulators, however they are out of print and out of date. Other sources include EA guides on erosion control and publications produced by specific projects e.g MOPS. Internationally there is a wealth of information from providers ranging from the FAO and the CG centres e.g. International Rice Research Institute (IRRI), to individual NGOs.

●**Consolidate** - We therefore need to bring together soil knowledge and advice together in one place which is freely accessible to soil users, see IRRI knowledgebank website for a good example of how this might be done and the UK soil portal for how this has been done for soil data that is publically available.

●**Link academia with industry** - Stronger ties are also needed between academia and industry so that research results can be put into practice. There are good examples of academia working with Industry, for example Lancaster University's partnership with Waitrose's supply chain. There is potential for an initiative similar to the agri-tech centres, but this should not solely be to support the agri-industry, but rather to bridge between agricultural, water industry and urban stakeholders reflecting the central role that soil plays in delivery services to all these sectors

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

●**Cornerstone -** Soil should be the cornerstone of the government's 25 year plan for the natural environment. This requires joined up thinking and a joined up strategy. In particular the government's agriculture and environment strategy need to be brought together. Soil health provides a focal point around which to integrate both.

● **Policy -** Soil is facing a number of threats: notably in the UK soil sealing (by concrete and tarmac), compaction, erosion, land use change and the oxidation of carbon. Mitigating these threats will require the government to imbed soil into policy. For example the French have made soil carbon central to their strategy to reduce carbon emissions (see Quinton 2015). There is potential to think about how soils interact with flooding in both rural and urban settings, enhancing infiltration and the storage of water.

●**Research -** To support the government's plan for the natural environment research is needed to provide the evidence base for impacts, management best practice and remediation. This would be best provided through cross-disciplinary research schemes with the involvement of government departments and industry.

January 2016

Written evidence submitted by CIWEM

Background to CIWEM

1. CIWEM is the leading independent Chartered professional body for water and environmental professionals, promoting excellence within the sector. The Institution provides independent comment on a wide range of issues related to water and environmental management, environmental resilience and sustainable development.

2. CIWEM welcomes the opportunity to respond to the Environmental Audit Committee inquiry on soil health. This response has been formulated with the assistance of our Natural Capital Network of technical members. Further information on the protection and enhancement of soils can be found in CIWEM's Policy Position Statement on the subject[i].

Summary

3. Soil is a fundamental and essentially non-renewable natural resource. Soils perform a number of valuable functions, or ecosystem services, for society including nutrient cycling, water regulation, carbon storage, support for biodiversity and wildlife, and providing a platform for food and fibre production and infrastructure.

4. Soils in the UK continue to be degraded by human activities, such as intensive agriculture, industrial pollution and urban development. Future climate change has the potential to exacerbate these impacts, resulting in further degradation.

5. Legislation and policy around soil protection is limited. A European Framework Directive is needed to protect and enhance soils. Current initiatives on soil monitoring, sewage sludge and biowaste are likely to be more successful if tackled as part of a wider integrative framework than if approached in a piecemeal way.

6. Soil health must be made a priority in the Government's upcoming 25 year plan for the natural environment with sufficient resources made available to ensure the aims can be delivered.

Response to consultation questions

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

7. This inquiry into soil health is welcomed and needed. The importance of getting this right and creating a framework which allows repeated monitoring should not be underestimated. As such, the team set up to deliver this need to have adequate and appropriate resources (with a long-term and secure remit) and draw on the expert knowledge within the UK soil science community.

8. Soil health cannot be measured directly, so indicators (physical, chemical, and biological properties, processes, or characteristics) are generally used. Any new measurement/ monitoring scheme for soil health should ensure it draws upon previous work, such as the National Soil Inventory and the Countryside Survey. Here work has been undertaken in terms

of identifying what the best metrics for determining soil health are, and again these should be referenced and built upon.

9. Measurements should additionally seek to assess soil function overall, for a given set of required services and not just individual attributes. There should also be some measure of total available soil resource to ensure soil loss through sealing is captured, as well as account taken of the potential effects of climate change.

What are the benefits that healthy soils can provide to society?

10. The benefits of soils and the central role they play in the delivery of multiple ecosystem services is known and accepted. Healthy and functional soils are critical for sustainable food production, for reducing flood risk and filtering water, storing carbon as well as actively removing carbon from the atmosphere in some cases. Healthy and functional soils support the biodiversity and landscapes we see which can contribute significantly to our health and wellbeing. The diversity of soil microorganisms is also likely to lead to further medical discoveries.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

11. Failing to protect soil health with result in greater flooding, costlier food and water and reduced production yields. The recent flooding has highlighted the vulnerability of homes and assets to changing climatic patterns. The speed at which water runs off land which has limited vegetation cover and where the soils are compacted is part of the problem; these soils are not healthy and are not fully functional.

12. Soil loss as a result of increased overland flow causes problems not just to the potential future productivity of the land but also to the water environment through silting up of watercourses and eutrophication. The mismanagement of soil can affect their ability to store carbon which is a particular issue in the uplands where organic soils are drained. With soils so central to the provision of ecosystem services all these will be affected if we do not focus on ensuring our soils are healthy.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

13. Legislation and policy around soil protection is limited. Biodiversity, water and air are covered by substantial European legislation, transposed into English law. The lack of a similar framework for soils is noticeable and would help secure the required commitment to protect and improve the health of our soils.

14. There are a range of guidance documents, for example those produced by Defra (such as the Soil Strategy and the Construction code) and previously MAFF, but these require review, consolidation and updating, and need clear ownership and enforcement. The planning system, and those who work within this, also need to better understand the importance of soil health; more resources will be needed within Natural England, the Environment Agency and within Local Planning Authorities to ensure this can be achieved.

15. Compliance requirements for soil health are needed including soil testing and removal of compaction. Restricting the areas currently growing ‘at risk’ crops such as maize and winter harvested vegetable where climate or rainfall makes them tricky to harvest, and insist on rough cultivation within 24 hours of harvest would reduce soil loss.

What role (if any) should soil health play in the Government’s upcoming 25 year plan for the natural environment?

16. Soil health must be made a priority. As noted in the response to the previous question, along with air, water and biodiversity it needs to be given equal status and focus. The strategy developed must recognise the interrelationships between these aspects and the ability for healthy soils to deliver multiple benefits to society. This must be enshrined in policy and sufficient resources made available to ensure the aims can be delivered.

January 2016

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[i] CIWEM. 2012. Protecting and enhancing soils, policy position statement. Available from: http://www.ciwem.org/media/1684753/Protecting%20and%20enhancing%20soils.pdf

Written Evidence submitted by Steven J. Pye

I am a professional soil scientist with thirty years experience specialising in contaminated land, risk assessment and remediation, land reclamation and urban soils. These are the principle issues of this submission. However, coming from a farming background I maintain an active professional interest in agricultural soils and am cognizant of degradation issues encompassing soil erosion, compaction and loss of soil organic matter. With due regard to the Terms of Reference and "the Report" (1), I present the following comments.

1.0 How could soil health best be measured and monitored?
When considering and assessing its function in agriculture and the urban/natural environments the term, "the soil" inevitably relates to the upper 1.0m of the earth's surface. This, the principle soil profile, the "workhouse" of the soil medium might comprise one or more stratum types. This depth is the maximum adopted when assessing potential risks to human health in contaminated land.

To successfully measure and monitor soil health and acquire meaningful and viable data the fundamental question should be asked "What is being assessed and Why"? It would therefore be of benefit to establish, possibly by definition, what is meant by "soil health" i.e. "What is a healthy soil and what constitutes a healthy soil"? A suggestion might be that a healthy soil.

"*is one in which the physical, chemical and biological components are, individually at optimum levels and collectively in balance such that the medium wholly facilitates and maintains its capacity to support its specific contemporary role, with or without minor anthropogenic intervention".*

Examples of minor intervention would encompass actions such as fertiliser application, drainage installation or creating a topsoil to conform to the British Standard BS 3882:2007.

The parameters constituting a healthy soil would very much depend on its contemporary role. Relevant data would indicate that either (a) a soil is fully functional and no actions need be taken, (b) is temporary malfunctioning but matters can be easily and simply rectified or (c) the soil could be permanently damaged, and might constitute a risk to the environment and necessitating [immediate] remedial actions. Two examples of permanently damaged soils are, in agriculture – seriously poached localised areas at risk of erosion and, in the urban environment – elevated lead concentrations in garden soils and potential human health risks.

There is also the question "When to measure and monitor"? Routine exercises will of course form part of current/future academic research projects; contaminated land is reasonably well address both through Part 2A of the Environmental Protection Act 1990, but more importantly through the palling process, governed by Local Planning Authorities. Soil would also be assessed when signs of deteriorating quality arise, e.g. in ecosystems. There would appear therefore to currently be reasonably adequate provision with respect to monitoring and measuring.

2.0 What are the benefits that healthy soils can provide to society?
There is no doubting the benefits healthy soils can provide and which have been thoroughly recognised throughout time, the most important being food production. Healthy soils, the mineralogical/organic surface blanket, instil a quality of life and there cannot be any substitute. It is crucial that the resource is protected.

3.0 What are the consequences of failing to protect soil health for the environment, public health, food security and other areas?

Failure to protect can ultimately lead to permanent loss, the classic case of course being soil erosion through wind and water. The upper soil surface is at the uncontrollable mercy of the climate but management systems can and should be adopted to ensure climate impact is minimal. Research and actions encompassing impacts through climate change will be crucial to protecting the resource.

4.0 What measures are currently in place to ensure that good soil health is promoted? What further measures should be considered to secure soil health?

The Report states the Government's objective to ensure soil protection would be delivered through (a) improving the evidence base, (b) providing information and guidance and (c) using regulation and incentives as drivers for action. I consider (b) to perhaps be the important one to take forward and secondarily, (a).

Improving the evidence base firmly rests with academic and technical research and should continue as such. Whilst there are decades and decades of soil data and information for agricultural soils, worldwide, this needs to be adapted to modern day circumstances. There is a depth of technical information and guidance relating to human health risks and contaminated land. However uncertainties still exist and there has been a danger of being "overzealous" such that extensive remediation schemes have occurred which might not necessarily have been needed, actions contrary to soil sustainability. Further research should continue to finalise practical risk assessment criteria.

As stated I consider (b) to be a key element within the Government's Strategy. Current guidance namely The Code of Good Agricultural Practice (2009) and The Construction Code of Practice (2009) would appear to be appropriate and easily followed. Guidance on applying wastes to soils would also appear to be adequate (e.g. sewage sludge). However, no Code of Practice can be of benefit if the respective industries are unaware or oblivious to their availability. Therefore more promotion and training should be put in place, perhaps through schemes directly from central government or ngo's and agencies. Soil quality should an integral part of any construction project. This has occurred with major schemes such as Crossrail but the principles might not be as readily recognised and adopted in the much smaller "every day run of the mill (housing) schemes. Safe handling and sustainable use of construction soils should be earnestly promoted, particularly given the current expansion in rural housing development.

The two aforementioned guidance documents however ideally relates to current times. The Soils Strategy should therefore take the opportunity to include education, thereby instilling knowledge and a keen interest in or future generations, those who have yet to become the "guardians of the soil". I am not aware of the current circumstances at curriculum level but suspect that, whilst soils are taught, the subject is considered boring and the relevance not seen. This present circumstance should be reviewed and amended as might be necessary. Promotional materials and information such as that produced by the British Society of Soil Science (BSSS) should be widely distributed and teachers made more aware of what is available. Schools should be aware of and actions taken to "celebrate" World Soil Day (5th December 2016).

On a personal; basis, I should like to see further emphasis given to Urban Soils, not just contaminate land and construction soils but urban soil as an important resource in parks and private gardens. More public perception should be encouraged.

5.0 What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Quite simply, soil health should be at the forefront of the Government's 25 year plan, with equal status alongside air and water.

January 2016

Written evidence submitted by Rothamsted Research

1. **Executive Summary**

- Soil health is an important but complex concept. It is multidimensional, and its monitoring requires measurements that evaluate the biological, chemical and physical properties of a medium that generally changes slowly over time but much in space.
- No existing measurements give a comprehensive way of monitoring soil health, but simple measurements are needed for monitoring soils, and the recognition that the optimal values of these will vary according to the desired land use.
- Healthy soils provide society with products such as food and fibre, but also regulate air and water quality and climate, as well as cultural services derived from recreation and landscape.
- No one type of management or soil health can fit all of the services required from soils and so trade-offs are required for all of the required uses of soil and the landscape.
- Management and government action are required to bring about the behaviours that are required for what society wants from soils now and in the future.

2. **Rothamsted Research**

Rothamsted Research is the oldest agricultural research institute in the world. It dates from 1843 and is credited with laying the foundations of modern scientific agriculture and establishing the principles of crop nutrition. Its research spans crop, beef and sheep production. Over its 172 years of existence, Rothamsted's researchers have made many significant contributions to agricultural science including pioneering contributions in the fields of virology, nematology and soil science as well as the discovery and development of pyrethroid insecticides. The benefit of its many scientific contributions have, and continue to, impact on the productivity and quality of the UK agricultural industry's output thereby greatly improving its cost efficiency and competitiveness. Rothamsted has one of the largest groupings of soils researchers in the UK, with the most publications in Web of Science soil science category journals, and the highest citation of those publications compared with international institutions in the subject in the last 5 years. Our research into soil science has shown us that soils are precious and need to be cared for. We are committed to promoting good soil management to maintain healthy soils.

3. **How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?**

Soil health is important but is a complex concept (e.g. FAO, 2008); therefore, there are few indicators that embrace all that soil health is and delivers. The concept of soil health generally includes reference to the importance of soil as a living system and stresses the importance of soil biology, which differentiates soil health from the related concept of soil quality (i.e. the capacity of a soil to function). The activity of soil organisms helps to create many of the characteristics we associate with a healthy soil, e.g. good structure - tilth, resistance to erosion, drought and water logging, good plant growth. In this context, greater soil biodiversity might provide resilience against stresses such as climate change, and this is an area of active investigation.

Various measures of soil biology such as microbial biomass (the totality of living microorganisms in the soil), soil respiration, earthworm species and abundance, and more complex analyses such as Phospholipid Fatty Acids (PLFA; from the membranes of living soil bacteria and fungi), enzyme activity, and metagenomics (the assessment of the potential genetic diversity of species and function) are being used to attempt to qualify and quantify the biological status of soils. Soil organic matter is usually used as a good indicator of soil health (and quality) because it provides the energy for soil biological organisms. *'The health of soils, for which sufficient organic matter is the main indicator, strongly controls agricultural production'* (UNFCC, 2015). Other measurable indicators include pH, bulk density, texture (the proportions of clay, silt and sand), cation exchange capacity and nutrient content which are very important for the type of ecosystem and agricultural production that land can support. None of these give a comprehensive measure of soil health

4. What are the benefits that healthy soils can provide to society?

These are best defined in terms of Ecosystem Services: Supporting Services such as primary production, nutrient and water cycling; Provisioning Services such as food and fibre; Regulating Services such as air quality and climate regulation through carbon sequestration; Cultural Services such as recreation and landscape. It is unlikely that a soil can provide all of these at the level required for a particular service at the same time, so trade-offs are important for the different uses and management of soils. For example, a 'healthy' peaty soil is likely to have a pH less than 4, be very wet and contain few nutrients; it will provide carbon sequestration, landscape and recreation, but could not grow crops. A healthy biodiverse grassland soil will have a pH of about 5 and be nutrient poor; it might sequester carbon, provide landscape and recreation and feed some livestock but would need to be cultivated and receive considerable nutrient enrichment to grow crops and might lose a lot of carbon in the process. A 'healthy' and productive arable soil will be nutrient-rich but diversity poor; turning it into a biodiverse hay meadow would take many years. In other words, soil health must be viewed in the context of what society wants a soil to deliver, and assessed accordingly.

5. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

5.1 Soil loss

There have been a number of recent statements on soil loss such as "the world on average has just over 60 years of growing crops". This appears to have been said by Maria-Helena Semedo of the United Nations Food and Agriculture Organisation (FAO) at a forum in 2014 to mark World Soils Day (see: http://www.scientificamerican.com/article/only-60-years-of-farming-left-if-soil-degradation-continues/). George Monbiot made a reference to it in his article lamenting support for soils in 'The Guardian', while also stating that there were only 100 harvests left for Britain (http://www.theguardian.com/commentisfree/2015/mar/25/treating-soil-like-dirt-fatal-mistake-human-life). Other experts at the FAO forum claimed that the causes of soil destruction include chemical-intense farming techniques, deforestation which increases erosion, and global warming. The above statements seem to suggest that modern farming destroys soil. Does it?

Firstly, regarding soil loss. The mean soil erosion rate for global cropland has been calculated recently as 0.2-1.5 mm/y (Amundson *et al*., 2015; note also papers referred to therein). This is 10-

100 times the rate for the past 500 million years. Estimated rates for global soil production range from 0.06-0.08 mm/y (Amundson et al., 2007). Thus a value for the number of years before all soil is eroded (= number of harvests remaining), T, can be estimated from: T = S/(E-P) (Montgomery, 2007) where S is the soil thickness in mm, E the erosion rate and P the production rate in mm/y. If we take E = 0.9 and P = 0.07 (E-P ~ 0.8) we have:

a) for a thin soil over limestone (300 mm as in the Cotswolds), T = 375 years.
b) for a deeper soil of 1000 mm, T = 1250 years.

Montgomery (2007) summarises global soil lifespans as being 500 to several thousand years. These values are more realistic than those quoted by Monbiot and in the statement by Maria-Helena Semedo, but show that soils are clearly a finite resource. It is also important to note that restoring degraded soils is difficult and can take a very long time.

There are some clear examples of where soil is being lost quickly, where bare soil is left between crops on hillsides and so rapidly eroded, e.g. under poorly managed maize cultivation. That has been especially true in China in the area called the 'Loess Plateau', and much work is going on there to change practices and stop that soil loss. See http://eempc.org/loess-plateau-watershed-rehabilitation-project/. John Liu, Director of the project, is a Rothamsted International Fellow for the Communication of Science. He studied for his PhD with us at Rothamsted and Reading University.

Secondly, regarding intensive farming, in 2014 we had the best yields ever from our Broadbalk Wheat Experiment, over 13 tonnes of wheat grain per hectare from land that has received chemical fertilisers for 172 years, and herbicides and pesticides since they were invented. The diversity and abundance of macro-organisms (e.g. earthworms) has declined, as has the content of soil organic matter, but the diversity of microorganisms remains the same (but at much lower abundances) as on the plot that has received manure for 172 years and has three times the organic matter content, but which yields much less wheat. A lengthy period of very intensive farming has changed but by no means destroyed the soil on Broadbalk.

5.2 Soil compaction and flooding

Both droughts, floods, and their interactions with processes that cause soil compaction, either by livestock or farm machinery, reduce crop yields significantly and compromise on crop persistency. In the UK, the cost of dealing with flooding runs into billions of pounds, e.g. it has been estimated that the devastating floods of summer 2007 cost £3.2B (Environment Agency). Excessive run-off erodes top soils and soil organic matter, and depletes valuable nutrients (nitrogen and phosphorus), with negative impacts on water quality. Eutrophication of surface and ground-waters in England and Wales is estimated to cost £75-114M/y due to loss of amenity value, reduced biodiversity and increased costs of water treatment. The cost of damage to agricultural soil in England and Wales, and water treatment for pollution, has been estimated at nearly £500M/y (UK Parliamentary Office of Science and Technology 2006). The cost of damage to agricultural soil in England and Wales has been estimated as £264M/y, and that of treating water contaminated with agricultural pollutants as £203M/y (UK Parliamentary Office of Science and Technology, 2006). Over an 80 hour period in November 2012, more than 46 million litres of rain fell on the 62 hectares North Wyke Farm Platform (NWFP), 90% of which was immediately lost as overland flow or in drainage.

6. **What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?**

Good Agricultural and Environmental Conditions standards set Cross Compliance baseline requirements for farmers to safeguard soils, habitats and landscape features on their farmland. Further measures are best summarised in the inactive 'Safeguarding our soils' document (Defra, 2009), the vision of which is that: agricultural soils will be better managed and threats to them will be addressed; soils will play a greater role in the fight against climate change and in helping us to manage its impacts; soils in urban areas will be valued during development, and construction practices will ensure vital soil functions can be maintained; and pollution of our soils is prevented, and our historic legacy of contaminated land is being dealt with. There is an active Scottish Soil Framework for soil protection (Scottish Government, 2009). There is no space here to go into more detail, but we suggest that these are rather weak policies when set against the many soil-related global concerns and required actions.

The Inquiry should note the Council of Europe's Soil Charter (1972), the World Soils Charter (FAO, 1982) and the World Soils Policy (UNEP, 1982). Related UN policy instruments such as the Convention on Biological Diversity (1992) and the Convention to Combat Desertification (1994) also link to soil health, specifically conservation. In 2002 the European Union published a communication 'Towards a Thematic Strategy on Soil Protection.' This led to a proposal for a Soil Framework Directive in September 2006, which failed in its first passage through the European Parliament. We would encourage the Inquiry to reconsider the Directive.

7. **What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?**

Soil health has a critical role in supporting the natural environment. Research is showing the above- and below-ground biodiversity are inextricably linked (Bardgett and van der Putten, 2014). Therefore soil loss or degradation will make it impossible to maintain the current natural environment let alone deliver the improvements in biodiversity and landscape that are in the plan such as planting an additional 11 million trees (and where best to plant them), tackling air and water pollution, and ensuring the value of Green Belts and AONBs, National Parks, SSSIs and other environmental designations are appropriately protected (not possible if the soil degrades).

8. **Recommendations**

- National and international research to build a consensus on appropriate indicators of soil health, and their optimal values for different soil/land uses needs to be stimulated.
- A set of soil health indicators that can be monitored economically in space and time need to be agreed and are urgently needed. These are likely to be simple, but need to be those most relevant to the use of soils and all of the varied ecosystem services they provide.
- Government needs to revisit the Soils Strategy for England and the EU proposal for a Soils Framework Directive.
- Soil health and its trajectory need to be considered in the environmental plans for the future, including food, feed, and energy production, air and water quality, as well as biodiversity and landscape issues.

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Written evidence submitted by Dr Peter Shaw, University of Roehampton

One fundamental, but often overlooked, aspect of soil health that is habitually overlooked is its biological diversity. There are currently no soil-dwelling life forms used as indicators of restoration success, no sites protected for supporting a rare soil community. Given that most of the significant transformations that occur in soil are biotic phenomena this is a gaping omission. Modern genetic techniques (notably high-throughput analysers) allow entire communities to be profiled with relatively little human effort. Given a bucket of dead insects or mites, a high-throughput platform can identify and estimate biomasses of all the species present, merely from the DNA extracted. The same genetic tools are revealing that we have under-estimated “cryptic diversity”, whereby what appears to us to be one species consists of several isolated populations that may differ in behavioural and functional responses. I therefore suggest that the committee does two things:

1: Recognise the potential importance of soil biota in indices of soil health. Being a soil zoologist, I naturally lean towards favouring the visible edaphic life forms (earthworms, springtails and mites) for this role, but accept that genetic profiling of microbes could achieve the same end.

2: Explore developing methodologies for using soil biota as indicators of soil health, not just in relation to physical functionality (permeability, bulk density etc) but to compare with pre-intervention conditions as a more holistic indicator of restoration. This will probably require modern genetic techniques in addition to classical microscope-based approaches.

January 2016

Written evidence submitted by SRUC

Introduction

SRUC (Scotland's Rural College) welcomes the opportunity to contribute to the UK Government's Environmental Audit Committee's Soil Health Inquiry.

SRUC is an innovative, knowledge-based organisation that supports the rural sector through research, education and expert consultancy services. SRUC wishes to see, and contribute significantly to delivering, a sustainable agricultural and rural land use sector in Scotland. SRUC staff work in a broad range of areas (for more information see www.sruc.ac.uk) and our responses to the questions below reflect this broad expertise, but draw on specific research projects where appropriate.

Several SRUC staff have contributed to this submission[1] which has been co-ordinated by SRUC's Rural Policy Centre.

Question 1: How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

- Structural deterioration and soil organic matter (SOM) loss in agricultural soils are major concerns and the soil management strategies that represent the greatest risks are understood. Most answers are already well established and have been in the public domain and supported by UK Government funding for years. Political will is required for their implementation

- Soil health could best be measured and monitored by a defined monitoring programme using standardised methods probably as prescribed by the EA (Environment Agency) (1. Design and operation of a UK soil monitoring network Science Report – SC060073 or 2. The development and use of soil quality indicators for assessing the role of soil in environmental interactions Science Report SC030265) and by the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) (Project LQ09 National Soil Monitoring Network: Review and Assessment Study).

- The countryside survey http://www.countrysidesurvey.org.uk/ has already made a start to tracking soil health, mainly based on above-ground parameters, but with some soil health-related measures included. It would be logical to extend this survey to include soil health.

- Another possible approach may be to devise a system for assigning a 'risk' element to monitoring using simple proxies for how 'at risk' or 'fragile' soil health might be due to location, current status and land use. To make this widely used it could be based on the use of soil visual assessment e.g http://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure that could extended to the surrounding environment and geology.

[1] Bruce Ball, Bob Rees, Joanna Cloy, Bryan Griffiths, Bill Crooks and Sarah Buckingham.

- As erosion and flooding occur more frequently with increased soil losses, it may be necessary to monitor the volume of soil at key locations by measuring the depth and area extent of topsoil.

- Information on soil management at the field level is not currently captured but there is a potential mechanism for doing so through the EU CAP program. This could be developed to provide an evidence base to determine the management risks facing agricultural soils.

- A key gap in existing monitoring schemes is the lack of information on the affects of crop rotational management and carry-over between rotations. This is critical to long term sustainable management.

Question 2: What are the benefits that healthy soils can provide to society?

- Healthy soils can provide the essential ecosystem services of:
  a) Production of biomass
  b) Storage, filtration and transformation of nutrients, substances and water
  c) Provision of habitat, species and genetic biodiversity
  d) Provision of the physical and cultural environment for humans and their activities
  e) Provision of raw materials
  f) Carbon storage and cycling (C stores have economic value)
  g) Protection of archaeological heritage (EC 2006)
  h) Flood protection
  i) Waste management
  j) Sustainable food production
  k) Climate change mitigation
  l) Protection of land against adverse weather conditions that can lead to wind and water erosion, flooding, land slides
  m) Storage of contaminants
  n) Economically productive land leading to a healthier and happier society

- Healthy soils can also provide support for foundations for buildings and roads

Question 3: What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

- Deterioration in soil services and in their resilience. Poor quality soils are less capable of adapting to change resulting from factors such as unpredictable weather and provide less of the services we require from them as outlined in 2. The services expected from soils now and into the future require them to be robust and flexible.

- We note that there are already levels of degradation or instability that can restrict management options with the result that more investment may be required to maintain their health.

- The reduced resilience to environmental threats is particularly important with regards to yield stability of agricultural crops

- Increased risk of greenhouse gas emissions from soils (nitrous oxide in particular).

- Increased exposure to contaminants with potentially damaging effects on human and environmental health.

Question 4: What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

- In terms of EU policy, the "greening" requirements such as cover crop establishment under the CAP reforms have had many positive secondary soil quality protection benefits.

- The British Society of Soil Science (BSSS) has actively promoted knowledge transfer measures to ensure good soil health, particularly in 2015, the International Year of Soil (IYS).

- Several initiatives in Scotland have proved successful. The provision of detailed technical knowledge by the Scottish Government on efficient and effective nutrient and soil management for agricultural production is promoting the sustainable use of soils.

- Currently the Scottish Centre of Expertise for Water (CREW) is producing a guidance booklet for farmers, advisors and general agriculture to promote good soil management practices and to improve understanding of the importance of soils and the potential cost savings of sustaining soil health.

- Scottish activities conducted within BSSS, IYS and World Soils Day that were aimed towards knowledge exchange and public/school engagement proved successful (e.g. demonstrations at the Edinburgh Royal Botanic Gardens, Royal Highland Show at Ingliston, school visits and workshops throughout Scotland).

- Further measures to improve soil health would be possibly to extend 'good practice guides' towards urban soils/allotments/gardeners.

- Advice for good practice, as currently being done by the Scottish Environment Protection Agency (SEPA) and Scottish Natural Heritage (SNH) should be promoted for windfarm developments, to minimize soil degradation and to monitor restoration. Minimum standards may need to be produced.

- Support for improvements to drainage of agricultural soils (not peats) should be reinstated to help mitigate GHG emissions and reduce flood risks.

- In the past year, several soils knowledge transfer events were aimed at linking soil scientists with artists and writers, an important area to develop to take soils awareness more into the public eye.

Question 5: What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

- Soil heath should be at the heart of any plan for the natural environment because of its role in mitigating and controlling the health of the vegetation, water and atmospheric environments.

- Soil health is also essential for sustainable food production (which has economic & trading implications too).

- Soil health is important for food quality. The level of minerals in fruit and vegetables reflects those of the soil in which they are grown.

- Soils should be directly recognised as a non-renewable resource the health and integrity of which determine the quality of essential and evolving services.

- There should be an effort to define what a "healthy soil" is so that future changes in soil quality can be mapped and the impact of initiatives and land use change can be fully understood.

January 2016

Written evidence submitted by ADAS UK Ltd

Executive summary

- Soils provide multiple ecosystem service (ES) benefits, notably food production, water and climate regulation, public health and support for biodiversity.
- Soil degradation due to erosion, compaction, loss of organic matter and acidification threaten the ability of soils to deliver these services, with implications for sustainability of agricultural production and hence food security, water and air quality, biodiversity and societal health and well-being.
- A wide range of measures exist for measuring the health of soils, but no one measure fits all circumstances and there remains much work to establish clear links between soil quality indicators and the delivery of specific ES, as well as establishing local benchmarks, thresholds or acceptable levels of change.
- Soil organic matter (SOM) plays a central role in soil fertility and functioning and consequently maintaining healthy soils is fundamentally about managing SOM through crop rotations, cover crops, organic material inputs and tillage.
- Good Agricultural and Environmental Conditions (GAEC) standards for soil management provide some level of protection, as well as the Common Agricultural Policy (CAP) greening rules and Countryside Stewardship agri-environment measures. However, given the fundamental importance of soils in underpinning the delivery of multiple ES, including crop production, reducing flood risk and maintaining public health, it is arguable that soils should be afforded the same level of protection as water and air.

1. Introduction

Soil is the foundation of all terrestrial ecosystems and provides multiple ecosystem service (ES) benefits; the most prominent of these being the provision of food and fibre, the maintenance of public health, climate regulation and carbon storage, the regulation of water flow and quality and the support of both above and below ground biodiversity. Different soils deliver some ecosystem services more effectively than others, with lowland mineral soils under arable and grassland management important for food production, while deep peats in upland areas support semi-natural habitats and are arguably more important for carbon storage and climate regulation. However, the ability of soils to deliver these services is threatened by a number of degradation processes such as erosion, compaction, loss of organic matter and acidification. UK governments are committed to promoting sustainable soil management to secure the delivery of these essential ES for future generations. Indeed, as part of Soil Security Programme (SSP) co-ordination activities, NERC, BBSRC, Scottish Government and Defra recently commissioned a review of all UK-affiliated research evidence on sustainable soil management for the delivery of food production, water and nutrient cycling and climate change mitigation, focusing on agricultural land and peatlands (*Soils Research – Evidence Review*, October 2015). Understanding the characteristics of sustainably managed soils, soil quality indicators, soil degradation and soil management practices were key themes in this review and are central to the concept of soil 'health'.

ADAS is the UK's largest independent provider of agricultural and environmental research and consultancy, and policy advice. The ADAS Soils and Nutrients team are particularly involved in the research and development of soil and nutrient management policy, translating the results from field-based research and desk-based studies into practical information and advice for Government, regulators and land-based industries. The concept of soil 'health' is of increasing importance to many key ADAS clients and as much of our work is focused on delivering research and practical advice on sustainable soil and nutrient management, we are particularly interested in the outcomes of this Inquiry. Moreover, as authors of the recent Soils Research Evidence Review, we hope our submission to this Inquiry is of value.

2. What are the benefits that healthy soils can provide to society?

Soil health has been defined as '*the capacity of a soil to function as a living system with ecosystem and land use boundaries, to sustain plant and animal production, maintain or enhance water and air quality and promote plant and animal health*' (FAO, 2008 http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/soil-biodiversity/the-nature-of-soil/what-is-a-healthy-soil/en). This definition encompasses the key functions (or ecosystem services – ES) of a healthy soil; to support healthy crop and livestock production and to maintain or regulate water and air quality. Soils provide the growing medium, water and nutrients for crop production, with soil nutrient cycling an essential element of all ecosystems and a pre-requisite for all agricultural production and consequently food security. The role soils play in regulating water flow is also becoming increasingly important, given the cost of flood control measures and remediation following flooding, particularly at a local level. Soils facilitate infiltration and store water, thereby influencing the rate of surface run-off (and drainflow) and time to peak flow.

The majority of carbon (C) in the UK terrestrial pool is stored in soils and hence it has been argued that this is one of the most important soil ecosystem services i.e. regulating the balance of greenhouse gases (GHGs), particularly in the case of peat soils. Emissions of nitrous oxide (N_2O) and methane (CH_4) from soils are particularly important as their respective global warming potentials are around 310 and 21 times greater than CO_2.

Soils provide a variety of habitats for a multitude of organisms of different size, physiological behaviour and ecosystem function, from bacteria and fungi for which the species richness and functional diversity is yet to be fully established, to larger species, such as earthworms, whose role has been more clearly defined. Moreover, the diversity of soil types support a distinct diversity of below-ground biota and above-ground habitats. These provide cultural (recreation, health and well-being) benefits, as well as potentially new sources of pharmaceuticals.

3. What are the consequences of failing to protect soil health?

Given the central role of soils in delivering a wide range of ES (outlined above), failure to protect soil health has implications not only for the sustainability of agricultural production and hence food security, but also has impacts on water and air quality, as well as biodiversity and societal health and well-being.

Accelerated soil erosion, by water, wind, cultivation or livestock, can have serious implications not only on food production due to the loss of productive topsoils, but also impacts on water flow and quality (due to increased sediment loads and nutrient enrichment) as well as carbon storage (due to loss of soil organic matter-SOM). Land use change, particularly the removal of permanent vegetative cover (e.g. deforestation or ploughing grasslands for arable cultivation) can accelerate these processes.

Compaction of soils due to machinery trafficking or livestock trampling, particularly when soils are wet, can cause a significant deterioration in soil structure, reducing the number and connectivity of soil pores and increasing bulk density. This has a direct impact on a number of key soil physical and biological processes, notably water infiltration, gaseous exchange, root access and soil faunal activity, with implications for crop productivity, water quality, flood management and biodiversity. Increases in runoff and erosion from compacted fields result in higher nutrient and sediment loads in water courses, while reduced infiltration rates increase the risk of flooding.

4. How could soil health best be measured and monitored?

The development of soil health/quality indicators has been the subject of considerable scientific effort, with a wide range of metrics proposed for national monitoring schemes and for use on-farm. However, there is a marked distinction between methods that improve our understanding of soil processes and functions and those which provide a practical assessment of soil condition. Various chemical, physical and biological 'indicators' of soil quality have been proposed (e.g. Defra projects SP1611, SP0529 & SP0534: http://randd.defra.gov.uk; EA SC030265: www.environment-agency.gov.uk), but no one indicator covers all aspects of soil health and to be meaningful, links to soil functions need to be established. There have been various attempts to integrate measures into a holistic assessment of soil health (e.g. Muencheberg soil quality ranking – M-SQR; Mueller *et al.,* 2010), with visual soil assessment of soil structural condition a promising tool for use on farm (e.g. www.healthygrasslandsoils.co.uk).

The majority of soil ES are largely driven by biological processes, underpinned by soil organic matter (SOM) decomposition. Organic matter provides a food source and habitat for the soil biological community, drives the cycling of nutrients within soils and is a central component of soil aggregation and the maintenance of structure and water relations. It is therefore widely recognised that SOM is fundamental to the maintenance of soil fertility and function, and a key indicator of soil quality. However, as with many potential soil health indicators, establishing a threshold or trigger value below which soil functions may become impaired is problematic. Instead, monitoring of soil health may require assessment of a soil in comparison to statistical assessment of the 'norm' for that soil type, land use and location. Given the wide spatial variation of soil properties, diversity of soil types and timescales over which soil properties change, there is a need to develop sensitive indicators of soil health and local benchmarking. Moreover, rather than measuring absolute values and comparing to a threshold, it is likely that any monitoring scheme should look at the rate and direction of change in a soil property and establish ‘acceptable levels of change’.

National soil monitoring schemes, such as the Representative Soils Sampling Scheme (RSSS), National Soils Inventory (NSI) and Countryside Survey (CS) provide valuable data on the state of UK soils and should be continued in order to detect long-term trends and changes in soil properties. However, the development of practical and rapid methods of assessment of a soils condition, with clear links to measurable soil functions and potential management options is required for use at a local scale. Long-term experimentation is also required in order to evaluate the impact of management practices on soil properties and establish links between soil health indicators and ES delivery.

5. What measures are currently in place to ensure good soil health is promoted?

Given the central role of soil organic matter in maintaining healthy soils, sustainable soil management is fundamentally about managing SOM (through use of crop rotations, cover crops, organic material inputs and tillage). Indeed, the protection and maintenance of SOM is a key requirement of the Basic Payment Scheme and the need to maintain land in Good Agricultural and Environmental Condition (GAEC). Farmers claiming the Basic Farm Payment must protect soil by maintaining a minimum soil cover (GAEC 4); minimising erosion (GAEC 5); and maintaining good levels of soil organic matter (GAEC 6). These minimum standards replaced the requirement to complete and retain a Soil Protection Review (SPR) as part of a more ‘outcome-focused’ approach (Defra, 2011a). Some farmers in England and Wales are also assisted with completing and maintaining a Soil Management Plan as part of ‘Catchment Sensitive Farming’ and ‘Farming Connect’ Initiatives within priority catchments; and workshops on improving soil health and sustainable soil management are offered as part of the ‘Farming Advice Service’ in England. The principle measures that farmers are being encouraged to undertake to improve SOM, soil structure and water holding capacity are application of organic materials, growing cover crops and adopting reduced tillage practices. Indeed, use of catch/cover crops is one of the measures that can also count towards the ecological focus area (EFA) greening rules, as part of the Basic Payment Scheme (Defra, 2016).

Developing nutrient management, landfill and circular economy policies has led to increasing amounts of organic materials being directed away from landfill (e.g. biosolids, compost and digestate etc.) and beneficially recycled to agricultural land, thereby completing natural nutrient and carbon cycles. Recent research has confirmed the benefit of the long-term application of organic materials such as farm manures, composts and biosolids to soil quality, as well as crops yields and quality (e.g. WRAP/Defra DC-*Agri* experimental programme: www.wrap.org.uk/dc-agri; UKWIR *Bios* project: 15/SL/01/8 www.ukwir.org). The research has highlighted the importance of integrated nutrient management plans using both organic materials and manufactured fertiliser to provide improved soil health and reduced environmental pollution as well as financial benefits in terms of improved crop yields and less reliance on manufactured fertiliser inputs.

‘Safeguarding our soils’ was developed as a strategy for soil protection in England (Defra, 2009) and was maintained as a key commitment in the Natural Environment White Paper, 'The Natural Choice' (Defra, 2011b), with research focused on exploring how soil degradation affects a soils ability to support vital ES and how best to manage lowland peats. 'The Natural Choice' set a goal that by 2030 all soils in England should be managed sustainably and degradation threats tackled successfully, in order to improve the quality of soils and to safeguard their ability to provide essential ES and functions for future generations (Defra, 2011b). There was also a commitment to reduce peat use to zero by 2030.

6. What role should soil health play in the Governments 25 year plan for the natural environment?

Given soil is the foundation of all terrestrial ecosystems and provides multiple ES benefits (as outlined above), maintaining, protecting and enhancing soil health should play a key role in the Governments 25 year plan for the natural environment. Furthermore, soils should be afforded the same level of protection as water and air.

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January 2016

Written evidence submitted by Sue Everett

1. Who am I and why am I submitting evidence?

1.1 A professional ecologist and land management adviser with >35 years' experience ecological land management and nature conservation. Regular columnist (Conservation News) in *British Wildlife* magazine for the past 25 years. Co-contributor to a major research agenda-setting exercise for former DETR in 2000. I am submitting evidence because I am concerned that inappropriate land management practices are prevalent and have caused serious degradation of soils and biodiversity. This is storing up problems for the sustainability of food production in the future, wrecking freshwater ecosystems and exacerbating runoff that contributes to flooding of places where people live. Urgent action is required.

2. Preliminary remarks

2.1 It is a mistake to consider soils outside their context and relationship with vegetation, hydrology, river basins and land management. These are inter-related. Over the past 30 years I have observed (and still see) a considerable area of land across England and Wales that is not farmed in ways conducive to conserving soils and wildlife. Similarly, much of this farmland (owing to soil damage and loss of semi-natural vegetation[1]) has lost a considerable degree of its capacity to intercept rainfall and hold water - with implications for the quality of freshwater ecosystems and flooding of settlements.[2]

2.2 Moreover, agricultural cross-compliance is a joke. There are regular breaches on farmland close to where I live, especially spreading of organic matter (slurry from dairy and pig units especially) close to watercourses and across springlines. I am aware of considerable ignorance among (not just a few) people involved in managing land and this is partly related to inadequate education and training (for farmers and contractors) and the age profile of farmers (the median age being 59). Unsustainable soil and land use is also related to bigger drivers, such as fiscal sustainability of farms and the commoditisation of food and global market prices,

2.3 Fixing soils will require a radical rethink to address all the drivers that have created a food-farming system that is inherently unsustainable, while better education and mandatory competences framework for people who drive farm machinery, carry out farm operations and manage land needs to be a priority.

3. What are the benefits that healthy soils can provide to society?

3.1 Protecting **healthy living soil** is vital for:

- sustainable food production
- intercepting rainfall and reducing flood risk to people and property
- carbon storage and climate change mitigation

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[1] e.g. Biodiverse grassland, wetlands, scrub, trees, hedgerows

[2] For example our local river, the Somerset Frome, is in a dire state owing to land drainage and abstraction for agriculture, and diffuse agricultural pollution. Recent field trials have showed that 38% of soils in SW England show signs of enhanced surface water runoff due to soil degradation. (Source: http://bit.ly/1SfV8n0)

- biodiversity.

4. Needs and gap analysis for ensuring good soil health

4.1 Agricultural Cross Compliance (GAEC) and farm subsidy

4.1.1 The current (rather few) requirements for protecting soil are inadequate; good practice guidance as well as rules, for what they are, are widely ignored. The Defra Soil Strategy published in 2009 contained good words but little action followed and agricultural soils across much of the countryside are damaged by cultivation, compaction from farm machinery and overgrazing. Moorland soils are consistently being damaged by frequent burning to maximise grouse production for shooting. There is plenty of evidence available on this.

4.1.2 GAEC cross compliance for Basic Payment is inadequately enforced and monitored. Many farmers/land managers and their contractors are either deliberately ignorant of good land management practices or just don't care. In 2014 I spoke to one contractor who was spreading slurry who had no knowledge of cross compliance; he had never been given a map from the farmer he was working for (showing watercourses & springs) and did not know the rule for no spreading within 10m of a watercourse and 50m from a spring; contractors here are still consistently breaching rules on spreading near watercourses, despite the case being investigated by the Environment Agency and the farmer having been visited in 2014. Much permanent pasture was deliberately ploughed up to pre-empt new rules introduced recently and many fields in SW England and in other high rainfall areas are now regularly re-cultivated, causing soil organic matter/nutrient loss and compaction. This will compromise future ability of the land to produce good food and also contributes to increased runoff, soil eriosion and watercourse pollution.

4.1.3 Needs

1. In the short term, better enforcement of agricultural cross compliance and tighter rules.
2. A complete rethink of how land managers should be supported through the farm subsidy system. This public money should be wholly reorientated to pay for ecosystem services delivered through appropriate land management practices, not used as a welfare payment to support incomes for those who own or lease rural land.
3. Mandatory training/competence framework and permit system for anyone involved in cultivation, sowing crops, spreading organic manure - requiring a complete overhaul of the education and training currently provided by agricultural colleges and skills-based training & qualifications. (See section on Education)
4. Ban on intensive and frequent management of heather moorland by burning. This is vital to restore resilience to soils in upland catchments, to reduce carbon losses from peat soils and promote more varied and mature vegetation that will increase carbon storage and rainfall interception/storage for flood risk reduction.
5. Prohibition of moorland drainage except to reduce erosion of public footpaths and established trackways, to protect existing occupied properties and for environmental conservation purposes; greater investment into blocking moorland drains.

6. Prohibit maize-growing without undersown catch crop; encourage this to be a N-fixing crop. Consider a similar approach for other crops that create bare ground in winter. (Potatoes create a big problem.)
7. Develop criteria to identify Soil Sensitive Land that should not be cultivated (except for conservation reasons). This would include many areas of land in high rainfall areas and on slopes. Without this requirement, we can expect further erosion of soils across Britain. This restriction would apply to recultivating for ley grassland as well as arable crops, and would require a return to diverse permanent grassland swards in landscapes that historically were pastoral for good reason.

4.2 Agricultural extension, training and education

4.2.1 Advice to farmers ("extension") is a vital tool to help farmers understand how to manage their land to prevent soil erosion. However, there isn't enough of it. Advisers are too few and even "Priority Catchments" at risk of diffuse pollution from agriculture (usually associated with nutrient laden silt coming off farmland) do not all have at least one adviser. Very obvious and simple actions, that could be adopted very easily with major benefits for soils, runoff and nutrients, such as undersowing maize crops with grass, clover or other catch crops, are largely absent.

4.2.2 I suspect that soil management is not adequately considered within the education syllabus for trainee farmers and contractors and this suspicion was recently borne out following a discussion with a student who is studying agriculture at Cannington College, Bridgewater, Somerset. This student had studied for a Diploma and Foundation course and told me that the only training he had been given on soils was to differentiate between sand, silt and clay. This is wholly inadequate training for someone who will be in charge of looking after land that is to produce food and other ecosystem services.

4.2.3 I am also aware that environmental conservation is not necessarily a compulsory option within agricultural education courses.

4.2.4 There is no mechanism for Continuing Professional Development of farmers and contractors. This is ironic as farmers claim to be professionals, but they are not. As a group they do not have a professional accreditation scheme nor a professional institute to accredit them. This is needed. All farmers should have a minimum qualification in understanding soils and how to protect them through farming practice. As the people in charge of managing this public resource, upon which future generations depend, a degree of professionalisation and recognised competences in the industry are long overdue.

4.2.5 Needs

8. A complete, independent review of the integration of environmental conservation principles and practices within the current agricultural education syllabus and in agricultural colleges; creation of mandatory modules for land manager training covering managing land to deliver ecosystem services, including healthy living soil, clean water, pollination and biodiversity.

9. People who are going to be managing land (or giving land management advice), including tractor drivers and farmers, extension advisers, MUST be taught about how to look after and restore healthy living soils: Agricultural training and education needs a complete overhaul, covering both formal education and vocational skills-based accreditation via LANTRA.
10. Professionalisation of the farming industry: Establishment of a professional accreditation body (Institute) to professionalise the farming industry, set qualifications, competences framework, professional code of practice and have in place a programme and requirements for Continuing Professional Development.
11. More qualified extension advisers to visit farmers and advise on land management for improving soil health. Compulsory farm visits where known problems exist. (Currently farm visits are predicated on those farmers requesting visits whereas many of the farms that are causing the biggest problems do not engage with advice.)

4. 3 Farming within the capability of the land and agroecology

4.3.1 It is very clear that bigger and more powerful machinery, agrochemicals and subsidy paid to support the incursion of intensive farming into more ‘marginal’ land, have allowed for the intensification of farming of land and landscapes that should have remained as semi-natural vegetation or under ‘extensive’ type farming systems. Farmers have also been pushed to intensify as food has become a globally traded commodity to a much greater degree than in the past. As such the products of farming have fallen victim to the fickle commodity markets, while farmgate prices have also suffered as a result of the dictats of supermarkets. Lower unit prices continue to force further intensification to realise so called ‘economies of scale’[3]. The environmental and social costs of this intensification treadmill are never accounted for in the price paid for food.

4.3.2 The controls in pushing into ‘marginal’ land have been and remain inadequate and proposals for greater control have been largely rejected. For example, in the last round of CAP negotiations it was proposed to prohibit the cultivation of steeper land but this was objected to by UK and other member states and was left out of the reform package.

4.3.3 There has been an over reliance on agrochemicals in arable farming, coupled with a change from more sustainable mixed farming systems; across arable landscapes soils with no organic matter in them are now prevalent. This is as a result both of cultivation (leading to oxidation of soil organic matter and direct destruction of life in the soil) and from the barrage of pesticides used to grow crops[4]. Environmental impacts of many pesticides, and combinations in use, have been inadequately assessed - this is now becoming clear

[3] Alternative models, with less intensive systems, are already beginning to demonstrate that the current business model fails to stack up even when not accounting for the externalised costs (social & environmental impacts) associated with some intensive systems.

[4] One of the fields I worked on had lost six inches of soil since the 1970s when it was ploughed up, leaving just six inches of “puffy” soil, above the bare chalk. This field was relatively level, not on a slope. I worked with the farmer, under an agri-environment scheme, to sow a floristically diverse grassland on this land and have worked with other farmers to do the same because they realised their land (in their words) was “farmed out”. Much of the land I have worked on should never have been cultivated in the first place, but was ploughed in the 1970s when arable subsidies were introduced. In the pastoral north and west we are now seeing the same thing having happened more recently - with vast acreages of permanent grassland cultivated and converted to rye grass leys that are recultivated every five years as well as conversion to arable to grow maize or potatoes.

following the growing concerns associated with pollinator health and neonicotinoid pesticides. A lethal combination of fungicides, insecticides and weedkillers mean that living soil cannot be sustained under chemical-based intensive farming systems. Research from the USA also shows that growing herbicide resistant GM crops has been lethal for soil biota, and growing such crops in the UK needs to be resisted.

4.3.4 This situation has been promoted through the power of increasingly large corporations whose business is agrochemicals in support of industrial farming systems, and by the farm subsidy system which has included historic grants for drainage and improvement of land for intensification and the promotion of arable cultivation on any land that could be drained and cultivated. This has led to large areas of landscapes having been drained, cultivated and improved either for arable or for ley grassland, the latter now the backbone of the prevalent industrial livestock farming business model. The widespread loss of permanent, diverse grassland swards, containing a mixture of grasses and deep-rooted perennial herbs that once characterised ‘old’ hay meadows and pastures has also been a disaster for wildlife, soils and river quality and has reduced the capacity of land to retain water.

4.3.5 Needs

12. It is time for a complete rethink about how land is used and farmed. This needs a massive amount of investment, to educate farmers and change farming practices and the systems within which farming operates. Farmers need agro-ecological training, and agro-ecological management approaches need far more research funding and finance to support their widescale adoption.[5]
13. The country needs a new cohort of young farmers, willing to take on board a role of ecological land managers while at the same time producing good food for people living in the UK.
14. “Semi”-natural vegetation (consisting of communities of species native to the UK) needs to be used more widely as a means of restoring resilience to soils, land and landscapes. This includes restoring floristically diverse wetlands, pastures and meadows[6] in critically important areas (especially along springlines and in floodplains[7]), a halt to over-management of hedgerows that are currently harshly cut annually, and using techniques such as grass banks and grass margins to reduce runoff and keep soil in fields.
15. Reform of how food is treated as a commodity, requiring a significant change in the economic mindset that is currently prevalent.

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[5] Funding Enlightened Agriculture (FEA) is a network of organisations and individuals who wish to support agricultural and food production practices that are economically sound, socially just and promote long-term protection of natural resources. Within the UK this initiative forms the beginning of a big push and the growing momentum of farmers, land managers/advisers, academics, foodies and others wishing to see a sea change in current food-farming policy and practice, that was recently showcased at the sixth and biggest to date, Oxford Real Farming Conference. See www.orfc.org.uk and www.feanetwork.org

[6] For example, a keystone species for semi-natural grassland is native Bird’s-foot Trefoil (*Lotus corniculatus*), which has a tap root of up to one metre long and a very extensive root system that is an ecosystem in its own right.

[7] Requiring some stopping up of land drains dug since the 1970s

4.4 Addressing soil erosion from road verges

4.4.1 It is now known that a considerable quantity of soil entering rivers is originating from road verges that are being continually damaged by large vehicles, primarily farm vehicles but also lorries using small rural roads. Farm vehicles have got too large, creating more problems for land, soils and also for other rural road users.

4.4.2 Needs

16. Research to identify solutions. However, unless farm machinery gets smaller, and tractor drivers are trained not to drive on verges, I don't know what the solution is to this.

4.5 Addressing the problem of cultivated peat soils

4.5.1 The Defra Soil Strategy (2009) completely ignored these soils, the cultivation of which is a significant source of carbon emissions. These soils continue to be rapidly eroded and will eventually leave uncultivable low lying (often marine clay) soils that will not be cost-effective to drain and farm.

4.5.2 Need

17. Government needs to consider how to address the problem of cultivated peat soils within the context of climate change and a sustainable food-farming system.

4.6 Horse keeping

4.6.1 Recreational horse keeping is often associated with bad land management - overgrazing and soil compaction. This is particularly prevalent, but not exclusively, on the urban fringe. These poor practices are associated with horse-keepers who have no understanding of grassland management and soil conservation, and fly-grazing. However, this issue is a relatively minor one in comparison to the huge issue of farming and it can be argued that many of the horse-grazed pastures are the ones that have not been cultivated and reseeded; even though heavily grazed they still contain deep rooted herbs and are less liable to soil erosion than reseeded leys nearby. Should there be additional controls over land where horses are kept? Perhaps, but this is not such a priority as the rest of the farmed landscape.

4.6.2 Needs

18. Mandatory environmental land management module incorporated into college training for horse-keepers (equine management) that covers grassland management, rotational grazing, benefits of diverse swards, soil conservation, etc.
19. Registration of land maintained primarily for recreational horse-keeping.
20. Provision of advice and equine land management information network to registered horse-keepers.

21. Removal of basic farm subsidy for recreational horse-keeping (this will need defining), but provision of ecological land management payments for maintenance and good management of diverse grasslands and other biodiverse open habitats grazed by horses.

January 2016

Written evidence submitted by the Game and Wildlife Trust

The Game & Wildlife Trust is pleased to be able to respond to this consultation, drawing on our own extensive research and practical experience at the Allerton Project research and demonstration farm at Loddington, Leicestershire

We congratulate the Environmental Audit Committee for setting up this inquiry. We believe that maintaining soil biodiversity and the soil habitat as a whole is key to maintaining soil health, decomposition and nutrient cycling. Soils deliver numerous ecosystem services, food production being foremost in the public's attention. However, soil also regulates the environment (e.g. reducing surface water run-off, reducing flood risk) and has a key role in both the carbon and nitrogen cycles. Soil also provides cultural ecosystem services, supporting the local community as a readily utilisable green space, improving aesthetics and the public's health and wellbeing.

1. **How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?**

Understanding how to measure soil health properly is essential to monitoring and also for improving soil health in the long term. Soil degradation leads to the loss of soil micro and macronutrients, as well as losing the soil itself through poor management; nutrient-poor soils are less healthy, potentially producing lower quality crops with lower micronutrient contents. Measuring micronutrient content within the soil, at regular intervals could be effective in understanding soils changing nutrient status. The ability of a soil to maintain ecosystem function could be considered a good measure of soil health. However, conflicting land use could for example lead to a soil being "healthy" in relation to soil biodiversity, whilst at the same time not being sustainable for food production.

A high organic matter content improves the amount of water that can be stored within the soil profile (its water holding capacity) and can reduce soil erosion and maintain summer soil moisture whilst simultaneously providing a habitat and food source for soil fauna. Understanding the impact of variable levels of organic matter could provide the basis for a monitoring programme, particularly when comparing soil organic matter across productive land. Earthworms are commonly referred to as "ecosystem engineers" because of the large impact they have on their surrounding environment. Earthworms are soil creators, redistributing nutrients throughout the soil profile, improving the soil's fertility whilst also improving the soil aeration and water infiltration, leading to reductions in both surface water run-off and soil erosion. A soil with high earthworm abundance, if managed correctly will become a healthy soil over time. A number of scientific studies have already suggested that soil fauna abundance and diversity could be used as a proxy to monitor soil health, so there is already an evidence base for the Government to use to develop into a strategy. Both organic matter and earthworms therefore provide useful and practical indicators for monitoring soil health.

It is important to look at the composition of the soil overall – what are the percentages of substrate, air, water and organic matter? How do these change through a season? Will these changes affect the stability and resilience of the soil in the context of changing land use and climate? Understanding how the composition varies will allow practitioners to get the best out of their soil. Implementing a strategy that provides appropriate advice and rewards good practice and good soil health will get the best results.

Since the start of the Allerton project in 1992, we have been keen to focus on the whole farm ecosystem, implementing management practices that have multiple benefits. We monitor soil health, as part of our standard farm practice and also as a demonstration to the agricultural community through our ongoing programme of knowledge exchange events. We recently started benchmarking soil organic matter (as well as economic performance) across farms in our Welland Arable Business Group. The Allerton project will also be contributing to the establishment of a freely available web based mechanism for tracking soil health nationally, as part of a new SARIC initiative led by Newcastle University. These initiatives will be linked to others across Europe through the new EU funded SOILCARE project with exchange of knowledge and ideas. We are keen to help to develop a strategy for monitoring and understanding soil health in the long-term.

2. What are the benefits that healthy soils can provide to society?

Agricultural profitability and sustainability are crucial to farming successfully – without a healthy soil this is impossible. Soil is under pressure to sustain agricultural output, whilst agricultural land is reduced as part of agri-environment schemes and greater urbanisation of rural areas. There is an ever increasing need within agriculture to produce more from less and the only way to do this is through sustainable intensification. To do this we need to think about the health of the soil in the long term. At the Allerton Project, understanding soil health has always been a priority. For example one collaborative project we are part of is the "Sustainable Intensification Research Platform" (SIP). The SIP is a DEFRA funded initiative to develop and test productive, profitable farming systems that reduce risks to the environment and deliver a range of ecosystem services. Recently, as part of SIP research, an experiment has been set up to monitor the health and productivity of the soil under different cover crop mixes, with the aim of improving future crop yields alongside soil quality and function. We are monitoring biological, physical and chemical properties of the soil, as well as crop yields, to get an overview of how different cover crops function in real life to improve soil conditions for future crops.

A "healthy" soil, should have a large water holding capacity, providing a buffer within the system during times of large rainfall events, and moisture retention for crops during periods of drought. However, different soils respond differently to management and cultivations and this needs to be accounted for within a strategy to develop and maintain healthy soils. Reduced tillage for example is known to improve water holding capacity and structure of the soil, whilst also reducing crop establishment costs and carbon emissions. At the Allerton project, over the last 20 years we have moved to a reduced tillage system, and often a no-till approach, to provide an example of best practice on a working farm. It is important to recognise, that soil is only healthy and useful if it remains where it should be – in the field. Assessing where surface run-off occurs within the farm is important in order to reduce soil loss from productive land and the impacts on water quality and ecology in streams and rivers, as well as reducing flood risk. Our research has found that tramlines running with the slope were responsible for 80% of the surface run-off, despite occupying just 3% of the field surface area. Because of this we assessed various methods of improving management of tramlines. We have found that on our clay soils, low ground pressure tyres are the best for reducing soil compaction occurrence, reducing run-off from tramlines by 50%. Such management of soils in headwaters can reduce the risk of flooding in lower-lying areas with higher population density. At the Allerton project we are investigating the role of soil management and health in managing flood risk in our landscape scale "Water Friendly Farming" experiment.

Carbon sequestration – storing carbon in the long-term (off-setting emissions of fossil fuels) is both vital for a healthy soil and part of the benefits a healthy soil can provide. As a carbon store the soil currently offsets about 15% of agricultural GHG emissions. The addition of organic matter (plant residues) to the soil increases the carbon content and thus increases the water holding capacity of the soil aiding flood prevention; it also can improve crop yields providing an energy source for soil microbes. Ploughing is one of the main ways organic matter is lost from the soil; at the Allerton project, we have moved to reduced tillage, and where possible a no-till system to increase the build-up of organic matter within our soils.

A 1 m^2 area of healthy soil is full of life, supporting millions of microbes, kilometres of fungal hyphae, 100,000s of protozoa and nematodes, as well as thousands of meso- and macrofauna. These organisms can be found across the soil globally, from the poles to the equator, and whilst species and abundance vary depending on plant species, soil type and management, the vast majority of species are unknown. However, it is important to consider that a healthy soil supports wildlife aboveground too. For example, at the Allerton project, we have found that song thrush and blackbird nesting success is lower in arable areas with impoverished soil fauna, compared to pasture supporting higher earthworm numbers. PhD research here in conjunction with Cranfield University, has also found that greater abundance of meso- and macrofauna reduced soil erosion.

Agriculture and degraded soil can be a large source of greenhouse gas (GHG) emissions, but maintaining a healthy soil can reduce the likelihood of this. Improving the quality of forage crops through better soil management can improve animal productivity leading to reduced emissions. As well as a continual green cover (e.g. under sowing arable crops or planting winter cover crops) will affect the nitrogen content within the soil, reducing the amount of nitrous oxide (N_2O a GHG) that could be emitted into the atmosphere. An unhealthy soil is unable to do this, as either due to structural problems or poor growth conditions, a green cover is difficult to establish. Compacted soils also tend to be more anaerobic, leading to increases in N_2O emissions.

A healthy soil will quickly obtain a green cover which provides erosion protection and maintains water quality. Plant cover will reduce the volume of water flowing over and into the soil, thereby reducing the leaching of nutrients from the soil into waterways and lessening soil particles being washed off the surface. Research at Loddington revealed the importance of soil microbial biomass in reducing the sediment moved from land to water via both surface runoff and sub-surface flow. Healthy soils therefore contribute to meeting Water Framework Directive (WFD) targets for water quality and ecology, an important focus for our recent research through the Water Friendly Farming project and related work.

3. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The consequences are diverse and wide reaching – without soil we would have no food security, or nature; without a healthy soil the consequences are more insidious. An unhealthy soil reduces crop yields, increasing intensive management to maintain yields at the expected level, whilst reducing aboveground and aquatic biodiversity. Soil biodiversity will be reduced if the soil health is reduced. This could lead to the extinction of as yet undiscovered species. It is very easy to degrade soil, and much harder to improve it. If a soil becomes compacted, surface run-off increases – posing a flood risk downstream and sedimentation of stream beds (reducing the ability of fish to spawn), biodiversity is impoverished, and N_2O emissions are increased. Where a soil is compacted or is eroding there is an increase in the surface run-off of soil particles and associated phosphorus, a major contributor to WFD water quality failures. This can lead to sedimentation of drainage channels (increasing flood risk further) which is also costly to rectify. For example, sediment removal from the river Welland to reduce flood risk around Stamford last year (2015) cost the government £109,000.

Historically, soil loss has contributed to increasing poverty and environmental disaster e.g. the Dust Bowl of the USA southern plains in the 1930s. Losing soil, could have an impact on food security, potentially reducing yields. It could also damage the surrounding environment through fertiliser or pesticide pollution, as these can bind to soil particles, therefore when soil is lost through erosion, these chemicals are also lost to the aquatic environment. Agricultural systems that are not managed for soil health in the long term, will quickly experience soil degradation and unprofitable. There is a greater risk of blackgrass proliferation and competition with crops in areas with increased soil compaction. Here, the increased use of herbicides and greater number of vehicle movements on the soil surface leads to a cascade of problems from surface runoff to increased herbicide concentrations in water.

The soil is often referred to as the "poor man's tropical rainforest" because of the abundance and diversity of soil fauna residing there. There is a greater number of microbes living in a teaspoonful of soil than there are humans alive globally. Across a hectare of farmland, there can be a greater weight of earthworms living belowground, than the weight of livestock grazing aboveground. Part of the work performed at the Allerton Project focuses on the landscape scale, for example, we have the WFF project across 3,000 hectares of agricultural land and three headwater catchments. Monitoring the turbidity of the tributaries within these catchments provides a measure of soil loss through erosion which will also provide an assessment of chemical loss to the environment. Sediment monitoring suggests that 0.3 – 0.6 tonnes of soil move from the land into water courses per hectare per year. As well as representing the loss of farmers' most valuable resource, this reflects poor soil function affecting other ecosystem services including food production. Assessing ways of reducing and preventing this will reduce the level of soil degradation that occurs across the landscape, as well as reducing water pollution.

4. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Agricultural soil management is linked to both Countryside Stewardship and cross compliance, providing a mechanism for promoting soil health that is linked to the Basic Payment Scheme; providing farmers with options to protect, enhance and rejuvenate their soil. Soil management is a core theme of Catchment Sensitive Farming, which provides a joined-up approach focusing on the risks of soil loss / management at the catchment scale. The Allerton Project is working closely with CSF to develop this approach further. The cluster farm initiative and Facilitation Fund could be used as another approach to bring farmers together to consider soil health at the catchment scale. Utilising schemes already running will reduce the administrative complexity and increase participation.

Knowledge exchange and education are essential to managing soils, promoting soil health and good practice as well as maintaining profitability within farming, protecting the environment in the long-term. Knowledge exchange extends to all organisations that work within the farming community and natural environment (e.g. farm advisors, agronomists, land-agents and supply chain managers, nature reserve wardens and volunteers) so that a greater understanding can be achieved. At the Allerton project, we have been training many of these groups through the BASIS Conservation Management course – promoting best practice. Training advisors increases the sphere of influence throughout the farming community and beyond. There is a great need for 1:1 advice so that it can be tailored specifically to the individual farmers' needs as they are the custodians of soil health.

As exemplified by the Sustainable Intensification Platform, Allerton Project research is a collaboration with other research organisations and through co-supervised PhD and MSc studentships. Getting the next generation of scientists interested in soil, is pivotal in providing answers to the food security problems of the future.

The government needs to promote soil monitoring and benchmarking across farms, as well as supporting financially the conversion to reduced / no-tillage, lessening the economic burden that often occurs during the conversion period. Short-term tenancies create a barrier to long-term objectives for improving soil health, while the increasing trend for small and medium sized farms to be managed by contractors reduces the likelihood of approaches such as no-till being adopted.

It is important to identify synergies between multiple objectives for land management. Sometimes different schemes may create conflict by discouraging best practice for maintaining a healthy soil. A serious example is soil degradation and erosion associated with support provided for the growing of maize for anaerobic digestion. Renewable energy is an essential strategy for mitigating climate change and meeting targets for CO2 emissions, but support should be diverted to renewable energy generation such as wind and solar panels on buildings in order to reduce pressure on land (soil) for food production and to avoid perverse consequences for other policies such as improvement in water quality.

5. What role (if any) should soil health play in the Government's upcoming 25-year plan for the natural environment?

Specific examples are given in the answer to the previous question. Soil is the building block of life – its health is central to food security and the natural environment. A house built on poor foundations will fall down, hence why soil health is so important when considering the natural environment of the future. A healthy soil will provide a buffer to extremes in temperature, rainfall, and drought, therefore reducing the impact of future climate change, it is also necessary to sustain our future food production. The 25-year plan for Food and Farming should be considered within this 25-year plan for the natural environment, and soil health has a fundamental role to play within both. It is imperative the government links current and future schemes (e.g. CAP, cross compliance, WFD, FIT, etc) with an ongoing programme of research, education and advice; to support and encourage soil rejuvenation and the promotion of soil health. The government should utilise these current policies to persuade or direct farmers on the journey to healthier soil. We have seen other journeys in the past with IACS, Linseed, protein, OSR, Ewe and Lamb premium. Greening has endeavoured to start this process, but there is still a long way to go. Understanding from our past experiences to make farming more sustainable and profitable is crucial.

January 2016

Written evidence submitted by Dr Robert Evans, Global Sustainability Institute, Anglia Ruskin University

Introduction

1. This is a welcome consultation. It is just over 20 years since the Royal Commission on Environmental Pollution began to gather evidence on the Sustainable Use of Soils. The Report was published in 1996 (RCEP, 1996). I was an advisor to the Commission. Since then, it is unlikely that soil health has improved, especially of lowland soils. However, in some places such as moorland SSSIs soil health will have improved as soil erosion has been curtailed. These sites are no longer grazed as heavily by sheep which initiated and maintained bare soil and substantial efforts are being made not only to fence out sheep but also to vegetate bare peat surfaces and stop up gullies and drainage ditches.
2. Soil Health concerns both physical and biodiversity aspects. The physical aspects relate to the state of the soil's structure. The biodiversity aspects relate to the flora and fauna in the soil profile. I will concentrate on the physical state of the soil as I have spent much of my working life assessing and monitoring soil erosion and runoff and their impacts.
3. There is a growing body of evidence that lowland soils are becoming more compact, probably related to the greater weight of the machinery used to cultivate, drill and harvest the land and that that machinery allows operations to be carried out when the land is not in a fit state (too wet) to carry that machinery without damage to the soil. Similarly cattle and sheep can be outdoors when topsoils are saturated so puddling and compaction take place.
4. It seems likely that the extent and severity of rill and gully erosion is little changed since the late 1980s, except where outdoor pigs and maize have become more common. Land going into set-aside and then being included in the Campaign for the Farmed Environment will have slightly lessened the area of land at risk of rill erosion. But wash from the land is likely to have become more widespread as soils have become more compact. Indeed, it is likely that agricultural diffuse pollution of water bodies by pesticides and nitrate, and possibly by sediment and phosphate though there are other important sources of sediment (damaged roadside verges, farm tracks, eroding river channels) and phosphate (septic tanks, small water treatment plants), has increased because of such widespread wash. Such diffuse pollution is higher on the agenda than it was in the 1990s, partly due to environmental regulations that have come into force since then and because of the realised problems and costs caused to the water industry to treat water to comply with these regulations, but also as diffuse pollution of water bodies has likely become more widespread.

Response to the questions posed in the Terms of Reference

How could soil health be measured and monitored. How could the Government develop a strategy for tracking soil health?

5. With regard to the physical health of the soil, a programme of field assessments of soil structure should be carried out similar to those described by Palmer and Smith (2014) or Palmer *et al*. (2006) in areas where it is considered soils may have become, or will become damaged. Or a rolling programme put in place to sample soil landscapes. Farmers and advisors can make their own assessments (e.g. Ball & Munkholm, 2015), but those assessments need to be placed in an open access database.

6. Assessing and monitoring soil erosion should, as with soil structure, be done in the field. Models to assess, monitor and predict erosion using data from experimental plots are unsatisfactory (Evans 1995; Boardman 1998; Evans et al. 2015; Evans & Boardman, 2016) and see below. Field-based monitoring in those landscapes known to be most at risk of rill and gully erosion should be carried out, and suspended sediment loads monitored in selected catchments not only to relate load to rill and gully erosion, but also to wash from farmers' fields and from other sources (Collins et al., 2013). Modelling may have been the preferred approach to assess soil structure and erosion, possibly because of person power and cost constraints, but gives results which may or may not be realistic. Indeed, it may well be that erosion is an overstated problem with regard to loss of the soil as a basic resource as mean rates of erosion are very low but the impacts off-farm – muddy floods, pollution of water courses – can be great.
7. The figure (2.2million tonnes yr^{-1}) given for soil erosion in lowland England and Wales in a number of sources, including Defra's Soil Strategy (2009), is based on a three year study (Harrod, 1998), and equates to 0.85t ha^{-1} yr^{-1} (= 0.65 m^3 ha^{-1} yr^{-1} if the soil's bulk density is 1.3 gm cc^{-3}), a surface lowering of 0.065 mm ha^{-1} yr^{-1}. In the three year study erosion was assessed annually at selected national soil Inventory points (nodes). The selection was based on (untested) slope categories, soil texture, if rainfall was more or less than 700mm yr^{-1}, and assuming a winter cereal crop. Evidence of erosion was sought both within the field containing the node and within a 10m radius of the node and the amount eroded assessed volumetrically, a technique used by other researchers in Britain (Evans et al, 2015). "Since at the wider, field scale some complicating change of soil texture or hydrology or slope becomes more probable" (Harrod, 1998, p. 10) only the data collected within the 10 m radius of the node was analysed as this data was "considered more statistically robust" (Harrod, 1998, p. 13). Of the 772 observations made over three years in only 63 (8%) was erosion observed. The 10 m radius around the node is approximately equivalent in scale to an experimental plot, and many of the world's assessments of soil erosion are based on such plots (e.g. Panagos et al., 2015), except in England and Wales (Evans et al., 2015). The mean rate of erosion (0.85 t ha^{-1} yr^{-1}) is high when compared to suspended sediment loads in rivers which are dominantly below that value (Evans, 2006, Table 1, p. 85) and sediment loads incorporate sediment from other sources - farm tracks, roads and river channels. It could be that much eroded soil was deposited within the field so explaining the discrepancy.
8. A 5 year monitoring scheme in the 1980s carried out by members of the Soil Survey of England and Wales found a much larger number of fields (*c.*1700) eroded by rills and gullies. Other field-based assessments of erosion in Britain relate well to those obtained in the monitoring scheme of the 1980s (Evans et al., 2015). From the 1980s data estimates of soil eroded by rills and gullies transported out of fields, mostly clay particles (Evans, 2002), when compared with suspended sediment loads in rivers suggest that wash from farmers' fields or fine particles from other sources (see above) accounts for a further 0.1-0.3 t ha^{-1} yr^{-1} (Evans, 2006). Estimates made from the 1980s monitoring scheme suggest that in lowland England and Wales 287 623 t ha^{-1} yr^{-1} of soil is eroded, much of it from a small number of soil landscapes (Evans et al., 2015), a much smaller volume of soil than that quoted in the Soil Strategy (Defra, 2009) and equivalent to a surface lowering of 0.027 mm yr^{-1}. The discrepancy may be explained by the difficulties of scaling up results from plot experiments to field and landscape scales.
9. With regard to monitoring wind erosion, areas known to be susceptible should be monitored in the field for the occurrence of wind-blows, and their impacts recorded. As for water

erosion, the monitoring and data collection should be organised nationally with data collected to a central source and accessible to all.

What are the benefits that healthy soils can provide to society?

10. A healthy, better structured soil will absorb more rainfall and reduce and slow down runoff from the land, and will resist wind erosion.

What are the consequences of failing to protect soil health for the environment, public health, food security and other areas?

11. Over the short-term more runoff from the land and soil erosion will lead to more muddy floods and more pollution of water courses by pesticides, nutrients and faecal matter washed off the land; and a greater loss of crop by crops being buried by deposits or floodwater. Where soils are prone to wind erosion, erosion will remove the crop or windblown particles will damage the crop and sand and peat particles infill ditches and pollute water courses. Over the long-term soil thinning will lead to lower crop yields as rooting depth is reduced and moisture available to the plant decreases.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

12. Under the Common Agricultural Policy, to receive payments farmers have to comply with CAP regulations and keep their land in Good Agricultural and Environmental Condition: to prevent soil erosion, maintain organic matter and soil structure, ensure a minimum level of protection of the landscape and biodiversity, and protect and manage water. These are praiseworthy aims but from my observations appear to have little impact on how the soils are managed in ways that are less damaging to the soil. There is very little in Defra's Environmental Stewardship Scheme or its successor Countryside Stewardship Scheme, a higher level scheme than CAP compliance, which directly concerns soil health. There are payments for beetle banks and grass margins for instance which may alleviate runoff and erosion, and payments to encourage wildlife and birds and to protect habitats.
13. That soils themselves are not well protected is understandable, because since the 2nd World War farming in England and Wales has gone down a large machinery/high input route to promote high yields and efficient use of capital without, it would seem, much thought of their impacts on the soil. Organic matter declines in soils continuously under arable and soils become less structurally stable. The economics of farming now make it difficult to care for the soil, as timing of cultivation, harvesting and spraying with heavy machinery or the need for animals to be on the land for longer in larger numbers cannot always be managed to protect the soil in a timely way. To change such ways of farming the land: for example, less intensive use of the land, lighter machines, fewer animals, better timing of agricultural operations, better crop rotations, greater return to the land of farmyard manure or composts, all will have severe financial implications for the farmer and probably lead to less production of crops and animals. The implications of carrying out those actions with regard to feeding ourselves and the balance of payments are serious. Under the present economic and social circumstances, although it may not be difficult to outline what measures Government and farmers should take in order to secure soil health, it is difficult to envisage how those measures can be carried out. Perhaps the work of the Allerton Project (www.gwct.org.uk/**allerton)** and LEAF (www.leafuk.org) could point the way forward?

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

14. Soil health should play an important role in the Government's plan for the natural environment. Indeed, it is probably only through the Government taking measures to protect soils that soil health in the state it is now will be maintained, never mind it being improved. Archaeological and historical evidence suggests that soils have probably never been considered as something that should be protected. Once land in England was cleared of its native vegetation for cultivation and raising animals it became vulnerable to accelerated erosion, and more vulnerable as more land was cleared and used more intensively as populations grew (Evans, 1990). Only when a crop rotation incorporating animals, especially sheep either folded on stubbles, root crops or grass, began to be widespread after the onset of the Industrial Revolution does the evidence for erosion in lowland England decline as population increased. This change in agriculture was in response to an increasing need to feed a burgeoning population and was greatly encouraged around the turn of the nineteenth century by Arthur Young who made it his life's work to report on the state of farming and to persuade large estates to change how their land was worked. More productive breeds of animals were also introduced at this time. Not only were yields greatly increased but farming became very profitable. Following the collapse of profitable agriculture after the mid-1870s much arable land reverted to grass. Until the rapid expansion of intensive agriculture after 1945 soils were probably in better health than they are now. Perhaps going back to a more sustainable use of the land based on that which greatly improved productivity in the nineteenth century would help improve the health of the soil?

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January 2016

Written evidence submitted by Dr Karen Johnson, School of Engineering and Computing Sciences, with Jennifer Jeffes, Senior Policy Engagement Manager, Durham University

1.0 Introduction

1.1 This evidence submission is based on the findings of Dr Karen Johnson's extensive research into urban soils, working with communities to use recycled minerals to regenerate brownfield sites to improve human health and wellbeing as well as soil health (Bambra et al, 2014, ROBUST). Dr Johnson is an expert on carbon sequestration in soil minerals (eg Greathouse et al, 2014, Johnson et al, 2015) and is passionate about the role soil has to play in both climate change adaptation and mitigation. Dr Johnson believes we must protect soils for future generations by making soil explicitly one of the UK's Sustainable Development Goals (as outlined in Johnson and Jeffes' submission to the Environmental Audit Committee's inquiry on this topic in November 2014).

2.0 How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

2.1 Soil health is difficult to define as it is dependent on the underlying geology. Soil can also contain anthropogenic inputs which may or may not result in soil not being able to perform its essential ecosystem services. The most important ecosystem services are, arguably, being able to grow plants, storing water (enhancing flood resilience), filtering our water resources and provision of greenspace for human health and wellbeing. In order to understand soil's capacity to do this, we need at the very least to assess plant growth, water holding capacity, degree of compaction, hydraulic permeability and soil organic carbon (SOC). SOC is of paramount importance in soil function; it is the glue which holds soil together and the food that feeds the microorganisms that a healthy soil needs. SOC is therefore important to both plant growth and to water holding capacity – yet SOC in soils is dropping (Rusco et al, 2001). A major reason for this is because since the agricultural revolution we have used Nitrogen, Phosphorous and Potassium in a chemical form to maintain plant growth instead of adding them in an organic form. Soil microorganisms have therefore been using old SOC as their food source which has therefore become depleted. We take the majority of our food from soils but we have not been putting the organic wastes back into the soil. In fact in the UK, we only return 70% of our organic waste streams to the soil (House of Lords, 2014). The maths doesn't add up and it is soil (and the ecosystem services it provides) which is losing out. Engineers have the skills to close the loop for soil, by preprocessing organic waste streams in order to put stabilised carbon back into soils where it belongs. With the Paris Climate Change talks recently making carbon storage an explicit part of the agreement it is fundamental that we measure and explore the fate of SOC in our soils as well as explore opportunities to maintain and enhance it.

2.2 In terms of strategy to track soil health, we believe that the Government should make soil health a central tenet of the National Planning Policy Framework. At the moment, urban planning does not take into account the opportunities for improved human health that healthy soils can provide communities, as well as the provision of its ecosystem services to help with flood resilience. We should also strongly encourage land-owners to take SOC measurements before and after tenant-ship. These strategies would be timely in providing an opportunity for the UK to lead in soil carbon management - utilising our strong research and engineering skills to establish methods of how to preprocess our organic waste streams back into the land to improve carbon storage, flood resilience and human health and wellbeing.

There is also a need and an opportunity to prioritise coordinated schemes between local authorities, food industries and communities for community composting - where high quality organic matter could be produced and returned in a stable form to soils to maintain soil health and flood resilience.

3.0 What are the benefits that healthy soils can provide to society?

3.1 Soil provides essential ecosystem services. For example, this includes land for both agricultural and city-grown food, greenspace for public health and wellbeing, land for flood mitigation and carbon storage, as well as providing ground to build on. Flooding is of key national and international importance, and extreme weather events are likely to increase with climate change. It is clearly essential that any measures to address this risk include provision for the *best possible* solutions – in our view, one of these solutions is to prioritise increasing the water-holding capacity in soils (Kerr et al, 2016) which in turn helps to alleviate flooding by holding water in the soil for long enough to stop flash flooding in rivers, and to prevent excessive overland flow actively removing soil. The best possible solutions will involve restoring SOC levels by adding organic matter to soils in many cases.

Taking the UK as an example, the social and economic devastation (estimated at £6Bn for the latest December 2015 set of storms[1]) caused by flooding is readily apparent, and this is a problem that everyone agrees must be tackled as soon as possible. But the hidden (in plain sight), arguably even bigger issue, is that the muddy flood waters are taking even more organic matter *and minerals* out of our soils, exacerbating the vicious circle of climate change - soil degradation - climate change - soil degradation. Water retention, slowing the transfer of water into rivers, would have a significant impact on the occurrence and/or severity of this flooding.

4.0 What are the consequences of failing to protect soil health for the environment, public health food security, and other areas?

4.1 Environment: Healthy soils are more biodiverse, and more biodiverse soils are better for human health (Wall et al, 2015). Healthy soils (ones which store carbon and water) provide opportunities for carbon sequestration and flood resilience which improve the environment both locally and globally (Lal, 2003; European Commission, 2012). The world's ecosystems are reaching a tipping point and it is vital to put carbon and minerals back into the soil. Water retention will follow, improving soil quality and reducing carbon turnover to atmospheric greenhouse gases.

4.2 Public health and wellbeing: In terms of flooding, there are wellbeing effects associated with the devastation caused, but there are physiological effects too (e.g. respiratory illnesses caused by resultant damp and moulds). The findings of Durham University research exploring the regeneration of brownfield land (land that has previously been used for industrial purposes) shows that there are wider negative impacts on the general health of communities that live in proximity to it (Bambra et al, 2014). The remediation and redevelopment of brownfield land should also be considered as a public health policy issue because of the detrimental impact brownfield has on the health of surrounding

[1] http://news.sky.com/story/1613230/flood-impact-could-be-nearly-6bn-report

communities. Brownfield land is regeneration using organic and mineral wastes (ROBUST technologies, see reference) should be seen as an opportunity to enhance not only soil health but also community health and wellbeing.

5.0 What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

5.1 Agricultural soils have a range of measures (mainly encompassed within EU legislation, with a focus on water quality) designed to ensure the effective stewardship of agricultural soils (for example, the EU's Common Agricultural Policy). However, although farmers clearly understand the importance of organic matter in soils, it is not currently mandatory to measure SOC in farming – this is problematic because, particularly where organic waste streams are less prevalent (e.g. in East Anglia), SOC levels are not being maintained.

Urban soils are particularly vulnerable to degradation and are currently completely unprotected by UK and international law. Although through Pt2A of the Environment Act, a new site must be investigated to ensure it is fit for purpose and not 'contaminated', engineers can and do deal with this by sealing the surface of the soil resulting in a loss of soil ecosystem services. Soil sealing usually involves covering the soil surface with concrete; this reduces infiltration of water which in turn causes surface water flow which contributes to urban flooding. In addition, urban soils are what the public comes into contact with most frequently (over 80% of the UK's population lives in cities) and will therefore be critical in raising the awareness of soil value to the wider population.

5.2 In terms of agricultural soils, SOC must be included as a measured parameter for soil health. For urban soils, if the National Planning Policy Framework document had guidance on alternatives to soil sealing and specifically on how to maintain soil ecosystem services then engineers would be able to work with soil to implement more sustainable on site drainage solutions. At the moment there is nothing to stop every house-owner (and landowner) in the country concreting over soil on their property which would result in increased surface flow and contribute to the problem of urban flooding. It is engineers who work with urban soils and yet engineers are currently largely excluded from the narrative of sustainable soil management and this must be addressed. **Engineers need to be trained in the value of natural capital** in higher education and taught to work with the environment instead of on top of it.

6.0 What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

6.1 Soils must be examined all three national strategies that are currently being written: Defra's 25 year plan for the natural environment, the Natural Capital Committee's 25 year plan and the 25 year plan for Food Security. By maintaining and even improving soil health, specifically SOC levels, we can improve soil's water holding capacity, increasing resilience to flooding and drought scenarios, public health and wellbeing and improve food security. However, any goal to restore degraded land and soil is unachievable without training our engineers to work with the natural environment rather than on top of it. We also need UK government guidance defining soil health and legislation to protect urban soils.

7.0 Relevant publications

Bambra, C., Robertson, S., Kasim, A., Smith, J., Cairns-Nagi, J.M., Copeland, A., Finlay, N., Johnson, K., 2014, 'Healthy land? An examination of the area-level association between brownfield land and morbidity and mortality in England'. Environment and Planning A 46(2)

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January 2016

Written evidence submitted by Smart Growth UK

Introduction

Smart Growth UK is an informal coalition of organisations and individuals interested in promoting the Smart Growth philosophy in the UK.

The Smart Growth concept, pioneered with great success in North America, is an holistic ethic of spatial, transport and community planning which aims at long-term sustainability rather than short-term gain. It has several aspects, but the principle most relevant to this inquiry is that of planning compact communities. "Smart Growth promotes well-designed, compact, functional communities and rejects land-hungry sprawl and wastage of greenfield land," say the principles agreed by the coalition in 2008.

In this response, therefore, we will focus on selected questions concerning the need to protect healthy soils from degradation or destruction by development and to promote a preference for brownfield land for development, where suitably located and appropriate, and the importance of reclaiming and remediating the soils on derelict and contaminated sites to facilitate redevelopment and for their own sake. We consider in particular the two issues of soil sealing and land contamination.

This evidence is specifically supported by the following organisations:-

British Land Reclamation Society
Chartered Institute of Environmental Health
Environmental Protection UK

How could soil health best be measured and monitored?
See below.

How could the Government develop a strategy for tracking soil health? -
See below.

What are the benefits that healthy soils can provide to society?
Soils provide a wide range of ecosystem service functions. These include production of food, water, timber and fibre and flood control. Soils support directly and indirectly most terrestrial biodiversity, both above and below the surface. Soils control the flow of precipitation to both surface and groundwater, evening out supplies and mitigating flooding. They can help regulate microclimates in urban environments and healthy soils can, potentially at least, sequestrate prodigious amounts of atmospheric carbon. Farm soils also provide ecological services for cities, including recycling urban wastes such as sewage sludge and compost. Soils also support the intangible but important benefits that countryside and open space offer people.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

Soil Sealing Soil sealing is the covering of land and soil by impermeable artificial material and includes building development and transport infrastructure such as roads or airports, etc.. The process is almost always destructive to the soils so sealed, preventing them carrying out most, if not all, their ecosystem service benefits. Very occasionally, sealing may prevent rainwater mobilizing the contamination within the soil, but in the vast majority of cases there is no benefit to the soils and huge damage to the environment.

Land contamination Land contamination can threaten human health, the natural environment (including animals and crops), the water environment and buildings and their services. Sites which are contaminated, or which it is believed may be contaminated, present obstacles to their reuse as the perceived difficulty, inconvenience and costs involved in their investigation, risk assessment and, if need be, remediation, may be considerable. Although these obstacles may not be as great as feared, left unaddressed, contaminants may continue to pollute ground and surface water and adjoining land, they may threaten the health of those who use the sites or live or work beside them and their dereliction may blight the local economy, environment and society. Work by Durham University in 2014[1] indicated that derelict land, of itself, can have a deleterious effect on local people's health. Where contamination is known or suspected, this effect is likely to be worse; work done jointly by Glasgow University and the British Geological Survey, published in 2013[2], showed a statistically significant association between soil metal content and respiratory illness which the authors describe as `interesting` given the contribution soil may make to airborne particulates, although the study did not actually measure airborne metals. DEFRA has said that though 'it is inherently difficult to prove causality…there are good science-based reasons to be concerned that some sites pose significant risks [i.e. to human health] from long-term exposures'[3].

What measures are currently in place to ensure that good soil health is promoted?

Soil Sealing There is no UK-wide legislation or strategy to restrict soil sealing and what protection there is comes via weak prescriptions in the planning system (see below). In 2006, the European Commission published a Soil Thematic Strategy based on four pillars – increasing public awareness, improved knowledge, soil protection and legislation. It estimated the costs of soil degradation across the EU at the time as:-

- erosion €0.7-14bn
- organic matter decline €3.4-5.6bn;
- compaction – no estimate possible;
- salinization €158-321m;
- landslides – up to €1.2bn per event;
- contamination €2.4-17.3bn;
- sealing – no estimate possible;

- biodiversity decline – no estimate possible.

The Strategy was adopted by the EU in 2007. Contained within it was a proposal for a European soil framework directive[4] which proposed "an approach to soil sealing to ensure a more rational use of land in accordance with Article 174 of the EC Treaty and to maintain as many soil functions as possible. Identification of areas at risk of erosion, organic matter decline, salinization, compaction and landslides, and establishment of national programmes of measures".

The draft directive noted: "Sealing is becoming significantly more intense in the Community as a result of urban sprawl and increasing demand for land from many sectors of the economy, and this calls for a more sustainable use of soil. Appropriate measures are needed to limit soil sealing, for instance by rehabilitating brownfield sites, thus reducing the depletion of greenfield sites. Where sealing does occur member states should provide for construction and drainage techniques that would allow as many soil functions as possible to be preserved." It would have required member states to: "take appropriate measures to limit sealing or, where sealing is to be carried out, to mitigate its effects in particular by the use of construction techniques and products which will allow as many of those functions as possible to be maintained".

The European Commission developed *Guidelines*[5] on soil sealing following concerns expressed, including adverse effects on the natural water cycle. The *Guidelines* showed that detected land take between 1990 and 2000 across the European Union was around 1,000km² annually and settlement increased by 6%. From 2000 to 2006, there was a small decrease in the rate of soil sealing to 920km² each year. In just 16 years, therefore, Europe's urban footprint expanded 9%. Total sealed area across Europe was estimated to be 100,000km² or around 200m² per citizen.

The draft directive attracted strong opposition from European farmers and there was also disquiet among UK contaminated land professionals about the degree of prescriptivity in its approach, and although they accepted that several member states may require stronger legislation in the land contamination field, there was concern about the ability to provide the level of resource implied. Faced with a continuing "blocking minority" at the European Council, the Commission abandoned the draft directive in 2014 but stated it remained committed to its objectives and adopted the *7th Environmental Action Programme*[6]. This provides that, by 2020: "land is managed sustainably in the Union, soil is adequately protected and the remediation of contaminated sites is well underway" and committed the EU and member states to: "increasing efforts to reduce soil erosion and increase organic matter, to remediate contaminated sites and to enhance the integration of land use aspects into coordinated decision-making involving all relevant levels of government, supported by the adoption of targets on soil and on land as a resource, and land planning objectives". It also stated that: "The Union and its member states should also reflect as soon as possible on how soil quality issues could be addressed using a targeted and proportionate risk-based approach within a binding legal framework".

The *7th EAP* admitted soil contamination and sealing are persistent problems but, to date, no proposals have been put forward to meet this commitment. With the Commission in deregulatory mood, it is likely any action in this direction in the short-term will need to be taken by member states, including the UK.

The 2009 DEFRA soil strategy *Safeguarding our Soils – A Strategy for England*[7] does mention soil sealing and says it is caused by pressure for development. It claims that "Some degree of soil sealing is an unavoidable consequence of development. The planning system provides a framework within which consideration can be given to the environmental, economic and social costs and benefits of the development and use of land. The planning system is also increasingly recognising the importance of mitigating the impacts of soil sealing, particularly in relation to urban drainage and maintaining green infrastructure". Sadly, it is the case that the planning system, especially in England, has become less and less of a framework to prevent soil sealing since 2009.

Current UK planning policy contains little in the way of protection against soil sealing.

England's *National Planning Policy Framework*[8] notes the importance of "protecting and enhancing… soils" and of preventing development causing unacceptable risks of soil pollution (Paragraph 109). It says local plans should safeguard "the long-term potential of best and most versatile agricultural land and conserving soil resources". It makes no mention of soil sealing and, indeed, in practice has tilted planning policy since its adoption in 2012 towards increased soil sealing to stimulate house building on greenfield land. It has recently been persuasively argued[9] the *NPPF* was "set up to fail" as far as protection of greenfield land was concerned, with the strategic housing market assessments it demands deliberately designed to produce more housing than areas actually needed.

Quantifying the degree of recent sprawl is difficult as the Government stopped the collection of data under the National Land Use Database in 2011, with the consequence of obscuring the increasing rate of urban sprawl and soil sealing brought about by new planning policies in England designed to increase the rate of greenfield house building. A large trunk road building programme and possible airport expansion also threaten significant increases in areas of soil sealed.

Scotland's *Third National Planning Framework*[10] (currently under review) notes that Scotland's principal physical asset is land and that the most productive soils extend along the east coast and across the central belt to Ayrshire. It notes too that peatlands store 1.6 billion tonnes of carbon. *Scottish Planning Policy*[11] advises: "avoiding over-development, protecting the amenity of new and existing development and considering the implications of development for water, air and soil quality" (Paragraph 29). It contains some provisions on protecting peat soils and also says the planning system should seek to protect soils from damage such as erosion or compaction (Paragraph 194). It does not mention soil sealing.

Planning Policy Wales (Edition 7)[12] says the functions and benefits of soil should be promoted (Paragraph 5.1.3). Northern Ireland's *Strategic Planning Policy Statement*[13], however, contains a rare reference to soil sealing, saying: "In managing development, particularly in areas susceptible to surface water flooding, planning authorities should encourage developers to use sustainable drainage systems (SuDs) as the preferred drainage solution. Such systems are widely used in other UK jurisdictions and have been shown to be more effective than traditional piped drainage in reducing surface water flooding as well as providing other environmental, economic and social benefits. Furthermore using permeable materials for hard landscaped surfaces in new developments can reduce soil sealing."

Most planning policy makes some kind of nod towards protecting agricultural land from development, but in practice local authorities seldom attach great weight to this and planning inspectors even less. Everywhere, increasing house building is the central objective and the question of how the land is to be protected which will supply their inhabitants with food and water and protected from flooding in the long-term is seldom, if ever, asked.

Land contamination A very high proportion of the remediation of land contamination has always been carried out by land owners and/or developers as part of their work to develop or redevelop sites. However, this only results in the remediation of that minority of sites for which development proposals are made and for which the expected return will cover the cost of the remediation work, in addition to the cost of the development itself and still leave a profit for the developer. There is no doubt that this has led to some inadequate remediation in the past, and the need for some redeveloped sites to be revisited by local authorities more recently.

There are many cases, however, where the investigation of potential contamination and its remediation where it is confirmed is not covered by potential development returns, either because the sums do not add up or the site is not under consideration for development anyway, particularly where it has already been developed. The contamination may be suspected of threatening human health or the environment in the long-term, or has been shown to be doing so; Part 2A of the Environmental Protection Act 1990, implemented after opposition from the property industry only in 2000, is intended to cover such cases.

Under Part 2A, local authorities have a duty to seek out land which is "contaminated" in a defined sense and to ensure its remediation by appropriate means. The costs of that (though not of initial investigation) are borne under a hierarchy of liability, primarily by the original polluter. But where such a party cannot be found (for example, where the pollution is very old or a company has been dissolved), legal responsibility falls on the current land owner or, finally, on the local authority. Local authorities also have "hardship" powers to meet costs that fall on householders where they are judged unable reasonably to afford them, though some councils have, in some cases, recently struggled to find such funds.

Funding for such work by local authorities has always come from the government, initially in the form of Supplementary Credit Agreements but, since 2006 in England, as capital grants through the Local Authorities' Contaminated Land Capital Programme. This was initially administered by DEFRA but, since 2010, by the Environment Agency. This provided in excess of £10million annually, but has been run down and DEFRA has now announced that the funding will cease next year. Meanwhile, it has been cut it to a mere £500,000 per year, reserved for "absolute emergency cases" and for "on-going remediation projects of the highest priority". As the mean value of remediation projects approved in recent years has been around £106,000, that will clearly not stretch very far and indeed £340,000 of the £500,000 in 2014-15 was spent on just one scheme. Once the funding ceases, from 2017, this will provide a powerful disincentive to local authorities even to begin investigations into a potentially contaminated site without having first identified an appropriate third-party able to pay for remediation.

Scotland, Wales and Northern Ireland have not had dedicated central funds specifically for local authority land contamination work, though public funds have sometimes been made available through other funding streams such as Scotland's Vacant and Derelict Land Fund.

Government support for local authorities' performance of their statutory duties in this area has seldom been wholehearted, however. Soon after the commencement of Part 2A, the Environment Agency (in which most of the historic expertise resided) closed its specialist Groundwater and Contaminated Land Centre and, despite having been paid through additional grant-in-aid to provide training to local authority staff, never did so. The Agency also did not deliver expected technical guidance, in the form of the set of "soil guideline values", on which determination of whether land is "contaminated" was intended to hinge. Several years were spent in the mid-2000s addressing this problem, with a Soil Guideline Values Taskforce established, an unsuccessful intervention by the Cabinet Office and long discussions involving DEFRA, the Environment Agency, the Health Protection Agency etc. still failing to resolve the issue.

DEFRA imposed revised Statutory Guidance in April 2012 with a new, qualitative test together with a number of other changes. Risk assessment of land contamination is an extremely complex process but the new guidance has not secured the degree of support that might have been hoped for. Arguably, it also raised the bar on what is regarded as "contaminated" so as to reduce the number of potentially contaminated sites, along with the degree of remediation sites require and the cost of that. Nevertheless, according to a DEFRA-commissioned report based on work by Cranfield University and CL:AIRE[14], at the end of 2013 over 10,000 potentially contaminated sites awaited detailed inspection by local authorities.

And what further measures should the Government and other organisations consider in order to secure soil health?

Soil Sealing There is plainly a need for the UK Government and the devolved administrations to make provision to limit, and even reverse, the current rate of soil sealing. The primary route for this should be the planning system and central planning guidance should require local planning authorities, through their local plans and development control work, to restrict, or eliminate, increases in the proportion of their land area which is sealed. There needs to be a national inventory of sealed land and regular monitoring.

The Government and devolved administrations also need to consider the requirement to limit soil sealing in their own infrastructure and development work. Road and airport building and other forms of major infrastructure are particularly significant causes of soil sealing so bodies like the Infrastructure Planning Commission and others involved in major infrastructure need to review their policies to limit or mitigate sealing.

Land Contamination

The Government should reintroduce a programme of funding for local authorities and government agencies to investigate, address and improve the condition of the worst contaminated sites.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

The health of soil is as fundamental to the health of the terrestrial natural environment as is the health of other media – air and water. It should enjoy equal attention.

January 2016

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[1] Clare Bambra, Steve Robertson, Adetayo Kasim, Joe Smith, Joanne Marie Cairns-Nagi, Alison Copeland, Nina Finlay, and Karen Johnson: *Healthy Land? An Examination of the Area-Level Association between Brownfield Land and Morbidity and Mortality in England* (*Environment and Planning A*, February 2014; vol. 46, 2: pp. 433-454)
[2] Morrison S et al: *An initial assessment of spatial relationships between respiratory cases, soil metal content, air quality and deprivation indicators in Glasgow, Scotland, UK: relevance to the environmental justice agenda* (*Environ Geochem & Health*. 2014; 36(2): 319–332)
[3] *Simplification of the contaminated land regime: impact assessment*, (DEFRA, 2011)
[4] *Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC*
[5] *Guidelines on Best Practice to Limit, Mitigate or Compensate Soil Sealing* (Luxembourg: Publications Office of the European Union, 2012)
[6] *DECISION No 1386/2013/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'*
[7] *Safeguarding our Soils – A Strategy for England* (DEFRA, 2009)
[8] *National Planning Policy Framework* (DCLG, 2012)
[9] Housing Vision and Tibbalds Planning and Urban Design: *Smarter SHMAs: A Review of Objectively Assessed Need in England* (London: Campaign to Protect Rural England, 2015)
[10] *Third National Planning Framework*, 2014
[11] *Scottish Planning Policy*, 2014
[12] *Planning Policy Wales (Edition 7)*, 2014
[13] *Strategic Planning Policy Statement for Northern Ireland*, 2015
[14] *Examination of Contaminated Land Sector Activity in England, Science Project 1011,* (DEFRA, June 2014)

Written evidence submitted by the British Society of Soil Science (BSSS), assembled by Professor Phil Haygarth with input from members of the BSSS Council

How could soil health best be measured and monitored?

- Soil health should be monitored regularly (at least every 5 years) to enable an understanding of trends and changes.
- The way in which this is conducted needs full reflection and should be determined with contribution from the Nation's Soil Scientists, this needs a carefully thought out strategy perhaps involving BSSS and The Soil Security Programme.
- The purpose of the monitoring should be clear and links between the monitoring activity and the soil function (and policy) should be explicit.
- There is a need for a systematic and structured framework to gain better information on soil health targets for different soils under different land use and to protect different outcomes.
- Soil health assessments should consider the full soil depth (e.g. for carbon stocks), should include evaluation of nutrient reserves and should be followed by a systematic system of preservation and archiving of samples as a reference set for future comparisons. The measuring and monitoring needs to cover the range of different soils, landscapes and climates, found in the UK and should include urban areas, which have often been overlooked.
- It is necessary to develop a full understanding of the processes that control soil health. Biological, climatic and physical characteristics of soils are known to impact their function, with the interactions between them also of critical importance.
- There have been various Defra funded projects looking at indicators: SP1611 looked at physical properties and SP 0529 & 0534 was the SQUID project looking at biological indicators
- Some requirements for a national scale monitoring programme have been determined by Black et al (2013) . Past initiatives, based on traditional soil survey approaches, have given us the fundamental baselines for soil health monitoring (Loveland, P.J., Thompson, T.R.E., Webb, J., Chambers, B., Jordan, C., Stevens, J., Kennedy, F., Moffat, A., Goulding, K.W.T., McGrath, S.P., Paterson, E., Black, H. and Hornung, M. (2002). Identification and development of a set of national indicators for soil quality. R&D Technical report P5-053/2/TR, Environment Agency, Swindon).
- Previous monitoring schemes in the UK include the National Soil Inventory, the Representative Soils Sampling Scheme (RSSS) and Countryside Survey and new monitoring schemes are in place in Scotland and Wales. Much can be learned from these efforts, but there is also potential to harness new technology for rapid infield analysis e.g x-ray fluorescence and near infra-red spectrometry with some potential to reduce costs (Archer et al 2014). Another reference of more biological focus is Black et al (2003).
- Existing international soil monitoring frameworks may also offer opportunities for the involvement of citizens e.g. Cornell Soil Health Monitoring, OPAL project – open air lab run by Imperial college has initiated various surveys of this kind (e.g. earthworms).
- This is still an ongoing debate – what are the best metrics for determining soil health? As part of this, there is an urgent need for rapid, reliable and reproducible approaches for determining broad components of soil biodiversity. Need to consider digital soil mapping techniques. To allow a degree of "future-proofing", it is recommended that a systematic approach to soil sample preservation and archiving is adopted so that historic samples can be analyzed with new and as yet unknown techniques and so that currently unforeseen

parameters can be measured in response to new challenges of changing information requirements.

- Although many metrics of soil health have been proposed, links between measured properties and specific soil functions are poorly understood and establishing thresholds or trigger values below which soil functions become impaired can be problematic. Given the wide spatial variation in soil properties, diversity of soil types and timescales over which soil properties change, there is a need to develop sensitive indicators of soil health and local benchmarking.
- Long-term experimentation is also required in order to evaluate the impact of management practices on soil properties and establish links between soil health indicators and soil functions

How could government develop a strategy for tackling soil health

- This is such an important opportunity and the strategy could be developed with a delegated team of policy makers, regulators and soil scientists working together, properly resourced and facilitated. Members of the BSSS and the Soil Security Programme could assist with this exercise.
- The approach of the "Terrrestrial Umbrella" used by Defra for atmospheric pollution was highly successful and could be emulated here. This approach brought all the relevant organisations together to coordinate on addressing monitoring, managing, mapping, supporting policy and providing guidance on the issues of atmospheric pollution.

What are the benefits that healthy soils can provide to society?

- It is well established that soils are essential to society and have high values that can be evaluated through an Ecosystems Services Framework (Haygarth and Ritz, 2009).
- Soils are fundamental to our national food security.
- Sustainable soil management is vital in the delivery of many societal benefits.
- A unique aspect of soils is that we require multiple benefits from soils at individual locations and across landscapes, although we may only see the obvious value from the primary use e.g. soils managed for agriculture are also critical in climate regulation, diffuse pollution control, disease regulation etc.
- Healthy soils contribute to the production of food in sufficient quantity and quality to feed a growing population
- Good soil health is critical for food production and the provision of a range of ecosystem services, including water regulation (reducing flooding risk); protecting water and air quality; carbon sequestration and promoting health and well being (Powlson et al., 2011).
- Soils play a critical role as carbon stores and have the potential to mediate or amplify climate change. Several studies have shown the potential for this.
- Soil is the source of actinomycetes on which our earliest antibiotics are based, and is a potential reservoir for new antibiotics. Soil health is also an important factor influencing the quantity and quality of food that humans consume.
- http://www.fwi.co.uk/machinery/reaping-the-benefits-of-healthy-soils.htm - an interesting link in Farmers Weekly that should hopefully explain the benefits of healthy soils, certainly in a farming context

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

- There are notable historical precedents for failing to protect soil health. Most recently, the American Dust Bowl and China's river eutrophication are results of inappropriate soil management.
- Mostly this is the converse to the above section. However, the most pressing issues are associated with the role of soils in food production and the protection of water resources. Globally pressures on food production will increase and the degradation of soils is a serious problem (Quinton et al 2010), reducing capacity for crop growth by an estimated 15% by 2050. This is particularly important in developing countries where there is an imbalance between nutrients lost from the soil through crop offtake and erosion and the amounts added to the soil in the form of inorganic or organic amendments.
- In the UK, losses of nutrients, chemicals and soil particles from soils to waters are significant and contribute to eutrophication and sedimentation of surface waters, leading to higher treatment costs for water companies, changes in aquatic biodiversity and loss of amenity value.
- Soil management options do exist to help prevent pollution. These are designed to minimise off site effects such as water pollution, reduce GHG emissions, reduce the risk of soil erosion and compaction in addition to protecting soil quality and health *per se.*
- If soils are not managed for carbon storage then climate change could be heightened.
- Soils that become compacted can reduce their hydrological conductivity and therefore their ability to store water and reduce flooding. There have been anecdotal suggestions that soil compaction has contributed to the impacts of Storms Desmond and Frank.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

- Sustainable soil management is a key component in the delivery of a suite of societal benefits; poor soil management can hamper that delivery and in extreme cases produce catastrophic outcomes and result in a range of levels of conflict between involved parties.
- There are relatively few statutory measures promoting sustainable soil management and contribute to healthy soils.
- Safeguarding our soils' was developed as a strategy for soil protection in England (Defra, 2009, Safeguarding our Soils. A Strategy for England. www.defra.gov.uk) and was maintained as a key commitment in the Natural Environment White Paper, 'The Natural Choice' (Defra, 2011, The Natural Choice: securing the value of nature. HM Government CM 8082), with research focused on exploring how soil degradation affects a soils ability to support vital ecosystem services and how best to manage lowland peats. 'The Natural Choice' set a goal that by 2030 all soils in England should be managed sustainably and degradation threats tackled successfully, in order to improve the quality of soils and to safeguard their ability to provide essential ES and functions for future generations (Defra, 2011).
- GAEC has recommendations for maintaining soil organic matter, erosion control and preventing compaction but these are not about promoting soil health *per se* and it needs to be considered that promoting soil health is not just a local issue. A major driver of soil health improvement since the 1990s has been action to reduce atmospheric pollution (acid rain and then nitrogen deposition). These recognised the importance of soil health in maintaining habitats and in links to acidification and eutrophication of freshwaters. Following on from these requirements to address diffuse pollution also recognise the need

to promote effective soil use and management but this has not led to equivalent monitoring or specific guidance on what to achieve in soil health to address these aims.

- Currently sources of advice on the management of soil health are disparate. Defra and previously MAFF Codes of good agricultural practice did provide a reference point for land managers and regulators, however they are out of print and need to be updated. Other sources include EA and SEPA guides on erosion control (e.g. PEPFAA - Prevention of Environmental Pollution from Agricultural Activity) and publications produced by projects e.g. MOPS - (Mitigation Options for Phosphorus and Sediment)
- Some farmers in England and Wales are also assisted with completing and maintaining a Soil Management Plan as part of 'Catchment Sensitive Farming' and 'Farming Connect' Initiatives within priority catchments; and workshops on improving soil health and sustainable soil management are offered as part of the 'Farming Advice Service' in England.
- Internationally there is a wealth of information from providers ranging from the FAO to individual NGOs
- There are good examples of academia working with Industry, for example Lancaster University's partnership with Waitrose's supply chain.

What role (if any) should soil health play in the Government's upcoming 25-year plan for the natural environment?

- Soil should be the cornerstone of the government's 25 year plan for the natural environment. It sits between air, water and the biology that lives on it and within it. This requires joined up thinking and a joined up strategy. In particular the government's agriculture and environment strategy needs brought together. Soil provides the mechanism to do this since it is integral to both.
- There is a need for a 'championing body' to coordinate this inclusion; currently soil cuts across a number of policy sectors with different objectives and is not treated in a sufficiently integrated manner.
- Many government policies and international obligations (e.g. Aichi, IPCC, Water Framework Directive) cannot be met if soils are not explicitly included in land, ecosystems and freshwater management.
- Soil is facing a number of threats: notably in the UK soil sealing (by concrete and tarmac), compaction, erosion, land use change and the oxidation of carbon. Mitigating these threats will require the government to imbed soil into policy. For example the French government has made soil carbon central to their strategy to reduce carbon emissions (see Quinton 2015). There is potential to think about how soils interact with flooding in both rural and urban settings, enhancing infiltration and the storage of water.
- Identify the areas where soil health is below optimum and could be improved – updating and unifying maps of critical loads, below optimal organic matter levels, low nutrients, high nutrient loadings, erosion risk etc. and have this at spatial scales that can be used by land managers
- Establish where the opportunities lie to improve soil health cost effectively under different land uses. The approach applied to peatland restoration could equally be applied to other soils.
- The UK needs continued investment in fundamental and applied soils research and the training and education of a new generation of soil scientists.

January 2016

Written evidence submitted by the Newcastle University Student and Staff Soil Science Society

Executive Summary

- The Society's response to this inquiry reflects upon its recognition of the intrinsic value of soil health and its subsequent aim to promote it through public education and engagement.

- The term 'soil' is present in the science and geography national curricula, but soil health is mainly implied. Awareness of soil health could be improved through incorporation of soils into plants, rocks, and geography topics, teacher training, and provision of soil related outreach activities (such as eco-schools initiatives).

- Greater integration of soil science across departments (such as DEFRA and the Department of Education), universities, schools and local authorities would support the training and development of the generation battling some of the most problematic soil health issues.

Newcastle University Student and Staff Soil Science Society

1. The Newcastle University Student and Staff Soil Science Society aims to make soils and the wider environmental sciences accessible to all. It was established in 2013 and currently remains the only student-led soil science society in a UK university, with a core membership ranging from undergraduate students to lecturing members of staff[1].

2. The authors of this response are the President and Secretary of the Society and undergraduate students studying MEnv Environmental Science programmes. Through studying this holistic subject, participation in conservation volunteering and industrial experience, they have learned to appreciate soil as a foundation fundamental to humanity. Hence, they have become active in promoting good soil health through public education and engagement.

3. Since establishment, the Society's members have delivered educational activities to a wide range of audiences including school students, families, community groups, estate gardeners, farmers, academics, government and policy makers.

Introduction: Society response to the soil health inquiry

4. The Society's response to this inquiry intends to answer the question "What measures are currently in place to ensure that good soil health is promoted and what further measures should the Government and other organisations consider in order to secure soil health?" It provides evidence of the current state of public education and engagement, explains the contribution of the Society, and then gives recommendations for future improvement in this area.

Current stage of public education and engagement

5. Soil is one of the three major natural resources alongside air and water, offering vital ecosystem services. However, the strong links between soil health and human health are undervalued in the

[1] Newcastle University Student and Staff Soil Science Society: https://www.societies.ncl.ac.uk/sfive/home/

current society, which greatly contributes towards soil degradation. If we are to ensure sustainable soil health, it is essential that action be taken now to educate current and future generations about the importance of soil to our lives and wellbeing.

6. Several prominent academic soil science institutions have taken steps to promote outreach education within their own remit. Currently, the British Society of Soil Science (BSSS) Education Committee promotes soil science through its 'Young Soil Explorers' web resource aimed at school students[2]. It also supports the 'soil-net.com' free internet resource, developed by the Cranfield University National Soil Resource Institute[3]. This provides online activities for KS1-4 students as well as information and advice for teachers wishing to integrate soil science into lessons. The James Hutton Institute provides a 'Learning and Resources' section within its website, aimed at the general public as well as school students[4].

Soils in the national curriculum and eco-schools schemes.

7. While DEFRA and delivery partners (such as Natural England, Environment Agency and Forestry Commission) promote sharing of best practice in soil protection and effective information exchange in relation to soil research, the Department of Education aims to give pupils a deeper understanding of all climate change issues, and has recently incorporated soils into the curriculum[5].

8. Throughout the national science and geography curricula[6], soils are now mentioned. Specific reference to 'soil' is present in the geography curriculum (KS1 and KS3) and science (Year 3) in relation to rock weathering and soil formation, and implied in association with climate change and pollution in science KS4 (for evidence, see tables 1 and 2). Information available to pupils on soil health is mainly implied through topics such as 'plants', 'everyday materials', and 'living things and their habitats'. Plant growth is taught in all key stages, however little reference is made to the great influence that soil has on plant growth (with the exception of Year 3, see table 1).

9. Presently, Eco-Schools programmes[7] have been set up to enhance the national curriculum by introducing environmental and sustainability topics. Although soil health is not one of the main topics in the Eco-Schools programme, it is implicit in their 'biodiversity', 'school grounds' and 'healthy living' topics, and could be implied in Eco-Schools gardens. Eco-schools programmes were supported by the National Framework for Sustainable Schools until 2010[8], and are now supported by Sustainability and Environmental Education[9]. With nearly 17,000 schools registered to the programme this is a highly successful way of increasing awareness. The motivational aim for schools to participate is the opportunity to receive internationally recognised awards[10]. On a local scale, Newcastle City Council produced its own environmental education programme 'Enviro Schools', involving 50 schools out of 108 over 3 years, showing great success of smaller initiatives[11].

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[2] British Soil Society (2014). *Young Soil Explorers*: http://soils.org.uk/young-soil-explorers
[3] See: http://www.soil-net.com/
[4] The James Hutton Institute 'Learning and Resources': http://www.hutton.ac.uk/learning
[5] DfE (2015) National curriculum in England: science programmes of study. Statutory guidance. https://www.gov.uk/government/publications/national-curriculum-in-england-science-programmes-of-study/national-curriculum-in-england-science-programmes-of-study (first published 11 September 2013, Last updated: 6 May 2015)
[6] DfE (2013a) National curriculum in England: geography programmes of study. Statutory guidance. https://www.gov.uk/government/publications/national-curriculum-in-england-geography-programmes-of-study
[7] Eco-Schools (2016) The Eco-Schools Programme. Available at: http://www.eco-schools.org.uk/aboutecoschools/theprogramme
[8] DfES (2006) Sustainable Schools National Framework. Department for Education and Skills. . http://webarchive.nationalarchives.gov.uk/20090608173126/teachernet.gov.uk/sustainableschools/framework/framework_detail.cfm
[9] SEED (2016) Sustainability and Environmental Education. http://se-ed.co.uk/edu/
[10] Eco-Schools (2016) The Eco-Schools Programme: http://www.ecoschools.org.uk/aboutecoschools/theprogramme

10. Universities and colleges play an important role in progressing understanding of soil health. Although there no longer exists a specific BSc Soil Science degree within a UK university, soil science is often taught within wider subjects, such as environmental and earth sciences, agriculture, civil engineering and geography. This shows a trend towards widening the scope of teaching soil health to a broader range of disciplines. As this will be the generation battling some of the most problematic soil health issues, it is therefore important that the practical value of good soil health is appreciated across disciplines and industries.

Current action by Newcastle University Soil Science Society

11. The Newcastle University Soil Science Society's primary activity has been delivering the 'Soil's Got Talent' competitions at local schools and family events across the North East of England. It is an educational workshop, created by members of Newcastle University, the British Science Association North East branch and the British Society of Soil Science. Its aim is to raise awareness of soil health in an enjoyable format and promote interaction between academics, university students and the public. The workshop encourages children and adults from the local community to explore the role of soils in the environment, stimulate interest in soil health, and promote discussion on the need for consideration of soil health in debates around food security and climate change. It uses materials originating from the James Hutton Institute's 'Meet the Dirt Doctor' resource[12] and links the practical experience of a local allotment association (North Highbury Allotment Association, Jesmond) with disciplinary expertise in soil science and land management at Newcastle University to give a balance of science and practice.

12. The 'Soil's Got Talent' workshop was originally hosted as part of the Young People's Programme during the British Science Festival 2013 at Newcastle upon Tyne. Participants were KS1, KS2 and KS3 pupils. Supporting material is freely available in the Newcastle University Teacher's Toolkit[13]. As a short activity it included meeting experts with practical experience, as well as those actively engaged in growing their own food, seeing soils in their natural setting and activities on an allotment. Pupils assessed four different soil types in groups, using straightforward experiments, to determine some indicators of soil health. Each group then presented their results to determine which was the best, or most talented, soil. A plenary discussion covered the questions: "what makes a healthy soil" and "how do we keep soils healthy"?

13. Supporting materials allow teachers to tailor the workshop to KS4 pupils, which includes the above but with a more detailed soil assessment and discussion of why it is important to have healthy soils and how soil quality could be improved. At subsequent family events, 'Soil's Got Talent' has been adapted from the formal lesson structure into an activity for passing visitors, with the emphasis changed to participants comparing each soil in turn and engaging in discussion with demonstrators about their own experiences of local soils. The workshop has been further adapted for a non-specialist adult audience as a training session for staff members in the Newcastle University Estates Team.

14. Overall, this activity has received positive feedback from participants. Following sessions held with schools at the British Science Festival 2013, children ranked the workshop highly (9.5/10) and

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[11] Newcastle City Council. (2015) Enviro-schools Programme: http://www.newcastle.gov.uk/education-and-learning/curriculum-and-school-services/enviroschools-programme

[12] The James Hutton Institute 'Meet the Dirt Doctor': http://www.hutton.ac.uk/learning/dirt-doctor

[13] Newcastle University Teacher's Toolkit 'Soils Got Talent Competition' http://toolkit.ncl.ac.uk/resource/soils-got-talent-competition

wanted to learn more about it (97%)[14]. The format has proved versatile and the topics covered relevant to the range of audiences, whilst increasing understanding of environmental issues.

Future recommendations

15. **Soil health should be explicitly incorporated into the national curriculum.** The term 'soil' is present in the science and geography curriculum, but little reference is made to soil health. Due to the importance of soils to humanity this should be clearly embedded in the national curriculum. Although there is competition to for content to be incorporated into the curriculum, it may be possible to incorporate it into existing compulsory science geography topics (see tables 1 and 2 for examples) to ensure the younger generation is aware of the significance of maintaining good soil health.

16. **A one-stop-shop of soil health educational resources needs to be created.** Educational resources are available for teachers (as described in paragraph 6), however the 'Audit of soils-related education and awareness initiatives'[15] found that "although there is a huge wealth of soil-related information, services education and related activities, this information is often hard to find and hard to interpret". A single, co-ordinated initiative unifying these resources could effectively address this problem. Dissemination of information and training would also be needed to support schools to deliver new content in the curriculum. In order to increase interest and participation there is a need to consider approach as well as information provision, for example in a practical, enquiry or project based format, as this Society has demonstrated in its own activities (see paragraphs 11-14). Institutions may be able to support the delivery of schools outreach and public engagement activities[16] through existing initiatives (such as BSSS grants[17], Sustainable School National Network[18] and STEM network[19]) and new long term funding initiatives. Greater integration of soil science across government departments (such as DEFRA and the Department of Education), universities, schools and local authorities would support training and development.

17. **An inter-disciplinary approach needs to be taken to integrate soil health into tertiary education programmes.** Soil health, as opposed to pure soil science, is important across many industries, such agriculture, environmental conservation, civil engineering and sustainable development. Recognition of the intrinsic value of soil health would help prepare the younger generation to tackle impending national soil health issues. Training, information dissemination and collaboration with government departments, such as DEFRA and delivery partners could promote effective communication and information exchange with stakeholders.

[14] Soils Got Talent Competition at British Science Festival 2013 Outcomes: http://toolkit.ncl.ac.uk/sites/default/files/Soils%20got%20talent%20outcomes%20Sept%202013.pdf

[15] Defra (2005) Audit of soils-related education and awareness initiatives. SP0549. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=13359&FromSearch=Y&Publisher=1&SearchText=soils&SortString=ProjectCode&SortOrder=Asc&Paging=10

[16] http://www.publicengagement.ac.uk/do-it

[17] http://soils.org.uk/grants

[18] DfES (2006) Sustainable Schools National Framework. Department for Education and Skills. . http://webarchive.nationalarchives.gov.uk/20090608173126/teachernet.gov.uk/sustainableschools/framework/framework_detail.cfm

[19] SEED (2016) Sustainability and Environmental Education. http://se-ed.co.uk/edu/

Table 1. Statutory and non-statutory soil science associated content of the National curriculum in England: science programmes of study published in 2015.

		Statutory	Non-statutory	Soils incl.
Year 1	Plants	•identify and name a variety of common wild and garden plants, including deciduous and evergreen trees •identify and describe the basic structure of a variety of common flowering plants, including trees	Pupils should use the local environment throughout the year to explore and answer questions about plants growing in their habitat. Where possible, they should observe the growth of flowers and vegetables that they have planted.	No But implied in 'habitat'
Year 1	Everyday materials	•identify and name a variety of everyday materials, including wood, plastic, glass, metal, water, and rock •describe the simple physical properties of a variety of everyday materials •compare and group together a variety of everyday materials on the basis of their simple physical properties	Pupils should explore, name, discuss and raise and answer questions about everyday materials so that they become familiar with the names of materials and properties such as: hard/soft; stretchy/stiff; shiny/dull; rough/smooth; bendy/not bendy; waterproof/not waterproof; absorbent/not absorbent; opaque/transparent.	No. But implied in 'rocks'
Year 2	Living things and their habitats	•identify that most living things live in habitats (a natural environment or home of a variety of plants and animals) and 'microhabitat' (a very small habitat)to which they are suited and describe how different habitats provide for the basic needs of different kinds of animals and plants, and how they depend on each other •identify and name a variety of plants and animals in their habitats, including microhabitats •describe how animals obtain their food from plants and other animals, using the idea of a simple food chain, and identify and name different sources of food	They should raise and answer questions about the local environment that help them to identify and study a variety of plants and animals within their habitat and observe how living things depend on each other, for example, plants serving as a source of food and shelter for animals. Pupils should compare animals in familiar habitats with animals found in less familiar habitats, for example, on the seashore, in woodland, in the ocean, in the rainforest.	No but implied in 'habitat'
Year 2	Plants	•find out and describe how plants need water, light and a suitable temperature to grow and stay healthy	Pupils should use the local environment throughout the year to observe how plants grow	No. But implied
Year 2	Everyday materials	•identify and compare the suitability of a variety of everyday materials, including wood, metal, plastic, glass, brick, rock, paper and cardboard for particular uses •find out how the shapes of solid objects made from some materials can be changed by squashing, bending,	They should think about the properties of materials that make them suitable or unsuitable for particular purposes and they should be encouraged to think about unusual and creative uses for everyday materials.	No

		twisting and stretching		
Year 3	plants	•explore the requirements of plants for life and growth (air, light, water, nutrients from **soil**, and room to grow) and how they vary from plant to plant	Pupils might work scientifically by: comparing the effect of different factors on plant growth…	YES
Year 3	Rocks	•recognise that **soils** are made from rocks and organic matter	Linked with work in geography, pupils should explore different kinds of rocks and soils, including those in the local environment. Pupils could explore **different soils** and identify similarities and differences between them and investigate what happens when rocks are rubbed together or what changes occur when they are in water. They can raise and answer questions about **the way soils are formed**.	YES
Year 4	Living things and their habitats	•explore and use classification keys to help group, identify and name a variety of living things in their local and wider environment •recognise that environments can change and that this can sometimes pose dangers to living things	Pupils should explore examples of human impact (both positive and negative) on environments, for example, the positive effects of nature reserves, ecologically planned parks, or garden ponds, and the negative effects of population and development, litter or deforestation.	No. But implied in habitats
Year 5	Living things and their habitats	•describe the differences in the life cycles of a mammal, an amphibian, an insect and a bird •describe the life process of reproduction in some plants and animals	Pupils should study and raise questions about their local environment throughout the year. They should observe life-cycle changes in a variety of living things, for example, plants in the vegetable garden or flower border.	No. But implied in garden and flower border
Year 6	Living…	classifying plants and animals based on specific characteristics		no
KS3	Biology	Relationships in an ecosystem: how organisms affect, and are affected by, their environment, including the accumulation of toxic materials		NO. But soil health implied
KS3	Chemistry	Earth and atmosphere: composition		No.
KS4	Biology	Ecosystems: how materials cycle through ecosystems		No
KS4	Chemistry	Earth and atmospheric science: climate change, pollution		No

Table 2. soil science associated content in Human and physical geography. Source: National curriculum in England: geography programmes of study 2013.

Stage	content	Soils incl.
KS1	•use basic geographical vocabulary to refer to: •key physical features, including: beach, cliff, coast, forest, hill, mountain, sea, ocean, river, **soil**, valley, vegetation, season and weather •key human features, including: city, town, village, factory, farm, house, office, port, harbour and shop	YES
KS2	•human geography, including: types of settlement and land use, economic activity including trade links, and the distribution of natural resources including energy, food, minerals and water	implied
KS3	•physical geography relating to: geological timescales and plate tectonics; rocks, weathering and soils; weather and climate, including the change in climate from the Ice Age to the present; and glaciation, hydrology and coasts	yes

January 2016

Written evidence submitted by Dr Franciska T. de Vries, University of Manchester

Summary

- A healthy soil is a functioning soil
- A healthy, functioning soil underlies nearly all fundaments of society
- Soils harbour an immense diversity of organisms and provides a new frontier for testing and developing ecological theories
- What constitutes soil health depends on soil type, ecosystem type, and biome
- Here, I will focus on soil health in managed systems
- A clear distinction has to be made between indicators of agricultural intensity (sensitive soil organisms) and indicators that have a proven link with soil functioning
- A minimum set of indicators with a proved link to soil functioning consists of soil organic matter content, pH, nutrient availability, fungal/bacterial ratio, microbial community composition and mycorrhizal fungi
- A national soil monitoring and research programme is crucial for progressing fundamental and applied knowledge on the functioning of soils
- The government has a central role in integrating soil protection and management in legislation and current protection programmes for the environment
- Soils have to be included more explicitly in the national curriculum to accomplish a shift in attitude towards soil

Introduction

1. I am a soil and ecosystem ecologist. My research broadly focuses on impacts of land use change and climate change on soil biodiversity, and on subsequent consequences for ecosystem functioning. I have extensive (15 years) research experience in this field.

2. I have contributed to a response coordinated by the British Ecological Society, as well as to a response from the NERC, BBSRC, Defra and the Scottish Government funded Soil Security Programme. Below, I outline my personal response to the questions raised in the context of the national enquiry into soil health. This response is the result of my 15 years of research experience in the field of soil biodiversity and soil functioning, and is a mix of my own research findings, findings that have been reported in the scientific literature, and expert opinion. I am passionate about soils and the role they play in shaping managed and natural ecosystems.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

3. A healthy soil is a functioning soil. What constitutes a functioning soil varies immensely with soil type, ecosystem type, and biome, and it is not possible to evaluate soil function using a single set of criteria. For example, peat soils contain huge amounts of C through a unique combination of environmental properties and processes (low pH, low decomposition, relatively low microbial and faunal diversity and activity, low nutrient availability, water logged conditions) and it is generally assumed desirable to maintain this state. In contrast, agricultural soils are most productive when they have high nutrient availability, good soil structure, high C content, and high microbial activity. Intensive agriculture negatively affects these soil properties, but is needed to produce sufficient food, fibre, and biofuel. As a result, indicators of soil health generally focus on the functioning of agricultural soils.

4. A huge number of indicators for soil health of agro-ecosystems have been proposed, and are used in a number of European soil monitoring programmes, varying from relatively cheap and easy to expensive and time-consuming [1, 2]. It is important to distinguish between indicators that correlate with a change in management intensity but do not necessarily mechanistically underlie functioning (for example, sensitive groups of soil organisms such as certain groups of nematodes) and indicators that mechanistically underlie highly valued soil processes (for example, nitrifying bacteria). Here, I will focus on the latter category, which is, in my opinion, more informative.

5. A very simple indicator of (agricultural) soil health is organic matter content (or organic C content). This soil property correlates with many highly valued soil properties such as high microbial and faunal diversity, high microbial biomass, high microbial activity, a high proportion of fungi relative to bacteria, and total amount of nitrogen present in the soil [3]. These properties are reduced by intensive agricultural management [4]. Importantly, these properties together, including soil organic matter content itself, underlie important soil functions, such as high water holding capacity, good soil structure, high capacity of the soil to retain carbon and nitrogen, and high capacity of the soil to release nitrogen for plant growth [3]. Although there is a lot of attention and promise for measures of microbial biomass, community composition, and activity to assess soil health, these measures are expensive and time consuming. Moreover, for many of these properties the link with soil functioning has not been well established yet.

6. Biological measures for which there is an established link with soil functioning include:

- the ratio between fungal and bacterial biomass (the fungal/bacterial ratio), which has been linked to efficient C cycling [5, but see 6], a high ability to

degrade recalcitrant organic substrates [7], reduced soil N losses (in the form of leachates and N_2O) through immobilisation of inorganic N [8, 9], and a higher resistance of soil functioning to disturbances such as drought [10, 11]
- the biomass of mycorrhizal fungi, which is linked to increased aggregate formation and the protection of organic matter [12, 13, but see 14]
- the abundance, but more explicitly expression, of functional genes involved in the N cycle [15]
- the abundance of microbial taxa with a known function, for example (de)nitrifying or ammonia-oxidising bacterial species [15]
- the abundance of earthworms, which is linked to better soil structure and increased plant growth [16]. However, earthworm abundance has also been linked to higher emissions of the greenhouse gases CO_2 and N_2O [17]

7. Because all of these biological properties are strongly correlated with soil organic matter content [3, 15], organic matter content (total organic C and N) is the most important measure to include in a soil health monitoring programme. This basic measure should ideally be accompanied by the above measures that have a proven link with processes of C and N cycling, as well as with promising properties that have a hypothesised link with soil function (for example, bacterial and fungal diversity, which might be linked to disease suppressiveness or resistance to invasive microbes [18]). Finally, other basic soil properties such as pH and available C, N and P should also be measured, which can explain observed patterns in the abovementioned biological properties, and inform on soil function themselves.

8. I'd like to draw attention to a Special Issue that was recently published in Applied Soil Ecology [19] that contains a selection of papers that are the outcome of the EU-funded Ecofinders project. Papers in this Special Issue detail the methodology for setting up a large scale monitoring of soil biodiversity, for selecting indicators of soil functioning, and provide information on factors that influence the geographical distribution of groups of soil organisms across Europe.

What are the benefits that healthy soils can provide to society?

9. A healthy, functioning soil underlies nearly all fundaments of society. Soil provides nutrients for plant growth, soil sequesters carbon, soil regulates the flow of water, soil controls the balance between carbon and nitrogen that is kept in the soil and carbon and nitrogen that leaves the soil as the greenhouse gases CO_2 and N_2O, and soil can be a source and a sink of the greenhouse gas CH_4. By regulating these processes, soils are fundamental to crop production for food, fodder, fibre, and biofuel, climate mitigation, flood regulation, and supporting aboveground productivity and biodiversity [20].

10. Soils can aid in mitigating climate change in two ways. First, soils form the largest terrestrial C sink, and managing soils to store carbon can reduce or delay high atmospheric concentrations of CO_2. But in addition, soils themselves are vulnerable to the effects of climate change, such as increased temperatures, drought, and flooding. Importantly, it has been shown that healthy soils with high organic matter content that harbour a high diversity of organisms are better able to withstand disturbances such as drought, and continue to function better after these disturbances [10]. This highlights that a maintaining healthy soils might be the key to adapting food production systems to future climate change.

11. Soil also contains other valuable resources. For example, the majority of antibiotics are derived from soils [21]. In addition, soils are the fundament that cities, buildings, and other structures for human use are built on, and provide many human uses such as allotments, sports grounds, parks, and nature reserves.

12. Soils also harbour an immense diversity of organisms that is probably greater than that found aboveground, and of which we still don't know the full extent [22]. Importantly, this belowground biodiversity is not always linked to aboveground biodiversity, and can display patterns that are very different from patterns in aboveground biodiversity. These organisms are woven together in the soil food web, and together decompose organic matter, thereby controlling all the above mentioned functions. Due to this tremendous diversity of organisms that can differ a factor 1000 in their size and biomass but live intimately together, feed, predate, and compete with each other, and perform a whole suite of different functions and processes, soils provide a new frontier for testing and developing ecological theories on, for example, species biogeography, food web ecology, metabolic theory, and many more.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

13. The mistreatment of soil can result in a loss of soil functioning, which impacts on all functions and services that I mentioned above. In particular, the overexploitation of soil results in a loss of organic matter, which has cascading effects to increase rates of physical loss of soil (soil erosion), and reduces the productivity and ability of soils to withstand disturbances. Probably the most pressing consequences of the mismanagement of soil however are reduced productivity, with consequences for food production, and the reduced ability of soil to withstand future climate change, which might result in soil becoming a source of CO_2 and may thus exacerbate climate change.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

14. As far as I am aware, currently no UK legislation exists that explicitly addresses the protection of soils. However, soils do benefit from legislation that protects vulnerable areas and nature reserves.

15. A major shift in attitude towards soil is needed. Soil needs to be viewed as a domain in its own right, rather than something that benefits from protecting aboveground ecosystem properties. Soil needs to be viewed as the fundament that sustains aboveground productivity and biodiversity, and hence the benefits for humans (ecosystem services) that I have outlined above and that are described in much more detail in the UK National Ecosystem Assessment. Soil protection has to be explicitly included in legislation. However, before we can meaningfully do this we need to identify vulnerable and unique soils (for example, soil that harbour unique species or high biodiversity) that need protection, as well as highly valuable soils that provide important functions or ecosystem services. Further, we need to identify the trade-offs between ecosystem functions and services in agricultural soils. A next step would be the identification of indicators to evaluate the state of the UK soils, followed by the implementation of a set of standards that different soils have to meet.

16. Most current knowledge on soil functioning and how this is affected by land use change and climate change comes from individual, isolated studies. To understand the functioning of our soils, and how to protect them from degradation, on a national scale, a concerted, coordinated effort is necessary. Although there are current RCUK funded national research programmes that focus on the resistance of soil functioning to land use change and climate change (for example, the Soil Security Programme that I mentioned in the introduction), these still support research that is concentrated in particular areas. What we need now is a national effort to map soil biodiversity and functioning to provide a baseline for future mechanistic research. Such as programme should not be a one-off – the same locations should be monitored through time to understand temporal changes in, and the impacts of real climatic events on, soil functioning. This monitoring programme should be accompanied by targeted, mechanistic studies to understand the links between land use, vegetation, soil properties and soil functioning, with a specific focus on climate change. Importantly, this network could provide the tools and infrastructure for fundamental research on soil functioning, including, for example, testing and developing ecological theories on, for example, species biogeography, food web ecology, and metabolic theory, as mentioned in my response to question 2.

17. In sum, key questions that could be addressed by such as soil research programme would be:
- How are soil communities and soil functioning distributed over the UK, and how are they affected by environmental conditions (land use, soil type, climate, plant community composition)?
- Which soil organisms are consistently linked to functioning on a national scale?
- How do soil communities and soil functioning fluctuate over time?
- How do extreme climatic events, such as drought and flooding, impact on soil communities and soil functioning?
- How can we manage our soils to make them more resistant to climate change?
- How can we manage specific soils for the delivery of desired ecosystem services?
- Which soils are hotspots of belowground biodiversity?

18. Finally, I believe that to accomplish a shift in attitude towards soil, and highlight both its importance in delivering ecosystem services as well as its tremendous potential to test ecological theories and discover new species, soils have to be included in the national curriculum (both in primary and secondary schools). Currently, soil science has a severe image problem [23]. If we want to raise the next generation of soil scientists to investigate, protect, and manage our soils sustainably, we have to start at the source.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

19. Given the central role that soils play in the delivery of many ecosystem functions and services, both in managed systems and in (semi) natural ecosystems, soil protection and management should not only be addressed in a separate programme (as outlined above), it should also be explicitly integrated into legislation and management and protection programmes for agriculture and natural areas.

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January 2016

Written evidence submitted by Professor Jonathan Leake, Grantham Centre for Sustainable Futures, University of Sheffield

1. How could soil health best be measured and monitored?

1.1 The most important measures of soil health for sustainable crop production and other critical ecosystem service functions of soil, such as water and carbon storage and drainage across UK landscapes are provided by assessment of soil:
(**a**) Organic carbon content;
(**b**) Structure (including bulk density, water-holding capacity, infiltration rates, and water-stable macroaggregates >1mm diameter);
(**c**) Biological activity, such as the abundance of key functional groups of soil macro fauna like earthworms that generate macropores; and
(**d**) Nutrients (N, P, K and micronutrients) and pH- these latter two parameters being the only ones which are routinely measured on most farms.

1.2 <u>Currently, the numbers of measurements taken for monitoring parameters **a-c** above (soil organic matter, soil structure and key functional groups of biota) are inadequate for assessing at a national scale the health of the nation's soils.</u> It has been estimated that it would require the monitoring of 96,000 sites across the whole of England and Wales to detect a 1% change in national soil organic carbon stocks (Saby *et al.,* 2008; *Global Change Biology* **14**, 2432–2442). Recent monitoring has relied on The Countryside Survey which has measured soil organic matter stocks to 15 cm depth (using combined measurements of soil bulk density and coil organic matter concentrations in a total of 2614 samples taken from 591 squares of 1 Km from across Great Britain during 2007, together with some assessment of earthworm populations in small samples taken from most of the sites. The survey concluded that there was evidence of ongoing loss of carbon (0-15cm) from intensively managed "Arable and Horticulture Broad Habitat / Crops and Weeds Aggregate Vegetation Class", revealing that "current policies in place to limit soil degradation are not maintaining soil quality in cropped land". However, for several other landuse types the Countryside Survey data suggested that organic carbon concentrations in surface soil was increasing- but the small sample size limits the confidence we can place in these conclusions, and provides an inadequate base from which to assess changes.

1.3 Since nearly half of our national stocks of soil organic carbon are found in subsoil (30-100 cm depth), (Gregory *et al.,* 2014; *Soil Use and Management* **30**: 10-22) and recent changes in management such as the increasing use of minimal-tillage and subsoiling rather than conventional inversion-ploughing will change the vertical distribution of soil organic matter to 1 m depth (Sun *et al.,* 2011; *Plant & Soil* **338** 17-25), monitoring of samples only to 15 cm depth in the Countryside Survey is insufficient to determine changes in carbon stocks. In addition, subsoil compaction and poor structure affect many arable soils and assessment of this problem requires measurements of these features whether by bulk density coring or by use of other techniques. Nonetheless, measurements to 15 cm depth are particularly important as they include the critical topsoil component that plays the most vital role in soil functioning. To maintain a national inventory of soil organic matter and to meet our obligations under the 2008 Kyoto Protocol requires that both the concentration of organic matter (mass per unit mass of soil) and bulk density (mass of soil per unit volume) be determined, to a depth of 1 m. Because the bulk density and concentration of soil organic matter vary by depth and are differently influenced by management, direct remote sensing of soil organic matter is not possible.

1.4 There is an urgent need to conduct a comprehensive assessment by measurement of baseline soil conditions and periodic monitoring on a time frame of at least once every 5 years for topsoil (at much higher spatial intensity of sampling than in the Countryside Survey) and at least every decade for subsoil (with less spatially intense sampling required than for the topsoil)- in order to establish rates of change in soil health. The most urgent requirement and highest priority must be to measure and monitor soil organic carbon stocks on arable fields. The sooner we seek to properly assess the health of the nation’s soils and incentivise farmers and land managers to achieve soil sustainability the easier and sooner it will be possible to achieve it.

2. How could the Government develop a strategy for tracking soil health?

2.1 Central to the development of a strategy for tracking soil health is the need to establish an effective national programme of monitoring of the key soil health indicators (**1.1 a-d** above). The highest priority is to provide a much richer data set for arable soils where there is greatest scope for improvements in soil quality and where the consequences of soil degradation for food security, economic loss, and environmental damage if soil quality is not improved (e.g. crop losses, soil erosion, silting and polluting of water-courses, flood damage) are especially acute.

2.2 The 2009 report ‘*Safeguarding our soils - A strategy for England*’ reveals the current miss-match between the £5M per year spent by DEFRA on soils and water management research and the scale of the environmental costs and problems that need to be addressed (£45M per annum losses due to soil erosion, £82M per year due to organic matter decline due to cultivation). Mechanisms to increase soil organic carbon, improve soil structure and earthworm populations are fairly well established. However, some additional research may help to establish the optimal and most cost-effective ways of achieving these goals for different soil types under different crops and management and varying economic values of crops and their by-products such as straw. The urgent need is now to combine monitoring and incentivising soil quality improvement, and to build this into Common Agricultural Policy farm payment and stewardship regulations and incentives.

2.3 Crucial to the maintenance of soil health is minimizing soil losses due to erosion- and a major underlying cause of erosion is loss of organic matter, resulting in loss of soil structure, compaction and reduced macropore space, decreasing the capacity to absorb water and as the soil becomes less well aggregated it is more easily washed or blown away. Given that it takes about 250-500 years to form 1 cm of topsoil soil, erosion losses which typically exceed this rate of formation by at least a factor of 10 in UK agricultural soils, need to be reduced as a matter of critical urgency, and a key tool to achieve this is to increase soil organic matter content by using less intensive tillage, and reduce soil compaction. As we have highlighted in our briefing note on sustainable intensification of agriculture (http://grantham.sheffield.ac.uk/wp-content/uploads/2015/12/A4-sustainable-model-intensive-agriculture-spread.pdf) soil loss is an unfolding global disaster.

2.4 The 2009 report '*Safeguarding our soils - A strategy for England*' set out objectives for improving soil health, including to '*significantly reduce the rate of loss of stored soil carbon by 2020*'- which was mainly focussed on peat soils, and there were no specific goals with respect to improvements to arable soils, yet these were noted to be amongst the most degraded as a result of historical management. Given the known severity of the consequences of loss of organic matter from UK soils for soil functioning this target is appallingly lacking in ambition, and will result in significant avoidable losses to the economy. The current aspiration merely to slow the rates of soil degradation, thereby persisting in degrading our soil resource, rather than seeking to reverse soil organic carbon loss from UK soil in order to put us back onto a trajectory of soil sustainability, is not acceptable as a goal and explains why organizations such as the Soil Association have justifiably criticised current policies as failing adequately to protect soil. More fundamentally, even this modest goal is currently impossible to meet since we do not know the rate at which carbon is being lost from soils.

2.5 We identify the most urgent priority in addressing the issues of monitoring and management of soil quality, is for the establishment of a high-through put low-cost national capability for measuring soil organic matter content of soils- as this is the single most important indicator of soil quality. Soil samples need to be taken from fields using a bulk-density sampling approach and are currently taken through a series of routine but labour-intensive processing steps that are therefore expensive. More cost effective analysis would be facilitated by a major capital investment in a purpose-built robotics-driven analytical facility that keeps labour costs to the minimum making routine monitoring of topsoil across the UK on a 5-yearly basis possible, together with the decadal monitoring of subsoil.

2.6 Other important technological developments that may facilitate better monitoring and management of soil health include high spatial and temporal resolution land cover changes that will soon be resolvable from ESA Sentinel-2 data, enabling better constraints to be applied to flood and drought prediction modelling, and for monitoring land use impacts on soil quality through established data on crop-type effects on soil, with verification by in-field soil sampling and measurements. *In situ* sensing is developing at a fast pace, towards near-continuous sensors designed around wireless sensing hubs, supported with low-cost, Raspberry-Pi or Arduino microprocessors, uploading data to local hubs for global use. Sensor costs are falling too, allowing for greater spatial coverage. Whilst still only operating at a localised level presently, the technology has the potential to record parameters such as temperature, pH, soil moisture, and conductivity at high-resolution for extended time periods, and could be drone, wire or tractor mounted for even greater utility. Ongoing refinements to lower cost and power consumption are key to more pervasive usage, assisted by the adoption of standards, e.g. the

Open Geospatial Consortium is now developing 'Sensor Web Enablement' geospatial standards. Soil sensing should embrace new technologies, from photo-electronic erosion pins to transient infrared spectroscopy to cosmic ray soil moisture sensing (COSMOS). Innovative products are continually emerging on to the market, e.g. the SenSprout inkjet-printed, low-cost soil moisture and leaf wetness sensor.

2.7 These technological innovations open the door to far more affordable and data-rich monitoring of soil health using integrated soil sensing – combined moisture, temperature, gas flux and stress/strain sensing; which can both inform local soil management decisions to minimize soil losses, and increasing soil and food security, but also longer-term trends in how soil health is changing, in response to stresses such as extreme weather, and long-term improvements from appropriate in management- the latter opening the potential for bonus payments via the rural payments agency to incentivize soil quality improvement.

2.8 With a greater quality and quantity of real-time data, synthesis and modelling approaches could enable, in addition to real-time forecasting, sustainable development, improved regulation and increased public engagement, the ability to study alternative future scenarios through adaptive scenario management. Significant investment is required to establish cost-effective ways of developing and using these data synthesis and modelling capabilities to deliver affordable, long-term soil heath monitoring at the National Scale.

3. What are the benefits that healthy soils can provide to society?

3.1 Healthy soils are ultimately 'useful soils', offering a wide variety of functions or ecosystem services. Soils filter and store water, provide us with food, fibre and fuel, and support a biodiverse ecosystem, harbouring a quarter of the world's biodiversity. Specific benefits of healthy soil include better resilience to floods and droughts, self-sufficiency in certain crop types, agricultural exports, carbon storage, the retention and breakdown of contaminants, the supporting of structures and resistance to erosion. Healthy soils are even beneficial for air quality, reducing the particulate load within the air and thus protecting human health. Properly managed soils capture carbon and importantly can bind it for long periods of times. Whilst the principal benefit of higher soil carbon would be in its 'health', climate mitigation is be an important co-benefit, contributing to UK's ambitious climate targets. Finally, and generally, a healthy soil is able to support an aesthetically pleasing environment that is culturally important.

4. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

4.1 The consequences of failing to protect soil health are largely the opposite of the benefits listed in **3.1**. Degraded soil quality leads to significant knock-on effects for the environment, public health and food security. Soils that are functionally compromised as a result of poor structure and low organic matter content have increased greenhouse gas emissions, and increased runoff, washing away pesticides, nutrients, and topsoil causing sediment loading of rivers, reduced water and air quality, creating environmental and water quality problems that are expensive to treat. Soil degradation also leads to reduced genetic diversity and depleted topsoil stocks soils that form slowly over thousands of years. Farmers in nitrate vulnerable zones are unable to add optimal amounts of fertiliser to maximise crop yields because of the risks of causing groundwater and surface water pollution- but if the soil quality was better crops can produce deeper roots and a greater proportion of the nutrients will be retained in soil and used by the crop giving win-win outcomes.

5. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

5.1 We see little policy support currently for improving soil health on farms, although guidance provided by the Rural Payments Agency and DEFRA is generally sound and scientifically based with respect to methods to reduce soil erosion and improve soil properties. <u>However, the removal of annual Soil Protection Reviews from the Standards of Good Agricultural and Environmental Condition published by the Rural Payments Agency in 2015, is of concern as this appears to signal reduced priority to ensure soil protection and improving soil health.</u> Bad practices are still permitted under the current rules, with the Agency granting as "*acceptable agronomic reasons*" for not providing vegetation cover to soil in winter "*land where the action of frost on the land over winter is used to break down the soil naturally to create a seedbed for spring cropping*". There is a large body of work demonstrating multiple benefits of winter cover cropping for long-term soil quality and substantially reducing risks of soil erosion, and the clear evidence that bare soil over the winter season is detrimental to long-term soil quality. Continued granting of permission to have bare winter fallow plots represents an unnecessary ongoing degradation of the soil resource. The current advice and inspection system of the Rural Payments Agency, overseeing single farm payments is under-resourced with only 1200 farm inspections per year out of about 100,000 farm businesses in England, so on average each farm will be inspected once in 83 years! <u>A serious commitment to address maintaining and improving soil health will require a greater investment in monitoring compliance and incentivising management that secures the future for our soils.</u>

5.2 Aspirations to increase soil organic matter articulated in the Rural Payments Agency guidance to farmers, and awareness of the problems of organic matter depletion from arable soils clearly articulated in the 2009 report '*Safeguarding our soils - A strategy for England*' have not resulted in significant policy leavers to help farmers achieve these goals. This links back to the first points we have made- the need for more comprehensive monitoring of soil structure and organic matter content, and for this monitoring then to feed into financial incentives and rewards for farmers that adopt actions that demonstrably result in increased soil carbon storage and improved soil health as verified by measurements taken on a 5 yearly basis.

5.3 We welcome the recent investment in research to help address the issue of soil health, including the BIS Agritech strategy, DEFRA platform, and SARIC (Sustainable Agriculture Research & Innovation Club) and the £12M Soil Security Programme. This should be seen as a start of capacity building for a major reprioritization and investment into soil health for national food and soil security and hydrological management. The HEFCE investment in agrifood resilience with the N8 Universities, is also building important capacity and collaboration across Northern Universities, strengthening the regional agri-food research base in a major region of arable and livestock farming in the UK. National scale projects have helped to determine the baseline biogeochemistry of our soils, from land-use databases to the NSRI 'Soilscapes' viewer. However, limited information is available nationally regarding organic matter quantity and composition and distribution by soil depth, and is limited also for soil structure, certainly not at the spatial resolution necessary for predictive modelling and toolkit design.

5.4 We have proposed (http://grantham.sheffield.ac.uk/wp-content/uploads/2015/12/A4-sustainable-model-intensive-agriculture-spread.pdf) that the agricultural system itself needs to be re-engineered if we are to genuinely create a sustainable agricultural system. Our model puts soil health at the forefront and combines the lessons of history - developing conservation agriculture practices including greater use of crop rotation and leys - with the benefits of modern biotechnology, to wean plants off the artificial world we have created for them, enabling plants to initiate and sustain symbiotic relationships with soil microbes which give them access to soil organic nutrient reserves, and prime plants to better defend themselves against pests and diseases.

6. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

6.1 Soil health is vital for provision of food, good quality drinking water, reducing the risks of floods and sedimentation of drains and rivers and underpins the rural economy, food security, plays a major role in the global carbon cycle and is the foundation of terrestrial ecosystems, providing or underpinning most of the ecosystem services from which humans benefit. Soil health must be key and integral to both the UK's 25 year natural environment plan and the 25-year food and farming plan. It is essential that these 25-year plans establish and promote goals that deliver long-term soil sustainability and reverse the long-term trend in soil degradation that has followed decades of inadequate prioritisation of protecting and restoring soil quality.

January 2016

Written evidence submitted by Dr Neil Humphries

Executive Summary

- The Soil Strategy for England sets out the Government's vision and objectives for the improvement and safeguarding of essential soil-based services. The Strategy emphasises the importance of having an evidence-base for reporting its achievement. However, the Strategy lacks a monitoring and reporting methodology at a national level.
- Traditional approaches based on field-based sampling are impractical, too costly and difficult to interpret. An alternative approach is suggested. It is based on the consistent relationship between land use/land capability and potential soil health, and would enable consistent and meaningful reporting at a national level. The methodology is based on registered land parcels as the basic unit of output and the landuse as the unit of outcome which can be scaled to local, regional and local and other levels (such as river catchments) as required.
- Infrastructure for implementing the methodology at a national level already exists, as does sources of data, in the form of the CAP administration and other Government schemes. The methodology is familiar with Defra and other Government agencies and compatible with the UK's wider reporting obligations, including the Water Framework and Habitats Directives. The methodology can also be applied to disturbed and contaminated land.
- It is recommended that the proposed approach is investigated by means of a workshop with the view of setting up a pilot scheme for full scale implementation.

1. Introduction

1.1 I am a practising chartered soil scientist with 40 years of experience in the utilisation and management of soils, and the monitoring and evaluation of soil health as a land resources manager and academic. I have held a Visiting Professorship at the National Soils Resources Institute, Cranfield University. I have authored national guidance for MAFF and the Highways Agency, contributed to research for Defra, and carried out assessments for JNCC and English Nature of their ability to report on land-based performance monitoring to the UK Government and the European Commission. I am actively involved in the development of monitoring and reporting methodologies and have recently presented discussion papers in the USA and Australia. My evidence is concerned with *how could soil health best be measured and monitored* and *how could the Government develop a strategy for tracking soil health*.

2. Strategic Vision and Objectives

2.1 The Soil Strategy for England (Defra, 2009) sets out the UK Government's ambitious vision and objectives for the improvement and safeguarding of essential soil-based services in the strap-line of Chapter 1 and in the body of text. Chapters 2 to 7 and Chapter 9 are concerned with land management and organisational measures necessary for the delivery of the Strategy as well as emphasising the importance of having a robust evidence-base.

2.2 Chapter 8 (para 8.5) rightly sets out that monitoring will be necessary to provide the evidence-base needed to underpin the Strategy and any policy measures required, however as paragraphs 8.6-8.9 openly demonstrate, this aspect of the Strategy is notably lacking in direction and foresight for a monitoring and reporting methodology for soil health beyond the field level; this is despite nearly 40 years of debate and continuing research (para 8.9). Whilst noting the reluctance in paragraph 8.7, there is a strong case to rethink and think beyond traditional perspectives on how soil health can be monitored and reported meaningfully at a national level.

3. How could soil health best be measured and monitored

3.1 The scientific basis of physical, chemical and biological soil health in terms of sustainable landuse are long established (eg Russell, 1961), as are techniques and methodologies for describing and assessing soil condition (Allen et al, 1974; MAFF, 1982 & 1986; USDA, 2001; Defra, 2011). The latter, whether physical, chemical or biological are dependent on field-based sampling. This is time consuming and costly to implement, besides being subject to the confounding effects of within-site variation and sampling-error, timing etc; thereby making traditional approaches impractical, and difficult to extrapolate and interpret on a national basis. An alternative is to use landuse and land capability/quality criteria whereby a risk-based approach to soil health could be developed.

3.2 There is a clear and consistent relationship between landuse and the health of soils (Jenny, 1980; Soil Survey of England and Wales, 1984). For example, soils are likely to be in a greater state of good health (with concomitant less threat from erosion, compaction and organic matter decline) under woodland and permanent pasture than under arable or intensive livestock systems. A hierarchy/gradient approach can be used to identify and differentiate between, and grade the likely states of health within each landuse type. For example, peat bogs would be classified to be in a poor condition in respect of their carbon storage capacity should they be drained and/or afforested, whereas they are likely to be in a good condition (relative to the prevailing climatic condition) in the absence of modifications. Similarly, hay-meadows would in terms of porosity, soil carbon and nutrient cycling would be expected to be in a better condition than dairy grazed short-term grass leys dependent on cultivation and artificial fertiliser inputs. Here, land-husbandry practices could be integrated into a health-based grading system. For example, soil health in organic farming enterprises would be expected to rate higher in soil health than for intensive chemical-based systems.

3.3 Potentially, land capability/quality also has a role and could be integrated with the above landuse-based classification to further develop the risk-based approach. For example, it is of some significance that some grades of land are termed 'best and most versatile' in terms of cropping whereas others are not (MAFF, 1988). Climate, flooding, topography, soil texture etc all have influence on soil health and resilience to climatic and landuse changes. Consequently, certain landuses and cropping are not suited to particular climatic conditions (temperature, rainfall), altitude and topography, soil texture and droughtiness/wetness, and if practiced, could result in soil degradation and the concomitant effects the Strategy seeks to avoid and remedy.

3.4 As set out in the Strategy, there are various practices and measures which can manage and minimise the risk of soil degradation and aid remediation and recovery. These can be included and accounted for in the above methodology.

3.5 The output (ie the evidence-base) of the suggested risk-based approach would be the identified landuse types and their suitability within the context of the local and regional land capability for each landholding (field, woodland, peatland etc). The outcomes enabling reporting by the Government of the achievement of its Strategy would be the quantifiable metrics of the grade of landuse type suitability (Suitable / Un-suitable), and corresponding status of soil health/condition (eg Favourable / Unfavourable / Unfavourable-declining / Unfavourable-recovering *or* Not-at-risk / At-risk / At-risk-declining / At-risk-recovering) or other descriptors to be devised.

4. How could the Government develop a strategy for tracking soil health

4.1 The following sets out how the Government could implement the above methodology to track soil health in measurable and cost effective manner.

4.2 The basic *unit* of the outputs and outcomes (monitoring and reporting) of the proposed methodology is 'field-based' (ie registered land parcel). This is the same *unit* as used by the Government for the administration of the European Commission's CAP cross compliance, the English Environmental Stewardship and the UK Forestry Standard schemes. Importantly, the infrastructure for the proposed methodology and reporting is already in place and familiar to those who need to be involved. In addition, much of the necessary unit-based data sets are already used by Defra and its agencies (Natural England & Forestry Commission) in order to implement the above schemes. Relevant and specific soil and landuse data is held by the Cranfield Soil and Agri-Food Institute in the form of their *LandIS* land information system. Other data is likely to be held by the Environment Agency and Local Authority Biological Record Centres.

4.3 The proposed methodology is also compatible with the Water Framework Directive and its implementation through River Basin Management Plans, and can contribute to the Government's reporting to the European Commission. The health of soils with river catchments can be defined by their component land parcels. The methodology can also be applied to disturbed and contaminated land.

4.4 The format of the proposed output is also familiar to Defra and Natural England, and the UK Government and the European Commission. It is used by Defra to report the condition of the UK's Natura 2000 assets and compliance with the Habitats Directive (Williams, 2006).

5 Recommendations

5.1 The above approach provides pragmatic, cost effective and consistent means where by the UK Government can monitor and report on soil health at a national level in respect of its European and UK obligations. The approach uses existing data and data which is collected routinely in respect of its administration of other schemes. It does not necessitate the establishment of new reference sites or the calibration of largely unproven methodologies, and could be implemented without significant investment.

5.2 It is recommended that the above approach to tracking and reporting on soil health is investigated further by means of a technical workshop with the view of setting up a pilot scheme for full scale implementation.

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January 2016

Written evidence submitted by David Dunlop, the Wildlife Trust for Lancashire, Manchester & North Merseyside

The Wildlife Trust for Lancashire, Manchester and North Merseyside is a local wildlife charity, working to protect wildlife and nature for the future in Lancashire, most of Greater Manchester and Merseyside, and the adjacent Irish Sea. We are a key voice for nature, both locally and nationally. We manage nature reserves; stand up for wildlife on land (rural, urban and coastal) and at sea; deliver specialist projects; and have a people & wildlife team engaging local people in sustainable living and conservation from the very young to the retired. We don't receive any direct Government funding, so our members' and volunteers' support is crucial. Membership currently stands at around 29 000.

David Dunlop BSc (Hons) Zoology has been a Conservation Officer with the above wildlife trust since 1992. Previously, he worked in similar roles with the Berks, Bucks and Oxon Wildlife Trust (1987-92) and Ulster Wildlife (1985-87).

1. **Past and current land use policy has led, and is leading to progressive loss of peat-based soils in the artificial Alt-Crossens catchment straddling southwest Lancashire and north Merseyside.**
2. **The historic and current cost-benefit analyses driving policy have and are failing to account financially for the local and national ecosystem services provided by this peat soil resource.**
3. **If this approach continues unaltered, evidence indicates that the peat soil resource will be lost from the catchment by 2040.**
4. **An opportunity to address this loss of natural capital presents itself in the proposed cessation of state-funded, pumped drainage of the catchment, but delivery would require sustained leadership and commitment to engage all stakeholders in managing the transition to a more sustainable land use system; a local 25-year plan for Nature.**

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The peat soils in the Alt & Crossens catchments that straddle Lancashire and Merseyside have been the subject of drainage for intensification of agricultural production for at least 300 years, the Crossens catchment having previously fed Martin Mere; once the largest lake in England, albeit a shallow and seasonal water-body containing several islands and surrounded by lowland raised mire, fen and reedbeds. The history of the catchments' early land drainage is comprehensively documented in a paper by Gritt (2008). Since then, major technological advances, especially in fossil-fuel powered mechanical machinery, allowed further new drainage of the land to be undertaken. This resulted in the formation of the current, artificial Alt-Crossens catchments, maintained and controlled ever since by a series of pumping stations. Currently, two large pumping stations serve the Alt and Crossens catchments supported by nine secondary pumping stations. All are operated by the Environment Agency (EA).

Alt-Crossens is made up of arable land classified as Grade One and Two in terms of agricultural productivity, and is also an important salad-producing area. The catchment's current agricultural productivity could and can be maintained only by unsustainable drainage of carbon-sequestering lowland raised mire and fen (known locally as “mosslands”) leading to loss of the peatland’s wildlife communities, the cessation of natural peat accumulation and an end to carbon sequestration. The dried and exposed mineral peat then oxidises and is lost to the atmosphere as the “greenhouse gases” CO_2 and CH_4 and in particulate form as dust removed through wind-blow and as silt in surface water run-off, and particularly when compacted by heavy agricultural machinery.

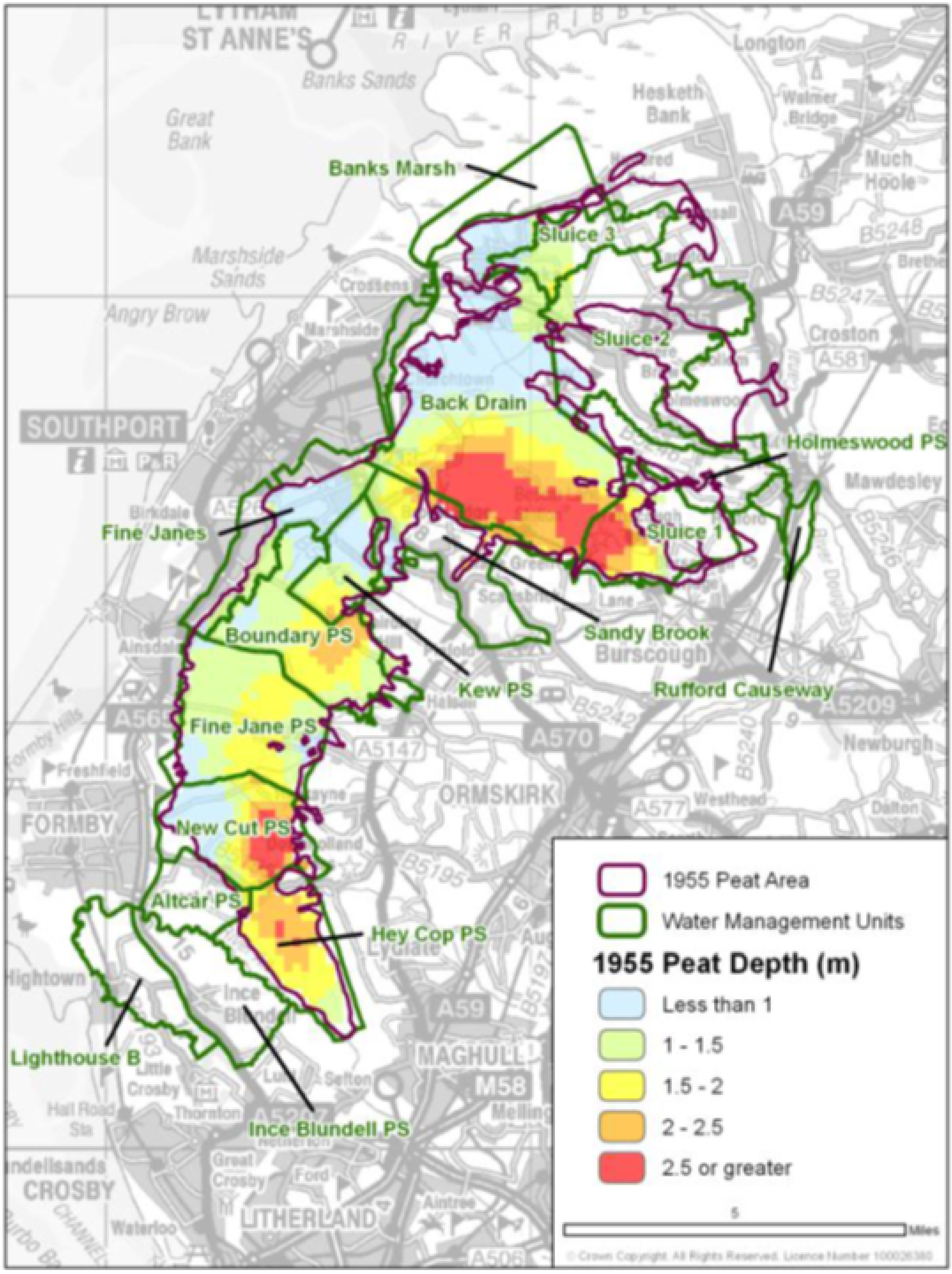
The consequence is progressive loss of the productive soil and silting up of watercourses. The resultant lowered land-levels then produce an understandable demand from local established agricultural businesses for increasing pumped drainage to keep water off that land - currently at public expense and largely using energy derived from fossil fuels - to maintain their profitability. It also requires purchase and addition of more and more, mainly fossil-fuel-derived fertilisers to maintain previous levels of production, with resultant eutrophication and silting of watercourses, the former and some of the latter also remedied by the EA at public expense; a vicious circle.

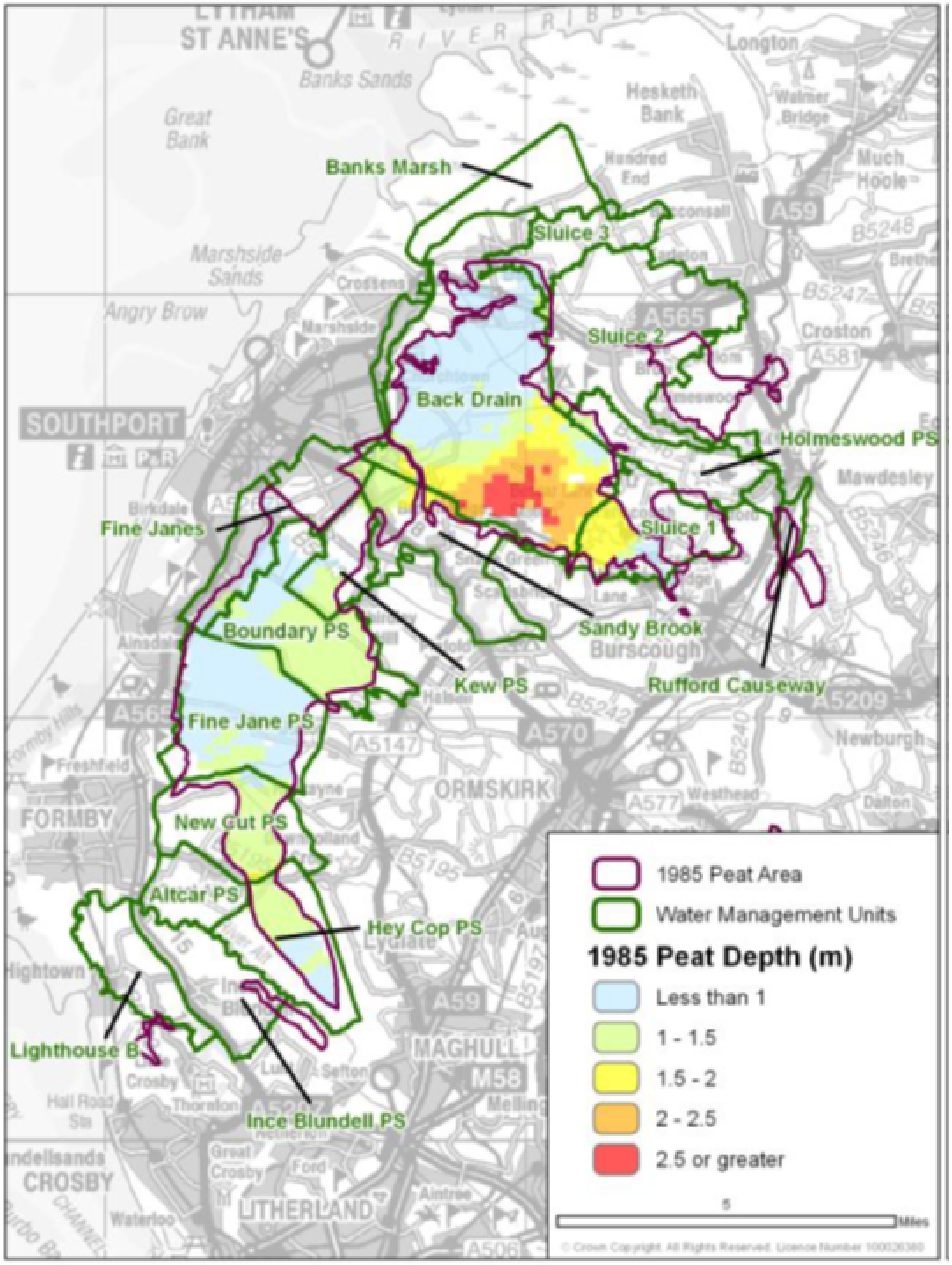
In principle, the cultivated lowland peat soils in this part of Lancashire are managed in a very similar way to the peat soils of the Cambridgeshire Fens. However, the Lancashire peat soils are somewhat different in that these require input of nitrate to grow crops, whereas the Cambridgeshire Fens do not. At the time of writing, we’re unclear on the nutrient situation in the other drained fenland soils of East Anglia.

Based on data collected in 1955 and in 1985 (see Figure 1 below), the EA estimates a 1.6cm/year average wastage rate of peat soil in Alt-Crossens between 1955 and 2010 resulting in a mean loss of about 72cm depth of peat (ref), which may be reasonably extrapolated to 78cm by last year (2015). That being so, large areas of the catchment should now be approaching residual peat depths of less than 50cm. Observations from Stephen Watson (ADAS) and most recently Lindsay Beaton (The Wildlife Trust, 2016, in conversation with a local kale grower) already suggest that, in places, the underlying Downholland Silt is being ploughed up into the cultivated peat layer, particularly at the former Halsall Moss. At the moment this soil-mixing is not affecting the range of crops being grown. However, the water-holding capacity of these silts is far less than that of peats so more summer irrigation water would be needed to grow the same crops as the silt content gradually increases in the future, particularly if summers become warmer and drier as predicted. Increased hectarage of silt-based soils would also require additional nutrient inputs as silts are naturally infertile due to their low organic content. Another 20-25 years of wastage at the same rate will seriously deplete the peat resource in the catchment and the areas of peat with a depth in excess of 1.5m will become very restricted. The potential impact of climate change on peat wastage rates (through shrinkage, compression and oxidation) would suggest enhanced wastage rates during the projected drier and warmer summers, if effective land drainage be maintained.

From: R A Shirres; 29 Sept 2011; Water Framework Technical Group Funding Bid: Lower Alt & Crossens Lowland Peat Survey – Summary Technical Note

Figure 1 a) 1955 Peat Depth & b) 1985 Peat Depth





The peat resources in the Alt / Crossens catchment directly affect surface water quality, resources, and flooding across the catchment: continuing wastage of the peat poses challenges for future sustainable water and land management in that catchment.

In response to Government policy and budgetary constraints, the EA proposes to cease funding the operation of the pumped drainage system in July 2017 in regard to those pumps that drain only agricultural land. Environment Agency modelling suggests that, if these five pumps were no longer operated, there would be no increase in flood risk inside residential properties. It is then open to local farmers or their landlords to take on the costs of operation and maintenance of these pumps themselves. Alternatively, a Water Level Management Board could be established, but this has been locally resisted to date owing to the expense exceeding the benefit to council tax payers in the eyes of West Lancashire Borough Council, which would be required to contribute. Some local landowners, including ourselves, are also unhappy to be obliged to pay a rate to continue an unsustainable *status quo* from which we receive more dis-benefit than benefit in our efforts to retain freshwater on our land.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Current Government guidance to landowners and managers is contained in Defra's '*Cross-compliance in England: soil protection standards*' publication of 2015. See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/397046/CCSoilPS_2015_v1_WEB.pdf

This is silent on the need to keep peat soils wet if these are not to oxidise and be lost, though it does provide guidance on reducing the lesser losses from the consequential wind erosion: the relevant text is reproduced below in its entirety:

*"**Protecting bare soil from wind blow***
Wind erosion can be a problem in some years in the flat, drier parts of England, especially on sandy and peaty soils.

The risk of wind erosion tends to be high during the spring in crops such as onions, carrots and sugar beet where the soil is bare for a relatively long period before there is protective crop cover.

Problems occur with fine, smooth seedbeds and loose soils where blown soil can abrade and bury crops. Soil loss can also affect neighbouring land, roads, ditches and watercourses."

"Wind erosion can be limited by:
creating coarse seedbeds where possible
sowing nurse barley crops to protect the soil where appropriate
using a fleece over vegetable crops
applying regular applications of organic wastes to improve soil stability
planting shelter belts to break the speed of the wind"

This appears rather fixated on the context of East Anglia: although certainly flat, the Alt-Crossens catchment, in the Lancashire & Amounderness Plain Natural Character Area (NCA), is actually in one of the *wetter* areas of England. However, the issue is also of significance here as it is certainly no less windy. Some additional content would be welcome on the desirability of keeping the water table in lowland peat soils as high as practicable in order to reduce the rate of loss to oxidation rather than risk promoting maximum drainage rates into the conurbations and sea, and losses to the atmosphere.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

The Government proposal for a 25-year plan for Nature results from its acceptance of its Natural Capital Committee's recommendation.

Our ancient soils are one of the most fundamental components of our natural capital and the ecosystems services that provides. They also support their own soil-based faunal and floral communities and the UK's characteristic terrestrial semi-natural vegetation communities and the faunal communities dependent on those. Most are in profound decline: see *State of Nature* reports. Omitting measures to maintain, restore and enhance soil health would be like building without foundations and so recklessly risking collapse of the whole edifice.

In the context of the Alt-Crossens catchments, a report produced by Cranfield University for Natural England is apposite (Morris, J *et al*, 2010). This examines the hypothetical restoration of lowland peatland in England and the consequent potential impacts of that on UK food production and security.

The study explores the case for peatland restoration in four study areas and, within these, specific target areas identified for restoration as part of the aspirational "Wetland Vision". These were the East Anglia Fens, the Humberhead Levels, the Somerset Moors & Levels, and the Lyth Valley, Cumbria: there are particular parallels with the Alt-Crossens catchments in the largely arable East Anglia Fens and Humberhead Levels, though rainfall is much higher in northwest England.

The study compiles alternative scenarios of peatland management to consider the impact on: (i) agricultural output and food security, (ii) farm incomes and profitability, and (iii) environmental costs and benefits, with particular reference to carbon emissions and landscape benefits.

Under the current *Baseline* situation, it concludes that farming on remaining deep peats in the Fens and Humberhead, is relatively profitable with net margins, that is financial value-added, of about £360 - £420/ha/year, rising to £1 000 - £1 300/ha/year where vegetable and salad production approaches 60% of the cropped area. Environmental costs, particularly associated with carbon released from arable peats and carbon emissions from farming systems, are estimated at between £450 and £950/ha/year, resulting in overall negative returns from peatland soil farming.

Continued Agricultural Production, involving intensive drainage and cultivation of arable peats will eventually result in wastage of peat soil in Alt-Crossens and other peat soils, as described above, leading to loss of agricultural productivity. The report calculates that combined agricultural and environmental effects of continuing agricultural production in the Target Areas gives an estimated net annual cost of between -£200 and -£500/ha/year, mainly due to the impact of 'greenhouse gas'-related emissions associated with loss of soil carbon on arable land.

Assuming resumption of peat-forming conditions under permanently high ground water levels and surface flooding, and excluding agriculture (other than some cattle-grazing to help manage habitats), the report estimates that *Peatland Restoration* could generate a net benefit of about £950/ha/year, due to a combination of assumed carbon sequestration and the cultural benefits of landscape, wildlife and recreation. Relative to '*Continued Agricultural Production*', this gives a net benefit, including changes in the value of environmental effects, of about £1 200/ha/year - £1 500/ha/year in the study sites at 2010 prices. For arable land, the opportunity cost of taking land out of agricultural production is likely to reduce over time as peatland soils are degraded and become less agriculturally productive.

Global food shortages in 2006/7 prompted a resurgence of interest in national food security and the role of UK agriculture. Restoring peatland soils to even an approximation of their natural condition would take land out of farming. For the assumptions made, it seems that taking land out of intensive farming in peatland areas could result in an overall welfare gain because the net environmental costs generated by continued agricultural use (indicated by environmental burdens and the loss of potential benefits from peatlands in a restored condition) are greater than the net benefits of retaining farming there (indicated by value added). Famers would, however, suffer loss of incomes, unless they were compensated in some way, either through land purchase or through payments for environmental services under new land management regimes.

Taking land out of farming is clearly a sensitive issue, especially in arable & salad-crop areas like Alt-Crossens, where farming productivity is obvious. In the context of Alt-Crossens it also raises significant nature conservation issues. The arable land is currently internationally important for foraging and roosting Pink-footed Goose, Whooper Swan and Bewick's Swan that are significant features of the nearby Martin Mere and Ribble & Alt Estuaries Special Protection Areas. The area is also of national importance for Water Voles and farmland bird communities. It is important therefore that any review of options for future peatland management should fully engage the farming communities involved, taking a long-term view that respects the interests, livelihoods and history of those who work the land.

The Lunt Meadows project provides some illustration of the possibilities. Lunt Meadows is a new wetland nature reserve in the Alt-Crossens catchments, covering 77ha and created by the Environment Agency between 2012 and 2014 on what was previously intensively farmed arable land. The project involved diverting part of the flow of the adjacent River Alt through a system of ditches and reedbeds by lowering the embankment and installing a wind-powered pumping system at the outflow. It has restored floodplain connectivity to a channel that is predominantly embanked all of its length, which will improve the morphology and ecology of the River Alt catchment as well as improving water quality. The scheme has brought flood risk management benefits to adjacent farmland and rural properties and the larger urban areas in the vicinity.

The site functions as a flood storage basin for the tidal River Alt, and is now managed by The Wildlife Trust for Lancashire, Manchester & North Merseyside as a wetland nature reserve. Our creation of reedbeds on site allows filtering out of contaminants such as ammonia, phosphorus and tributyl tin compounds.

Just a year after we took on management of Lunt Meadows, we were receiving astonishing photographs of birds on the reserve, particularly short-eared owls and barn owls. Since 2014 the biodiversity of the site has increased amazingly with recently recorded species including Bittern and Cetti's warbler. Habitats are currently developing and include reedbed, wet grassland, marsh and open water. The site is already of great interest for bird life, particularly waders and water fowl. Typical species include lapwing, redshank, sedge and reed warbler, and marsh harrier. Lunt Meadows also has a large population of water vole and is increasingly noteworthy for dragonflies. As well as a nature reserve, Lunt Meadows is currently the subject of an archaeological investigation by the National Museum Liverpool of one of few surviving Mesolithic settlements. Information on finds and the site's history can be found on the National Museums Liverpool website. As a totally new site, habitats and infrastructure at Lunt Meadows are still very much developing and this will take time. A programme of work is currently underway with support from the Landfill Communities Fund through the Veolia Environmental Trust, and the Heritage Lottery Fund. We run a weekly practical day on the site and also need daily volunteer help checking grazing animals and locking and unlocking the main gate.

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NO WEBLINK

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January 2016

Written evidence submitted by Dr Joanna Wragg, Dr Andy Tye, Dr Mark Cave, Dr Fiona Fordyce, Dr Andy Kingdon, Russell Lawley and Dr Kate Royse on behalf of the British Geological Survey, Keyworth, Nottingham.

This submission is from research scientists active in the fields of soil science, soil geochemistry and soil-informatics working at the British Geological Survey (BGS). We conduct a range of research on UK soils and their physical and chemical properties. We have developed national datasets for public use and advise, or collaborate with, academic, governmental and commercial partners to improve our understanding, use of, or remediation of, soils in the UK and globally.

Main points of the evidence:

- A requirement for future funding of measurement and monitoring programmes
- Impact of poor understanding and education on the multiple functions and uses of soil that span different sectors and stakeholder needs
- The range of economic benefits (and detriments) of a good (or lack of) understanding of soil function
- The importance of soil to the government plan for 'air' and 'water'
- The impact of soil health on human and ecological health
- The role of data and information in improving stakeholder decision-making

1 How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

1.1 Measurement and Monitoring

- To continue to fund measurement and monitoring programmes e.g. Countryside Survey, Geochemical Baseline Survey of the Environment, National Soils Inventory. Implementation of and improvements to urban surveys (to account for higher population densities in urban areas).
- To measure and monitor soil health so that it performs all of the ecosystem services required of it whilst recognising that it is a finite resource.
- 'Soil Health' includes physical, chemical and biological aspects which can have positive and negative effects and should be interpreted according to the appropriate sector, e.g. Agriculture, Ecology, Energy, Urban environments.

1.2 Future strategy

- Committed spending on existing and future soil monitoring programmes.
- Regular monitoring of soil parameters relative to e.g. location type and environmental events (i.e. flooding).
- Provision of new fit for purpose data (addition to existing data sets) to meet the multiple demands from society.
- Targeted funding for open-data (soil and environment)
- Provision for strategic release of legacy data (from research centres and archives) to allow data mining and big-data techniques to be developed and applied to model change from past monitoring/assessment campaigns

- Development of new monitoring methods which make use of the most up to date technology which includes combining data form sources such as satellite imagery and rapid in-field measurements using portable equipment.

2.0 What are the benefits that healthy soils can provide to society?

- A number of the benefits are well known and include: food and fibre production; biofuel and building material production; water filtration; quality regulation; storage and retention (and flood prevention); enhanced air quality and greenhouse gas regulation; provision of infrastructure foundation; stability and erosion mitigation; aesthetic and recreational resources; biodiversity and a potential gene pool for novel medical solutions (antibiotics-cancer treatment). It is also the substrate for both conventional and renewable energy generation as well as being a resource in its own right. It acts as a crucial medium for the preservation (and discovery) of our cultural heritage.
- Unseen benefits from healthy soil e.g. improved biodiversity and ecosystems for both soils and river catchments; also, cleaner, healthier more attractive environments that encourage exercise and interaction with nature and make locations a desirable place to live. The latter being a particular benefit of urban and peri-urban soils (which can be relatively poorly researched and understood, compared with rural/ non anthropogenic soils).

3.0 What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

Not protecting soil has a detrimental impact on:

- Urban soils and peri-urban agriculture: reduced ability for food production for local communities that positively impact on diet/economy/food miles travelled/community engagement; provision of green spaces for community use (e.g. allotments, 'green gyms'); sustainable drainage strategies and flood mitigation.
- Rural soils and agriculture: UK Food security and associated economy; Reduction in the ability of soils to provide nutrients as a substrate for plant and animal growth and biofuel production.
- Public health:
  - Composition of soils in public gardens/private gardens and potential threats to food production and human health via soil interaction
  - Impact of soil pollution on water quality
  - Soil particulates impact upon air quality
  - Loss of green space and natural resource areas for exercise and recreation with proven links to well-being.
- Water quality and associated ecosystems: Phosphates, nitrates, eutrophication, particulate and diffuse pollution all have negative impacts on aquatic ecosystems and fish stocks on fresh water systems but also in near shore marine environments.
- Water holding capacity/soil stability: Prevention of flooding. Soil structure is known to improve the capacity of soil to store water and prevent surface run-off, improving their role in flood prevention.
- Soil erosion: Defra (2009) estimates 2.2 millions of soil are lost per year. This loss of substrate for agriculture/food/biofuel production and for building has significant costs for

Great Britain in terms of lost/lower production. The increased sediment load within rivers and detrimental impacts on aquatic ecosystems and flooding incur additional costs and the direct loss of the resource (at £30 per tonne) has implications for remediation and improvement in rural and particularly urban environments. This also risks remobilisation of historic anthropogenic contaminants that are currently sequestered in the soil profile

- Climate change: Greenhouse gas retention in soils and by woodland/biomass grown on soils as well as production of these carbon-neutral energy sources is significant. Loss of organic matter from soils and changes in soil hydrology in organic soils can significantly affect GHG emissions.
- Natural soils are slow to develop and are highly sensitive to change and anthropogenic alteration. Soils are naturally variable and play multiple roles, traditional analysis has focussed on soil quality for agricultural purposes, but this should not be the only way of determining functionality/ value of soil. Soils with good characteristics for a range of functions need to be identified and maintained and if necessary protected. Poorer quality soils (more limited functions) need to be assessed to see how they can be improved (strategically and nationally) so that we maximise their functions/benefits. Damaged/threatened soils need to be managed or remediated to reduce their impacts on society and again, maximise their remaining benefits.
- Soil sealing and contamination, particularly in urban environments, are inevitable. However these impacts can be managed, these soils can still provide service to our environments (even if they are not seen), but too little is known about our urban and sealed soils.

4.0 What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Good soil health is promoted by legislation such as the Environmental Protection Act, Water Framework Directive and numerous agricultural regulations. Bodies such as DEFRA, EA, SEPA, Scottish Government, the Soil Association etc. also provide guidance on best practice for the agriculture, forestry and land owner sectors (for the rural environment); as well as for planning, development and contaminated land in the urban environment. Much of this legislation and advice is available online. This is backed up by research and technical guidance from research institutions, university and other educational institutions, many of whom have some outreach activities aimed at schools, the public and farming communities. However, these programmes tend to be small scale and ad hoc.

Soil health can be secured by greater support for education on the importance of soils to our lives, particularly to schools and the agricultural and building/infrastructure sectors. Wider support for engagement with the public would also stimulate greater awareness of the value of soil.

Best practice and guidance is only as good as the evidence base. Continued support for research into impacts of soils on health in the UK context will better inform future guidance, so that protection is adequate but not over precautionary, and ensuring value for money and UK competitiveness. The UK is a world leader in soil research and this should continue to be supported, as this expertise can be (and is) exported globally.

Problems of land ownership-stewardship need attention as users are not necessarily always considerate of long term requirements e.g. land use may result in soil compaction or erosion.

Support research institutes and Universities in their outreach projects to stakeholders and public (particularly children and students). Such as funding data and educational resources, and enabling knowledge transfer through open days and national awareness campaigns.

A key problem is that stakeholders still encounter difficulties in identifying their soils, the threats to their soils, and the functionality, characteristics and benefits of their soils (not just their use for agriculture) and this can influence how they can then apply the available guidance to meet current legislation. There is a need to develop wider use of soil data and soil informatics by encouraging open-data and data-sharing between researchers, and the gamut of environmental stakeholders and the wider public. We need to build better "observe-report-model-explain-decide" approaches to a collective understanding of soils and their characteristics and benefits. There are some academic-led initiatives for soil informatics (such as www.UKSO.org), but better awareness and clearer information (targeted at all levels of user-understanding, not just research) can encourage wider acceptance of the need to treat soils as a national resource and a vital component of the UK environment.

5.0 What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil health underpins the whole environment and should play a major role in government plans for the next 25 years and beyond. It is fundamental to both water and air quality and provides the essential substrate for society to build upon and feed itself. Climate change, population growth and economic development are likely to place increased pressures on natural resources nationally, and will have an even greater effect globally. With increased focus on food and energy security, coupled with a need to develop our living spaces and infrastructure to support a growing populace, it is imperative that the UK maintains a healthy soil base for development and the production of food, water and renewable energy. A national overview of soils, with sufficient resolution to answer the needs of the stakeholders who rely directly and indirectly on soils, requires a strategic and comprehensive approach that can only be delivered by government stimulus.

It is difficult to quantify the monetary benefits of soil, due in part to a lack of relevant data. We need to consider how we can nationally improve resolution of our soil-data for some specific metrics (volumes, properties, processes and interactions) and improve the confidence in the data we develop (it's scalability, currency, terminology, accessibility). Our inability to accurately quantify the value of our soil (monetary or non-monetary) hampers a sustainable approach to our use of our resource. Strategic, UK Government-led funding (in partnership with key stakeholders), for improved soil metrics and dissemination of soil-informatics (as a public good- national benefit) could stimulate measurable growth (and benefits) across the agriculture, infrastructure and energy sectors; with direct and secondary benefits for health, society, tourism and the economy.

Government and industry investment in research and technologies for precision agriculture (sensors, techniques, equipment), and our highly efficient food-supply chains (processing, distribution, provenancing) has already yielded significant economic and societal benefit. These high-technology areas require good data-driven evidence about our soils and their capabilities to further enhance our sustainable use of soils (and understand its limitations) and this needs to be available across the UK in a consistent and readily accessible manner.

Changes in soils in urban and peri-urban environments pose particular challenges for our environment and economy (in terms of our understanding about how to preserve their useful function). Government investment in research, monitoring and remediation in these anthropogenic soils (and the marketable data, skills and technologies behind them) would be particularly beneficial as we develop our cities and connecting infrastructure.

January 2016

Written evidence submitted by the Woodland Trust

The Woodland Trust is the UK's leading woodland conservation charity with the vision for a UK rich in native woods and trees, enjoyed and valued by everyone. The Trust owns over 1,000 sites across the UK and has over 600,000 members and supporters.

General comments:

The Woodland Trust is a strong advocate of the need for healthy soils and the highly beneficial role trees and woods can play in their protection, restoration and creation. Soil is a finite multifunctional resource with complex biological communities that is a key component of most landscapes and underpins human wellbeing, as we rely so heavily on our terrestrial ecosystems for survival.[1]

It can take many years to develop – one centimetre of topsoil can take over a thousand years to form. But it can be lost or degraded all too quickly with serious negative consequences. The United Nations say around 40 per cent of all agricultural soils in the world are seriously degraded, meaning droughts and floods have greater impact, and food production is at considerable risk. A UK government report states we are losing 2.2 million tonnes of important topsoil each year from UK land. This costs the economy £45 million annually – nearly £10 million of which is lost food production.[2] Soil erosion losses can be greater than 100 T/ha per year in some hillside agricultural areas.[3]

Ecosystem services are vital in supporting human health. A loss of these services results in a decrease in our overall wellbeing and an increase in economic expenditure, through attempts to deliver these once free public services by alternate methods. However, many of these services cannot be substituted. So as their available supply or ability to deliver the services we need reduces, their price or value increases towards infinity – essentially making them irreplaceable.[4]

Soils provide a huge range of ecosystem services, especially supporting services that underpin ecosystem function and all other ecosystem services (provisioning, regulatory and cultural).[5] Key functions provided by soils include: production of biomass; storage, filtration and transformation of nutrients, substances and water; provision of habitat, species and genetic biodiversity; provision of the physical and cultural environment for humans and their

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[1] Natural England (2009). *Consultation on Natural England's Draft Policy on Soil*. Natural England, Peterborough.

[2] Melchett, P. (2015). *Magical, mysterious, essential - and being unthinkingly destroyed*. Soil Association. Available online: http://www.soilassociation.org/blogs/latestblog/article/1076/magical-mysterious-essential-and-being-unthinkingly-destroyed

[3] Penning de Vries, F.W.T., Agus, F., Kerr, J. (Eds.) (1998). *Soil Erosion at Multiple Scales: Principles and methods for assessing causes and impacts*. CABI publishing.

[4] Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Raruelo, Jl, Raskin, R.G., Sutton, P., van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature*, 387, p.253-260. Available online: http://www.esd.ornl.gov/9D499C84-5DD8-42F3-97E3-B83E34A291F3/FinalDownload/DownloadId-D16D24CB6007E26515C0688017AEA490/9D499C84-5DD8-42F3-97E3-B83E34A291F3/benefits_conference/nature_paper.pdf

[5] Finvers, M.A. (2008). *Application of e^2DPSIR for analysis of soil protection issues and an assessment of British Colombia's soil protection legislation*. M.Sc. Thesis. Cranfield University, UK. Available online: http://www.organiclandcare.org/files/education/organic_landscape_management/Ecosystem%20Services.pdf

activities; provision of raw materials; carbon storage and cycling; and protection of archaeological heritage.[6]

Key factors causing the degradation and loss of soils include intensive agricultural production, inappropriate techniques and poor land management. Intensification of agriculture to maximise production yields often includes, for example, the heavy use of fertilisers and pesticides, and mechanised systems. However, it can also severely impact on beneficial insects and plants, degrade and deplete the soil, create polluted runoff (through sedimentation and leaching/transport of chemicals) and lead to obstructed water systems, increases susceptibility to flooding. Modern intensive production can also lead to a reduction in the genetic diversity of crops and livestock species around the world, impacting on local traditional agricultural systems. An expansion of the area of intensive agriculture can also be seen to lead to a loss of biodiversity, and natural habitats. Agriculture is a major contributor to certain greenhouse gases in the atmosphere.[7]

The removal of hedgerows and trees outside woods (often done during agricultural intensification to increase field size or during building development) can increase soil erosion, as these features can act as windbreaks reducing wind erosion, or act as physical barriers to reduce runoff and loss of topsoil.[8]

Soil degradation may be reflected by declines in soil fertility, soil organic matter and organic carbon content; loss of biodiversity; loss of water retention capacity; disruption of water, nutrient and gas cycles; and reduced capacity to degrade contaminants.[9] So it is crucial we protect the UK's soil resource and ensure its long-term health.

Ancient woods are irreplaceable habitats and essential biodiversity reservoirs that provide important ecosystem services. Ancient woodland covers just two per cent of the UK's land mass and soils are a vital component, as the time (centuries or millennia) these soils have taken to form mean they are hugely complex and diverse. Soils house a large proportion of the Earth's biodiversity and a large percentage of ecosystem services provided by soils are actually provided by the soils biotic community, which takes time to develop. This is found in the active rhizosphere of a soil profile, the section most closely associated with plant roots and soil microorganisms.

The loss of soil profiles through ancient woodland destruction is a serious issue, as they cannot be recreated or translocated.[10] For example, large scale land disturbance can

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[6] European Commission (EC) (2006a). *COM 2006/231, Thematic Strategy for Soil Protection, 2006 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - Commission of the European Communities*. Brussels, 22.9.2006. Available online: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52006DC0231

[7] Everything Connects (2014). *Intensive farming.* Available online: http://www.everythingconnects.org/intensive-farming.html

[8] Woodland Trust (2012). *Benefits of trees on arable farms: research report*. Available online: http://www.woodlandtrust.org.uk/publications/2012/07/benefits-of-trees-on-arable-farms/

[9] Tóth, G., Stolbovoy, V., Montanarella, L. (2007). *Soil Quality and Sustainability Evaluation - An integrated approach to support soil-related policies of the European Union*. EUR 22721 EN. Office for Official Publications of the European Communities, Luxembourg, 44pp. Available online: http://eusoils.jrc.it/ESDB_Archive/eusoils_docs/other/EUR22721.pdf

[10] Ryan, L. (2013). *Translocation and ancient woodland*. Woodland Trust. Available online:

irreparably damage the intricate networks of mycorrhizal fungal strands (key elements of the soil biotic community) that run through ancient woodland soils. These types of networks are essential to over 90 per cent of plant life in the world, benefitting their growth and assisting in adaptations to altering climatic conditions.[11]

Unlike other public goods, such as air and water, there is no specific legislation for soils. The EU's proposed Soil Framework Directive (withdrawn in 2014) was a missed opportunity to safeguard our priceless soil resource. Instead protection is afforded in a piecemeal way through other policies and legislation, such as the UK Forestry Standard and very basic requirements through agricultural subsidies. Systems and processes need to be in place to highlight and reinforce the responsibilities of all landowners, and provide the knowledge needed to educate and support these people who are the caretakers of our land. Current regulations and incentives are not enough to ensure this protection is carried out, yet our soils are the most precious land resource we have.

<u>Response to specific EAC inquiry questions:</u>

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

As agricultural land covers 70 per cent of the UK there needs to be a greater focus on its protection. At present there is very little requirement for farmers to safeguard their soils or report on their condition, yet they depend on them for their livelihoods as much as all of us depend on them for their ecosystem service support. While there is evidence of good practice in the countryside, such as the Pontbren farmer-led approach to sustainable land management[12], there is also far too much poor land management being carried out, such as excessive tillage and ground compaction. Impacts by some of the recent flood events, which are predicted to increase and will have carried large quantities of precious soil into the waterways and seas, could have been reduced with different practices – such as protecting or recreating hedgerows and appropriate winter crop management. Soil erosion needs to be seriously abated if we are to retain our ability to produce food, store carbon, keep our waterways clean, etc.

As previously discussed, the greatest proportion of the ecosystem service provision by soils occurs in the rhizosphere section and is delivered by the biotic community (associated with arbuscular mycorrhizal fungi, within soil aggregates and within soil carbon pools and detritus – organic matter).[13] It is also the biological elements of soil that need the greatest research focus, as there are big evidence gaps in our understanding of their importance and functions, and they have been studied far less than the physical and chemical characteristics

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http://www.woodlandtrust.org.uk/publications/2013/04/translocation-and-ancient-woodland/

[11] Amaranthus, M. (2013). *Mycorrhizae: Are they right for me?* Available online: http://mycorrhizae.com/wp-content/uploads/2013/03/Mycorrhizae-are-They-Right-for-Me-PDF.pdf

[12] Woodland Trust (2013). *The Pontbren project – a farmer led approach to sustainable land management in the uplands*. Available online: http://www.woodlandtrust.org.uk/publications/2013/02/the-pontbren-project/

[13] Finvers, M.A. (2008). *Application of e^2DPSIR for analysis of soil protection issues and an assessment of British Colombia's soil protection legislation*. M.Sc. Thesis. Cranfield University, UK. Available online: http://www.organiclandcare.org/files/education/organic_landscape_management/Ecosystem%20Services.pdf

of soil. Some recent research found invertebrates, including earthworms, have declined by around 45 per cent over the last 35 years.[14]

Lack of understanding around the significant role soil biota play in the physical and chemical properties of soil as well as its productivity needs to be addressed, along with the impacts of different land management techniques on soil biota. This must be done at a research and evidence level, to underpin the science, but also at a stakeholder (e.g. farmers) and public level. There are issues with this due to the huge diversity of soil organisms and difficulties in their identification, but there are many more techniques today to assist with this, such as environmental DNA (eDNA). This relatively new and effective method of monitoring takes *genetic material obtained directly from environmental samples (soil, sediment, water, etc.) without any obvious signs of biological source material* and enables species identification.[15] There is also lack of evidence surrounding soil biota's direct linkages to soil function.

Other areas that are of concern are the increasing quantities of chemicals and excessive nutrients found in soil chemistry. This is strongly linked to excessive chemical use through intensive agriculture and must be addressed and reduced.[16] Trees and woodland can be effective water filters and protect waterways.[17]

Government could look at the soil monitoring already being carried out, e.g. through Natural England's Long Term Monitoring Network (mostly on National Nature Reserves) and the UK Environmental Change Network. It could perhaps then focus on the areas where there may be gaps, such as effective soil monitoring on agricultural land that could be carried out by farmers.

What are the benefits that healthy soils can provide to society?

Good soil management is a critical component of more sustainable land management practice – in agriculture, forestry, woodland and recreational management, in construction, mineral working and restoration, waste disposal, in habitat restoration and re-creation and in urban design, green infrastructure and the creation of other greenspace.[18] Without healthy soils we will not be able to provide the goods we depend on, e.g. food and timber. We are also much more likely to suffer from the impacts of flooding and poor water quality, and loss of other ecosystem services that support healthy human living.

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[14] Dirzo, R., Young, H.S., Galetti, M., Ceballos, G., Isaac, N.J.B. and Collen, B. (2014). Defaunation in the Anthropocene. *Science* 345, 401. Available online: https://labs.eemb.ucsb.edu/young/hillary/PDF/Dirzo_et_al_2014_Sci_Review.pdf

[15] Thomsen, P.F. & Willersley, E. (2015). Environmental DNA – An emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation*, 183, p 4-18. Available online: http://www.sciencedirect.com/science/article/pii/S0006320714004443

[16] The Scottish Government (2006). *Prevention of Environmental Pollution from Agricultural Activity*. Available online: http://www.gov.scot/Publications/2005/03/20613/51368

[17] Woodland Trust (2012). *Planting trees to protect water: The role of trees and woods on farms in managing water quality and quantity*. Available online: http://www.woodlandtrust.org.uk/publications/2012/08/planting-trees-to-protect-water/

[18] Natural England (2009). *Consultation on Natural England's Draft Policy on Soil*. Natural England, Peterborough.

Healthy soils with diverse populations of soil biota (bacteria, fungi and nematodes) are extremely productive. Soil organisms have direct and indirect impacts on land productivity. Specific organisms can directly and immediately affect crop yield, such as mycorrhizal fungi. Indirect effects come from species participating in carbon and nutrient cycles, soil structure modification, and food web interactions that generate ecosystem services that ultimately affect productivity. Farming systems with a high efficiency of internal resource use require lower input requirements and costs.[19]

Healthy communities of soil organisms can also control a variety of pests and diseases. A healthy soil community has a diverse food web that keeps pests and diseases under control through competition, predation, and parasitism. Thus biological control can reduce crop loss and the need for excessive chemical use. Crops growing in impoverished soils are increasingly weaker as a result of poor nutrition and thus more susceptible to pest and disease attacks. There is a general consensus that a diverse soil community will not only help prevent losses due to soil-borne pests and diseases but also promote other key biological functions of the soil, which can lead to increased nutrient uptake and more vigorous plant growth/health. [20]

We do not yet understand the full extent of the benefits healthy soils provide. Much more research and action is needed in this area, so we can safeguard the future of our soils and indeed our own lives.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

Soils are a finite resource and cannot be easily recreated within short, human timeframes. The consequences of failing to protect soil health are a reduction in human health and well-being, and an increase in economic expenditure in an attempt to replace the large number of ecosystem services soils provide. Soils can only effectively support other habitats and species if they are healthy.

For example, in 2011 the total annual cost of erosion in England and Wales for all soilscapes was calculated to be about £177 million per year, of which about 23 per cent are onsite costs and 77 per cent are offsite costs. Onsite costs (£40 million per year) comprise loss of yield potential due to loss of soil medium and loss of soil nutrients valued at their chemical nutrient replacement cost.

Offsite costs (£136 million per year) comprise mainly the treatment cost of nutrient removal from drinking water, the damage costs of nutrients passing to the water environment, sediment removal from rivers and lakes, sediment removal from urban drainage systems, and greenhouse gas loss linked to erosion events.[21]

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[19] Barrios, E., 2007, Soil biota, ecosystem services and land productivity. *Ecological Economics* 64, p. 269–285. Available online: https://www.researchgate.net/publication/223391739_Barrios_E_Soil_biota_ecosystem_services_and_land_productivity_Ecol_Econ_64_269-285

[20] Barrios, E., 2007, Soil biota, ecosystem services and land productivity. *Ecological Economics* 64, p. 269–285. Available online: https://www.researchgate.net/publication/223391739_Barrios_E_Soil_biota_ecosystem_services_and_land_productivity_Ecol_Econ_64_269-285

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Changes in the current five-year cycle of the Common Agriculture Policy mean measures to protect soil have been greatly weakened, although they were inadequate before. This must be addressed if we are to safeguard their future.

Soil management practices involving organic residue management such as crop rotations, green manures, and improved fallow systems influence the soil community through changes in soil organic matter quantity and quality. As soil organic matter influences soil structure, soil nutrient availability, soil water holding capacity, and cation exchange capacity, it can be used as a management tool to favour greater soil heterogeneity and more diverse soil communities that are associated with the natural regulation of pests and diseases.[22]

Especial attention should be devoted to understanding the dynamics of ecological interactions taking place in the soil and root environments that are necessary to achieve successful and reproducible biological control under field conditions (Rosenheim, 1998). Future modelling efforts that view food webs as open and flexible structures that can accommodate changes in species and the dynamics of single and multiple attributes would be extremely useful to improve understanding of the ecosystem service of biological control of pests under scenarios of increased environmental change and disturbance.[23]

The planting of trees and woodland can be part of the solution to prevent soil erosion, increase soil fertility and decrease pollution. By strategically planting tree belts along contours, perpendicular to prevailing winds or in areas known to be vulnerable, natural barriers can be built that protect soil from the full impact of intense rainfall or strong winds, helping to prevent top soil erosion. Deeper rooting trees improve soil stability and additional organic matter from leaf litter and root debris can also promote soil structure reducing further surface water run-off.[24]

Even though more tree cover on farms could provide additional benefits such as shade and shelter for livestock, and woodfuel supply, current incentives and policy mechanisms are not

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[21] Defra (2011). *Project SP1606: Cost of Soil Degradation in England and Wales.* Final report available online: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16992

[22] Barrios, E., 2007, Soil biota, ecosystem services and land productivity. *Ecological Economic*s 64, p. 269–285. Available online: https://www.researchgate.net/publication/223391739_Barrios_E_Soil_biota_ecosystem_services_and_land_productivity_Ecol_Econ_64_269-285

[23] Barrios, E., 2007, Soil biota, ecosystem services and land productivity. *Ecological Economic*s 64, p. 269–285. Available online: https://www.researchgate.net/publication/223391739_Barrios_E_Soil_biota_ecosystem_services_and_land_productivity_Ecol_Econ_64_269-285

[24] Woodland Trust (2015). *The role of trees in arable farming*. Available online: https://www.woodlandtrust.org.uk/mediafile/100709171/pg-wt-110915-role-of-trees-in-arable-farming.pdf?cb=da0485e0e2af44938a7da507651f26ea

sufficient to encourage landowners down this route. It is also vital we ensure protection and replacement of existing woods and trees, particularly ancient woods, but also trees, hedges and other woodland in the wider landscape.

Case study: "Haywood Oaks in Nottinghamshire is part of an arable unit that covers over 1,000 hectares. In the last decade, owner Richard Thomas and farm manager Andrew Bainbridge have significantly changed their farm management methods, incorporating trees as a way to combat wind and water erosion.

It was common for strong winds to blow valuable topsoil away and for intense rainfall to wash the topsoil into neighbouring land and local communities. Andrew said: "There were instances where we could literally see the soil leaving the farm and once that happens, we've lost that forever. We knew we really needed to take steps to keep that in the field – we needed to slow the water so that we could ensure the sediment and nutrients stayed on the farm and that we weren't impacting on other land, local people and properties."

They contacted the Woodland Trust and during 2014/15, 4,000 trees were planted, amounting to one hectare across varying areas of the farm, with a further 0.2 hectares planted on another holding, Inkersall Grange Farm. Planting consisted of 10 metre wide shelterbelts with two metre spacing. Species chosen reflected those already on the farm, such as rowan and birch. Two rows of shrubs were also planted on the field side of each belt to act as an added buffer.

Trees can significantly help to lessen soil erosion and the loss of vital nutrients by acting as a natural barrier and improving the water infiltration rates of the soil. Similarly, the trees will also prevent strong wind gusts from lifting valuable top-soil away from the farm. By keeping the seedbed in situ, the cost of repeat practices will be significantly lowered and the risk of long-term soil degradation minimised. In addition, the trees are very much a visual statement to the local community, highlighting the action taken by Richard and Andrew and positioning the farm as proactive in relation to taking responsibility for any impact on the wider environment and community."[25]

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soils are the foundation on which all other terrestrial habitats and ecological communities are based. Soil health needs to play a key role in the Government's upcoming 25 year plan for the natural environment. The ecosystem services soils provide us are just too great to ignore and cannot be substituted. They must be safeguarded if we are to ensure a healthy environment and a healthy populace in the long term.

Key areas Government needs to look at are: the lack of awareness and understanding about the importance and fragility of soils, especially in those sectors that utilise them most (e.g. agriculture); the lack of real protection soils are afforded, by for example the Common

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[25] Woodland Trust (2015). *The role of trees in arable farming*. Available online: https://www.woodlandtrust.org.uk/mediafile/100709171/pg-wt-110915-role-of-trees-in-arable-farming.pdf?cb=da0485e0e2af44938a7da507651f26ea

Agriculture Policy; and the current evidence gap that needs to be bridged to ensure we have the scientific understanding to protect and restore our soil resource.

Government also needs to ensure there is strong support for and continuation of the elements of soil monitoring currently being carried out, e.g. through Natural England's Long Term Monitoring Network and the UK Environmental Change Network. However, more monitoring needs to be carried out on agricultural land, which is often the most hard worked and can be the most vulnerable to degradation. Safeguarding and monitoring soils should be a requirement of farmers and forest managers (especially), and other landowners

January 2016

Written evidence submitted by the CLA

Introduction

The CLA represents landowners, farmers and other rural businesses. We represent over 33,000 members who own and manage over 10 million acres of rural land in England and Wales, and safeguard the interests of landowners and those with an economic, social and environmental interest in rural land and the rural economy.

We welcome this opportunity to submit our views on soil health to the Environment Audit Committee.

CLA has been looking after the interests of our members, as well as promoting the positive aspects of land ownership, land management and rural business activities for the past 100 years. The quality of the countryside, and its natural resources, is of vital importance to our members. Most objectives for the countryside - economic, social and environmental - rely on landowners and managers for their success. Equally, a healthy environment relies upon a thriving rural economy and financially viable agricultural businesses.

1. How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

1.1 The Government needs to continue to take the work forward that was set out in England's first Soil Strategy (2004-2006). This initiated the research into developing soil quality indicators and monitoring, and would be the best way to continue to measure soil health.

1.2 The UK Soil Indicators Consortium has made some progress in developing soil indictors of soil function for soil quality. The important functions being food and fibre production, environmental interaction, support of ecological habitat and biodiversity, provision of raw materials and protection of cultural heritage.

1.3 CLA believes that work should be continued on the tiered monitoring scheme approach, which can be used to assess the status and change in a range of soil indicators that are related to the delivery of different soil functions.

1.4 If a completely new monitoring scheme were to be set up, then a stratified random sampling scheme would be the best approach. Stratification should ensure the best spatial coverage possible, and is consistent with adequate sampling of all classes.

1.5 Soil Quality Indicators need to be sensitive to human-induced changes, simple, cost effective to measure, and applicable to the majority of soil monitoring networks. They need to be able to indicate responses that can be distinguished from natural variability, and provide both a diagnostic and prognostic.

1.6 The soil quality indicator approach attempts to help address the degree of variation between different soil types and conditions in different geological and geographic locations at different times.

1.7 Government should ensure that the inclusion of soil health monitoring procedures are embedded in policy measures to protect soils, for example, in agri-environment schemes, and are implemented over longer periods of times. The desired outcome is to know if the measures are protecting soils.

2. What are the benefits that healthy soils can provide to society?

2.1 Healthy soils, which are more bio-diverse containing a greater richness of soil organisms and species, provide benefits to both the landowner/ farmer and to wider society including:

- sustainable crop yields and the contribution to food security and self-sufficiency nationally, and a decreased reliance on imports.
- reduced reliance on pesticides and artificial nutrient input.
- increased permeability of soils, reducing water run-off and slowing of water through the river-basin system, with potential to reduce flood risk.
- reduced soil erosion from both wind and water, which can reduce productivity and add to silt in watercourses and increased flood risk.
- reduced nutrient leaching.
- greater stability of soils for vegetation.
- great capacity to store carbon in organic matter.
- increased adaptive capability in the face of climate change impacts
- support the built environment and cultural heritage.

3. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

3.1 Failing to protect soils can cause irreversible damage; that said, potential restoration of soils can take decades and significant resource input. The consequences of poorly managed soils are the reverse of the benefits highlighted in the point above.

3.2 These issues are hard to measure and difficult to attribute. Typically, the costs to wider society of failure to maintain healthy soils could be wide reaching, with impact on food security, risks to life associated with flooding and water management, and over-reliance on pesticides.

3.3 The environmental consequences could also be considerable through loss of habitat and leaching of nutrients into watercourses.

4. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

4.1 Actions to maintain and improve soil health can be taken on the immediate land area and on adjacent land areas. The current framework for both regulating and incentivising soil management is based almost entirely on cross-compliance, the basic payment scheme and countryside stewardship. These schemes are too inflexible to meet the variety of measures that could be utilised, particularly when the greatest benefits are delivered by land use change, or implementing changes on adjoining land, e.g. tree planting or encouragement of natural vegetation.

4.2 Soil management good practice should be embedded in cross compliance, but good practice must be flexible and pragmatic enough to be applicable to all situations.

4.3 Greater emphasis could be placed on soil maintenance within environmental stewardship schemes, based on an outcome led approach. This should be consistent alongside the Basic Payment Scheme in offering measures to maintain soils, and soil structure in particular.

4.4 Cultivation and drilling methods should play a key role within the delivery of these. Measures could include the growing of structure-improving cover crops, such as oilseed radish and mustard, followed by direct main crop establishment without mechanical destruction, i.e. to reduce cultivation where possible.

4.5 Maize production can lead to soil and nutrient losses at harvest and during winter. Using early maturing varieties, sowing as early as possible, and planting under plastic can reduce the risk of harvesting in poor conditions later in the year. Certain management practices can also significantly reduce water, nutrient and sediment runoff during winter. Chisel ploughing, under-sowing and cover-cropping can reduce runoff compared with leaving maize stubble untouched.

4.6 Growing maize requires many more measures to meet Cross Compliance requirements than other crops. These include the need for good land drainage, use of early maturing varieties, growing the crop across a slope, the use of low ground pressure tyres on tractors and harvesters, introducing a cover crop or under-sowing. Taking care at every stage of production, from field selection to post-harvest management can reduce the negative impacts on soil health and the wider environment.

4.7 Overall, legislative and cross-compliance restrictions should be removed, which might limit a farmer's ability to use direct crop establishment or maintenance and improvement to the best advantage of the soil, recognising local climatic and other factors, which impact on timing and type of operations. Flexibility in greening rules to recognise multi-annual rotations is key to achieving this.

4.8 Currently, support schemes are short-term and annual or multi-annual. Farmers and land managers generally take a long-term approach to land and soil management, and support schemes and policies should be longer-term and consistent, enabling land managers to take real investment and business decisions; in turn these lead to improvements in soil management in particular. Constantly changing policy and uncertainty leads to short-term decision making.

4.9 While the EU Soil Directive is no longer being progressed, Defra took forward many of the proposals, which were spawned as far back as the preceding EU Soils Thematic Strategy, and embedded them in government policy. Indeed, the UK chaired the early EU soils working groups that developed the Soil Quality Indicator and monitoring approach as a tool to help protect soils. In addition, many soil protection measures are being introduced through EU climate change and ecosystems policy.

4.10 The good management of soils and good soil health is vital to the economic future of any land management business. It is therefore in the best interests of landowners/ managers to manage their soil appropriately with a longer-term view.

4.11 One of the most cost effective ways of protecting soils is in demonstrating to owners the measures they can take themselves, and showing how these can improve not only their soil, but also their business viability.

4.12 Organisations such as the Campaign for the Farmed Environment (CFE) and the Farming Advice Service are vital to promoting the value of healthy soils to owners. CFE's work on soils and cover crops is well received in the farming industry; it is based on farm-scale trials showing real benefits, and in many cases, cost savings from good soil management. Government support for these organisations must be maintained.

5. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

5.1 The continued development of soil quality indicators and the soils monitoring programme should be fully resourced (in terms of research and development), and integrated into both the 25 year Food and Farming Strategy and the 25 year Environment Plan.

5.2 Soil health, alongside water quality and flow management, should be embedded in both the 25 year Environment Plan and the Food and Farming Strategy, which should rationally be one plan. These should form the basis of policy, but need to look beyond 25 years. Soil health needs to be considered across all environments, and not be limited to an agricultural or rural context.

5.3 Typically, impacts of soil management on water and the environment are long-term, and, for example, nutrient leaching cycles can be up to 50 years. To make policies on a shorter view than this would limit effectiveness. There should, of course, be provision to review policies from time to time, whilst maintaining consistency in approach and desired outcomes.

5.4 Policies for England should be cognisant and informed by the developing soil indicator and monitoring work, including research from the rest of the UK, Europe and globally.

5.5 The role of private landowners and managers, as the main deliverers of improvements to soil management, must be fully recognised; policy must be designed to support them in this delivery, understanding their businesses, learning from their experience and assisting them in becoming better informed of best practice and new soil management techniques.

January 2016

Written evidence submitted by the All Party Parliamentary Group on Agroecology

Agroecology is rooted in an understanding of farms as ecosystems, both in themselves and as part of wider biological systems, and uses complex biological interactions and synergies to create resilience and productivity on farms. Agroecology aims to minimise the use of external inputs, relying instead on the capacity of farm ecosystems to produce their own fertility, conserve and recycle water and nutrients and make use of biological pest control.

Agroecological methods emphasise building and enhancing soil fertility and enhancing soil biotic activity. A healthy soil acts as a store of nutrients and water, which can be drawn on as necessary to produce food. Agroecological methods include maintaining soil cover (e.g. cover crops, agroforestry), adding and conserving soil organic matter (e.g. manure or compost) and the use of crop rotations and on-farm diversity to ensure that soil nutrients are not excessively depleted.

Soil has arisen as an important issue throughout the work done by the All Party Parliamentary Group (APPG) on Agroecology, interacting as it does with many of the wider issues around food security and sustainability. The APPG has been holding its own inquiry into soil health, with evidence sessions at the end of 2015. As a result we feel that what we have learnt so far would be useful for the EAC.

Below is a summary of some of the key messages and insights the APPG has heard from witnesses cross-examined so far. These witnesses have included:
Dr Andy Whitmore (Rothamsted Research)
Martin Rogers (National Farmers Union)
Peter Melchett (Soil Association)
Lord Deben (Committee on Climate Change)
Professor Mark Kibblewhite (Emeritus Professor, Cranfield University)
Robert Askew (Independent consultant and agricultural land classification expert)

Please note the submissions below do not necessarily represent the views of one or all witnesses unless stated as such.

1. <u>**Soil Testing and targets**</u>

Evidence we have heard suggests that an overarching national target on soil organic matter (SOM) levels, analogous to the emissions reduction target for greenhouse gases, could act as an impetus for better protection of soils across the UK.

In order to achieve such a target, there needs to be clear soil monitoring. The inquiry heard about the French system, which involves regular soil testing at sites across the country (one every eight square kilometres) and so helps to build a robust picture of the state of their soils.

While soils organic matter is relatively easy to measure and is a good indicator of overall soil health, witnesses recognised that it is not likely that the UK would be able to follow the French model exactly as it involves monitoring by public agencies. One model suggested is a series of regional centres to which farmers send soil samples. These would be analysed together with neighbouring samples to build up a picture of soil condition in the region. The advantage of this is that the data could be anonymised, but that the results would provide information that would be value to the farmer on the state of his soil relative to the regional average. As such farmers would have an incentive to pay for such testing and analysis, which would be more sophisticated than they could achieve on farm (e.g. using high tech statistical analysis). The regional centres could then send the anonymised data to a national centre for collation on a national scale. A precedent for this exists in the form of the national biodiversity network, which individuals can feed their data into.

2. Policy interventions

There is currently very little overarching policy aimed at soils and ensuring soil health. The soils directive at the EU level, which advocated recognition of soil as a non-renewable resource and therefore the gathering of disparate soil legislation into a coherent whole and a duty on landowners to prevent soil degradation, was blocked by several countries including the UK. At the same time the UK government has not updated its soils strategy in recent years. Dr Andy Whitmore questioned what policy area in the UK covered soils and how this interacted with other policies. For example the strain on soils will directly depend on the amount of food we wish to produce in the country, and it is unclear if there is a stated aim to increase the proportion of food produced for domestic consumption.

While soil monitoring is important, if only to provide a baseline from which to judge future progress, some including Lord Deben in his evidence to the APPG inquiry, argue that we are past the stage of monitoring and need to move towards an action plan. This is something that the Committee on Climate Change has recommended that Defra implement.

Lord Deben stated that it is not enough for the government simply to monitor the effects of CAP cross-compliance rules that promote food soil management. The situation regarding soil degradation is urgent and requires the uptake of soil conservation measures.

Such measures are already well-known and uncontroversial, the inquiry heard, including the use of cover crops to minimise the time land is bare, crop rotations including legumes to build soil fertility, and care as to the types of crops planted and when they are harvested.

The APPG has heard a general consensus that there is a lack of policy incentive to achieve this. The most obvious way to improve this would be though the Common Agricultural Policy and in particular Pillar 2 (agri-environment) measures. The general requirements for soil health under pillar 1 (cross-compliance measures) are often inadequate and allow practices that continue to produce soil degradation, such as allowing maize stubble to remain.

At the moment pillar 2 options (which pay farmers to adopt certain beneficial practices) include many which help to improve the soil but always as a secondary outcome. There are no pillar 2 measures which have the promotion of soil health as their primary aim.

3. Soil education and training/Farmer advice and best practice

A dual theme emerging from the APPG inquiry was the importance of knowledge. This includes both specialist soil knowledge - from well-trained scientists and experts - as well as the ability to translate that knowledge into clear, reliable and credible advice for farmers on how to manage their soil.

The need for education includes both general education to highlight the importance of soil (for farmers at agricultural college and for the public at school) with a view to changing behaviour. There is also a need for more technical education on soil and in particular on applied soil science and training of specialists to help disseminate soil research and knowledge.

There is also a lack of soil scientists, with no dedicated soil science degree in the UK available at undergraduate level and a decreasing provision at post-graduate level. Concerns were raised during evidence that his would have a direct impact on the quantity and quality of practitioners able to work in soil-related areas, from agricultural land classification to advice for farmers.

Once farmers are aware, as many already are, of the vital importance of soil to food production, the next question will inevitably be what they can do to improve it. Here there is a clear gap. One problem is that soil type varies widely throughout the UK and in most cases local knowledge and advice is more important than any generic or national information. The lessons of catchment sensitive farming, which has unfortunately seen a reduction in resources, show the value of bringing together farmers and other stakeholders from a single geographic region to work together and learn from each other and establish best practice. The National Farmers Union told the APPG inquiry panel that “the government needs to ensure that credible advisers remain there on the ground.”

Another solution would be the reinstatement (or replacement with a similar service) of the demonstration centres (experimental husbandry farms) which served to translate scientific research into locally appropriate practical advice that farmers could observe and repeat.

4. Economic incentives and valuing soil condition

An overarching problem is that soil health is a long term issue, in particular because it can take several years, if not decades, to see a marked improvement in soil quality following a change in farming practice. The farming industry and others claim that it is in farmers’ best interest to look after their soil as it is the basis for production. As the National Farmers Union’s Martin Rogers said when giving evidence, “soil is farmers most vital asset”. This is true but is not, as has been suggested, a reason to rely on a voluntary approach to soil conservation. Evidence heard by the APPG during the course of its own inquiry into the issue, suggests that this ignores the role of competing pressures on farmers, not least economic and regulatory incentives created by existing government policy. Given the strained economic climate facing agriculture, it is unlikely that farmers will be able, even if willing, to take measures to protect their soil in the long term if there is a negative financial implication to doing so. Dr Whitmore said, “Farmers facing hard economic times may be tempted to look for short term gains.”

Instead it would be better to take into account the economic consequences of soil degradation, valued by Professor Mark Kibblewhite (an inquiry witness) and others at £1.2 billion a year, of which only 20% is incurred by those using the soil (i.e. farmers). Once these economic externalities (including carbon emissions and increased flooding) are taken into account, it makes sense to find ways of valuing soil condition, for example in farm tenancies. This would provide an economic incentive for land users to maintain the soil in as good or better condition to how they found it and could be captured in an asset value.

In general the fact that soil is hard to regain once lost provides a strong reason for it to be valued more highly, including finding economic incentives for farmers to conserve it, to counteract some of the existing financial pressures which encourage production at all costs in order to achieve margins large enough to survive as a viable business.

January 2016

Written evidence submitted by Dr Jacqueline Hannam, Cranfield Soil and Agrifood Institute, Cranfield University

Executive summary

- Soil health can be defined as the capacity of the *whole* soil system including physical, chemical and biological components and their interactions to carry out essential functions. These functions lead to the delivery of essential ecosystem goods and services that bring socio-economic benefits to society.
- Soil quality indicators (SQIs), based on physical, biological or chemical soil properties should be directly related to soil functions and the associated delivery of ecosystem goods and services. Any significant change in soil properties that causes a change in soil function should be detectable by the SQI.
- Challenges in defining meaningful indicators of soil health could be circumvented by monitoring soil degradation instead.
- Measures of soil protection have to be practical, easy to implement and show tangible benefits to land managers in restoring and adding resilience to soils.

How could soil health best be measured and monitored?

Defining soil health

1.1 There are various phrases that describe the capacity of soil to carry out diverse and essential functions that ultimately support human health and wellbeing through the delivery of essential ecosystem goods and services. These include 'soil health', 'soil quality' and 'soil functional capacity'.

1.2 To some extent these terms are interchangeable and common to most definitions is the assessment of the *whole* soil system including physical, chemical and biological components and their interactions. Clearly this complexity has impacts on the ability to measure and thus monitor soil health in response to perturbations from climate and land management.

1.3 A simple definition of soil health is given by Karlen et al. (1997): Soil health is "*the soil's fitness to support crop growth without becoming degraded or otherwise harming the environment*". Many current references to 'soil health' relate to this definition where the focus is on the primary function of soil to support crop and livestock.

1.4 The concept of soil quality, which includes other soil functions, can be defined as "*the capacity of soil to function, within natural or managed ecosystem boundaries, to sustain plant or animal productivity, maintain or enhance water quality, and support health and human habitation*" (Karlen et al., 1997).

Soil health and soil quality indicators (SQIs)

1.5 It is important to know how soil health (and/or quality) changes over space and over time in response to natural factors (such as changing weather patterns) and to land management practices.

1.6 Soil quality indicators (SQIs), based on physical, biological or chemical soil properties should be meaningful in the sense that they are related to soil functioning and the associated delivery of ecosystem goods and services (such as food provisioning, water regulation, climate change mitigation and protection of cultural heritage; Black et al., 2008; Robinson et al., 2010; Rickson et al., 2013). Any significant change in soil properties that causes a change in soil function should be detectable by the SQI.

1.7 Several projects have assessed applicable SQIs (e.g. Defra SP0529; Defra SP1611) for national scale monitoring. In the latter project, candidate key soil physical properties were identified as: depth of soil; soil water retention characteristics; packing density; visual soil assessment / evaluation (soil structure assessment); rate of erosion; sealing (covering soil with built infrastructure); and aggregate stability.

1.8 Available evidence suggests that a meaningful change in the SQI will depend on soil type, current soil state, land use and the soil function under consideration. However, using the limited empirical base, no relationships were found over different land covers and soil types for two SQIs tested in Defra SP1611 (Rickson et al., 2013).

1.9 Schipper and Sparling (2000) identify the challenge: "*a standardised methodology may not be appropriate to apply across contrasting soils and land uses. However, it is not practical to optimise sampling and analytical techniques for each soil and land use for extensive sampling on a national scale*".

1.10 The relationships between SQIs, soil processes and soil functions is complex, as is how this influences ecosystem service delivery. Important gaps still remain in the development of conceptual models for these inter-relationships, let alone their quantification.

1.11 There is also a question of whether individual quantitative SQIs can be related to ecosystem services, given the number of variables affecting them. Lack of data (including uncertainty in measurement and variability in observed distributions) applies to individual SQIs; attempts at integrating more than one SQI (including physical, biological and chemical SQIs) to improve associations between soil properties and processes / functions are likely to propagate errors.

1.12 The absence of agreed and well-defined SQIs is likely to be a barrier to the development of soil protection policy and its subsequent implementation (Rickson et al., 2013).

How could the Government develop a strategy for tracking soil health?

2.1 For SQIs to be included in a robust national soil monitoring programme, it is essential to know a) the uncertainty in their measurement b) the spatial and temporal variability in the indicator as given by observed distributions; and c) the expected rate of change in the indicator.

2.2 Whilst a baseline is needed (i.e. the current state of soil), it is the rate of change in soil properties and the implications of that change in terms of soil processes and functioning that are key to effective soil monitoring.

2.3 Where empirical evidence is available, power analysis has been used to understand the variability of selected physical SQIs as given by the observed distributions (Rickson et al., 2013). This process determines the ability to detect a particular change in the SQI at a particular confidence level, given the 'noise' or variability in the data (i.e. the ability to detect a change of 'X' SQI at a confidence level of 'Y%' would require 'N' samples).

2.4 However, the evidence base for analysing candidate physical SQIs was found to be poor. Data are limited in spatial and temporal extent for England and Wales, in terms of a) the degree (magnitude) of change in the SQI which significantly affects soil processes and functions (i.e. 'meaningful change'), and b) the change in the SQI that is detectable (i.e. what sample size is needed to detect the meaningful signal from the variability or noise in the signal). This constrains the design and implementation of a scientifically and statistically rigorous and reliable soil monitoring programme.

2.5 Introducing SQIs in new or existing monitoring schemes (e.g. as a new national monitoring scheme; as part of the Countryside Survey; and as part of the National Soil Inventory) is possible but the challenge is to decide whether carrying out soil monitoring that is not statistically robust is still valuable in answering questions regarding current and future soil quality.

2.6 Equally, harnessing new and existing soil data from the agricultural sector (e.g. through 'big data' initiatives such as Soil-for-life) using innovations in agritechnology would increase the sample size for some SQIs necessary for detecting a meaningful change. However, sampling design and data quality issues may be difficult to reconcile at present.

2.7 Given these issues, an alternative to tracking soil health would be to track its opposite: soil degradation. This is defined in the EU's Thematic Strategy for Soil Protection to include soil erosion, compaction, loss of organic matter and decline in biodiversity (EU, 2006).

2.8 Mapping the degree (magnitude and frequency) and spatial extent of these processes has been attempted for some of these threats (e.g. primarily for soil erosion), but often only for distinct geographical areas (e.g. Evans, 1990; 2005; Chambers et al., 1992). National coverage is only possible at present through modelling, due to lack of empirical data (e.g. Defra SP1609). Defra project SP1311 (Piloting a cost-effective framework for monitoring soil erosion) is currently evaluating a wide range of erosion monitoring and modelling methodologies to develop cost-effective monitoring of soil erosion.

2.9 National assessment of organic matter decline has been investigated by using samples from two monitoring schemes, with both indicating reduction over time under arable land use (Bellamy et al., 2005; Reynolds et al., 2013). However there is disagreement between the two studies regarding the rate of change in other land use types.

What are the benefits that healthy soils can provide to society?

3.1 The Foresight Report (2011) recognised that soils hold the key to sustainable land management. They are the basis for all land-based agricultural and bio-resource production systems.

3.2 Soils deliver a range of ecosystem goods and services, which affect human health and wellbeing and these are widely reported (refer to table below for a summary). The most apparent is agricultural production but soil also delivers less obvious services such regulation of water quality and quantity, nutrient cycling and climate.

3.3 There is a large diversity of soil types in the UK that enables a variety of functions and services to society. Soil is multifunctional and in many cases the soil at a specific location is delivering a range of services. Land management tends to enhance one specific service (the most widespread in the UK is food production) often to the detriment of other services.

3.4 Soil is central to the UK economy, generating an annual income of £5.3bn through agriculture (Defra, 2014)

Ecosystem goods and services delivered by soil	Examples
Provisioning of material goods and services	• Agricultural production (food, fibre, fodder, fuel) • Water storage and supply • Land for development (residential, industry, infrastructure) • Raw materials (e.g. clay, sand, peat)
Regulation of ecosystem processes	• Flood control (water storage and catchment flow regulation) • Carbon storage (CO_2 emissions; climate change

	mitigation) • Nutrient cycling
Cultural, non-material services	• Landscape aesthetic • Recreation / amenity spaces especially in urban environments • Protection of heritage archaeology • Indirect well-being and health benefits (physical and mental)
Supporting services	• Land-based habitats • Above and below ground biodiversity • Soil formation

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

4.1 Degraded soil compromises the delivery of key ecosystem services.
4.2 The costs of soil degradation in the UK have been estimated at between £0.9 billion and £1.4 billion per year, with a central estimate of £1.2 billion (Graves et al., 2011).
4.3 There is a serious threat to the competitiveness of UK agri-food industry arising from poor soil management practices that lead to soil degradation processes (e.g. erosion, compaction, loss of organic matter and declines in biodiversity). These processes impact negatively on crop yield (quantity, quality and reliability), with associated consequences for food security (Rickson et al., 2015). FAO estimate that c. 95% of all food comes from the terrestrial environment.
4.4 Soil degradation also contributes to adverse environmental impacts such as excessive run-off (due to compacted soils) leading to enhanced flooding risk and accelerated soil erosion. This can lead to pollution by agro-chemicals and fertilisers of public water supplies and thus have associated clean-up costs.
4.5 Loss of organic matter within soils has consequences for carbon sequestration (associated with mitigation of climate change), as well as nutrient cycling and soil biology which is the primary driver behind soil health (Professor Karl Ritz, pers.comm.).
4.6 Society demands that agri-food production systems operate in a sustainable manner with minimal impact on the environment. There is major concern amongst the industry, researchers, practitioners and regulators that inadequate and inappropriate management of soils has led to significant, possibly irreversible damage to this national resource.
4.7 We do not yet fully understand how resilient our soils are to long term perturbations (e.g. from continuous land use practices or climate change). Further work is needed to ascertain the pattern of response (e.g. tipping points v. linear or exponential decline) for some of our vulnerable soils and whether recovery is possible through intervention.
4.8 The impacts of soil degradation are amplified by the slow rates of natural soil formation. It is estimated that it takes between 200 - 1000 years to produce 2.5 cm of topsoil (on arable land; longer under pasture and forest conditions). Soil from weathering of bedrock alone takes approximately 10 times longer (Pimental et al., 1995). Therefore soil is essentially a non-renewable natural resource.

What measures are currently in place to ensure that good soil health is promoted?

5.1 Under Cross Compliance, GAEC 4; GAEC 5 and GAEC 6 relate to soil conditions, notably minimum soil cover, reducing erosion and maintaining soil organic matter (the latter specifically related to crop residue burning rather than OM management), but do not encompass all issues related to soil health.
5.2 These GAEC rules replace the Soil Protection Review (SPR). However, non-completion of the SPR was one common reason for failure of cross-compliance inspections (and thus fines for non-compliance). This raises uncertainty as to whether the GAEC approach is the most effective at implementing soil protection guidance.
5.3 Other governmental bodies have produced practical advice for soil management (e.g. Environment Agency Think Soils manual) but these have often been developed under umbrella schemes such as the Catchment Sensitive Farming initiative.

And what further measures should the Government and other organisations consider in order to secure soil health?

6.1 Reduce incentives that promote the intensive use of land and the use of land beyond its capacity to support key ecosystem services. Soils should be resilient so they have the capability and capacity to resist and reverse the damage caused by soil degradation processes.
6.2 Incentivise good soil management practices and offer subsidies / support for longer term views on soil management to ensure a profitable but sustainable farm business.
6.3 Good land management practices can include: appropriate land use within capability of the land (related to current soil type and quality (see SQI monitoring above) and/or state of degradation (see above) and slope gradient); agronomic practices for soil conservation (including cover and companion cropping, agroforestry); cultivation practices for soil conservation (including reduced tillage practices); and field engineering solutions (e.g. grass waterways, contour banks, etc.)
6.4 It is essential that soil health 'indicators' and interventions that ensure good soil health are practical, easy to implement and show tangible benefits to land managers. This is crucial for securing soil health as land management decisions are focused at the local level. However, regarding erosion control for example, the evidence base on the effectiveness of soil protection measures is limited (Rickson, 2014).
6.5 Enable policies that close the gap between financial (short term) pressures on agricultural businesses and longer term soil protection targets. Many measures for soil protection are long-term investments in the land, which should be rewarded through policy objectives.
6.6 Enable knowledge exchange and encourage innovation in farming so that systems thinking can be embedded into mechanisms that promote soil health.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

7.1 Soils are fundamental to the functioning of the natural environment. "*Soil sustains, regulates and controls biotic and abiotic processes [e.g. crop production] through its interactions with the biosphere, hydrosphere, atmosphere and lithosphere*" (Yaalon, 2000).
7.2 The Government response to the recommendation of a 25 year plan from the Natural Capital Committee states several focus areas in which soil health has a central role. It states "*Place us a world leader in using data, tools and techniques to understand, map and monitor the condition and value of our land, water, air,*

sea and wildlife, the benefits they give us and how they are changing". Soil data and tools necessary to monitor soil condition or health are central to this concept (e.g. previously discussed SQIs).

7.3 "*Identify our most important and threatened environmental assets, prioritising where investment in them will deliver the greatest benefits and identifying how that investment can best be secured*." As previously described, soil provides numerous benefits to society and underpins food and environmental security.

7.4 *"Focus policies on delivering better environmental outcomes*" Incentivising soil health through policy mechanisms will result in the reduction of land degradation processes and their negative impact on our natural capital.

7.5 "*The 25 year plan will initially look to address outstanding monitoring and data issues, so we can make better informed decisions about where strategic investments in natural capital are needed and what form these should take*." Monitoring soil health is essential to ensure the protection and continued delivery of ecosystem services that soils provide. These include supporting terrestrial habitats under both intensively managed and semi-natural systems.

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Written evidence submitted by Compassion in World Farming

1. How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

The Environmental Audit Committee's own webpage states: "Soil health cannot be measured directly, so indicators (physical, chemical, and biological properties, processes, or characteristics) are generally used. These measurable properties of soil or plants provide clues about how well the soil can function."

Adequate levels of soil organic matter are a 'key indicator' of soil quality and essential for maintaining soil fertility and structure.[1]

Organic matter is essential for good soil structure, for porosity, for infiltration of water and holding water, and production of nutrients. It is contained within topsoil, which also contains plant nutrients, mainly nitrogen, phosphorus and potassium.[2]

The threats to soil quality include:

- erosion by water and wind: In many countries the rate of erosion is many times greater than the rate of topsoil formation.
- compaction
- loss of nutrients
- loss of organic matter
- salinisation
- agrochemical pollution

Soil degradation has always been a risk in agriculture because the process of cultivation involves uncovering the soil and the subsequent crops depleting nutrients and organic matter. A recent study concludes that "modern agriculture, in seeking to maximize yields ... has caused loss of soil organic carbon and compaction, impairing critical regulating and supporting ecosystem services".[3] It highlights "the extent to which modern agricultural practices have degraded soil natural capital". The study found that urban allotments have better soil quality than UK agricultural land.

According to the FAO's Plant Production and Protection Division in 2009, "In the name of intensification in many places around the world, farmers over-ploughed, over-fertilized, over-irrigated, over-applied pesticides." [4]

Industrial livestock production is a primary factor in the intensification of crop production and the subsequent decline of our soils. It is dependent on feeding human-edible cereals to animals which they convert very inefficiently into meat and milk. To meet the demand, more land is put into continuous cereal production, requiring applications of artificial mineral fertilisers rather than more sustainable methods of restoring soil fertility such as crop rotations and growing nitrogen-fixing legume crops. This has eroded soil quality.

If the quantity of crops needed as animal feed were reduced, arable land could be farmed less intensively. This would enable the quality of agricultural soils to be restored by methods such as the use of rotations, legumes, fallow periods, green manure and animal manure.

Big reductions in meat and dairy consumption are vital if we are to bridge the gap between current pledges to cut GHG emissions and the much bigger decrease needed to deliver the Paris target. The Paris Agreement requires countries to do all they can to store carbon rather than letting it escape into the atmosphere. Actively-managed (well-managed) pasture is an excellent way of storing carbon.[5] The Agreement also encourages Parties to reduce emissions from deforestation and to protect biodiversity.

A reduction in meat consumption in the developed world would free up land for more sustainable cropping practices such as legume rotations. Livestock farming should focus on pastures and integrated rotational crop-livestock systems as these build soil quality which allows huge amounts of carbon to be stored. However, we must not expand our pastures as this too would cause deforestation.

2. What are the benefits that healthy soils can provide to society?

"***Man's continued existence is completely dependent upon six inches of topsoil and the fact that it rains***": concept attributed to Confucius

A 2015 POST note points out that "Protecting soil presents an opportunity to address simultaneously several global challenges such as food security, climate change, water security, waste management and biodiversity loss."[6]

Fertile soil is needed to produce good crop yields. Soil organic matter is a key component of good soil; it builds fertility and sequesters carbon, helping to reduce greenhouse gas emissions. The organisms in soil organic matter (such as earthworms, spiders, mites, bacteria, fungi) decompose plant residues, turn them into humus, and distribute this fertility-giving substance throughout the soil.[7] Soil with plentiful organic matter is able to retain water thereby preventing flooding and mitigating droughts.

3. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

We all share the responsibility of protecting the world and its scarce resources and using them wisely. The consequences of failing to protect soil health are serious. The Natural Capital Committee's third report points out that "farming can produce large external costs to society in the form of greenhouse gas emissions, water pollution, air pollution, habitat destruction, soil erosion and flooding".[8]

Environment and climate change

Our soils have degraded over the last 200 years due to intensive agricultural production and industrial pollution. [9] Soils in England continue to face three main threats:

• Soil erosion by wind and rain. Erosion affects both the productivity of soils but also water quality and aquatic ecosystems.
• Compaction of soil, which reduces agricultural productivity and water infiltration, and increases flood risk through higher levels of run off.
• Organic matter decline. The loss of soil organic matter reduces soil quality, affecting the supply of nutrients and making it more difficult for plants to grow, and increases emissions to the atmosphere. [10]
The ‘4 per 1000’ initiative on soil protection explains: “Even small changes of the soil carbon pool have tremendous effects both on agricultural productivity and on global greenhouse gas cycle.” [11]

On erosion, the European Environment Agency (EEA) says, “Given the very slow rate of soil formation, any soil loss of more than 1 tonne per hectare per year can be considered as irreversible over a time span of 50-100 years. Water erosion affects 105 million hectares (ha) of soil or 16% of Europe's total land area, and wind erosion 42 million ha.”[12]

It is estimated that 2.2 million tonnes of top soil is lost every year costing British farmers £9 million in lost production.[13]

According to the European Commission, “45% of European soils face problems of soil quality, evidenced by low levels of organic matter”.[14]

The use of chemicals, particularly synthetic N fertilisers, has enabled farmers to abandon sustainable methods of ensuring soil quality (such as legume rotations, fallow periods and animal manure) and move to intensive and continuous cropping of cereals on soils that are kept going by larger applications of synthetic N and other agrochemicals.

Much of the N fertiliser is used on animal feed crops. Thus industrial livestock production entails nitrogen loss at 2 stages:

- During growing of crops to feed the animals
- During consumption of concentrate feed by animals

The nitrogen that is not absorbed by feed crops and then by the animals pollutes the environment; for example, it is washed into rivers and lakes and leaches from the soil into groundwater, contaminating sources of drinking water and damaging aquatic and marine ecosystems.

Nitrogen use efficiency is low for meat and dairy products (5-30%) as compared with plant-based commodities (45-75%).[15]

Biodiversity

25% of world’s biodiversity is found in the soil, and ample soil biodiversity is a key contributor to soil quality.

Soil organic matter contributes to soil biodiversity, which is an essential component of soil quality. A recent study has concluded that intensive agriculture reduces soil biodiversity.[16] One of the four European regions covered by the study is southern UK. The study stresses: "Given that the loss of soil biodiversity is ultimately linked to a loss of soil functions that underpin ecosystem services, we propose that future agricultural policies need to consider how to halt and/or reverse this loss of soil biodiversity".

Research shows that soil biodiversity is under threat in 56% of EU territory with intensive agriculture being a key factor in its loss.[17] Globally, approximately 33% of soils are facing moderate to severe degradation.[18]

A Defra study shows that by 2013, the UK breeding farmland bird index had fallen by 55% to a level less than half that of 1970. It adds that there has been a statistically significant on-going decline of 10% between 2007 and 2012.[19] Defra's study states that many of the declines in farmland birds "have been caused by land management changes and the intensification of farming".

There has been a marked decline in pollinating insects including bees in the UK and elsewhere.[20] A POST note briefing states that intensive farming has resulted in a significant loss of habitats; it points out that the resultant loss of food and nesting resources for pollinators - together with the use of pesticides and monocultures - has been a leading driver in wild pollinator declines. [21]

On soil biota, the EEA says, "Intensification of agriculture poses threats not only to biodiversity *on* farmland, but also to biodiversity *in* farmland soil. The total weight of microorganisms in the soil below a hectare of temperate grassland can exceed 5 tonnes — as much as a medium-sized elephant — and often exceeds the above-ground biomass. These biota are involved in most of the key soil functions." [22]

Food insecurity

The use of land to grow cereals for farm animals, most of whom are confined in industrial systems, promotes risk of food insecurity. It is argued that the quality of a proportion of the cereals fed to livestock is not suitable for direct human consumption. However, Defra statistics show that on average 52% of UK cereals (wheat, barley, maize, oats) are used as animal feed. Is it really the case that the entire 52% would not be suitable for direct human consumption?

Some argue that expansion of cropland can be avoided by intensification of existing cropland. However, increased production often has an adverse impact on soil quality.

Increased reliance on intensification and agri-tech risks exacerbating soil degradation as these are among the factors that gave rise to the problem in the first place. Indeed, not only may they harm soil quality but they may also undermine the very element they are intended to promote: productivity.

4. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Good practices should be integral to CAP payment rules and poor practice should be penalised.

Activities such as soil mapping and soil assessment by farmers, state- or EU-funded environmental measures such as low- or no-tillage and incorporation of crop residues into the soil (rather than removing them), avoiding ploughing vertically on slopes, etc., have probably led to improvements or stabilization of soil quality and should be encouraged.

Long term studies over 15 years at the Rodale Institute in Pennsylvania show that the use of legumes (green manure) or cattle manure for fertilisation results in the soil retaining more carbon (organic matter) and more nitrates. [23]

We believe the logical way to restore soil quality is not by intensification and agri-tech but through the use of factors such as rotations, legumes, fallow periods, green manure and animal manure, the latter matched to the land's ability to absorb it.

A nutritious diet, with a large reduction in meat consumption in high-consuming populations, would bring benefits for public health, the environment, food security, resource use, biodiversity and animal welfare.

Activities such as Soil Farmer of the Year,[24] World Soil Day (December 5) and World Meat Free Day (15 June),[25] can be used to raise awareness of the measures we can take to protect our soils.

5. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil health should be recognised for its central role in Government plans for the natural environment.

At a meeting launching the Government's 25 year plan on food and farming, we were told that the environmental impacts of farming would be addressed in a separate environmental policy that is being developed. Farming has a number of impacts on natural resources – including of course soil – while at the same time being dependent on those resources in order to be able to be productive. In our view a food and farming plan must take into account the inter-connected facets of environment, dietary health, and farm animal welfare. Defra should abandon its plan to produce two separate 25 year plans – one on food and farming, the other on the environment. Instead it should produce an integrated plan on food and farming that incorporates the environmental needs and impacts of farming into the plan. Developing two separate plans risks the production of a food and farming plan that puts its emphasis on increasing productivity while largely ignoring the detrimental impact of this on the natural resources on which farming depends. In the long term this will undermine farming's productivity.

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Written evidence submitted by the Anaerobic Digestion & Bioresources Association (ADBA)

I am responding on behalf of the Anaerobic Digestion & Bioresources Association (ADBA) to the House of Commons Environmental Audit Select Committee's request for written submissions on measures to improve the UK's soil health.

The committee will be aware of a recent Parliamentary Office of Science and Technology report that outlines how soil degradation is costing the UK £1.4 billion each year. The report notes that there is no UK wide monitoring of changes in soil health, highlighting how the issue has largely been ignored by government.

The biofertiliser produced from recycling organic material such as food and farm wastes, manures and slurries, and sewage through Anaerobic Digestion (AD) can be used instead of the expensive, carbon-intensive alternatives. Known as "digestate", this biofertiliser helps maintain pH and soil fertility; improving soil quality, crop yields and the availability of nutrients (principally including nitrogen, potassium and phosphorus) whilst, significantly, also replacing the organic matter component.

Anaerobic digestion also helps make break, catch and cover crops economic for farmers, while maintaining and enhancing biodiversity. Such crops can help tackle the spread of blackgrass and nematodes, reducing the need to use pesticides. By incorporating crops for AD into their rotations, which can increase subsequent yields of food crops, or on unproductive marginal land, the technology improves overall soil health and subsequent food crop yields.

Currently, however, AD plants are supported for the energy they produce but do not get recognition for the huge contribution that the technology makes to UK soil health and food security. Despite the fact that digestate can be enriched to compete in quality with peat, operators get little value for the digestate that they produce and limited R&D support to develop new commercially viable means of enhancing digestate.

While AD has a substantial role to play in improving the UK's soil health, it also: generates valuable baseload energy; decarbonises heat, electricity, farming and transport; improves farming business resilience; and supports over 4,000 jobs. By tapping into readily available organic resources, such as farm and food wastes, AD has the potential to supply nutrients worth £200m, while reducing the carbon footprint of farming and food production.

We would be happy to assist the committee with its inquiries however we can.

January 2016

Written evidence submitted by the National Farmers' Union (NFU)

Introduction:

The NFU represents more than 47,000 farming businesses in England and Wales and, in addition, some 40,000 countryside members with an interest in the countryside and rural affairs. The NFU welcomes the opportunity to submit a response to the Environment Audit Committees inquiry into soil health.

The NFU's response to the questions posed by the environment audit committee can be summarised as follows:

- The diverse range of soil types across England mean there is no single indicator to track soil health;
- It is vital that flexibility is maintained in the techniques available for farmers to sustain and improve soil health. This enables farmers to make informed decisions on the best ways to manage soils, taking into consideration the local soil and climatic conditions;
- The maintaining of soil health is required to feed the UK's growing population, as well as to increase resilience to future extreme climatic events such as flooding and drought;
- A diverse range of legislation and voluntary initiatives are in place for the protection of soil health. The NFU endorses voluntary schemes such as the Campaign for the Farmed Environment and Tried and Tested;
- Soil protection should form a vital part of the government's 25 year plan for the natural environment as well as the government's 25 year food and farming plan.

1. *How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?*

Measuring Soil Health.

Many biotic and abiotic parameters can be measured to give an indication of soil health. Common variables measured include: nutrient content- the primary nutrients monitored are different forms of nitrogen, phosphorus and potassium as well as 'micronutrients' such as sulphur, magnesium, cadmium, iron, aluminium and zinc; organic matter content; carbon content; acidity; cation exchange capacity; texture (distribution of particle sizes); permeability and compaction.

Soils are also host to very diverse and complex ecosystems; however uncertainty remains regarding the function of many of these organisms and subsequent impact on soil health. Some species such as Nemotodes (earthworms) are known for breaking down organic matter and reducing soil compaction, whereas nitrogen-fixing bacteria in the rhizosphere (root zone) work in a symbiotic relationship with the host plant organism to fix this vital nutrient required for plant growth. However, for many species, abundance or diversity has rarely been directly linked to soil health.

Soil health can also be interpreted differently by different stakeholders, for example some regard carbon content as a vital parameter to measure a soil's ability to mitigate against future climate change. However soil health can also be determined through its ability to produce food to feed the UK's growing population. In the UK, the Agricultural Land Classification grades land from 1-5:

grade 1 is excellent agricultural land with no or very minor limitations to agricultural use. Grade 5 is very poor agricultural land that is primarily limited to rough grazing or pasture.

Future Strategy for Tracking Soil Health:

The pedological and climatic variations in the UK mean that there is no one parameter or technique which can be used to track improvements in soil health. Future tracking of soil health must consider the wide range of variables which affect soil condition, and consider that no single method or panacea solution is available to improve soil health. Consequently, we would warn against using a single indicator as a measure of soil health and it is vital that farmers and growers remain able to make informed decisions about the best way to manage their soils.

Sampling remains key to understanding changes in soil health. Approximately 75% of farmers undertake soil sampling at least every 5 years[1]. This information can assist in varying application rates of fertilisers to land depending upon the nutrient index. Consideration must be given with any sampling to the time of year and depth at which the samples are taken as this greatly impacts on nutrient availability and other soil parameters.

2. *What are the benefits that healthy soils can provide to society?*

The benefits which healthy soils can provide to society are well documented. Soils are considered a farmer's most important asset for food production and maintaining a healthy environment. They also act to mitigate against and increase resilience to future climate change, act as a store for water, reduce loss of pollutants to water and enhance biodiversity.

3. *What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?*

In urban areas, activities such as new housing developments can cause significant amounts of erosion. The resultant deposition on roads can have an impact on local amenity and cause significant pollution events to local surface watercourses. Development on land can also contribute to loss of land or 'soil sealing'.

Other consequences of failing to protect soils are the opposite of the answers to question 2. The UK has more established, better structured soils than in other parts of the world, partly due to the UKs more temperate climate. Therefore, whilst soil management is vital, erosion rates, and the risks of the negative consequences of not protect soil, are less than in many regions of the world.

4. *What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?*

Current UK legislation and European Directives in relation to soil health:

Common Agricultural Policy (CAP):

In 2015, new soils cross compliance standards were introduced under CAP. All farmers eligible for funding from the Basic Payment Scheme (BPS) have to comply with three Good Agricultural and Environmental Conditions relating to soil management. These are summarised as:

- GAEC 4- Protecting soil by establishing a minimum soil cover unless there is an agronomic justification for not doing so;

- GAEC 5- Ensuring measures are put in place to minimise in-field and bank-side erosion;
- GAEC 6- Maintaining soil organic matter content through appropriate practices. This includes the prohibition of burning cereal straw, stubble or certain crop residues, except for plant health reasons.

Nitrate Vulnerable Zones (NVZs):

Nitrate Vulnerable Zones are designated as areas where nitrate concentrations within watercourses are at, or are at risk of exceeding 50mg/l. NVZs currently cover 58% of the UK and stipulate a maximum application rate of organic fertiliser to land with a high readily available nitrogen content. The legislation requires applications to land to consider crop requirements through nutrient management plans which refer to soil condition and nutrient status.

Water Framework Directive (WFD):

The Water Framework Directive requires all waterbodies to be at good ecological status by 2027. Soil management is required under the conditions of the WFD, because water quality is directly related to soil protection and erosion.

Catchment Sensitive Farming is an initiative that aims to help achieve Water Framework Directive's outcomes. Catchment Sensitive Farming provides practical advice and support for farmers and growers alongside raising the awareness of how to reduce diffuse pollution from agriculture. Support to farmers is delivered through practical workshops, demonstrations, farm walks and events giving training for the protection of water.

Waste Framework Directive:

The Waste Framework Directive provides the legislative framework for the collection, transport, recovery and disposal of waste. This includes the regulation of the application of waste products, such as composts or digestates, on agricultural land. The Directive ensures that any waste product applied to land provide agronomic benefit and does not endanger the environment within which it is used. This includes controls on the maximum application rates of waste, as well as controls on storage and timings of applications. This is particularly important to soil management as incorrect application of waste products can adversely affect soil health and quality.

Voluntary initiatives currently undertaken by farmers:

Farmers are involved in a large variety of voluntary schemes to maintain and improve soil condition. These highlight how local knowledge is vital in deciding the best way to manage the land; and that whilst these voluntary measures are widespread, there is no one-size fits all solution which will improve the condition of all soil types across the country.

Campaign for the Farmed Environment:

In 2014, 72,000 hectares of land was put into voluntary soil protection measures under the Campaign for the Farmed Environment (CFE). These measures included in-field and riparian buffer strips, maize management and winter cover crops using seed mixes with a diverse range of root lengths to reduce soil compaction. Many other voluntary initiatives are implemented on a wide-scale to improve soil condition including *Tried and Tested* and the *Voluntary Initiative*.

Nutrient Management:

Between 2000 and 2013, inorganic nitrogen fertiliser applications to land reduced by 18% and phosphate applications by 36%[2]. This change demonstrates a continued downward trend in the use of inorganic fertilisers as farmers and growers strive to use optimum quantities of inorganic fertilisers which match crop requirements. In 2015, 76% of England's farmed area was included within a nutrient management plan[3]. These figures show how farmers and growers are achieving the fine balance of applying the required nutrients to maximise productivity to feed the UK's growing population, whilst reducing over-application which could impact on ground and surface water quality.

One of the most recognised nutrient management systems is RB209. This document has been produced by a steering group containing leading soil research stations in the country including Rothamsted and the Scottish Agricultural College and main industry users such as the National Farmers Union. It provides reliable information on how to determine the nutrient index of phosphate (P_2O_5) and potash (K_2O) as well as estimate the soil nitrogen supply. This can be used in combination with extensive guidance to determine the recommended applications of different nutrients to land, dependent upon soil type, climate and the following crop.

This soil management plan, as well as others such as PLANET and MANNER, provides guidance which we believe Defra should continue to endorse. It takes into consideration how varying climatic and pedological conditions will vary requirements for nutrient application and soil management.

Precision Technology:

Technologies such as variable rate spreaders are also contributing to reduced applications of artificial fertilisers. Variable rate spreaders use Global Satellite Position (GPS) technology to locate the spreading machinery. Resultantly the fertiliser application rate can vary depending upon the nutrient status of the parcel of land.

Farmers are increasingly using minimum and no-tillage technology. Minimum-tillage cultivates land at a shallower depth compared with ploughing. No-tillage technology does not disturb the soil after harvest; instead the new crop is drilled directly into the soil. These technologies increase soil organic matter content in the top layers of the soil; however it is still not certain whether they increase soil organic matter content across the whole of the soil profile. Time is also saved through minimum or no-tillage due to a reduction in traction. However the success of minimum or no-tillage depends upon weather and current field conditions.

The NFU, as a member of the UKs Greenhouse Gas Action plan, undertook a survey in partnership with the National Association of Agricultural Contactors (NAAC). The survey asked contractors about the types of precision machinery they possess. Of those surveyed over 90% owned some form of minimum tillage equipment, with 50% possessing no-till equipment. Therefore these types of technologies are increasingly readily available for all farmers and growers.

Links between Practitioners and Academics:

During the 2015 *International Year of Soils* the NFU published a number of case studies on NFU online demonstrating the range of good soil management practices employed by NFU members. They represented how the voluntary initiatives mentioned above are widely utilised by all sectors.

To secure future health it is vital that the government and other organisations work to increase the links between practitioners and the academic community. During the international year of soils, the NFU co-organised an event, in partnership with the Game and Wildlife Conservation Trust (GWCT) and LEAF, hosted at Rothamsted's North Wyke research station. This provided an opportunity for over 60 farmers, academics and industry representatives to discover more about the work at the research station to improve grassland soil management.

5. *What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?*

The government's response to the Natural Capital Committee's third State of Natural Capital report[4] stated that a 25 plan for the natural environment must be produced to increase resilience to future pressures such as climate change and population growth. Maintaining soil quality will play a fundamental role in achieving these objectives. The NFU believes that the plan's aims can be achieved through:

- Ensuring that flexibility is retained in the soil management options available to farmers that do not contradict aims to develop rural businesses and feed a growing population;
- Protecting soils as a farmers most important asset which can increase resilience to future climate change;
- Utilising soils as one method out of many to mitigate against future climate change;

Given soil quality and health is of fundamental importance to food productivity and production, we believe that soils must also be referred to in Defra's Food & Farming Plan.

Increasing UK food production productivity and self-sufficiency:

The UKs population is expected to exceed 77M by 2050[5]. Productivity will need to increase to feed the UKs growing population, boost rural economies and increase UK self-sufficiency in food production. This includes maintaining soil quality and fertility as a farmer's most important asset for growing food. However there is no 'one-size fits all' solution to soil protection; and it is vital that options remain available for farmers to make informed decisions about how best to manage their land.

Some areas of land are suitable for current Countryside Stewardship options such as reduced nitrogen applications, these options remain vital to farmers to improve water quality and biodiversity. However consideration needs be given to the fact that more productive areas of land must remain available for food productivity to feed the UKs growing population. There is scope to increase the number of options under Countryside Stewardship which focus on improving soil condition and health to sustain or increase food production. This would enable farmers to take action to improve soil conditions to improve the environment and retain or increase productivity.

Resilience to future climate change

Summer mean temperatures are predicted to increase by 0.5-2.5 degrees Celsius and precipitation to either drop by 10% or increase by 25%[6]. Soils will need to be resilient to increasingly unpredictable and extreme climatic conditions such as flooding and drought. Actions such as cover cropping and maintaining organic matter in the soil profile reduces compaction and can increase infiltration rates ensuring the soils are more resilient to flooding events. Conversely on sandy, free-draining soils in parts of the country where rainfall is lower (such as Southern and Eastern parts of the UK), organic matter can lead to an increase in the water holding capacity of the soil.

These options need to remain available under schemes such as countryside stewardship and the Campaign for the Farmer Environment, to support farmers protecting soils to increase resilience to future climate change.

Mitigating against Future Climate Change:

Agricultural emissions have reduced by 22% since 1990[7]. The changes have derived from matching applications of fertilisers to land with crop requirements, reducing crop burning and increasing efficiency in animal feed. These reductions have also arisen from increases in the accuracy of data into Greenhouse Gas Emissions from different land uses in the UK. It demonstrates that the government must support increasing data collection into these areas to have a fuller understanding of agriculture's and other industry's relative greenhouse gas emissions.

Using soils as a method to mitigate against future climate change is only one of many options available, and uncertainty remains regarding the level of carbon uptake different soil management techniques provide. However in some parts of the country, organic matter content increases could act to improve soil condition and act as a carbon pool. However this is only appropriate in circumstances where soils have lower organic matter content which would benefit from the addition of organic matter to increase the water and nutrient retention capacity.

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January 2016

Written evidence submitted by the Technical Committee of the Landscape Institute

The responses below are largely in relation to soils that are used within designed and built landscape environments.

How could soil health be best measured and monitored?

Before this question can be answered, the definition of ‘soil health’ needs to be clarified. Is it ‘functional health of soil’ noting that soil is multi-functional and that the specific individual functions of soil may be affected by individual aspects of a particular soil (i.e. physical, chemical and biological soil properties, processes or characteristics). One facet of a particular soil may make it ‘healthy’ from a biological point of view, but that very facet may make it ‘unhealthy’ from a geotechnical perspective (for example).

The definition should be clarified, recognising the multi-functional role soil plays (and that soil is potentially valued in respect of ecosystem services as well as more obvious ‘services’ e.g. to support valuable crop growth). Additionally clarifying relationship of the work to soil-forming materials, soil ameliorants and artificial growing media would be useful.

How could the Government develop a strategy for tracking soil health?

As recognised in the Soil Health Inquiry documents, soil health can be measured by various indicators, such as physical, chemical and biological soil properties, processes or characteristics. These are *direct* indicators of soil health.

There are also *indirect* indicators of soil health, such as the health of the plants (individually and as plant communities (trees, shrubs, grass, wildflowers etc.)) growing in the soil, or the ‘playability’ of a sports pitch, or the performance of a swale or rain garden within a SuDS environment. These can also be used, although they are not always as accurate, as other non-soil related factors can also influence.

The specific properties, processes or characteristics that are selected to assess soil health will depend on the particular soil *function(s)* being assessed. For example, physical soil properties (soil texture, bulk density, water-holding capacity and permeability) would be relevant where a soil’s water attenuation and filtration potential is of primary importance. Likewise, where biodiversity is the main indicator, certain chemical and biological properties may be more relevant (e.g. soil organic matter/carbon, overall soil microbe populations and individual species numbers, presence/absence of target soil fauna/flora and plant flora diversity). Metagenomics and eDNA will potentially have an important future role in quickly/easily determining the biodiversity of a soil and samples could be collected without specialist knowledge, such that ‘citizen science’ techniques could be employed (see below*), warranting further examination as part of the Soil Health Inquiry.

To be of most use, measurement of soil health ‘parameters’ (direct indicators) needs to be undertaken on a regular basis (every 4-5 years). Initial baseline readings must be established first, and then subsequent assessments should be carried out at the same locations and at the same time of year to ensure comparable results. A period of 4-5 years is a compromise period that would allow sufficient time for changes of soil management (for example) to be translated into the follow-on effects (positive or negative), e.g. in relation to vegetation communities supported, crop yields obtained or number of flood event occurrences, whilst providing for an adequately short ‘reaction time’ to rectify most non-emergency issues.

It would be beneficial for a standard basis for comparison of data across the country to be established to allow reviews of the success of policy changes etc. to made on a regular basis This would allow the health of our soils, *as a whole*, across the country to be monitored (including aspects such as soil erosion), providing evidence for the success or failure of particular initiatives, policies, legislation etc. *Citizen science techniques could employed for this purpose.

The mechanisms for prompting such measurement and monitoring need firstly to look at current practices within the environmental sector to see if they are already being undertaken, in some shape or form, or whether existing surveys could be expanded. Such baseline data may already be available, and on-going monitoring may already be underway in some circumstances. For example, The Royal Parks has undertaken series of soil studies to primarily assist with the management of different habitats within the parks http://www.hortweek.com/soil-surveys-inform-royal-parks-ongoing-land-management-reveal-unexpected-insights/parks-and-gardens/article/1354592. On other occasions, on-going ecological or arboricultural studies could be expanded to also cover relevant soil parameters.

Where no such information or initiatives are available, a bespoke soil health strategy will need to be designed and implemented.

What are the benefits that healthy soils can provide society?

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The benefits of healthy soils to society are closely related to the many *functions* that soil fulfils. In the built environment, soils are generally present at the land's surface in the form of public open spaces and parks, gardens and allotments, derelict land, roadside verges, playing fields and wetlands. In these environments, soils carry out, to a greater or lesser degree, a number of functions and services for society. These are:

- **Landscape**: supporting the plants growing in the soil and influencing varying characteristic plant communities, other topographical features and land-uses and across the country.
- **Support of ecological habitats and biodiversity**: soil fungi, bacteria, macro-organisms and the birds, insects etc., which rely on the plants for food and protection.
- **Environmental interaction**: including the exchange of gases with the atmosphere, sequestration of carbon, regulating the through-flow of water and the degradation, storage and transformation of soil organic matter and nutrients, wastes and contaminants deposited by human activities.
- **Providing water attenuation and filtration**: acting as a natural reservoir for billions of cubic metres of water and is a key component of SuDS.
- **Providing a platform for construction**: providing geotechnical strength and support.
- **Protection of cultural heritage**: soils may cover the remains of buildings, burials and other archaeological features and include a variety of artefacts and other materials resulting from human activity.
- **Production of food** (which, in the urban environment, is largely limited to vegetable growing in allotments and gardens).

The consequences of failing to protect soil health will have an impact on its functions, so in turn will reduce the important *services* it provides society and the environment. For example, a deterioration in soil health due to *compaction* will reduce the soil's ability to *attenuate surface water inputs and flows* and thereby increase the risk of flooding, at that location or downstream. Reduced soil quality by excessive salts (e.g. from road salt) or high pH may reduce its ability to support favoured plants and ecological habitats, which may in turn affect the ability of a protected faunal species of conservation concern to survive at that location. The cumulative and indirect consequences, on people (society) and the wider environment, of changes to soils, must be considered in addition to the specific localised effects of changes to soils (themselves) through inadequate protection.

Soils also have a large social function, through providing the basis for public open space, gardens, and playing fields. These provide cultural and social benefits that include increased well-being, physical and psychological health, and connection with nature. This is demonstrated by the popularity and high use of parks and other open space with in our towns and cities. This is recognised within many new developments, where a proportion of developable land has to be green space, and much of this is for public use - where such spaces perform well and cater for the needs of the community, they add value to society. However, a loss in soil quality that results in a deterioration of these green spaces and sports facilities has negative repercussions for the wider society, with increased crime and unsocial behaviour.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

There are a number of *guidance* documents within the landscape, construction and sports amenity sectors that promote soil protection and encourage better soil health. When this guidance is implemented, within new and existing landscape schemes, the health of the soils is generally better. However, as there is no legal requirement to adhere to the practices set out in such guidance, there is a risk that poor soil design, management and protection often occurs. Mechanisms for legislating better soil management practices within the industry, for example, through the planning system and Local Authority targets, would help the situation.

A *selection* of examples is listed below:

- **Defra** - *Construction Code of Practice for the Sustainable Use of Soils on Construction Sites* https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69308/pb13298-code-of-practice-090910.pdf

- **Sport England** - *Natural Turf for Sport* https://www.sportengland.org/media/30865/Natural-turf-for-sport.pdf

- **British Standards Institute** – *British Standard for Topsoil BS3882:2015* and *British Standard for Subsoil BS8601:2013*

- **Trees & Design Action Group** - *Trees in Hard Landscapes : A Guide for Delivery* http://www.tdag.org.uk/trees-in-hard-landscapes.html

- **Ciria** - *SuDS Manual* http://www.ciria.org/Resources/Free_publications/SuDS_manual_C753.aspx

Defra - *Construction Code of Practice for the Sustainable Use of Soils on Construction Sites*

Some of the most significant impacts on soils occur as a result of activities associated with construction, yet there has been a general lack of awareness and understanding of this need within the construction industry. This was recognised by Defra who subsequently published in 2009 the *Construction Code of Practice for the Sustainable Use of Soils on Construction Sites*. The Code was developed to assist anyone involved in construction projects, from the developer, designer, contractor, sub-contractor (earthworks, landscape) and regulator, to better protect the soil resources.

Where the guidance from this document has been implemented, soil quality and health have been improved. However, the Code is still not widely used within the planning and construction sector. The Code needs to be publicised more and used more by planners, regulators, designers and contractors. Similarly, previous guidance specific to reclamation of minerals sites has now been archived and not replaced. Provision of such sector-specific guidance should be reinstated for the same reasons. The Code also needs to be considered and cross-referenced more with other 'soil management' guidance and regulation, such as the *CL:AIRE Definition of Waste: Development Industry Code of Practice (DoW CoP)* *http://www.claire.co.uk/index.php?option=com_content&view=category&id=977&Itemid=330*. It could also do with up-dating as some of the supporting information is a little out of date.

Sport England - *Natural Turf for Sport*

Within the sports and amenity sector, which accounts for a substantial amount of land within the built environment, Sport England promotes good sports pitch quality, and in doing so, better soil quality and function. As a consultee for many planning applications, and a major route for funding for sports projects (e.g. schools, clubs and Local Authorities), Sport England effectively ensures that the quality of playing fields is improved and their status protected. Sport England has also published a widely used and useful document *Natural Turf for Sport*, which offers up-to-date guidance to designers and contractors on how to achieve and maintain good soil quality.

Validation Testing

There is an increasing requirement for soils in new soft landscape areas to be *validated* for contamination. This is particularly the case within the housing sector, but also extending to other types of developments, such as parks, playing fields and commercial sites. It is common practice as part of any development's *remediation strategy* to confirm that the soils in the new development are sufficiently 'uncontaminated' for the proposed end-use. This system of checking soils is now widespread throughout England and Wales, and as a consequence, has improved the quality of soils used within the built environment.

However, 'contamination' is only one aspect of 'soil health' and 'soil quality', and other important soil properties (e.g. organic matter, fertility, permeability and compaction) are not being assessed. The soils are often still left in a poor state after construction, and it has an impact on overall soil function. One means of improving this aspect of soils in the built environment would be to *extend* the current system to encourage overall soil quality to be assessed at the same time as determining contamination levels.

What role (if any) should soil health play in the Government's upcoming 25-year plan for the natural environment?

Soil, Water and Air are three main elements of our natural environment. Each of these elements affects each other and therefore soil health cannot be ignored when considering a wider plan for the natural environment. Soil health is a key indicator of the ‘present’ as well as the ‘future’ health, function and security of the natural environment.

January 2016

Written evidence submitted by the Committee on Climate Change

1. The Committee on Climate Change (CCC) was established under the 2008 Climate Change Act. We advise the Government on carbon budgets and report to Parliament annually on progress towards meeting the 2050 target of an 80% reduction in UK greenhouse gas emissions. The Adaptation Sub-Committee (ASC) of the CCC advises the Government on the risks from climate change and reports to Parliament every two years with an independent assessment of the progress being made with preparing the UK for a changing climate.

Importance of soils

2. The depth, volume, amount of organic matter, and quality of soil, are all of critical importance for the productive capacity of agricultural land. Erosion and loss of soil organic matter reduces yields and imposes additional production costs such as increasing the need for fertiliser or irrigation.

3. Soils are also of critical importance for both climate change mitigation and adaptation:

- **Carbon storage and GHG emissions** - an estimated 10 billion tonnes of carbon are stored in UK soils. This dwarfs the 0.2 billion tonnes stored in UK vegetation. Where soils are degraded, a proportion of the stored carbon is emitted to the atmosphere as CO_2. Nearly 4% of UK greenhouse gas emissions in 2013 were due to losses of soil carbon – a total of 22.5 million tonnes CO_2 equivalent. [1] These emissions were higher than for many industrial and energy sources, for example petroleum refining (14.7 $MtCO_2e$), concrete production (6 $MtCO_2e$) and the chemical industry (5.2 $MtCO_2e$).
- **Water attenuation** - UK soils store an estimated 130 trillion litres of water, much more than are contained in all the UK's lakes and rivers combined. Soils in good condition help to slow the water cycle through infiltration of rainwater, and so play an important role in managing flood risk. Degraded and compacted soils can have the opposite effect, exacerbating flood risk by increasing the speed of rainwater run-off and silting up rivers.
- **Water quality** - soil erosion and loss of carbon has adverse impacts on water quality. Around 5% of rivers, lakes and estuaries in England do not currently meet good ecological status due to sedimentation. High carbon content in drinking water supplies can also create carcogenic by-products that can potentially make the water unfit for human consumption.

Risks to soils from climate change

4. Soils are highly sensitive to climatic conditions. Projected increases in rainfall volume and intensity are likely to change soil weathering rates and increase susceptibility to water erosion. At the same time, reduced soil moisture content and increased aridity as a result of higher average temperatures and changes in rainfall patterns will make soils more vulnerable to wind erosion and lead to an increased demand for irrigation. Sea-level rise will increase brackish water encroachment on lowland coastal areas, leading to soil salinization.

5. Warmer and drier conditions in the future are likely to accelerate the decomposition of organic matter and so exacerbate losses of soil carbon. This could have implications for the viability of upland peat habitats, especially blanket bogs. Some models suggest that the area of suitable climate for peat forming vegetation in the uplands could decline in extent by between one-half and two-thirds by the 2050s. However, paleo-ecological evidence stretching back over 9,000 years shows that peat forming vegetation has adapted to warming periods in the past. This suggests that when peat habitats are in a

[1] Total UK GHG emissions in 2013 were 570.5 $MtCO_2e$. Emissions of $CO_2$from soil carbon losses are recorded in the Land Use, Land Use Change and Forestry (LULUCF) section of the UK GHG Inventory and breakdown as follows: 12.4 $MtCO_2$ from croplands, 3.5 $MtCO_2$ from grasslands and 6.1 $MtCO_2$ from development. In addition to emissions from soil carbon losses, some 20 $MtCO_2e$ is emitted from the way soils are managed. This results from a range of factors such as the application of fertiliser and grazing from livestock and is primarily in the form of nitrous oxide (N_20). These emissions are recorded in the Agriculture section of the UK GHG Inventory.

good condition they can potentially continue to form peat even under warmer and drier climatic conditions.

6. The vulnerability of soils to the impacts of climate change has been exacerbated by patterns of land use and management in England over the last 50 years or so. This is particularly the case for arable and upland soils.

- **Arable soils** have been subject to increased mechanisation, the use of agrochemicals and synthetic fertilisers, and the introduction of new crop varieties such as maize. Many strategically important areas for arable production are reliant on continued pump-drainage, being located in low-lying land that in some places are well below current sea-levels.
- **Upland soils** were extensively drained in the 1950s/1960s and large swathes of moorlands are regularly burnt for grouse shooting. As well as land management, almost all upland soils are adversely impacted by air pollution in the form of nitrogen and ammonia deposition from energy, transport and agricultural emissions. The legacy of the industrial revolution means that many upland soils suffer from heavy metal contamination.

Trends in soil health – Soil Organic Carbon levels

7. The available evidence suggests that soil organic carbon (SOC) levels have been declining nationally in arable soils. The Countryside Survey for England reported a decrease in SOC of about 3 grams per kilogram per year in arable soils between 1978 and 2007.[2] The decline in SOC is primarily explained by changing land management practices, including: [3]

- **Reductions in the spreading of animal manure** – as a result of the steady decline in livestock numbers and the intensification of livestock production leading to the production of liquid slurry at the expense of farm yard manure.
- **More efficient removal of crop residues** -due to technological improvements in harvesting machinery and the replacement of traditional hay cropping with silage production.
- **Deeper ploughing depths** - due to increases in tractor power and improved cultivation apparatus, leading to increased mineralization of carbon and dilution of SOC levels.

8. There have been marked declines of SOC in the most carbon-rich arable soils, particularly lowland peats. The National Soil Inventory reported a decrease in SOC on organic arable soils of over 5 grams per kilogram per year between 1978 and 2003.[4] This is putting at risk some of the most productive land in England as lowland peat soils make up a significant proportion of Grade 1 and Grade 2 agricultural land. Peat soils tend to be very fertile and provide a comparative advantage for intensive high-value cropping, including vegetables, salads and horticulture.

9. The largest single area of lowland peat soils in the UK is the East Anglian Fens, covering around 130,000 hectares. The Fens account for around 10% of the national area of agricultural land given over to potatoes, sugar beet and vegetable production. Only 34,000 hectares remain as deep peat (i.e. over 0.4 metres in depth). The remaining peat soils in the Fens are now classed as 'wasted' following years of degradation, shrinkage and loss. Almost all of the area is dependent on continued pump drainage, as much of the landscape is now below sea-level following centuries of farming-induced subsidence.

10. The loss of peat soils in The Fens has been occurring for hundreds of years. Today, only around 16% of the peat stock recorded in 1850 remains. Arable production on deep peats requires deep ploughing and power harrowing, alongside intensive drainage, in order to achieve fine seedbeds. The rate of peat loss has been between 10mm to 30mm a year.[5] Climate change is expected to accelerate

[2] Carey, P.D. et al. (2008) Countryside Survey: UK headline messages from 2007.
[3] Smith et al (2007) *Climate change cannot be entirely responsible for soil carbon loss observed in England and Wales, 1978-2003*. Global Change Biology, 13.
[4] Cranfield University (2013) National Soil Inventory Database.

these losses, with every 1°C rise in temperatures increasing the rate of loss by 30%.[6] As a result, all the remaining deep peat soils in the Fens could be lost within the next few decades. The continuation of intensive cropping on peat soils also has a high price in terms of CO_2 emissions. The drainage of UK organic soils for arable and intensive grassland production currently results in emissions of 5.2 $MtCO_2$ a year.[7]

11. In the Fens and other areas of lowland deep peats, it would be possible for some form of agricultural production to continue in ways that conserve the peat resource. Reverting from intensive arable systems to extensive wet grasslands would conserve the peat and not increase CO_2 emissions. Other potentially viable alternatives that would potentially conserve peat are the production of perennial biomass crops and agro-forestry.

Trends in soil health –erosion

12. Actual soil erosion is difficult to monitor over time at the national scale. However, modelling of the factors associated with soil erosion suggests the risk has decreased gradually across all grades of agricultural land since the 1960s. This is primarily due to an increase in the area under low-risk crops. For example, the area of land under oil seed rape, where only one field in 100 is at risk of erosion, doubled between 1988 and 2010. At the same time, the area covered by high risk crops such as potatoes and sugar beet declined by around one-third.[8]

13. There has, however, been a substantial increase in the area of UK land under the high-risk crop of maize, from 27,000 hectares in 1988 to 196,000 hectares in 2014. Of this, the majority (93%) was grown in England. A survey of over 3,000 sites in south-west England found that the soil structure of three-quarters of fields under maize were damaged to the extent that rainfall is unable penetrate the upper soil layers, resulting in silt-laden run-off during periods of heavy rainfall.[9]

Trends in soil health – upland peats

14. The English uplands are dominated by blanket bog and heathland habitats, which tend to have highly organic and peaty soils. When in good condition, peat bogs actively soak up carbon, accumulating between 3 and 7 tonnes per hectare per year. Peatlands also play a vital role in the provision of drinking water to millions of people, as they form the headwaters for some of England's major water supply catchments.

15. England's upland peat habitats are widely degraded. A survey by Natural England in 2012 estimated that some 144,000 hectares (51%) of blanket bog habitat has completely lost its mossy, peat-forming vegetation.

- **40,000 hectares (14%) are eroding.** In these areas, deep channels have formed that can often erode down to the mineral soils under the peat. Gully erosion can eventually undermine the remaining vegetation and leave a landscape of bare peat. Vegetation loss can also result from severe wildfires. Bare peat is eroded by rain, frost heave, and wind, with much of the eroded peat soil being carried into rivers and reservoirs.
- **50,000 hectares (18%) has been drained.** Shallow ditches (known as 'grips') have been cut across significant areas. The grips drain water more quickly away from the mossy surface, which thins or disappears completely as the water table lowers.
- **76,000 hectares (27%) are regularly burnt.** Burning is used to promote a mosaic of heather of different ages. Heather is the preferred habitat for red grouse, the primary upland game bird.

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[5] See ASC (2013) Managing Land in a Changing Climate for references.

[6] Graves, A. and Morris, J. (2013) for the ASC.

[7] 1.7 $MtCO_2e$ from drainage of organic soils for croplands and 3.5 $MtCO_2e$ from drainage of organic soils for grasslands. Source: UK GHG Inventory.

[8] 1 field in 10 of potatoes and 1 field in 7 of sugar beet are at risk of erosion. Cranfield University (2015) for the ASC.

[9] Palmer, R.C. and Smith, R.P. (2013) Soil structural degradation in SW England and its impact on surface-water run-off generation. Soil Use and Management, 29 Issue 4

There are approximately 140 grouse shooting estates in the English uplands, with an average size of 2,000 hectares. Managed burning is also used to cut fire breaks in order to reduce the spread of wildfire

16. The area of burned moorland has increased significantly in recent decades across much of northern England. A comparison of aerial photography from the 1970s and 2000 of over 200 km^2 of the English uplands found that the extent of new burns had doubled (from 15% to 30%) over this period. A recent study found that the annual number of burns between 2001 and 2011 increased by 11% per year, with an accelerating trend in more recent years.[10]

17. There is increasingly strong evidence that managed burning reduces peat accumulation, causes declines in carbon storage, and increases dissolved organic carbon (DOC) levels in watercourses.[11] Levels of DOC in UK upland water bodies have doubled over the last 30 years. Some of this observed increase in DOC is likely to be due to reductions in sulphur deposition (more commonly known as acid rain) since the 1990s. However, there is evidence that managed burning is the primary cause of DOC export in parts of the English uplands.[12]

18. Degraded peatlands can be restored, through measures such as blocking drainage ditches, re-seeding bare peat and reducing adverse management practices such as intensive burning and over-grazing. There is increasing evidence from field studies that restoration reduces carbon losses, both as CO_2 and DOC, as well as delivering biodiversity and landscape benefits.[13] A number of water companies operating in the English uplands have been investing in peatland restoration in recent years to help reduce the carbon content in raw water, and therefore lower the costs of drinking water treatment.

Response to specific inquiry questions

1. *How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?*

There is currently no systematic monitoring of key trends in soil health at the UK or England level. Key metrics of soil health exist that could be tracked, such as SOC levels, CO2 emissions, DOC levels in water bodies, etc. The uptake of soil conservation measures could also be monitored.

2. *What are the benefits that healthy soils can provide to society?*

As noted above, soils provide fundamental societal benefits beyond just their importance for agricultural production. From a climate change perspective, the key benefits of healthy soils are storing carbon, alleviating flood risk and improving water quality.

3. *What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?*

Some of the adverse consequences of poor soil health for climate change mitigation and adaptation are discussed above. Protecting soil health will become ever more difficult with climate change.

[10] Douglas et al. (2015). *Vegetation burning for game management in the UK uplands is increasing and overlaps with soil carbon and protected areas*

[11] Natural England (2013) *Effects of managed burning on upland peatland biodiversity, carbon and water* NEER 004.
Brown, et al (2014) *Effects of Moorland Burning on the Ecohydrology of river basins*. University of Leeds.

[12] Clutterbuck and Yallop (2010) *Land management as a factor controlling dissolved organic carbon release from upland peat soils.* Science of the Total Environment 408, 6179–6191

[13] See ASC (2013) *Managing the land in a changing climate* for references.

4. *What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?*

Announced in 2009 and reiterated in the 2011 Natural Environment White Paper, the Government has set a policy ambition that all soils will be managed sustainably by 2030. This is an ambitious goal and an aspiration that we fully support.

In our recent advice to Government for the 5th Carbon Budget we identified a range of cost-effective measures that farmers could implement that could deliver both GHG emissions savings and improvements in soil fertility/quality. These include amongst other things, measures to increase the efficiency of fertiliser use, loosen soil compaction, and the use of catch and cover crops.

There is a number of existing policy interventions that provide farmers with some incentives to improve soil health. These are primarily based on the Common Agricultural Policy (CAP). In theory, farmers must provide minimum soil cover, take measures to prevent erosion, and maintain soil organic matter levels in order to qualify for the full single farm payment. However, in practice the low levels of inspection make it difficult for these requirements to be enforced.

Voluntary agri-environment schemes funded under Pillar II of the CAP are also important mechanisms for encouraging soil conservation, although soil health is not a priority objective of the new Countryside Stewardship Scheme. The Catchment Sensitive Farming programme led by the Environment Agency also provides advice and capital grants to farmers to reduce soil erosion. However, this initiative only covers a relatively small area of total agricultural land, being focussed on around 80 key catchments, and has a very small budget to fund capital works.

In the uplands, Natural England has been working with the Upland Stakeholder Forum to produce a blanket bog restoration strategy, although this has not yet been published. As noted above, water companies in the uplands are also delivering restoration schemes, with an estimated £45 million invested between 2010 and 2015. However, the amount of restoration that will be delivered over the next five years is unclear, as individual schemes are not specified within water company business plans for the new Asset Management Plan period (AMP6, 2015-2020).

Despite these actions, the on-going declines in soil carbon, increases in the area of some high erosion risk crops (e.g. maize) and the degraded condition of upland peats suggests that current policy interventions will not deliver the 2030 aspiration for all soils to be sustainably managed.

5. *What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?*

The CCC recommended in both its 2015 statutory progress report to Parliament on reducing emissions and in our 5th Carbon Budget advice that stronger policies may be required to deliver emissions reduction consistent with the Committee's estimates of the cost-effective path to 2030. For certain measures such as increasing the efficiency of fertiliser use, this would also deliver a beneficial impact on soil health. Although these measures are feasible to implement, securing their wider uptake would need to be underpinned by a strong policy framework that goes beyond information and advice as is currently the case in England with the voluntary approach of the GHG Action Plan.

The ASC recommended in its 2015 statutory progress report to Parliament that Defra should publish an action plan within a year describing how the goal of all soils being sustainably managed by 2030 will be achieved. The action plan should:

- establish a scheme to monitor the uptake of soil conservation measures, with enforcement

where soils are not being appropriately managed; and
- include specific proposals to reverse the on-going loss of lowland peat soils.

In its response, the Government stated that “*we are considering how the development of the framework for the environment could support the implementation of this recommendation but are not able to make any announcements on this at this stage”.*[14] We therefore expect to see the Government’s forthcoming 25 year environment plan set out the specific measures that will be taken to meet the policy goal of all soils being sustainably managed by 2030 and beyond.

Further information
A summary of the CCC and ASC 2015 progress reports to Parliament can be found here. The ASC’s 2015 report can be found here, where chapter 5 of the report covers Agriculture & Forestry and Chapter 6 the Natural Environment. More detailed technical annexes to both chapters, which contain the range of data underpinning the ASC’s analysis, can be found here.

January 2016

[14] HMG (2015) Government Response to the Committee on Climate Change

Written evidence submitted by Professor Chris Collins, the Soil Security Programme

The Soil Security Programme (SSP) is a multimillion pound investment by the Natural Environment Research Council, Biotechnology and Biological Sciences Research Council, Defra and the Scottish Government (www.soilsecurity.org). It aims to understand the responses of the soil system in response to land use and climate change at the range of geographical and temporal scales that can influence policy. The programme represents >60 scientists across 14 universities and research institutions along with many commercial collaborators; they have contributed to the responses below. This response is provided by the Soil Security Programme and the Soil and Rhizosphere Interactions for Sustainable Agriculture grant-holders and reflects their independent views which are not necessarily those of the programmes' funders.

Our overall view is that healthy soils are critical to providing a range of ecosystem services (i.e. food production, water storage and purification, and carbon storage) essential to mankind and the environment. The UK has considerable expertise in soil science to develop the evidence base to underpin regulatory frameworks to monitor and evaluate soil health. Our current understanding of soil processes could develop new frameworks to ensure we maintain soil health. Soil is the forgotten environmental compartment; clear guidelines exist for water (Water Framework Directive) and air (Ambient Air Quality Directive) and need to be developed for soil given the important functions and ecosystem services it delivers.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

A range of indicators have been developed to evaluate soil health. These are usually categorised into biological, chemical and physical measurements. Soils are highly complex and variable, so no one indicator can be used in all settings and a basket of measures across the three categories is required with reference to optimal ranges within each land use and soil type. Defra, the Environment Agency the Devolved Administrations and the academic community could quickly agree on a list of these and their implementation. It may not be perfect, but it would enable a considerable step forward in protecting our soils. In the past there was a UK Soil Indicators Consortium (Environment Agency, Countryside Council for Wales (CCW), Department for Environment, Food and Rural Affairs (Defra), Forestry Commission, Scottish Executive, English Heritage, National Assembly of Wales, Scottish National Heritage and the Scottish Environmental Protection Agency) this could be re-instated, but it also requires input from the academic and user community. Critical to adoption of these measures will be their cost and ability to communicate them to end users.

These adopted soil health indicators could then be used to assess the impacts of land use and climate change within a routine monitoring programme. The Countryside Survey is an excellent example of this but has only been undertaken 5 times since 1978, the last survey was in 2007. We would recommend establishing a new national scheme to evaluate soil health, with monitoring being undertaken every 5 yrs to fit within a policy cycle.

Significant data sets are also being generated by individual groups e.g. the Sustainable Intensification Platforms, Farmers Clubs and experimental farms of the research and agribusiness communities. With new opportunities in data analysis offered by the Innovate UK supported centres e.g. Agrimetrics, these can be combined with existing data sets to track changes in soil health. Analysis of these data may also identify those indicators revealing soil health changes.

The academic community should be supported to investigate and develop new, robust indicators of soil health that reflect the physical, chemical and biological complexity of the soil system, and which enable low cost assessment of soil health over appropriate temporal and spatial scales.

What are the benefits that healthy soils can provide to society?

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

These two questions are intimately linked. Healthy soils provide the ecosystem services outlined below all of which directly or indirectly benefit society. If soil health is compromised the ability to provide these services is degraded. These services are essential to societal function and emphasize that the requirement for healthy soils goes well beyond the UK.

Environment: pollutant breakdown, carbon storage and climate mitigation, water storage and provision of clean water, nutrient retention, control of pests and diseases, biodiversity (N.B. above and belowground)

Health: 50% of antibiotics are derived from soil organisms, soils also underpin green spaces which have positive impacts on wellbeing, soil biodiversity is also required to suppress soil borne diseases e.g. listeriosis and anthrax.

Food security: sustainable food production and resilience of crops to extreme climate events

Others: Non-food crops e.g. oils, timber; cultural services; providing the fundament for human structures and infrastructure

The following illustrate the scale of the contribution from soil:

- Production from UK soils is worth £5.3 billion and soil degradation costs between £0.9 and £1.4 billion per year in England and Wales.
- The costs of damage arising from the current floods is expected to exceed £5 billion.
- The Chief Medical Officer for England has stated that anti-microbial resistance poses a catastrophic threat, with people dying from routine operations within 20yrs.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

The Global Food Security programme states ‘there is little statutory protection for soils’. Existing measures include: the Single Farm Payment, where farmers must meet the standards of Good Agricultural and Environmental Condition (GAEC); CAP cross compliance, which requires farmers to assess their soil and take actions to address identified problems; Environmental Stewardship, which includes options that reduce soil erosion from wind and water; the Biosolid application rate controls which aim to limit any build-up of soil contaminants. **None of these directly address soil health.**

To ensure healthy soils we need to move away from regarding soil as a "growth medium" - it is an ecosystem in its own right that requires management to maintain diversity of soil types and the biota within them. There needs to be clear policy direction, evidence based, that defines what soil health is, and critically the measures to be used to evaluate it (using the suite of indicators discussed above).

To secure that definition of soil health, policy instruments should adopt farm payment structures that encourage farmers in management practices that optimise the metrics for soil health. In parallel there needs to be encouragement from the all arms of Government and acceptance from everyone, that these policy instruments may result in landscapes that are different to what we expect/are used to and that benefits may not be proximate, i.e. the maximum benefit may be measured at distance from site of the management either in time or space.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil health should be central to any Government plan for the natural environment, and soil issues need to be embedded in all future land use decisions for agriculture, forestry, flood prevention, urban design, industrial development, or the protection of land to conserve biodiversity. The previous Defra target of sustainable soils (Healthy Soils) by 2030 is still an achievable goal and should be incorporated into the plan. There should be clear recognition of the role of soils in underpinning key ecosystem services, the monitoring required to ensure these are delivered and the need for continued investment in developing the evidence base to support Government regulation.

The SSP would be happy to provide further evidence to the committee either as a group or individually as required.

January 2016

Written evidence submitted by Professor Richard Bardgett

Introduction

1. I am Professor of Ecology at The University of Manchester and have more than 25 years experience of working on aspects of soil science and ecology in many parts of the world. I was lead author of Chapter 13 of the *UK National Ecosystem Assessment*[1], which considered evidence for the current status of UK soils and the ecosystem services they provide, and contributed to the recent UN Report on the *Status of the Worlds Soils* (2015)[2]. I was also a founder member of the Global Soil Biodiversity Initiative, established in 2011 (and now has more than 730 members worldwide) to create a coherent global platform for promoting the translation of expert knowledge on soil biodiversity into policy (https://globalsoilbiodiversity.org).

2. I have contributed to two other responses: one from the British Ecological Society and the other from UK Soil Security Programme. Here I provide an independent response to the questions asked by the enquiry.

What are the benefits that healthy soils can provide to society?

3. The benefits that soil provides are numerous and considered in depth elsewhere[1,2,3] and in other responses, so I wont go into too much detail here. Suffice to say that throughout history, few things have mattered more to humans than their relationship with soil.

4. Not only does healthy soil underpin food production, and hence the farming industry, but also it plays a critical role in buffering climate change, and in storing and filtering the water we drink. Soils are also home to an incredible diversity of organisms (it has been estimated that around one quarter of all living diversity on Earth lives in soil) that drive the biogeochemical cycles on which the functioning of the Earth depends, as well as playing a key role in soil formation, the control of pests and diseases, and in shaping the structure and diversity of natural plant communities. Soils also play a major, but mostly forgotten role, in towns and cities: urban soil represents an under appreciated carbon store; it helps excess water drain away after storms; it helps to regulate the heat and quality of urban air; it binds and breaks down the pollutants that industry yields; and it provides a foundation on which city dwellers grow their vegetables and flowers, and play their sports. Put simply, soils have a profound, but largely unappreciated, impact on society.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

5. The consequences for society of failing to protect soil are numerous. In extreme cases soil degradation can have a major impact on society, with

declining food production, environmental quality, and human health. In the UK, the biggest issues are probably loss of soil organic matter (which is strongly linked to soil biodiversity) and soil erosion, caused both by land use and climate change, although soil sealing, contamination of land with organic and inorganic pollutant, and soil compaction, are also key threats. Detail on threats to soils and the consequences of declines in soil health are given in other responses, and well documented in the literature[1,2], so I only make a few additional points here.

6. The diversity of soil types across the UK is enormous. This not only reflects high variation in soil-forming factors, but also the UK's rich history of agriculture, forestry, mining and industry, which has transformed the properties of many soils[1]. Given this, UK soils vary tremendously in vulnerably to land use and climate change, and other threats, but also in the interventions needed to protect and restore their health.

7. Soil is a non-renewable resource. The speed that soil forms varies greatly, but as a general rule, the rate of soil formation is extremely slow (the global average is about 0.1 mm a year[4], or one meter every ten thousand years), which effectively means that soils are a non-renewable resource. Given that rates of soil erosion can far exceed renewal if soil is poorly managed, the most drastic consequence of failing to protect soils is the loss of one of the UK's most valuable non-renewable resources.

8. Threats to soil health can be strongly interrelated. While land use probably represents one of the biggest threats to UK soils, being a major cause of soil organic matter loss, declining soil biodiversity, and soil erosion, its impact on soil health is strongly linked to climate change. Not only do changes in land management have the potential to exacerbate the vulnerability of soils to climate extremes (e.g. rendering them more vulnerable to drought, and/or wind and water erosion following extreme rainfall events); but also, future shifting patterns of land use resulting from climate change could potentially accelerate soil organic matter and biodiversity loss and increase the vulnerability of soils to erosion[5]. Given this, the consequences of failing to protect UK soils are likely to intensify with climate change.

How could soil health best be measured and monitored?

9. The global soil science community have developed a raft of measures for measuring aspects of soil health, and can characterise in great detail the physical, chemical and biological nature of soils. Many indicators of soil health are already used routinely in soil monitoring programmes and research teams are developing new sets of biological indicators for monitoring soil health[6]. Soil biological indicators are considered to be especially good[6] because most soil processes are mediated by soil biota, and they are very sensitive to changes in climate and soil management[7].

10. No single measure can define soil health. Soils are highly complex and variable, and hence their functioning depends on a range of biological, chemical and physical factors, not just a single factor. Moreover, the measures that indicate a healthy soil differ from place to place, depending on soil type and other factors, such as how the land is used. Given this, soil health needs to be measured using a targeted suite of cost-effective measures that provide an integrated view of soil fertility and which can be applied to a wide range of situations.

11. Based on current knowledge, the UK soil science community could advice government on an appropriate list of measures that best represent soil health. Arguably, the best measures are those that provide an integrative picture of soil health and the processes that contribute to it, such as organic matter content (the bastion of soil health), soil aggregate stability (which has profound importance for soil organic matter dynamics, nutrient cycling, and the movement of gases and water through soil), biological measures of soil that we know relate well to important soil functions (abundance and activity of functionally important groups of soil organisms), and, potentially, measures of soil nutrient ratios, which play a fundamental role in the functioning of soils (e.g. C:N, N:P ratios)[8].

12. New approaches for measuring aspects of soil health need to be developed, especially low cost, simple assessments that can be used to monitor changes in soil heath at large spatial scales (e.g. remote sensing). As an example, using data collected from an extensive national survey of English grasslands, we recently showed that surface soil carbon stocks could be predicted at both regional and national scales from simple measures of soils, climate, and vegetation. This suggests that readily available climate, soils and plant survey data could be effective in making regional to landscape-scale soil carbon stock predictions[9].

How could the Government develop a strategy for tracking soil health?

13. There is an urgent need for baseline measures of soil health at relevant spatial scales in order to effectively measure soil change (e.g. national, regional and farm scale). Soil change is, and will continue to be, a major challenge for the UK, so an effective baseline of appropriate spatial resolution is essential, covering different land use types (including urban areas) and intensities of management. Monitoring also needs to be done over relevant temporal scales, in order to detect rapid soil change, or its onset, and for some measures, it needs to be done to depth, given growing evidence that land use and climate change can have significant consequences for soil properties at depth. As an example, most soil carbon inventories only

consider surface soils, whereas significant stores of carbon occur at depth, and this carbon is vulnerable to current and future changes in land use.

14. Monitoring programmes need to be established for measuring soil health at a range of spatial scales (i.e. national, regional and farm scale), but also to provide a national framework for fundamental enquiry into soil variation at large spatial scales. We currently lack a deep understanding of the factors that control soil functioning over large spatial scales; a national framework of soil monitoring could provide a valuable national resource for advancing our understanding of the drivers of soil variation, but also a platform for future experimental work. Large scale sampling frameworks have been especially effective in macro-ecology for establishing theory on large-scale patterns of species diversity and plant form, and have also been used to advance understanding of drivers of large-scale patterns in soil microbial communities across the UK[10,11]. Such a monitoring programme could provide a national platform to facilitate major leaps in scientific understanding of the drivers of variation in soil properties that underpin its health, and provide a network for future experimental research.

What further measures should the Government and other organisations consider in order to secure soil health?

15. There is a need for greater awareness among society of the vital importance of soil for human lives[3]. Some already appreciate the value of soil, but the majority doesn't. There is therefore a fundamental need for educational programmes to build knowledge of the importance of soil, and for the UK to train a new generation of scientists and practitioners with the skills needed to understand and protect soil health.

16. History can tell us much about how best to manage soils to maintain their health, and the UK soil science community has a wealth of understanding about how best to manage soils. But, there is a pressing need for scientific understanding to advance: new science is needed that takes a more holistic view of soil, integrating new knowledge on the physical, chemical and biological behaviour of soils into wider understanding of how to manage soils for growing food, protecting clean water, and mitigating climate change.

17. In order to be of use, there need to be mechanisms to ensure new scientific understanding is translated into practice; soil issues need to be embedded in all future decisions on the use of land, whether that be for farming, forestry, flood prevention, the design of cities, industrial development, or the protection of land to conserve biodiversity.

18. Finally, attitudes to soil need to change. Soil needs to be considered by members of society as an investment to be protected and cared for, and as part of the support network for human life.

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January 2016

Written evidence submitted by the Geological Society

1. The Geological Society (GSL) is the UK's learned and professional body for geoscience, with about 12,000 Fellows (members) worldwide. The Fellowship encompasses those working in industry, academia regulatory agencies and government with a broad range of perspectives on policy-relevant science, and the Society is a leading communicator of this science to government bodies, those in education, and other non-technical audiences. Of our 12,000 Fellows, probably 30-40% work with soils, principally urban soils associated with construction and land remediation.

2. Soil health and geoscience intersect in many important ways. The UK has over 700 soil types and these are determined by variations in underlying geology among other variables such as climate, plant and animal ecology. The highly diverse nature of geology in the UK and its associated soil structures underpins and supports the large diversity of landscapes and biodiversity that are found across the country. Soil quality and health is an important consideration for a number of areas of applied geology. These include the quality of soil for foundations in construction which is important to geotechnical engineers, and linked to this, the assessment and remediation of polluted and contaminated soils, to enable them to be used for construction or agriculture. This is of particular importance in former mining areas such as parts of Wales, a country with a legacy of 1300 former metal mining sites which has led to polluted soils and rivers in the local area. A large number of our Fellows work in this remediation area. Additionally, geologists work to locate and source the essential mined materials that go into the fertilisers added to soils to maintain food and biomass production. Soils also form a vital first stage in the groundwater recharge process and are critical in flood management processes. Soils also have a key role in the Earth system that regulates atmospheric CO_2, and has done so for a substantial part of geological time.

3. It is important for policymakers and other decision makers to recognise that the collective term 'soil' can be used to describe different things by different scientific communities. Soil - to an engineering geologist or a soil mechanic – can include much more material than what is meant by a soil scientist and can refer to non-fertile soils not able to support plant life. This can mean that what an engineering geologist describes as a soil function - such as holding up engineered structures - is incompatible with the biological function of soil - to support plants or fauna. In the text below we have used the term 'soil' in the sense that a pedologist or soil scientist would understand it, and not, as it is sometimes understood, as all

material that is not a rock. Understanding of this nuance is vital to designing and implementing effective soil monitoring and protection policies.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

4. Soil is a key part of the support system for life on Earth and its conservation is imperative to living sustainably and equitably. Soil is a finite and non-renewable resource and effective measuring and monitoring is key to understanding and preserving this important resource. Soil health underwrites many functions that are an integral part of society and environmental processes. Careful soil management is an essential element of sustainable agriculture and has important implications for climate regulation and the safeguarding of ecosystem services. Healthy soils have other important roles in maintaining a sustainable environment. They store carbon, produce food and timber, filter water, support wildlife and underpin urban and rural landscapes. However, there are signs within the EU and around the world that the condition of soils has been neglected, and without an effective regulatory framework this cannot be properly addressed.

5. The vast array of soil compositions seen in the natural environment results from a complex set of interactions which influence their properties and structure. These in turn support a wide variety of ecosystem services. The specific supporting functions of soil are governed by the suite of chemical, biological and physical properties of the soil. Knowledge and understanding of the state of these properties, their interaction and the effect of change is essential to living sustainably. Good soil governance requires that this complexity is understood and built into any strategy.

6. Soil health can be measured in a number of ways. It can be measured in terms of the quantity and type of organic matter it contains, levels of biodiversity (plant, invertebrate and higher animals) and the range of ecosystem services it supports. A useful source of information on the importance of soil and how to develop a strategy for tracking soil health can be found in the recently published 'Status of the World's Soil Resources' (http://www.fao.org/3/a-i5199e.pdf) by the Natural Resources and Environment Department of the Food and Agriculture Organisation of the United Nations. Box 1.1 in the report details the 'Guidelines for Action' from the World Soil Charter aimed at individuals, groups, governments and international organisations. The Agri-food and Biosciences Institute in Belfast produced a soil quality programme in 2004 which included methodology on

monitoring, risk assessment and promotion of their work. Their work may be instructive in devising a soil health strategy.

7. There is currently no national monitoring programme in the UK. Long-term monitoring of soil quality is essential to provide an early warning of the potential effects different land use activities may be having on long-term soil and water quality e.g. the impact of changes in fertiliser usage (organic and mineral). Monitoring can help identify whether soil quality is degrading over time and what factors may be contributing to soil degradation e.g. the impact of climate change on greenhouse gas emissions from soils and carbon sequestration rates. This information can then be used to help manage our soil resources in a sustainable manner into the future and to guide the development of policies to protect soil, water and air quality across the UK.

What are the benefits that healthy soils can provide to society?

8. Healthy soils are the essential basis for human life; without healthy soils we have neither food nor drinking water. They support rich and sustainable environments for people to live in and are an enabling resource for the creation of many goods and services that sustain people’s livelihoods and quality of life. This is achieved through the provision of a secure and sustainable supply of food, and safeguarding the quality of surface and groundwater, especially for drinking. Soils also absorb rainfall, and loss of this function threatens worse flooding events, which in turn remove soils through erosion. The World Soil Charter describes the current status of soils as reaching ‘critical limits’ and shows that effective soil management is key to prevent any further degradation. This is particularly important in the context of future increases in food and fuel production and the projected increase in climate volatility which could put UK residents at significant risk from hazards such as flooding and water contamination.

9. On the role of soils and climate regulation: the ‘Status of the World’s Soil Resources’ report states that ‘all soils, whether managed or not, provide ecosystem services relevant to global climate regulation and multi-scale water regulation’. Degradation in the quality of soils around the world will result in the deterioration of the global ‘common-good’ services that are provided by soils in respect of climate. For this reason, a far reaching, international and joined up approach to soil protection is necessary to raise awareness of the importance of soils and to develop a strategy for its conservation.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

10. In addition to the impacts on ecosystems and climate regulation there will also be significant health and welfare costs linked to increased pressure on food security and demand. A failure to properly protect soils for agriculture could lead to an increased reliance on imported food. This could set up a vicious cycle as current levels of degradation place pressures on food security which in turn leads to more irreversible degradation of soil quality. There is also a threat to the quality of drinking water and the potential for a rise in groundwater contamination. This would result from the breakdown of soils and the removal of the soil column as a filter for rainwater before it passes into the saturated zone. The removal of this uppermost section of the subsurface would also have significant implications for flood risk in the UK: an important natural barrier to flooding would be removed.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

11. The question of current measures is best answered by the relevant regulatory bodies and scientific societies whose remit includes environmental management and hold the relevant data. Improved understanding of soil and evaluation of its potential should be at the heart of this strategy. A one size fits all protection policy is not workable; there is now wide acceptance of this conclusion on groundwater policy, but only after the roll out of the water framework directive. It would be prudent to take on board these lessons when designing a soil protection policy.

12. Further measures to consider include interrogation of existing water quality data (flow, suspended solids) in order to assess soil loss through flooding. The determination of the amount of soil organic matter, as a key proxy for soil quality, could be part of the basic description of any land, tagged to property transactions to demonstrate improvement or otherwise in the same way that energy efficiency is tagged to house descriptions. The Environment Agency and SEPA are the organisations that would be best placed to hold and manage these data, although there may be potential for the Centre for Ecology and Hydrology and/or the British Geological Survey to play a role in collecting them.

13. Soil pollution arising from both legacy contamination and new industrial processes and agricultural practises could pose a risk to human health and the

environment. In order to understand potential risks, we must improve our evidence base by funding research in this area to monitor trends in soil pollution and examine links between concentrations of pollutants in soils and concentrations in other media (for example food and water).

14. Many of our respondents in compiling this submission recommended that the relevant UK regulatory bodies should be strongly encouraged to progress 'joined up' soil health policy and strategy development across England and the devolved nations as currently this is lacking. It was also suggested several times that the UK should be pressing for the EU Soils Directive to be implemented as soon as possible. The draft EU Soil Framework Directive was introduced by the European Commission in 2006 and, although this has not been brought forward as legislation, the commitment to sustainable soil use is in line with the Seventh Environment Action Programme.

15. Some of our colleagues responded on current policy in soil health as it relates to the regulatory environment in Northern Ireland. Currently, the legacy of contaminated land in Northern Ireland is dealt with solely through the planning regime as, although it has been enacted, Part 3 of the Waste and Contaminated Land (Northern Ireland) Order 1997 is not yet in force. The planning regime is effective in dealing with sites that are to be redeveloped, however there is no statutory means to clean up contaminated sites that are not intended for redevelopment (i.e. potentially high risk sites that have insufficient market value to drive redevelopment). Part 3 of the Waste and Contaminated Land (Northern Ireland) Order should be reviewed and amended as necessary to reflect European , national and local government policy changes related to soil and should be adopted to address this gap in statutory powers, with provision of appropriate funding to ensure this can occur effectively.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

16. Soil health should play a key role in the 25 year plan for the natural environment. Healthy soils are a key component to food security, a reduction in flood risk and climate change both of which are key areas of policy development over the next 25 years. As noted above, soils are an important control on CO_2 removal from the atmosphere. We know how to manage them (and have done for almost 10,000 years), and if we ignore soil health or fail to manage it correctly then we will be creating the potential for US dustbowl type conditions to occur in key agricultural areas in the UK. In terms of food security, the quality of food grown

depends primarily on the quality of soil and the availability of mined resources for agricultural fertilisers. The reliable sourcing of both is currently under threat and will be put under further pressure in the coming decades. In light of the recent flooding events of December 2015, the implications of poor soil health and soil degradation cannot be overstated. A failure to manage this resource carefully will lead to increased erosion of the soil column which will increase the risk of flooding in the UK and overseas.

17. At present, promotion of soil health in some parts of the UK is primarily in terms of the economic benefits to farmers and growers. While this is an important consideration, development of a holistic soil health strategy and monitoring programme would be a useful opportunity to raise awareness of the broader impacts of soil quality and its decline among regulators, those in industry and the public.

January 2016

Written evidence submitted by the James Hutton Institute

Executive Summary

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

- Although techniques are constantly evolving and further work is needed to develop cost-effective, easy to use and rapid indicator methods, current knowledge is sufficient and appropriate to establish robust soil monitoring in the UK;
- Monitoring should utilise a range of techniques and tools – field, laboratory, remote sensing and citizen science – in partnership with other ongoing initiatives;
- The purpose of the monitoring should be clear, and links between the monitoring activity and the soil function (and policy) should be explicit.

What are the benefits that healthy soils can provide to society?

- Soils are fundamental to national food security;
- The UK National Ecosystem Assessment (2011) highlights the vital role that soils play in the delivery of ecosystem services;
- There is a lack of economic data relating to soils and many of their benefits;
- Sustainable soil management is vital in the delivery of many societal benefits;
- The costs of impacts on soil health are often borne off-site of the location of the soil in question.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

- There are notable historical precedents for failing to protect soil health, such as the American Dust Bowl and China's river eutrophication, each the result of inappropriate soil management;
- The UK will experience reductions in food production with consequences for food security, difficulty in achieving water quality standards, increased flood risk, increased GHG emissions, and loss of biodiversity.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

- Generally, measures rely on voluntary principles and opt-in from practitioners; GAEC (Good Agricultural and Environmental Condition) standards are limited in relation to securing soil quality;
- The DEFRA "Terrestrial Umbrella" approach relies on coordination by all relevant organisations and, given the multi-benefit and cross-cutting role of soils, a similar approach should be extended to soil quality and its off-site impacts.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

- Given the multiple benefits it supports, soil must feature strongly in the Government's upcoming 25 year plan for the natural environment;
- There is a need for a 'championing body' to coordinate this inclusion; currently soil intersects a number of policy sectors with resultant issues of adequate integration;
- Many public policies and international obligations (e.g. Aichi, IPCC, Water Framework Directive) cannot be met if soils are not explicitly included in land, ecosystems and freshwater management;
- The training and education of soil scientists should form part of the strategic planning by government for the natural environment.

Introduction

1. The James Hutton Institute's response to the Soil Health Inquiry has been collated from Institute experts including soil scientists and researchers across several soil-related disciplines. The Institute has a long track record in soils research, including investigation of soil properties and processes, agricultural and environmental impacts of soil management, and policy development and implementation. We hold the National Soil Archive of Scotland and the national soils mapping for Scotland, resources which have been extensively used in the study of soils and change over time.

Response to Consultation Questions

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

2.1. All soils are multifunctional and provide multiple benefits, making their monitoring especially challenging (UK National Ecosystem Assessment, 2011 www.uknea.unep-wcmc.org). Any soil health monitoring strategy must accommodate the inherent variability of soils, which reflects their capacity to deliver multiple benefits. The definition of 'healthy' may be different for different types of soil.

2.2. So, to enable effective implementation of a strategy and to deliver consistent monitoring and measurement of soil health, there must be a common definition of 'Soil Health'. There is no universal definition but we consider the following as a suitable definition for UK purposes:

'The capacity of the soil to function in order to sustain life'

2.3. Under this definition, a healthy soil can be used productively without adversely affecting its future productivity, the ecosystem or the environment.

2.4. The James Hutton Institute has been working on numerous projects in recent years on the question of soil health and how it might be changing, often in collaboration with partners in the UK, Europe and inter nationally, such as:

- National Soil Inventory of Scotland - resampled in 2006-2011 (www.hutton.ac.uk/about/facilities/national-soils-archive/resampling-soils-inventory), funded by Scottish Government;
- To assess change under afforestation and deforestation, with Forest Research and Cranfield University, funded by Forestry Commission ;

- To develop simple assessments of soil erosion that can be carried out locally by SEPA staff, with SEPA and Scottish Government;
- To produce unified soil maps of the UK, initiated under the UK Soil Observatory funding from BIS, with Cranfield University.

2.5. Under the auspices of the UK Soil Indicators Consortium led by the Environment Agency (2006) www.gov.uk/government/uploads/system/uploads/attachment_data/file/290729/scho0306bkiq-e-e.pdf), there has been substantial UK research into indicators that could be deployed to measure soil health. Although further work is needed to develop cost-effective, easy to use and rapid methods, **current knowledge is sufficient to establish robust monitoring**. A monitoring programme needs to be based on a combination of physical, chemical and biological indicators based around measurable parameters. It must also operate within the framework of a sampling baseline and ongoing strategy for monitoring, reporting and interpreting change. Approaches to monitoring will increasingly combine innovative methods including remote sensing, smartphone technology and hand-held sensors, all supported by traditional field surveying and soil characterization.

2.6. Remote sensing techniques include satellite, airborne and unmanned aerial vehicle (UAV) sensors. The new suite of ESA Sentinel satellites is of particular interest, and offers improved opportunities for ready access to medium-level spatial resolution imagery (10m). Radar (Sentinel-1) can provide imagery even in cloudy conditions, and below the vegetation canopy, while multispectral imagery (Sentinel-2) provides information on vegetation as indicators for soil contamination, moisture content, and inherent fertility. Access to Sentinel data products will increase over the next 2 to 5 years.

2.7. There is a need for rapid, reliable and reproducible approaches for determining components of soil biodiversity. In the Defra document 'Safeguarding our soils' (Defra, 2009 www.gov.uk/government/publications/safeguarding-our-soils-a-strategy-for-england), biodiversity is mentioned as something that soils support, but it should be recognised that the reverse is also true, as habitats have characteristic soil biodiversity which in turn reflects the soil functional capacity.

2.8. The requirements for a national soil monitoring programme were set out by Black et al. (2012 www.environment.scotland.gov.uk/media/59999/Soil_Monitoring_Action_Plan.PDF). Past initiatives based on traditional soil survey approaches (e.g. Loveland et al., 2002) need to be incorporated into a more flexible approach that can capture data gathering activities across different organisations and approaches; organisations already undertake field visits as part of their statutory roles to which value can be added. This could help address a gap in updating soil information. It is also very important that the monitoring has distinct objectives that relate to specific soil functions and/or policies and that there are pathways to transfer results of monitoring activities to stakeholders.

2.9. The Scottish Soil Monitoring Action Plan (MAP) is a first step towards a broader integrating approach (Scottish Government 2012, www.gov.scot/Resource/0048/00482106.pdf) which includes investigations into citizen science in soil monitoring (Baggaley et al., 2014 www.sniffer.org.uk/files/2814/0291/8541/DP02_Soils_and_Citizen_Science_Final_Report_June_2014.pdf).

What are the benefits that healthy soils can provide to society?

3.1. Soil is a valuable but vulnerable part of our natural capital and provides many often unseen benefits. These benefits are recognised in some existing strategies, for example 'Safeguarding our Soil: A Strategy for England' (Defra, 2009) and the Scottish Soil Framework (Scottish Government, 2009 www.gov.scot/resource/doc/273170/0081576.pdf), where a number of high level soil functions and their maintenance are key components. When soil and associated functions are degraded or lost, it can take several decades to restore or re-establish useful functioning soil; the costs of doing so (in terms of restoration and loss of functions in the intervening time) are significantly in excess of the short-term value gained from unsustainable management. Soils are complex systems and it is this complexity that has given them a degree of resilience without which we would already be experiencing even more serious issues.

3.2. Soil functions are similar to ecosystem services, which explicitly have benefits to society. The UK National Ecosystem Service Report (2011) recognises the fundamental need for healthy soils in the delivery of ecosystem services:

'*Soil quality is linked to almost all other regulating services (e.g. nutrient cycling, biomass production, water quality, climate regulation, pollination, etc.) through the soil's capacity to buffer, filter and transform'* (page 80, Synthesis Report).

This Report also states:

'*The condition of many soils in the UK – absolutely fundamental to continued productivity and support of biodiversity – is considered degraded, mainly because of atmospheric deposition and inappropriate management*' (page 10, Synthesis Report).

3.3. The benefits of healthy soil to society are already well recognized by the FAO (www.fao.org/globalsoilpartnership/en/) and the recently published Status of the World's Soil Resources (www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/). The soil functions and associated benefits listed in the Scottish Soil Monitoring Action Plan (Black et al., 2011) cover those relevant to the UK. These are:

- providing food, wood and biomass production;
- controlling and regulating environmental interactions;
- regulating water flow and quality;
- storing carbon and maintaining the balance of gases in the air;
- providing valued habitats and sustaining biodiversity;
- preserving cultural and archaeological heritage;
- providing raw materials (including new medical products);
- providing a platform for buildings and roads;
- human and animal health;
- human health and wellbeing from urban green spaces, and from working the soil and growing food in allotments.

3.4. For the above benefits, it is important to understand that soils are different from one another and have different primary functions/values. There is a lack of contemporary monetary and non-monetary valuation of soil to society but it is well established that soils are essential to society and have high values (Banwart, Noellemeyer and Milne eds., 2014 www.soilcarbon.org.uk/volume71.html). Comprehending and quantifying the less obvious benefits is vital in making the case for investment in soil health.

3.5. Glenk et al. (2010 www.sepa.org.uk/media/138663/socio-economic_data_soils.pdf) provided a comprehensive overview of the socio-economic impacts associated with a number of soil pressures. Key findings were: (a) difficulties in sourcing robust economic data directly related to soil, and (b) the majority of costs associated with poor soil health were off-site (e.g. water and air quality, above ground habitats, human health, built infrastructure).

3.6. Sustainable soil management is a key component in the delivery of a suite of societal benefits; poor soil management can hamper that delivery and in extreme cases produce catastrophic outcomes and result in a range of levels of conflict between involved parties.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

4.1. The consequences are reductions in the benefits outlined above and in some circumstances (e.g. urban expansion), their entire loss. A healthy soil is the result of appropriate and sustainable soil management and there are many examples of past civilizations that have suffered due to poor soil management (www.sciencemag.org/content/342/6158/565.full).

4.2. We run the risk of failing to learn from these past experiences, with consequences that will have significant economic impacts. These include:

- Reduced ability to produce food, fibre & biomass for a growing population, putting increasing stress on national economies and global markets;
- Reduction in biodiversity and loss of associated benefits;
- Increased rainfall run-off and increased risk of flooding;
- Reduced ability of soils to buffer environmental pollution;
- Increased erosion and the transfer of minerals, soil carbon, nutrients and pollutants to rivers, lakes and oceans;
- Reduced ability to handle future environmental, political and societal challenges.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

5.1. Numerous initiatives are in place and have been implemented to promote good agricultural and environmental soil management, but these generally rely on voluntary principles and opt-in from practitioners. From the summary in the UK NEA (2011), these initiatives appear to have had limited success. Examples include:

- the Scottish Government's Farm Soils Plan (www.gov.scot/resource/doc/47121/0020243.pdf);
- a number of articles on DEFRA's website (e.g. www.gov.uk/guidance/soil-management-standards-for-farmers) ;
- advice from agencies (e.g. www.snh.gov.uk/land-and-sea/managing-the-land/soils/carbon-management/);

- advice with specific objectives (e.g. www.sruc.ac.uk/downloads/file/648/practical_guide_-_improving_soil_quality);
- advice from NGOs (www.soilassociation.org/LinkClick.aspx?fileticket=OqHhW2Cjj44%3D&tabid=313).

5.2. Part of the requirements for farmers to receive the Single Farm Payment is through Cross Compliance and maintaining soils in Good Environmental and Agricultural Condition (GAEC). Precise requirements vary across the UK but the main objectives are to maintain soil organic matter and prevent erosion. However, GAEC is not about promoting soil health in a wider context, soil health is not just a local issue, and the SFP and GAEC do not have relevance to all environments (e.g. forests and urban areas).

5.3. There are few statutory measures that explicitly address soil health or protective measures. Examples are: sewage sludge to land, which is regulated by statute; prime agricultural land in Scotland has some protection from new development; and, new woodlands are not allowed to be established on peat over 45 centimetres deep. These are applied in specific contexts and there remains a lack of an overarching framework for managing and monitoring soil health.

5.4. Some of the wider influences on soil health are not directly associated with soil-specific actions. For example, a major factor in soil health since the 1990s has been action to reduce atmospheric pollution (acid rain and then nitrogen deposition). The approach of the “Terrestrial Umbrella” used by Defra for atmospheric pollution was successful and could be applied more widely. This approach brought relevant organisations together to coordinate on monitoring, managing and mapping, supporting policy and providing guidance on the issues of atmospheric pollution. A similar approach to promote effective soil use and management and to address diffuse pollution has not led to equivalent monitoring or specific guidance on what to achieve in soil health.

5.5. Consideration is needed regarding who pays for public as well as private goods and services (monetary and non-monetary). Since many benefits from, and impacts on, soils are off-site there needs to be appropriate interventions to encourage the land owner / manager to manage soils for wider benefits e.g. water quality improvements, flood control or storage of carbon to mitigate climate change. Recent peatland restoration initiatives are an example of how this can progress. However, continuing difficulties in meeting the Water Framework Directive through effective soil use and management illustrate how challenging this will be.

5.6. Government should also give additional support to the delivery of:

- Information resources to stakeholders in easy to read and easy to apply language;
- Freely available and accessible soil information and data with appropriate explanations to broaden its use among stakeholders.

5.7 Good progress has been made in the provision of such information over recent years (www.soils-scotland.gov.uk/, www.ukso.org/) but much is based on legacy data. A soil monitoring strategy with new data collection would ensure these data remain fit for purpose as well as informing of any changes in soil health.

5.8 Lastly, since soil health is cross-sectoral, there has to be some overarching "champion" body, independent of sectoral interests, that can ensure that soil health is not only managed for single-stakeholder benefits.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

6.1. Soil is the basis of life on Earth. It is vital to our future and should be included in all plans that relate to management of ecosystems and the environment. This is true regardless of whether specific objectives of these plans come from an agricultural, biodiversity, climate change or water quality perspective. The UKNEA (2011) raised awareness of the essential and irreplaceable role of soils in supporting many ecosystem goods and services. Many government policies and international obligations (e.g. Aichi, IPCC, Water Framework Directive) cannot be met if soils are not explicitly included in land, ecosystems and freshwater management. Therefore it is essential that soils are a clear component of the 25 year plan for the natural environment.

6.2. We believe that carbon should be a part of a UK's natural asset/audit register, which would raise the status of soil for all interested parties, including the general public.

6.3. Soil's underpinning of multiple ecosystem services means that impacts on soil should be considered in relation to a wide range of management activities. A particularly relevant recent example is that of flooding in the UK; there is growing scientific consensus on the relationships between soil management and increased runoff. Leaving arable soils bare and devoid of vegetation over winter leads to loss of valuable topsoil during flood events. Strengthening the importance of soils within land management legislation and planning would reduce the cost of damage and improve resilience to future flooding.

6.4. Multiple pressures exist on the ability of soils to sustain societal and economic wellbeing. Promoting solutions based on sound science and building upon the momentum of the UN International Year of Soils 2015 is key to this. Encouraging sectors other than environmental regulatory bodies to consider the importance of soil and potential impacts on its health should be encouraged.

6.5. There is a need for continued investment in fundamental and applied soils research and in the training and education of a new generation of soil scientists and the diversity of skills that this encompasses. In addition to adapting new technologies to the challenges of monitoring soil health, it is important to retain field-based and laboratory skills as these provide baseline information that often cannot be obtained in other ways.

Additional Reference

- Loveland, P.J., Thompson, T.R.E., Webb, J., Chambers, B., Jordan, C., Stevens, J., Kennedy, F., Moffat, A., Goulding, K.W.T., McGrath, S.P., Paterson, E., Black, H. and Hornung, M. (2002). Identification and development of a set of national indicators for soil quality. R&D Technical report P5-053/2/TR, Environment Agency, Swindon 2002).

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Written evidence submitted by Research Councils UK (RCUK)

Introduction

1. Research Councils UK (RCUK) is a strategic partnership of the UK's seven Research Councils which annually invest around £3 billion in research. We support excellent research, as judged by peer review, which impacts on the growth, prosperity and wellbeing of the UK. To maintain the UK's global research position, we offer a diverse range of funding opportunities, foster international collaborations and provide access to the best facilities and infrastructure around the world. We also support the training and career development of researchers and work with them to inspire young people and to engage the wider public with research. To maximise the impact of research on economic growth and societal wellbeing, we work in partnership with other research funders including Innovate UK the UK Higher Education Funding Councils, businesses, government departments, and charitable organisations. Further details are available at www.rcuk.ac.uk.

2. This evidence is submitted by RCUK and represents its independent views. It does not include, or necessarily reflect the views of the Knowledge and Innovation Group in the Department for Business, Innovation and Skills. The submission is made on behalf of the following Councils:

    - Biotechnology and Biological Sciences Research Council (BBSRC)
    - Natural Environment Research Council (NERC)

3. This response focuses only on those questions or parts of questions relevant to RCUK or the individual Councils that have contributed to the consultation.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

4. Soils are highly complex systems that provide the natural capital essential for the delivery of many ecosystem services on which societies depend, including those that are crucial to food security and production of non-food crops, climate mitigation, water and nutrient cycling. As systems, soils involve multiple physical, chemical and biological processes that interact to regulate the soil's functioning and its ability to resist and recover from perturbations. Soil health can be considered the capacity to deliver ecosystem processes and services derived from it, and a measure of soil health is the ability to both provide this functionality, and to have resilience to perturbations of that functionality.

5. Soil health cannot be measured directly; it can only be estimated by developing a series of metrics, and then understanding what each of these means for the particular type of soil being considered. This would probably need to involve models which could take a variety of parameters into account. There is currently no agreed definition of 'soil health' and a single definition may not be appropriate for all soils.

6. Soils are extremely variable in nature (including clay, sandy, peat and chalky soils). Not all soils can fulfil the full spectrum of services required for the future of the UK, so there is a need to protect their multifunctional attributes at a national level in order to preserve national and international natural capital. Soils' heterogeneity also means that not all measures of soil health will be appropriate for different soil types: soil organic carbon (SOC) is higher in peaty soils than in sandy ones; this is not a reflection of soil health but of the soils' intrinsic characteristics.

7. There is an urgent need to advance understanding of soils' abilities to adapt and respond to perturbations, resulting from events such as climate change, extreme weather and changing land use and management practices, which influence soil performance. Once soils have reached a 'tipping point', changes can be irreversible leading to loss of a variety of functions.

    Soil exists in a range of environments in the UK, and soil health status is important in the effective use of that land. Whilst agriculture is perhaps the most prominent form of soil management of soil, soil also has key roles in urban environments (as part of green infrastructure and brown field sites) as well as rural ones managed for non-agricultural purposes.

8. Soil health should also be considered at various spatial levels, and is definable from the rhizosphere, field, catchment, regional and higher levels up to the Earth system. Each level requires a different metric of measurement and monitoring infrastructure.

9. Over the past 15 years there has been a transformation in the nature of soil research. Traditional disciplinary distinctions, e.g. between soil physics and soil chemistry, have been largely replaced by broader, more integrative and multidisciplinary approaches. This reflects a shift of emphasis from understanding the nature of soil, to one of addressing soil-related strategic challenges of societal importance. It is exemplified by RCUK's current SARISA and Soil Security programmes, led by BBSRC and NERC respectively, but each co-funded by the other Council, which draw on expertise from a wider scientific community as well as that of soil researchers themselves.

10. As in other areas of environmental or biological science, this transition has been facilitated by new technologies that allow scientists to tackle previously intractable research challenges. Technological developments in, for example, genomics and imaging, have enabled the acquisition of new types of biological, chemical and physical information about soils at all spatial levels from the sub-cellular to the Earth system. Associated developments in informatics have enabled the analysis and interpretation of unprecedented amounts of data.

11. Measurement and monitoring requires novel approaches and tools for quantifying the dynamics of soil functions at different spatial scales. Examples could include: molecular tools such as eDNA for studying species, populations and functional diversity; high temporal resolution measurements of carbon and nutrient fluxes via sensors and stable isotopes; improved soil gas sampling; and in situ visualization of soil structures, roots and soil organisms. At the higher levels of organisation, the increasing capability of Earth observation (EO) instrumentation such as ground based systems for example the Centre for Ecology and Hydrology COSMOS[1] system, and the data portal provided by the British Geological Survey, and CEH Soils observatory[2]. EO data derived from the Sentinel and Earth Explorer satellite missions are available and assimilated for those who need to monitor and manage soil health through the Centre for Environmental Data Analysis (CEDA)[3]. Such infrastructure will improve understanding of soil functions and their response to perturbations across a hierarchy of scales and contexts.

12. The importance of long-term experiments should also be considered. Short-term research provides a 'snapshot' of soil parameters but need to be seen in the context of longer-term changes in soils which happen over the decade to century scale. The Long-Term and Classical Experiments at Rothamsted Research[4] have collected soil samples and data for over 150 years and these can be used to study changes in soils due to different management regimes a well as environmental factors. To develop a strategy, there is a need to engage the soils research community and make use of the considerable knowledge and experience of those researchers. Developing a strategy underpinned by science will require better understanding of the relationships between biological, chemical and physical process in soils at different spatial and temporal scales and in different soil types, and in different contexts (including the natural and managed and farmed environments). To achieve this, an interdisciplinary approach with expertise from the ecological, biological, atmospheric, biogeochemical, hydrological and geological sciences will be required. Adopting a more holistic view will also require an appreciation of the wider value of soil, such as economic value beyond that of food production, and values relevant to society as a whole.

[1] http://cosmos.ceh.ac.uk/
[2] http://www.ukso.org/
[3] http://www.ceda.ac.uk/
[4] http://www.rothamsted.ac.uk/long-term-experiments-national-capability

What are the benefits that healthy soils can provide to society?

13. Soil provides many benefits to society including those that are crucial to food security, climate mitigation, water and nutrient cycling, and carbon storage. Changes in the way we manage the land surface have resulted in widespread degradation of soils and their ability to deliver ecosystem services. For example, it has been estimated that currently 45% of European soils exhibit very low organic matter contents (0-2% organic C)[5], and degraded soils cover 15-17% of the world's land surface[6]. The functions performed by healthy soils include:

- Agriculture/food production: Soils provide more than just the support medium for crop plants, the microbial interactions in the rhizosphere environment are essential for providing nutrients to the plant. Soils are also essential for maintaining the grasslands which provide grazing for livestock.
- Carbon storage/climate change mitigation: Carbon is locked away in soils in the form of organic matter. Soils which maintain their SOC or increase it due to the addition of organic matter sequester significant amounts of carbon, preventing its release to the atmosphere. Soil degradation releases this carbon in the form of carbon dioxide. Degradation of peaty soils causes significant carbon loss.
- Water: Soils filter rainwater and are also able to remove some environmental pollutants, preventing them from entering watercourses. Some pollutants can be degraded by soil microbes. Soils also play a crucial role in absorbing excess rainwater and preventing flooding.
- Nutrient cycling: Soil contains a variety of nutrients including nitrogen, phosphorus and potassium, in the form of inorganic salts and organic matter. Healthy soils are able to maintain stable levels of nutrients and make them accessible to plants. Nitrifying bacteria in soils convert atmospheric nitrogen to nitrogenous compounds; the only other way to make nitrogen available to plants is to add fertiliser to soils. Waterlogged soils may lose their available nitrogen to the atmosphere through denitrification. Nitrous oxide, one of the products of denitrification, is a much more potent greenhouse gas than carbon dioxide. In addition, soil microbes are essential for the decomposition of dead plant and animal material and the recycling of the nutrients contained within them.

14. In addition, soils have been a source of micro-organisms which have yielded new antibiotics. It is possible that further antibiotics or lead compounds may be isolated from as-yet undiscovered soil microbes, and preserving the biodiversity of soil microbes is important to maintain this potential source of new antibiotic compounds.

15. Soil is at the centre of several 'Planetary boundaries' that are considered to have gone significantly beyond their steady state and to be being driven into new states. These include biogeochemical flows, and biodiversity levels[7].

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

16. Once critical functions are lost they can be irrecoverable, potentially for millennia, representing a loss of natural capital that is potentially highly detrimental to the UK's national livelihood and well-being. As well as being important in their own right, an understanding of soil processes and their potential tipping points for

[5] Jones et al. 2012. State of Soil in Europe. JRC Reference Report 80pp.
[6] Staring Centrum Instituut voor Onderzoek van het Landelijk Gebied., Oldeman, L. R., United Nations Environment Programme. & International Soil Reference and Information Centre. (UNEP ;ISRIC, Nairobi, Kenya, Wageningen, Netherlands, 1991).
[7] Steffen et al. 2015. Planetary Boundaries: Guiding human development on a changing planet. Science Vol. 347 no. 6223

the loss of these functions is essential to inform policy in a range of areas including forestry, agriculture, urban planning, flood alleviation, water quality, greenhouse gas emissions and biodiversity. In delivering policies to protect soils, there remains a significant challenge to (a) define suitable metrics of sustainability and (b) identify and prioritise appropriate management interventions.

17. Specific negative consequences of exceeding these tipping points and losing soil function include: loss of biodiversity; reduced agricultural production (crops and livestock); increased carbon dioxide loss to the atmosphere; greater tendency to flooding; and reduction in soils' capacity to filter water and degrade pollutants.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

18. The European Commission produced a thematic strategy on soils in 2006, which included proposals for a Soils Framework Directive, but this has not yet been established. In England, the UK Government has committed to safeguarding soils' ability to provide essential ecosystem services and functions by ensuring that all soils are managed sustainably and degradation threats are tackled before 2030, through the 2011 Natural Environment White paper[8]. The Scottish Government (SG) published the Scottish Soils Framework in 2009, and a State of Scottish Soils report in March 2011. Scottish policy recognises soil as a valuable but vulnerable natural asset, which contributes vital economic and environmental functions and requires sustainable and effective management for the long term.

19. Maintenance of a strong and adaptable community of academics with expertise in soils research and other relevant disciplines will be important in understanding soil health. The requirement for multidisciplinary approaches to understanding and addressing questions in soil science means that soil researchers will need to be able to draw on expertise in the wider scientific community. This will bring new technologies and multidisciplinary approaches to bear on soil-related challenges, complementing the expertise of established soil scientists.

20. In recognition of this need for researchers with broad soil research skills, NERC and BBSRC invested £3.8M in 2013 for a soil science Centre for Doctoral Training that has been awarded to the STARS (Soils Training And Research Studentships) consortium led by Lancaster University which will provide funding for 11 studentships each year for three years[9]. In addition, NERC and the SG have launched a £2M fellowship scheme for the next generation of soil research leaders[10].

21. NERC and BBSRC are leading research programmes to better understand the soil environment: 'Soil Security'[11] and 'Soil and rhizosphere interactions for sustainable agri-ecosystems' (SARISA)[12] programmes, both aligned to the multi-agency Global Food Security programme. A coordination team has been appointed to promote knowledge exchange and derive increased impact from the projects funded under these programmes.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

22. Soil is an underpinning component of the natural environment and is central to the well-being of most ecosystems and ecosystems services in the UK, either directly or indirectly, and therefore should play a central role in the upcoming plan.

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[8] http://www.official-documents.gov.uk/document/cm80/8082/8082.pdf
[9] http://www.starsoil.org.uk/
[10] http://www.nerc.ac.uk/research/funded/programmes/soilsecurity/news/ao-fellowshipawards/
[11] http://www.nerc.ac.uk/research/funded/programmes/soilsecurity/
[12] http://www.bbsrc.ac.uk/funding/opportunities/2013/2013-gfs-sarisa/

Written evidence submitted by Steven Townsend, BASE-UK

BASE-UK is a farmer based and farmer funded organization founded to promote and share information and experiences with Conservation Agriculture (CA) techniques in the UK

How could soil health best be measured and monitored?

Firstly you can't produce/improve soil health without providing organic forms of carbon in the soil which provides the energy source for the biology to live and thrive on. Therefore soil carbon levels should make up the backbone of soil health measurements.

There are plenty of options for measuring soil health available in this country and across the world. One lab in the UK, has just started it own soil heath suite that includes measurement of soil biology, fertility and organic matter. These tests can be supplemented with simple on farm water infiltration tests (to measure how fast water is moving through the soil) that could be carried out by the farmer or B.A.S.I.S trained advisor. Other simple tests can be used but I have covered the main ones that would give a good idea of soil health.

How could the Government develop a strategy for tracking soil health?

By encouraging farmers through both incentives and training to follow the principles of CA farming. CA is a sustainable farming system that puts soil carbon management first in soil cultivation plans and is designed to protect the soil, air and water. CA is based on 3 principles, which are as follows:

- Minimum soil disturbance with cultivation equipment (ideally no-tillage at all),
- Keeping the soil covered to a level of 60% (ideally 100%) with crop residues and/or cover crops/green manures to protect the soil from rainfall
- A rotation (minimum three crops species) that encourages soil, plant and animal biodiversity

By engaging directly with farmers who are actually improving their soil health and taking policy direction from them instead of relying so much on academic research which in our experience struggles with CA. This is because CA is a system of soil management and systems don't show up well or are difficult to manage in scientific trial work situation.

What are the benefits that healthy soils can provide to society?

A sustainable, secure and healthy food source produced with minimum inputs and minimal pollution whilst at the same time rebuild the country's soils via carbon sequestration. Healthier, minimally disturbed, carbon rich soils hold much more water, than those that are not, which would help to reduce the speed of water movement and potential flooding

Healthy soils produce healthier food with the obvious benefits to the population and reduced cost to the National Health Service (NHS) and improved productivity

Provide a lower cost carbon reduction policy via soil carbon sequestration verse emission reduction schemes. 1% increase in soil carbon equals 20 tnes/hectare more soil carbon

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

More soil loss and direct and diverse pollution of fertilizers and pesticides. Poorer public health and productivity, more cost to the NHS and social security, less secure food and a reduced UK agricultural business

What measures are currently in place to ensure that good soil health is promoted?

Various stewardship schemes aimed at improved soil management and awareness of potential soil related problems. These usually look at individual problems but fail to grasp that this is a system problem and needs a system solution.

And what further measures should the Government and other organizations consider in order to secure soil health?

Make CA the benchmark system for farmers to follow. Government led direction on training at farm and college level. Incentivize reduced tillage practices and make reduced tillage part of the qualification for the single farm payment. Currently changes in soil health are being led by farmers such as those who are members of BASE-UK because improving soil health is good for the farmer as well as the environment. Farmers are showing that fuel, fertiliser, and pesticide use can be reduced along with reduced machinery costs and still produce equivalent yields to other intensive cultivation systems.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil health should play a central role in the Governments 25 year plan but understand that as a time scale 25 years is not much time in the evolution of soil. The Government should offer direction, training & incentives for farmers to make the changes necessary to produce healthy soils. Past Government policies are part to blame for the current situation the country finds itself in when changes were encouraged at farm level to push for higher food production levels particularly during and after the second world war. Unsustainable systems of production were encouraged based on intensive mechanisation of soil management and the use of high rates of synthetic nitrogen fertilisers which has resulted in the subsequent loss of soil carbon and so soil health.

January 2016

Written evidence submitted by Soils Training and Research Studentships (STARS)

We are a cohort of 10 PhD students part of the STARS (soils training and research studentships) Centre for Doctoral Training, comprised of 4 universities and 4 research institutes. The aim of the STARS College is to encompass a wide range of soil science, but to primarily focus on the understanding of the soil-root interface, the delivery of ecosystem services and the resilience and response of soil function and global changes.

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8. Cranfield University

Executive Summary

- A healthy soil is one that reaches a level of fertility capable of supporting economically viable production of food and fibre to a quality level sufficient to meet human requirements for current and future generations, without compromise to existing and developing natural habitats.
- Soil health is dependent on the maintenance of four major functions: carbon transformations; nutrient cycles; soil structure maintenance; and the regulation of pests and diseases. These should be monitored with both abiotic and biotic measures. These may include soil density, aggregate size and distribution, organic matter content, water holding capacity, nutrient content, biodiversity, pH, electrical conductivity, soil respiration and top-soil depth.
- Soil health monitoring strategies should be developed on a 'fit for purpose' basis. This would allow for the inclusion of the heterogeneity of UK landscapes and catchments while incorporating site specific objectives and identified service management goals. It would prove prudent to capitalise on existing frameworks and knowledge bases present in current and past monitoring systems.
- To ensure valuable and justified returns on resource investment all monitoring and measurement should be designed and implemented in such a way that make it sustainable across timescales which span government office and short to medium term initiatives.
- Healthy soils can provide societies with nutrition, medicines and clean and safe places to live. It is imperative for society and the environment not to be viewed as separate entities. Relying on the fiscal quantification of benefits the environment provides society, to ensure and justify its protection, is myopic. Such approaches may appear to offer convenient inclusion into existing communication and value systems but can result in the dismantlement of the environments intrinsic values and societies interdependence.
- In summary, key areas the government need to tackle include: educating the public, an initiative to help fund more soil related research projects, and to provide incentives to encourage major produce buyers to incorporate sustainable strategies that will benefit the soil into their practice.

1) How could soil health best be measured and monitored?

1. "Soil health" is a far-reaching term that is hard to define. It incorporates many different factors within broad categories of biological diversity, chemical fertility and physical structure (Soil Health, 2016) and is interdependent on the health of the Earth's water, plants, animals, humans, ecosystems and climate. Resilience is an intrinsic aspect of health, which can be described as the ability to recover from severe or dramatic changes and disturbances (Döring et al., 2013).

2. At one end of the economic-financial spectrum soil health can focus on a soil's ability to produce economically beneficial crops (Kibblewhite et al., 2008). However, narrow focus on growing products for fiscal gain alone is not fundamentally inclusive of, or concerned with building and restoring healthy soils. A healthy soil is one that reaches a level of fertility which is not only capable of supporting economically viable production of food and fibre but to a quality level sufficient to meet human requirements (Kibblewhite et al., 2008) for current and future generations without compromise to existing and developing natural habitats. Current economic objectives and conservation initiatives would be compromised without inclusion of a soil's ability to perform ecosystem functions (Döring et al., 2015). Soil health in unmanaged natural systems (Schoenholtz et al., 2000) can be determined by its ability to support native plant growth, an idea reinforced by Haygrath and Ritz, (2009) who suggest that the concepts of soil quality and health centre on the soil being fit for its present purpose and the likelihood of it being able to maintain this in the future.

2) How could the Government develop a strategy for tracking soil health?

3. Existing pluralities on what constitute soil health, particularly across the wide variety of UK soils, leads to uncertainty over what characteristics should be tracked to monitor soil health. Primarily work is needed to identify what is a healthy state for different soil types and environments. As soils provide myriad services for multiple 'markets', soil monitoring needs to be designed on a 'fit for purpose' approach and encompass the spacial heterogeneity of landscapes and catchments.
4. In general, the health of a given soil is dependent on the maintenance of four major functions: carbon transformations; nutrient cycles; soil structure maintenance; and the regulation of pests and diseases. As soil functions cannot be measured directly by one variable, a number of indicators will normally be evaluated which may present difficulties for the development of effective monitoring programs, but should be assessed on a case by case basis. Programmes should cover a range of both abiotic and biotic measures, to determine the four major functions. These may include soil density, aggregate size and distribution, organic matter content, water holding capacity, nutrient content, biodiversity (Visser and Parkinson, 1992), pH, electrical conductivity, soil respiration and top-soil depth (Arshad and Martin, 2002).
5. Soil carbon is of particular importance to climate change. Declining carbon stock could be used as a cursorily diagnosis of an unhealthy soil and allow monitoring programs to extend into global initiatives on climate targets.
6. Once the parameters are selected, soils need to be assessed at considered yet realistic intervals. The temporality of measurements should reflect the specific soil environments they are set up to measure and be able to provide information on a soils' dynamic resilience. Arable land with an increased turnover of nutrients and more intrusive management practices may require frequent measurement time points. While perennial systems such as forest or moorlands may not require the same level of frequency. For example, some sites included in GMEP are resampled every four years (Emmett & the GMEP team, 2014). There is strong evidence that highlights the value of data from long-term experiments which maintain controlled monitoring practices over long periods of time (7-100 years), such as the classical experiments at Rothamsted Research. To ensure valuable and justified returns on resource investment all monitoring and measurement should be designed and implemented in such a way that make it sustainable across timescales which span government office and short to medium term initiatives.
7. There exist large scale environmental monitoring programmes in place across the UK which include soils. The Countryside Survey is such a program. The survey has tracked several soil properties since 1978 and previous assessments (Emmett et al., 2007) have allowed the Government to choose to foster some or all

of the parameters that have been used in the past. It could prove prudent to capitalise on existing frameworks and knowledge bases present in current and past monitoring systems.

8. The UK is geologically heterogeneous with extreme variation in soil types and habitats over relatively small areas. In addition, the country has been subjected to extensive historical and modern land-use changes, which can present issues with aspirations for specific landscapes. Furthermore, certain aspects of soil health may be more important than others at a regional-scale. Therefore, it may be more beneficial for the UK government to develop strategies for monitoring soil health where local knowledge and expertise would be fully engaged with and of most value. The ongoing Glastir Monitoring and Evaluation Programme (GMEP) in Wales is a good example of this (Emmett & the GMEP team, 2014). In this way, strategies can be developed to better suit a smaller and less complex area. This method may also allow better assessments of important regional ecosystems, such as peatlands, moorlands, and woodlands, without obfuscation by nationwide trends driven by urbanised and arable land. Reports from these bodies could be delivered to their respective governments as well as the UK Government. In this way, policy and funding partnerships could be established between the different levels of government such that members of government will be better informed of the state of their soils and their policy decisions can have a more positive impact.

3) What are the benefits that healthy soils can provide to society?

9. “Nature and society are not divisible things. The two live inside each other.” (Out of the Woods, 2014).

   Soils underpin the whole of society. A healthy society is made possible by a healthy environment and many essential ecosystem services are dependent on healthy soils (de Groot et al., 2002, Barrios, 2007, Robinson et al., 2014).

10. Soils regulate nutrient cycles, including the carbon cycle and thus play a major role in climate regulation. Minimally disturbed soils, high in organic matter can provide a buffer for drivers of climate change and air pollution by acting as a carbon sink.
11. Healthy peatland and moorland soils provide cleaner and cheaper water by filtering rainfall before entering waterways. Water flow patterns can be heavily informed by soil. Healthy stable soils can provide protection against floods and protect the built human environment from extreme weather events. This is because good soil structure can store ‘excess’ water or allow water to penetrate at a slower rate and drain away often to areas which have received less rainfall. In this way, excess water can be diverted to dryer soils with higher absorbance capacity or areas of lower bed rock. Such characteristics are of great benefit to water management requirements and flood control.
12. Food production is reliant on healthy soils that provide nutrients, water, and a physical substrate for crop growth. Healthy soils efficiently cycle nutrients and provide above and below ground pest protection. Such services allow economically viable and healthier domestic food production by lowering the cost of fertilisation and pest control which in turn reduce diffuse pollution and related ‘management’ costs.
13. Many common antibiotics used today originated from soil organisms. These have offered significant benefits to human and animal health. It is likely that many more could be undiscovered and prove essential in treating new bacterial strains and existing conditions. This is an incredibly valuable resource especially when considering that diseases are constantly acquiring immunity to current antibiotics.
14. In short, healthy soils in conjunction with healthy water and air can provide societies with nutrition, medicines and clean and safe places to live. It is therefore imperative for society and the environment not to be viewed as separate entities. Relying on the fiscal quantification of benefits the environment provides society, to ensure and justify its protection, is myopic. Such approaches may appear to offer convenient inclusion into existing communication and value systems but can result in the dismantlement of the environments intrinsic values and societies interdependence.

4) What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

15. The consequences of failing to protect soil health affect everyone and everything on the planet. Ecosystem services provided by soils and the wider natural community would be lost. Under the current system issues of food security are not coursed by limited food production but embedded in globally systemic failures underwritten by market forces (Aber, 2011; Elver, 2015; World Food Programme, 2016; Food and Agriculture Organization, 2016; Out of the Woods. 2014). However it is still imperative for food security that current methods which reduce soil health are abandoned. With the depletion of nutrients and soil degradation occurring at alarming rates, it is clear that we need to focus on sustaining healthy soils in order to sustainably produce food. A future without healthy soils would mean not enough food for everyone, and the food produced would be of lower quality leading to malnutrition as well as starvation. Throughout human history civilisations have collapsed due to an inability to maintain soil health.
16. Destructive agricultural practices (Aber, 2011), deforestation, mining and fracking (Lustgarten, 2012) can produce many devastating environmental effects, including contamination of soils and waters, pollinator eradication, soil compaction, crop failure, soil erosion, flooding, drought, antibiotic resistance, desertification, acidification and salinisation (Australian Government department for the environment, 2012).
17. Soil erosion can dramatically impact landscapes, leading to irreversible changes in fertility and the pollution of waterways. Degraded soil no longer filters water effectively and can itself become a pollutant. In such situations more intensive water treatment is required translating into increased costs to society.
18. Soil carbon stocks are estimated to contain a reservoir of 2300 Pg C (Jobbagy and Jackson, 2000) so failing to protect soil health would lead to a net release of greenhouse gases. A change in climate may alter the terrestrial biosphere causing it to turn from a carbon sink to a carbon source, which may have further detrimental effects on the environment.
19. Half of all antibiotic strains are found in soil and although there is needed concern in the overuse of antibiotics which has led to many bacterial resistances, it is vital not to neglect the valuable microbial resource present in healthy soils. Microbial interactions in soil are complex and not well understood and many remain unculturable; thus far we have not been able to fully assess the potential benefits that soil microbial communities can supply. What is clear, is that without soil biodiversity there would be a removal of potentially medically important microorganisms from soils, increasing the probability of a post-antibiotic world where diseases are immune to all antibiotic treatments. This would have long-reaching implications for pharmaceutical, chemical and biological research and development.
20. In short, the control and management of land is deeply political and its misuse is a major cause of environmental change, poverty and death. The devastating impact of illness, famine, population and displacement are unevenly distributed on a national and global scale. The global changes incurred by ignoring soil health and the implications for the environment and food security would not discriminate.

5) What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

21. Currently, soil quality is monitored as part of agri-environment schemes. For example, measuring soil quality is a unique work-package in GMEP (Emmett & the GMEP team, 2014). Perhaps developing standalone schemes to monitor soil health may lead to greater insights.
22. In the European Union soil is not subject to strict rules and regulations, and current policies on water, waste, chemicals, and agriculture do no specifically apply to soils but indirectly apply to the protection of them. This has led to insufficient scope for the protection of soils in Europe which is reflected in biodiversity and climate change objectives via unsustainable usage. The EU initiated the Seventh Environment Action Programme in 2014. It recognises the seriousness of soil erosion and proposes to tackle the surrounding issues by 2020 including: adequate protection of soil, sustainable land management, remediation and efforts to increase soil organic matter (European Commission, 2015).
23. Within agriculture, farmers that receive payments from the UK governments are required to keep their land in good agricultural and environmental condition (European Commission, 2015). Farmers are also issued with codes for good agricultural practice (Department for Environment, Food & Rural Affairs, 2013).

The government should move focus towards industries which place pressure on farmers and land managers to involve themselves in unsustainable practice. Major buyers of farm produce such as large super market and food manufacturers should be called on by the government to play a more active role in the protection of the land and our soil. Supposed consumer requirements should not shape detrimental practice or unrealistic market demands on the land. Availability should be dictated by primary producers who manage the land and so manage expectations.

24. However agriculture is not the only sector influencing soil health, and other sectors are often much less regulated. Construction has a massive impact on soil health through sealing off vast areas of soil, yet the only recognition from the government of this is a non-legislatively binding code of practice (Department for Environment, Food & Rural Affairs, 2011). Multiple industries pollute soil and there are thresholds and limits set out to prevent this becoming dangerous to health.

    There have been many attempts to communicate the value to soil, yet most still consider it to be of very little value. Further effort is needed.

6) What role (if any) should soil health play in the Government's upcoming 25-year plan for the natural environment?

25. Soil health should play a central role in the Government's upcoming plan for the natural environment. The current 25-year plan issued by DEFRA follows recommendation from the Natural Capital committee's third report. Its broad scope considers the better understanding of nature, recognition of key environmental resources, and careful management of these resources to safeguard the natural environment. Its strategy aims to implement research, data tools and techniques to place the UK in the forefront of environmental research as well as engaging local, national and regional organisations to understand the importance and significance of nature. Current funding is planned to protect marine habitats, and enhance England's countryside (£3 billion of funding issued toward planting new trees, reducing air and water pollution, national parks etc.) Although this is related to soil health more research should be carried out specifically to tackle the current knowledge gaps in soil by the implementation of interdisciplinary programmes focusing on soil health exclusively. Current programmes include: the biodiversity and ecosystem services for sustainability programme (BESS) and the valuing nature network (VNN).
26. The BESS programme aims to specifically identify new tools and indicators to track and identify ecosystem services and biodiversity, and the VNN programme aims to understand the complex nature of the natural environment in terms of decision making and valuation analysis in the context of the economic and cultural value in society as a whole (Department for Environment, Food & Rural Affairs, 2015). Monitoring soil health over such a timespan will give Government a continuous indicator of the effect local policy has and how British soils are progressing in the wider context of a changing climate. It may provide deeper insights into the natural world which could result in novel and beneficial discoveries.
27. In summary, key areas the government need to tackle include: educating the public- soil is a vital resource that is hugely underappreciated for its contributions towards human health and survival; an initiative to help fund more soil related research projects; and to provide direction to encourage market shareholders to incorporate in their business models demands that support sustainable agricultural practice and soil health.

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Written evidence submitted by DEFRA

SUMMARY

The Government recognises that soil is essential for underpinning a range of benefits, including food production, but also biodiversity, carbon storage and flood protection. The success of agriculture in England depends upon healthy soils, they are arguably a farmer's most valuable asset. Yet soil degradation costs in England and Wales could be up to £1.42bn annually.

Healthy soils underpin a beautiful countryside with clean water and flourishing wildlife. In the face of a changing climate and our long-term economic plan to produce more British food, we must guard against any risks to our long-term productive capacity and encourage famers to manage their soils in a way which will safeguard this asset for current and future generations.

The Government is taking a number of actions to protect agricultural soils, including outcome-based cross-compliance soils rules and funding to protect soil and water and improve flood resilience is available through existing Environmental Stewardship agri-environment agreements and through the new Countryside Stewardship scheme. There are also protections through planning to safeguard our best and most versatile agricultural land, restrictions on certain activities (e.g. fertilisers) and the Farming Advice Service along with the Catchment Sensitive Farming Service all play a role. We are also working in collaboration with the Research Councils on an ambitious research programme to improve our understanding of soil condition and resilience.

The Government has committed to develop a 25 Year Environment Framework. The framework is for a healthy, diverse, resilient natural environment that benefits people biodiversity and the economy. The framework will focus on the environment as a whole, including air quality, water, woodland/forestry, soils, marine, biodiversity, natural resources, designated landscapes plus cross-cutting themes such as data, new technology and mainstreaming the value of nature.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

1. Soil monitoring provides evidence on the state of and change in our soils. National scale soil monitoring tells us about the ‘population’ of national soils, in terms of their ability to perform different functions, but not about soils at individual sites as there is not enough sampling at each site.

2. The Countryside Survey[i] is an ‘audit’ of our countryside’s natural resources, and includes a suite of soil measurements. It was first conducted in 1978 and has been repeated every 6-7 years since, with the most recent taking place in 2007. Soil has only been sampled on three of these occasions – 1978, 2000 and 2007. Most soil properties change very slowly over time, so more frequent monitoring is not justified.

3. The key findings of the 2007 survey were:

   - Soil acidity decreased from 1978 to 2007 in England, mirroring declining emissions and deposition of sulphur.
   - No overall change in average carbon concentration in soils (0-15cm) in England since 1978. However, there was a significant reduction in carbon concentrations in the arable and horticulture land class.

4. Defra is working with partners, including the Devolved Administrations and the Natural Environment Research Council’s Centre for Ecology and Hydrology (CEH), to explore options for a future Countryside Survey taking account of advances in new techniques for surveillance and data analysis. A final decision on the scope, design and timing of a future survey has yet to be taken.

5. Defra has been working since 2003 to develop a suite of soil quality indicators (SQI) for use in monitoring. SQIs that can be reported on within policy cycles (i.e. less than 3 years) have not been identified. A minimum suite of physical and chemical SQIs have been identified to monitor changes in soil functionality (pH, soil organic carbon, bulk density, available (Olsen) P, total N, aqua regia-extractable metals (Cu, Cd, Zn and Ni), and extractable Mg and K). Potential trigger values for action have been identified for some SQIs for some soil functions. Potential candidate biological SQIs have been identified but these require further work to help identify and monitor the key role that soil biota play in soil health.

6. In 2009 the European Commission extended the Land Cover and Land Use Statistics (LUCAS) exercise to include an additional module on soil to monitor topsoils at 20,000 sites across 23 Member States, including the UK. This exercise is currently being repeated and plans are in discussion for a more

extensive suite of soil indicators to be monitored in 2018, though potentially on a fewer number of sites across the EU.

7. Defra is currently developing and piloting a national soil erosion monitoring framework for monitoring spatial distribution and quantity of soil erosion through different pathways (such as wind, water, excessive grazing and tillage)[ii]. The pilot is monitoring a random selection of sites across England (and Wales). Previous soil erosion monitoring exercises have been biased towards monitoring erosion at sites where erosion can be expected (as this is more cost effective); however, this has led to an overestimate of the extent of erosion. The outcomes are due to be reported in 2016.

8. Natural England's Long Term Monitoring Network assesses and monitors a wide range of environmental conditions on some of our National Nature Reserves to detect the impacts of climate change and pollutant deposition on biodiversity and ecosystem function. This monitoring includes the physical, chemical and biological characteristics of our natural soils in a range of habitats. Natural England also maintains a database of agricultural soil sampling results gathered during applications for agri-environment schemes.

9. For spatial planning, changes in land use are monitored by DCLG[iii]; whilst not designed to monitor soil health they provide an insight into the likely magnitude of development impacts on soil, most notably physical loss or sealing.

<u>Natural Capital</u>

10. Government is moving towards a natural capital approach to the environment, building on the science and evidence base laid by initiatives such as the National Ecosystem Assessment and the advice of the Natural Capital Committee (NCC). This will enable a better assessment of the benefits and trade-offs of different uses of our natural assets, including soil. In combination with other natural assets and inputs, soil produces flows of services, such as crops, carbon storage and water filtration that benefit people and the economy. Whilst the relationship between the condition of the asset and the services provided may be complex or unclear, the natural capital approach focuses attention on the need to maintain and monitor the underlying natural assets such as soil if the benefits are to be sustained and if irreversible degradation is to be avoided.

11. In the national natural capital accounts being developed by the Office for National Statistics (ONS) and Defra (2020 Roadmap[iv]), soil quality is one of the indicators of ecosystem condition for relevant broad habitats, following United Nations' statistical guidance. As part of this work a scoping study on accounting for peatland soils has been published and there are also plans to scope a soils account although this is likely to be constrained by data limitations.

12. On individual ecosystem accounts, there is a focus on carbon in soils, using National Forest Inventory[v] (NFI) data for woodlands and Countryside Survey data for farmland. Recognising its importance, consideration is also being given to a standalone peatland account.

Forest soils

13. Forest soil health needs to be considered separately from agricultural soil health because soil types and properties can differ significantly between these land-uses. The protection of forest soil health has been recognised formally since the publication of Forests and Soil Conservation Guidelines[vi] in 1998 and soil protection is an important element of government forestry policy today.

14. There are specific soil monitoring platforms to forest soils, such as ICP Forests Level II[vii] and Biosoil[viii]. Monitoring dedicated to forest soils provides the most interpretable information, primarily because they generally sample to greater depth (80-100 cm) than is typical for more general soil monitoring surveys (15-30 cm).

15. The Forestry Commission's NFI provides a consistent approach to forest monitoring within a five-year cycle, for which the first cycle's fieldwork is now complete with the results due to be published by the end of 2017.

16. The Forestry Commission Science and Innovation Strategy for Forestry in Great Britain[ix] identifies the importance of soil research. Through its funding, Forest Research has carried out a Soil Sustainability research programme[x] for several decades and gathered considerable information relevant to soil health.

Peaty soils

17. Over half of the UK's soil carbon is within peat habitats, so a key part of Natural England's work on mitigating climate change is the monitoring of peat soils. All Peatland Sites of Special Scientific Interest (SSSI) are assessed through Favourable Conservation Status (FCS) and Natural England has numerous peatland mapping data sets.

18. A summary of Natural England's assessment of key evidence relating to soils and their conservation and management is available[xi]. It also lists Natural England's research programmes.

Soil Biodiversity

19. Soils are estimated to support one quarter of the world's species but, due to the small size, and challenging nature of identifying soil organisms, the biodiversity of our soils has not been well explored. We have a reasonable idea of the diversity and number of earthworm, mollusc, insect, springtail, mite, nematode,

tardigrade and protozoan species that inhabit our soils. The diversity of fungal species is relatively well known, and bacterial strains are fairly well explored. However, our knowledge is currently poor relating to the distribution of these organisms, their habitat affinities, their response to management and environmental change, and the natural assemblages they form.

20. Natural England's Long Term Monitoring Network and the Countryside Survey 1998 and 2007 have examined soil communities, using a range of techniques, bacterial DNA has been used to characterise bacterial communities, but progress in identification of soil invertebrate samples has been slow due to a lack of expertise. Natural England and CEH have been working together, with other partners, to develop metagenetic techniques and apply these to assessing soil communities, and these provide an opportunity for future monitoring and assessment of soil communities, enabling distribution and trends among soil communities, and enabling communities to be linked with the soil functions they provide.

What are the benefits that healthy soils can provide to society?
What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

21. Healthy soils with high organic matter and good structure maximise crop yields, increase crop root growth and, for harvested crops, increase the residues that are returned to the soil. This leads to improved soil organic carbon levels, increases nutrient storage and increases water holding capacity thereby reducing soil susceptibility to erosion, drought and floods.

22. Soil performs several globally important functions:

- Around 95% of food production relies on soil. The global nature of the food system makes soil health (or quality) an international concern.
- Soils are home to a quarter of the Earth's biodiversity; organisms such as bacteria, fungi, and earthworms. These support plant growth, regenerate soil structure, help control pests and diseases and cycle carbon, nitrogen and other nutrients. Soil microbes are a source of antibiotics and may provide future drug discoveries.
- Soils absorb and store water; their capacity to do so relies the humus produced by soil organisms from organic matter. Humus also contributes to good soil structure, which is also maintained by soil organisms, and is improved by organic matter and appropriate management.
- Soils store three times as much carbon as is contained in the atmosphere; degradation of carbon-rich soils releases significant quantities of CO_2.

23. The ability of soil to perform these functions is reduced when it is degraded (its quality is reduced for example through compaction or loss of reduced organic matter) or eroded or lost (its quantity is reduced).

24. A study (Graves et al[xii]) reporting in 2015 found soil degradation costs could be up to £1.42bn annually, with over 55% of those costs due to Greenhouse Gas (GHG) emissions, 20% from lost agricultural output, and 20% from flooding. This is mainly linked to loss of organic content of soils (47% of total cost), compaction (39%) and erosion (12%).

25. The loss of soil through diffuse pollution from agriculture also impacts on water quality and aquatic biology through the increased risk of sediment, nutrient and pesticide pollution from surface run off and drainage e.g. smothering fish spawning areas, carrying phosphates that can cause eutrophication[1] of water bodies or degrading potable water supplies.

[1] Eutrophication is when the environment becomes enriched with nutrients.

Climate change

26. Soil plays a critical role in regulating our climate, as the biggest terrestrial carbon store. Increasing the resilience of soils to the impacts of climate change allows them to continue to deliver the societal, economic and ecosystem benefits they provide. Due to their role underpinning our farming, forestry and natural environment; healthy soils also support the adaptation and resilience of those sectors.

27. The first Climate Change Risk Assessment (CCRA) identified increased pressures on soils due to climate change, in particular by reducing soil organic matter and moisture content. In periods of increased climatic variation soil in poor health is more likely to be susceptible to degradation in times of high or very low rainfall and put strains on staple food crops.

28. In the long term, climate change is projected to affect our food production system. However, the indirect effects of climate change as a result of land use change and changes in crops and cropping patterns are likely to have a greater impact on soils than the direct effects of climate change through changes in temperature and rainfall.

29. Defra-funded research[xiii] suggests that reduced water availability could contribute to a significant decline in the suitability of land to support unirrigated agricultural crops in parts of England and Wales. Protecting soil health, particularly through maintaining higher organic matter levels, can help increase the soil's capacity to retain moisture, helping to make more efficient use of the water available.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

In England, a number of measures are currently in place that play a part in promoting good soil health:

Soils and Cross Compliance

30. New outcome based soil rules were introduced in January 2015 that anyone claiming a Common Agricultural Policy payment must comply with. The rules[xiv] require a basic level of protection for soils through management techniques that: maintain minimum soil cover, particularly in the wetter winter months; prevent and ameliorate erosion; and retain levels of organic matter, through a ban on burning arable stubble, management of heather and grass burning and not carrying out improvements on uncultivated land. Where breaches are found, farmers can receive a penalty between 1-5% from their Basic Payment Scheme.

Funding for farm improvements

31. England has had a succession of agri-environment schemes in place over the last 25 years funding a range of environmental management measures which, among other things, have sought to reduce the risk of soil erosion at source and intercept surface water runoff pathways carrying sediments and organic materials; reduce soil compaction (and thereby the risk of flooding and the need to dredge rivers); and mitigate the impacts on receptors, notably protected and priority river and wetland sites. Payment is made for the income foregone and any additional costs associated with managing land in these environmentally beneficial ways.

32. Under the last scheme, Environmental Stewardship, 3,411 new agreements were made during 2010-14 which contained at least one soil or water option. These options covered more than 16,000 hectares.

33. The new Countryside Stewardship scheme commits around £900m to benefitting the environment over the next 5 years. It includes a range of measures which have benefits for soil such as winter cover crops, stubble management, woodland creation and grazing management. The new scheme is more highly targeted that its predecessors focusing measures in areas where they present the biggest priority. This targeting is incentivised by a scoring system which rewards the choice of the right measures in the right areas for greatest benefit.

34. The protection of soil and water and the delivery of Water Framework Directive (WFD) objectives is a priority for Countryside Stewardship. A range of multi-annual land management measures and grants for capital works are available within CS to address diffuse water pollution from agriculture (DWPA). These aim to reduce the pollutant source, preventing the mobilisation and transport of pollutants and soil to surface water or slowing down transport mechanisms to allow time for other processes such as plant uptake to occur. There is also a wide range of revenue options that benefit biodiversity, many of which, if targeted effectively, can also reduce diffuse pollution.

35. Capital grants of up to £10,000 to carry out works that will improve water management and quality on farm land were available in the last Rural Development Programme for England and continue into this one. Providing a total of £10million per annum worth of funding to the farm industry from 2015, the grants will fund new projects that reduce the impact agriculture can have on our water quality. Investments that can be funded include sediment traps and ponds, measures to manage livestock access to watercourses. A total of 1,375 Water Capital agreements, worth almost £12million, have been set up by Natural England in 2015. A further c400 agreements are being offered to applicants for work starting in 2016.

Advice to Farmers

36. The Defra-funded Farming Advice Service (FAS) provides a national network of qualified and independent advisors to help farmers understand and meet their requirements, including the new soil rules under Cross Compliance. FAS provide a helpline, events, newsletters, guidance and technical articles. FAS have been running events on the new soil standards and have recently produced a technical article on the new soil rules. FAS works closely with the Campaign for the Farmed Environment who offer industry led advice, including on soil management.

37. Catchment Sensitive Farming supports improved soil health through four main activities:

- Building relationships with farmers and supporting them to consider soil health issues in association with reducing the risk of Diffuse Water Pollution from Agriculture (DWPA)
- Encouraging farmers to implement measures relating to improving and retaining good soil structure, soil organic matter and soil biology as defined within the DWPA user guide
- Working with industry and research organisations to develop new measures for improving soil health, demonstrating the measures to farmers and adapting them to a range of farming systems

- Supporting the development and deployment of RDPE based incentives for improving soil health across Catchment Sensitive Farming and Countryside Stewardship target areas

38. Government also provides support through the Environment Agency led Climate Ready Support Service to enable farmers to manage their soils in a changing climate.

Contaminated soil

39. Part 2A of the Environmental Protection Act 1990 came into force in 2000 and takes a strategic and risk based approach to identifying and cleaning up contaminated land in England. The legislation is supported by Statutory Guidance that expands on certain aspects of the legislation, such as risk assessment, remediation and liability. Since the regime was introduced in 2000 more than 600 contaminated land sites have been identified and dealt with in England.

40. Land is defined as contaminated under Part 2A if there is a significant possibility of causing significant harm to human health or property, pollution of controlled waters or the wider environment. Part 2A underpins planning policy with the National Planning Policy Framework requiring that after remediation, as a minimum, land should not be capable of being determined as contaminated land under Part 2A of the Environmental Protection Act 1990. It is estimated that 90% of remediation in England happens under planning during redevelopment.

41. Landfill tax discourages dig and dump remediation and encourages the reuse of surplus soils suitable for an alternative use as a resource and not waste.

Preventing new soil contamination

42. The Environmental Damage (Prevention and Remediation) (England) Regulations 2015 are in place to address concerns over an imminent threat of environmental damage to land or if such damage occurs. Where there is an imminent threat of environmental damage or actual environmental damage, the operator responsible is required to take immediate steps to prevent damage or further damage and to notify the regulator.

43. The Environmental Permitting Regulations (England and Wales) 2010 require that operators of waste and industrial activities protect soil and take action to remediate any contamination caused[xv]. Installations subject to the Industrial Emissions Directive may also have to submit baseline reports and carry our periodic monitoring of soil and groundwater for relevant hazardous substances.

Planning and Soils – legislation, national policy and guidance

44. The National Planning Policy Framework[xvi] (NPPF) states that the planning system should protect and enhance soils and prevent development from contributing to unacceptable levels of soil pollution. Local planning authorities must take into account the economic and other benefits of the best and most versatile agricultural land. Poorer quality land should be used in preference to that of a higher quality and the re-use of brownfield sites is encouraged.

45. Other soil functions are protected or managed by different mechanisms within the planning system, such as those for flood risk, pollution and contaminated land, or related to biodiversity, landscape and cultural heritage. Once the decision has been taken to develop an area of land, it is important to retain as many healthy soil functions as practicable by careful management of the soils during construction (Defra, 2009[xvii]).

46. The Agricultural Land Classification (ALC) is used to inform planning authorities, developers and the public if development is proposed on agricultural land or other greenfield sites. The ALC grading system is also used by commercial consultants to advise clients on land uses and planning issues.

47. Natural England is also responsible for giving soils and agricultural advice to planning authorities for larger developments[xviii] including where reclamation to agriculture on minerals and waste sites is proposed under Schedule 5 of the Town and Country Planning Act 1990 (as amended).

48. Under the Town and Country Planning Act (Environmental Impact Assessment) Regulations 2011[2], a development proposal that is likely to have a significant effect on the environment should be subject to an Environmental Impact Assessment. Impact on soils is one of the elements considered.

49. Section 19 of the Planning and Compulsory Purchase Act 2004 requires local planning authorities to carry out a sustainability appraisal of each of the proposals in a Local Plan during its preparation. Sustainability appraisals incorporate the requirements of the Environmental Assessment of Plans and Programmes Regulations 2004. This requires the preparation of an environmental report evaluates the likely significant effects on the environment of implementing the plan or programme, which include issues such as the likely significant effects on soil.

<u>Soils and the water environment</u>

[2] Directive 2014/52/EU amends Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment (‘the EIA Directive’) entered into force on 15 May 2014. Member States have to transpose the amendments into their national legislation by 16 May 2017.

50. Defra has recently consulted on a set of basic rules (proposed to take the form of regulated good practice) for farmers to improve the efficiency of farms and help to reduce water pollution from agriculture, which will deliver benefits to soils as well as water quality. These rules have been designed to complement the existing soil rules in cross-compliance and extend their coverage to all farmers, not just those claiming the Basic Payment Scheme. A decision will be taken on the introduction of any new rules in early 2016 once all the responses to the consultation have been analysed.

51. The Nitrates Action Programme applies measures to reduce nitrate leaching and protect water in areas vulnerable to pollution (Nitrate Vulnerable Zones). There is the potential for measures designed to prevent nitrate leaching to also protect soil.

52. Sewage sludge (also known as bio-solids) is a by-product of the waste-water treatment process. The residual matter is readily used in the process of anaerobic digestion and on agricultural land as a readily available alternative soil-building material. The nutrients and valuable trace elements essential to animals and plants make it an efficient and sustainable alternative to inorganic fertilisers and mineral fertilisers. As a source of slow-release nitrogen it is ideal for use in land restoration and is a good substitute for peat in land-reclamation projects thus conserving valuable natural peatland.

53. However, sewage sludge can contain heavy metals which may be harmful to humans and animals unless it is applied correctly. People supplying or spreading sludge on agricultural land must meet the requirements of the Sludge (Use in Agriculture) Regulations. The Regulations are supported by a suite of guidance which are important measures for the protection of soils as well as surface and groundwaters. These include the government's 'Code of Practice (CoP) for Agricultural Use of Sewage Sludge'. The food, drink and agriculture sectors have helped set higher standards and additional requirements to the regulations through the Safe Sludge Matrix. These include standards for pathogens, more restrictive application periods for bio-solids and a ban on the use of untreated sludges. Many food purchasers require farmers to follow the Safe Sludge Matrix in order to sell their produce.

Other measures protecting soils

54. There are a range of wider measures in place in England which provide protection for soils:

- Protection of semi-natural habitats through the Environment Impact Assessment (Agriculture) and SSSI regulations (particularly important for carbon rich soils like peats, woods and wetlands). These regulations are also covered in part through cross compliance requirements for farmers that claim Basic Payment Scheme.

- Farmers may need consents before undertaking activities which impact soil such as turf cutting and where a project increases the agricultural productivity of uncultivated and semi-natural land.

- Farmers may face prosecution if soil eroding from land pollutes a surface water, is from a protected site or is deposited on a highway. Further detail can be found in the Code of Good Agricultural Practice.[xix] This is also covered through cross compliance.

- EU Plant Protection Products (Sustainable Use) Regulations 2012[xx] regulate pesticide use, and is supported by two codes of practice.

- The Fertiliser Manual – RB209 is published by Defra providing nutrient management guidance for farmers.[xxi]

- Practices, such as the import and movement of plants, organic matter and soil poses a potential threat to plant and soil health. To ensure that good plant and soil health is sustained, plant health legislation[xxii] controls the import of plants, seeds and organic matter (including soil).

- Defra Code of Practice on the Sustainable Use of Soils on Construction Sites[xxiii] that helps anyone in the construction industry better protect the soil resources with which they work. The Code advises on planning before construction, including consideration of sustainable drainage systems, the management of soil during construction and on the creation of landscape, habitats and gardens.

- The Agricultural Land (Removal of Surface Soil) Act 1953 that makes it an offence to remove surface soil from agricultural land for sale or use in development.[xxiv]

Climate regulation and Soil Organic Carbon

55. Increasing soil carbon can reduce atmospheric carbon thereby mitigating against climate change. It also improves soil structure and a wide range of biologically-mediated soil functions. Defra has funded research on land use and land management practices to increase soil carbon (soil organic matter) since 2002.

56. The potential for genuine carbon sequestration to soil by agricultural management changes is limited under English conditions. Carbon sequestration is possible on mineral soils through permanent land use change, i.e. cropland to

grassland or forestry. However, gains in soil carbon may be offset by increased greenhouse gas emissions associated with the new land use, e.g. emissions from livestock used to manage the grassland.

57. Organic soils (peat) offers greater opportunity for carbon sequestration, although in the first instance improved management practices are required to halt losses of soil carbon. The amount that could be sequestered on an annual basis (through rewetting) though is considerably smaller than the potential from avoided losses.

58. At COP21 the UK joined the French “4/1000 Initiative: Soils for Food Security and Climate” which aims to ensure that agriculture plays its part in combating climate change. A 4/1000 annual growth rate of the soil carbon stock intends to show that even a small increase in the soil carbon stock (agricultural soils, notably grasslands and pastures, and forest soils) is crucial to improve soil fertility and agricultural production and to contribute to achieving the long-term objective of limiting the temperature increase to +1,5/2°C.

59. This is being used as an opportunity to highlight the research and good practice that has been carried out in the UK (by farmers and by government).

60. The farming industry’s Greenhouse Gas Action Plan contains soil management measures to reduce greenhouse gas emissions through control of nitrous oxide emissions .

Protection of Peatlands

61. Many of the environmental and societal benefits of soils are particularly important for peatland soils on a per hectare basis. Measures such as the UK Peatland Code[xxv], peatland restoration through agri-environment schemes, area designations and targets for the reduction of peat use in horticulture will help to achieve protection of English peatlands. For example:

- The UK sales of peat for horticultural use fell from 2.8 to 2.1 million cubic metres between 2011 and 2014, a decrease of 24%[xxvi].

- Between 2003 and 2013 the area of peatland blanket bog Sites of Special Scientific Interest (SSSI) in England in “unfavourable but recovering” condition increased from 15% to 85% (with 97% in the categories “favourable” and “unfavourable but recovering” combined)[xxvii], illustrating a major step forward in the restoration of degraded peats.

- Since its launch in September 2013, the pilot UK Peatland Code has identified an initial suite of restoration projects covering over 25,000 hectares of mainly blanket bog. Defra has supported the development of the Code since it was first proposed in 2011. This has included research funding to improve the evidence base underpinning the Code. The UK Peatland Code was launched in its latest form by the International Union for the Conservation of Nature's UK Peatland Programme at the World Forum on Natural Capital in November 2015 in order to bring in private sector sponsorship from organisations for peatland restoration projects in the UK.

Adapting to Climate Change

62. Government's second Climate Change Risk Assessment (CCRA) will address gaps identified in the first CCRA and cover areas where the science has advanced significantly. It will be laid before parliament in January 2017. Defra have commissioned the Adaptation Sub-Committee of the Committee on Climate Change to produce the underpinning Evidence Report. The ASC is being assisted by around 100 independent academics and consultants in the preparation and peer review of the report.

63. The first National Adaptation Programme (NAP) report, published by Defra in July 2013, recognised the importance of soils, and included actions to help address the impacts identified in the first Climate Change Risk Assessment (CCRA). Following the publication of the next CCRA, the second NAP report will consider the need for further adaptation action based on developments in our understanding. The development of the next NAP report will be aligned with work on the 25 Year Environment Framework.

Forest soils

64. The UK Forestry Standard (UKFS) is the reference standard for sustainable forest management in the UK. The UKFS, supported by its series of Guidelines, outlines the context for forestry in the UK, sets out the approach of the UK governments to sustainable forest management, defines standards and requirements, and provides a basis for regulation and monitoring. They are a requirement for grant aid, woodland management plans and forestry certification.

65. Compared to some other land covers, forest soils are relatively undisturbed and unaffected by operations that modify soil properties and processes such as fertiliser addition and regular cultivation. However, if best practice (as set out in the UK Forestry Standard (UKFS)) is not followed, there is a risk of soil compaction and erosion during harvesting.

66. Timber production is the chief provisioning service from woodlands and forests. UK domestic production has increased from an estimated 4% in the 1940s to 40% of UK consumption of timber, pulp and panel products in 2014[xxviii]. In 2014,

11.4 million green tonnes of softwood was produced in the UK and 0.5 million tonnes of hardwood were produced from broadleaves.

67. Carbon sequestration is one of the most important regulating services provided by woodlands and forests and their soils. The total carbon (C) stock in UK forests (including soils) is around 3780 Mt of carbon dioxide (CO_2) equivalent (Forestry Commission, 2015). Nearly 72% of total forest ecosystem carbon is found in the soil. Carbon sequestration is enhanced by the relatively acidic and moist soil conditions that prevail in forest soils, and by the low level of disturbance that they experience.

68. Usually covered by protective layers of organic matter, forest soils are resistant to erosion, and erosion events are rare if UKFS best practice is implemented

69. Failure to protect soil health may affect tree growth *directly*, for example through constrained nutrient or water uptake or *indirectly*, by stressing trees physiologically and thus making them more vulnerable to the impacts of climate change, pests and diseases or wildfire.

70. Evidence for forest soil health, together with the review of existing measures provided above, suggests that no new measures are required. However, it will be important to maintain existing policies and measures, strengthen delivery in some cases and continue to support forest monitoring. Future communication and Knowledge Exchange activities which promote woodland and forest resilience should include soil protection aspects.

71. Woodland creation provides a number of benefits including helping to stabilise soils, reducing erosion and slips. They can protect against pollution by providing a buffer between source and receptor, or help the recovery of contaminated land. A number of initiatives support the creation or improvement of woodlands including under Countryside Stewardship.

Research

72. Defra's evidence programme has undertaken over £3 million of research a year including soil related research covering climate change and soils, soil degradation, soil pollution, outcomes from land management, and protecting and enhancing peat soils.

73. The Evidence Strategy, published in June 2014, outlines Defra's evidence priorities and its role in good policy making. However with changing budgets and resources our approach to commissioning evidence is changing. We are reviewing how we can get the most from our investment and people across the Defra network, how we can work with external colleagues to deliver more of what we need, how to keep up with scientific advancements and how to ensure

we remain focused on delivering quality evidence which will support the Departments objectives. Improving collaboration with external and internal colleagues will allow us to take a holistic approach to soil evidence which hopefully will allow continued promotion of good soil health.

74. In 2015 Defra co-funded a systematic review of soil evidence as part of the NERC Soil Security Programme. The final report from this review describes the volume and characteristics of UK-affiliated research evidence on sustainable soil management for the delivery of three key ecosystem services, namely: food production; water and nutrient cycling; and climate change mitigation, with a focus on soil quality and management on agricultural land and peatlands. Multiple evidence gaps and priorities for new research to guide future soils policy were identified in the areas of Soil quality indicators and ecosystem services; Soil degradation, including soil erosion, soil organic matter decline, nitrogen deposition and soil acidification, and soil compaction; Sustainable soils / Aspirational soil quality targets; Soil management practices; and Economic value of ecosystem services.

75. Defra seeks to take a holistic approach to evidence and has funded two long-term, wide ranging projects, the Demonstration Test Catchments (DTC) and Sustainable Intensification Platform (SIP), which cut across Department objectives.

76. Defra has invested over £9m in the DTC project which focuses on four river catchments representative of the major English agricultural practices and landscapes. DTC looks at how diffuse pollution from agriculture can be cost-effectively controlled to improve and maintain water quality in rural river catchment areas, and therefore has co-benefits for soil management.

77. As part of our ongoing commitment to Soils research, Defra is investing £4million over three years through the SIP which seeks to improve the environmental and economic performance of farming. The project aims to demonstrate that environmental and production performance can be improved simultaneously through practices that improve the efficiency of nutrient, water and soil management. This includes exploring integrated farm management techniques and landscape scale opportunities, recognising the value of soil and the intrinsic link between soil health and productivity.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

78. Rural landowners reap private benefits from their soil in the form of agricultural production, and it is therefore in their interests to invest in soil health where the benefits outweigh the costs. However, soil also provides wider ecosystem services to society, for example through carbon sequestration, water quality regulation, and flood regulation.

79. It is imperative that these wider societal benefits are protected and enhanced, and yet it is not currently in the private interests of landowners to invest in doing so, nor is there any marketplace in which soil benefits can be transacted. Hence government has a clear role in protecting the wider social, economic and environmental benefits that non-degraded soil provides.

80. The Government has committed to develop a 25 Year Environment Framework. The framework is for a healthy, diverse, resilient natural environment that benefits people biodiversity and the economy. The framework will focus on the environment as a whole, including air quality, water, woodland/forestry, soils, marine, biodiversity, natural resources, designated landscapes plus cross-cutting themes such as data, new technology and mainstreaming the value of nature.

81. The development and delivery of the framework will bring together the range of organisations that influence how natural assets are managed and thus the health of our environment. We will consider how to equip local decision makers with the tools they need to assess the benefits that come from their natural assets so they can use them most effectively, be it to support livelihoods, their local communities, the economy, the provision of public goods, or personal enjoyment.

82. The Government has made a range of natural capital related commitments, including: spending £3 billion from the Common Agricultural Policy to enhance England's countryside over the next five years and ensuring the value of environmental designations such as AONB's, National Parks, SSSI's and others are appropriately protected.

83. The new approach to the environment builds on the science and evidence base laid by initiatives such as the National Ecosystem Assessment and the advice of the Natural Capital Committee (NCC). It will enable decision makers at all levels to better understand the value of the environment so they can develop and implement interventions that best fit their circumstances and priorities, maximising benefits to people and the economy.

84. The aim is to have the new NCC in place by March and we are in the process of recruiting the new Committee members, to help us develop the 25 year environment plan by the end of 2016.

85. We will also be working closely with Defra's 25 Year Food & Farming Plan throughout development of the Framework.

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Written evidence submitted by East Malling Research (EMR) – Dr Emma Tilston (Soil Scientist), Prof. Peter Gregory (Soil Scientist), Dr Mark Else (Plant Physiologist), Prof. Xiangming Xu (Plant Pathologist)

East Malling Research is a major independent research organisation in the UK for research on horticultural crops and plants and their interactions with the environment.

1. **How could soil health best be measured and monitored?**

1.1. 'Soil health' is a variously defined and often poorly understood concept. In order for soil health to be measured and monitored at national level it is necessary to adopt a definition of the concept which is applicable to cropped (agriculture, horticulture and forestry), 'natural' and other/urban (gardens and brownfield sites, including solar farms) soils, their long-term use and resilience to climate change. If soil health is defined from a systems perspective as "The functional interactions of soil organisms with the organic and inorganic components and physical properties of soil, with respect to the storage and release of nutrients and water required for long-term plant growth, but without deleterious impacts on air and water quality", then there are obvious analogies with human health. There are some properties that are core (e.g. is the patient alive?) and others that are specific to certain lifestyles (e.g. muscle mass for athletes). Once these are specified one could then suggest appropriate indicators (e.g. body mass index is a broad indicator of human health). For the majority of soil functions, we regard a diversity of biologically-mediated functions (e.g. nutrient cycling activity, organic matter decomposition rates and so on, rather than microbial/biological diversity per se) and structural (aggregate) stability as core indicators which integrate the biological, chemical and physical properties of soils. Suppressiveness to soil-borne diseases is one function however, where dependent on the pathogen(s), specific groups of microbes are associated with low inoculum potential and disease incidence. Organic matter content, low heavy metal concentrations etc. should be considered as land-use specific requirements.

1.2. Organic matter content is a good indicator of many properties of a soil, but in contrast with the properties targeted within the current suite of 'standard' soil tests (pH, N, P, K etc.) the routine methods and technologies for measurement are only able to detect changes occurring over periods of about 5 years. Thus, the spatial scale and frequency with which soil health is measured should be dependent on the functional relevance of the parameters being measured, the analytical sensitivity and reproducibility of the methodologies used and their relationship to the temporal dynamics of the parameter being measured. Furthermore, soil is a multifunctional system; it is therefore desirable that a range of parameters is measured, rather than relying on any one parameter.

1.3. The parameters measured should be directly attributable to soil management practices. For example, measuring the severity of symptoms exhibited by plants infected by soil-borne pathogens would be a less reliable indicator of soil health than explicit assessment of both the pathogen and microbial indicators of disease suppression. This is because although the incidence and severity of many soil-borne diseases is favoured by undesirable soil conditions such as compaction, water-logging/poor drainage and low organic matter content etc., the development of soil-borne diseases can also be profoundly affected by plant husbandry. The following, in either isolation or combination: seed planted too deep, seed planted too early, seed density too high, infected seed planted, no (or poor) biosecurity, susceptible cultivar planted, weed management failure, vector management failure, insufficient/excessive N-fertilization, nutrient deficiency/imbalance, inappropriate irrigation regime and inappropriate cropping sequence could result in the development of severe symptoms of soil-borne diseases, even in a soil described as being in ‘good’ health.

2. How could the Government develop a strategy for tracking soil health?

2.1. If this question is asking the method by which a strategy could be developed then the formation of an expert group would be able to guide the Government. There are numerous professional soil scientists employed within UK HEIs, research institutes, NGOs and industry with the necessary expertise, many of whom are members of the British Society of Soil Science. If it is asking for the content of the strategy then the operational scale (landscape e.g. as adopted for the national-scale Countryside Survey monitoring; or individual fields and land parcels e.g. as practiced by farmers and growers) needs to be determined, with more specific content reflecting the diversity of properties and use of UK soils. If soils under the full range of uses are to be covered by the strategy then soil health should be monitored for the direction of changes occurring over a period of time, rather than subjected to testing of ‘status’ at the time of measurement. Even for cropped soils, depending on how soil health is defined, without extensive long-term research effort it would be difficult to provide evidence for, and obtain expert consensus on, the numerical ranges indicating poor, adequate and good soil health status for the full range of combinations for soils and cropping systems. As it is, research is needed to determine the sampling strategy and frequency for any testing regime.

3. What are the benefits that healthy soils can provide to society?

3.1. Soils provide a number of ecosystem goods and services, typically these goods and services are grouped into four categories:

3.1.1.) Supporting life e.g. physical stability and support for plants and buildings; nutrient provision (e.g. biological N-fixation), renewal (e.g. phosphate solubilisation), retention (e.g. adsorption to soil organic matter) and delivery (e.g. soil water dynamics) to plants; a habitat for permanent and temporary (e.g. larvae or seasonal edaphic phases) soil biota.
3.1.2.) Regulation of ecosystem processes e.g. the hydrological cycle (inc. flood control); soil formation and structure modification; elemental transformations (organic matter decomposition and C sequestration, N-cycling, detoxification of environmental pollutants); pest and disease regulation.
3.1.3.) Provision of goods e.g. fresh water (filtration and storage); food; fibre; fuel; building and construction materials (e.g. muds and clays).

3.1.4.) Provision of cultural value e.g. sites with recreational (e.g. gardens, community orchards and allotments); heritage and scientific value (inc. preservation of archaeological artefacts and specimens of scientific value such as the pollen record); spiritual/religious value (e.g. burial grounds); clay and earth pigments for artists' media; local distinctiveness (e.g. cob buildings in Devon, flint buildings on the coastal plain of West Sussex, regional agricultural, horticultural and recreational landscapes; local soil colour – the red Devon soils, black fenland soils).

3.2. The 'value' of these benefits is greatly reduced if the soil is in 'poor' health and not fit for purpose.

4. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

4.1. The consequences of failing to protect soil health for the environment and food security are well documented and include enhanced risk of flooding, nutrient and pesticide contamination of water courses, increased reliance on irrigation in water limited areas and reduced soil depth through erosion. In summary, for both cropped and uncropped land the resilience of plants to combined stresses would be reduced. For crops this would jeopardise productivity and profitability and, more generally, it would impact industries such as tourism in regions with high landscape value such as the National Parks and counties such as Kent (the Garden of England).

4.2. With regard to public health, soil has direct effects on air and water quality and on the incidence of diseases related to the inhalation of dust, the spread of human pathogens and the reduced effectiveness of antibiotics. There are also indirect effects relating to root system development and nutrient uptake by plants and nutrient retention and availability in soil on the nutritional quality of the foods derived from crops. This is especially true for zinc, selenium, iodine and iron content; large proportions of the human population (in the UK and worldwide) are deficient in one or more of these elements.

5. What measures are currently in place to ensure that good soil health is promoted?

5.1. There are very few measures within current Government policies relating to land use which ensure that good soil health is promoted. Embedded within the Single payment scheme there are some guidelines, but in practice short-term commercial considerations (i.e. profit) take priority over the long-term consequences. Thus, there is little long-term incentive to implement soil management practices designed to promote soil health and this situation is reinforced by an increasing number of farmers and growers renting and swapping land for only one or two cropping seasons.

6. And what further measures should the Government and other organisations consider in order to secure soil health?

6.1. Government needs to take a leading role in highlighting the public good which results from good soil health and soil stewardship for the long-term. It then needs to work with the NGOs, academic societies and private enterprise to develop an economically viable and practicable strategy and plan for improving and maintaining soil health.

7. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

7.1. Soil is a critical component of the natural environment so; any plan for that length of time which does not explicitly include soil would be fundamentally flawed. Soil health must be a central component of the upcoming 25 year plan.

January 2016

Written evidence submitted by the British Ecological Society

The British Ecological Society (BES) is the UK's academic learned society for ecological science and the oldest institution of its kind in the world, established in 1913. The BES has nearly 6,000 members, representing the full scope of ecological research and practice and breadth of ecological careers, from undergraduate students to established professionals.

The Society welcomes the opportunity to respond to the Committee's inquiry on Soil Health. We would also like to point the committee to the *Journal of Ecology's Virtual Issue on Soil*, from December 2014, edited by Richard Bardgett & Amy Austin: http://www.journalofecology.org/view/0/VI_Soil.html

All 20 papers within this Virtual Issue are freely accessible, and have been selected to demonstrate the breadth and international scope of soil-related research, illustrating how ecologists are enhancing our understanding of the ecological and evolutionary significance of plant-soil interactions.

Summary

- Soil provides numerous services that are essential to human wellbeing and societal prosperity, including food production; storing and filtering water; storing carbon and regulating greenhouse gas emissions; and hosting an estimated quarter of the world's biodiversity. Soil 'health' is determined primarily by what function is prioritised.

- There are several threats to soil quality which impact on its ability to deliver benefits. These include localised impacts such as contamination, land use change and changes in nutrient status, as well as the impact of a changing climate.

- Soil formation is a long-term process - an average rate of one centimetre per century - therefore recovery rates for damaged soils are very slow.

- What constitutes a healthy soil depends on the service it is expected to deliver, and there is no single indicator suitable for all outcome measures of soil condition. Indicators of soil condition can be categorised as physical, chemical and biological; a monitoring programme should integrate all three.

- A soil strategy, linked to Government's 25-year plans for the environment, and food and farming, which includes sampling of a determined suite of nationwide sites at an appropriate temporal scale, is recommended.

- An effective strategy should incorporate both urban and agricultural soils; establish baseline data on soil condition; have a long-term commitment to monitoring and securing soil condition; include training provision and awareness raising, and be incorporated into decision-making processes.

Introduction

1. Soil health is the ability of soil to deliver key processes and ecosystem functions, and the benefits to society described later in this response. Soil health has been defined as:

> *"the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health"*[1]

2. There are many different soil types, and soil profiles are highly diverse both laterally and vertically, with soils serving different functions both regionally and locally. Indicators of health are therefore specific to soil type and function; what is healthy for one soil type, may not be healthy for another.

What are the benefits that healthy soils can provide to society?

3. Healthy soils are both a living system of intrinsic value and a key natural capital asset:[2] they deliver numerous ecosystem services that are essential to human wellbeing and societal prosperity. Major global functions performed by soils include: food production; storing and filtering water; storing carbon and regulating greenhouse gas emissions; and hosting an estimated quarter of the world's biodiversity.[3,4,5]

4. Approximately 95% of global food production relies on soil, which supplies essential nutrients, water, oxygen and root support required by agricultural crops. Soil condition underpins agricultural productivity and food security.

5. Soils perform a buffering function that mitigates extreme weather events including flooding and drought. Healthy soils and the vegetation they support have a greater capacity to absorb precipitation during high intensity rainfall events, reducing peak river flow and flooding, and to store and retain water during dry periods, buffering plants against rainfall deficit. Healthy soils also continue to function better under extreme weather events, thereby securing future crop growth.

6. Soils play an important role in the provision of clean drinking water through their capacity to remove contaminants, for example metals or organic compounds, via processes including absorption at the land surface and the microbial transformation of contaminants into non-toxic forms[3].

7. As the major terrestrial reservoir of carbon (containing approximately 1500 billion tonnes),[6] soils have a significant influence on the global carbon cycle and atmospheric CO_2 levels. Degradation of carbon-rich soils releases significant quantities of CO_2 into the atmosphere. In the UK, peat soils in upland areas play a particularly important role in soil carbon storage, holding around 40% of UK soil carbon.[7]

8. Healthy soils also play a significant role in regulating emissions of other potent greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4). Agricultural soils are the major source of nitrous oxide emissions, and better soil management, including more efficient fertiliser use, can significantly regulate this flow.[8] Anaerobic soils (e.g. wetlands and peat) are a major source of natural methane emissions, whilst aerobic soils act as methane sinks[3].

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[1] Pankhurst, Clive, Bernard M. Doube, and V. V. S. R. Gupta. *Biological indicators of soil health*. Cab International, 1997
[2] Natural Capital Committee (2013), *The State of Natural Capital: Towards a framework for measurement and valuation*
[3] FAO and ITPS (2015), *Status of the World's Soil Resources (SWSR) – Technical Summary*. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.
[4] Parliamentary Office of Science and Technology (2015) *Postnote 502: Securing Soil Health*.
[5] Decaëns, T., et al. (2006) *The values of soil animals for conservation biology*. European Journal of Soil Biology 42: S23-S38.
[6] Scharlemann, J.P.W., Tanner, E.J.V, Hiederer, R. and Kapos, V. (2014), *Global soil carbon: understanding and managing the largest terrestrial carbon pool*, Carbon Management, 5(1), pp81-91.
[7] UK National Ecosystem Assessment (2011) *The UK National Ecosystem Assessment: Synthesis of the Key Findings*. UNEP-WCMC, Cambridge.
[8] The Royal Society (2011) *Reducing greenhouse gas emissions from agriculture: meeting the challenges of food security and climate change*. Meeting report. http://bit.ly/1ZYveFI

9. Soils are home to approximately 25% of the world's biodiversity, including bacteria, fungi and invertebrates; 10 grams of soil can contain up to 10^6 species[3]. Soil biodiversity drives ecosystem functions and services such as soil formation, nutrient cycling, food production, and disease and pest control, and influences the structure and diversity of plant communities.[9]

10. Soil biodiversity also plays an important role in supporting human health, through the suppression of pathogens and provision of clean air, water and food.[10] Soil is also a major reservoir for biotechnological exploitation, with soil organisms the source of the majority of clinical antibiotics.[11]

11. These benefits are not exhaustive: Robinson *et al* [12] identify a number of additional ecosystem services that soils deliver, including the provision of goods such as peat and clay, and cultural services such as the support of recreational surfaces. Soil quality also cascades through wider ecological networks (i.e. plants and animals) and indirectly affects important ecosystem services such as pollination. Urban soils play a particular role in regulating temperature and air quality, and in the degradation of pollutants.[13]

12. The benefits that soils provide and the ecosystem services that they deliver cannot be considered in isolation: soils are a living ecosystem with complex interactions between their physical, biological and chemical components, and their ecosystem functions and processes. There will however be trade-offs between services: for example increasing agricultural productivity could be detrimental to water quality or biodiversity.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

13. There are a range of immediate and future threats to soil health (or soil condition) which will severely compromise its ability to deliver the essential services listed above. Broadly, soil condition is compromised through either soil degradation (reduction in quality), or erosion (reduction in quantity), due to threats that act both generally (for example, climate change) and locally. **Importantly, because soil formation is a long-term process (an average rate of one centimetre per century), recovery rates for these ecosystem services are very slow**[7].

14. Research by Graves *et al*[14] has estimated the costs of soil degradation in the UK as between £0.9bn and £1.4bn per year, with a central estimate of £1.2bn. This is linked mainly to loss of organic content of soils (47% of total cost), compaction (39%) and erosion (12%). 80% of costs occur offsite, limiting the concern of those whose actions may be causing degradation.

Threats and impacts:

Agricultural land use

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[9] Bardgett. R.D. and van der Putten, W.H. (2014). Belowground biodiversity and ecosystem functioning. *Nature*, 515, pp505-511.
[10] Wall, D.H., Nielsen, U.N., and Six, J. (2015) *Soil biodiversity and human health,* Nature, 528 (7580), pp69-76.
[11] D'Costa, V.M., McGrann, K.M., Hughes, D.W. & Wright, G.D. (2006). *Sampling the antibiotic resistome*. Science, 311: 374-377.
[12] Robinson, D.A., Hockley, N., Cooper, D.M., Emmett, B.A., Keith, A.M., Lebron, I., Reynolds, B., Tipping, E., Tyed, A.M., Watts, C.W., Whalley, W.R., Black, H.I.J., Warren, G.P. and Robinson, J.S. (2013), *Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation,* Soil Biology and Biochemistry, 57, pp1023 – 1033.
[13] Durham University (2015) *'A nation that destroys its soils, destroys itself': Pathways towards the sound management of urban soil*
[14] Graves, A. R., et al. (2015) *The total costs of soil degradation in England and Wales.* Ecological Economics 119: 399-413.

15. Soil carbon is a particularly important component of healthy soil, affecting its physical and chemical characteristics. Meta-analysis indicates that soil carbon stocks decline after land use changes from pasture to plantation,[15] and that cropping practices – the intensity and type of crops used, as well as the removal of crop residues from the land - impact upon soil organic carbon content.[16] Land management practices such as tillage, draining and persistent grazing also expose soil organic matter to oxidation, causing a loss of organic carbon.

16. This loss of carbon into the atmosphere will not only compromise the UK's ability to meet greenhouse gas emission targets, but also degrades soil structure, having major impacts on agricultural productivity, increasing costs of water purification and making land more vulnerable to climatic extremes.

Sealing of urban soils

17. The UK National Ecosystem Assessment (NEA) [7] highlighted the degradation of urban soils, stating that many of their supporting and regulating functions have been reduced or restricted through widespread sealing (covering soil with impenetrable surfaces) and degradation, with concomitant increases in hazards such as flooding.[17] The capacity of urban soils to regulate water, nutrient, pollutant and sediment transfer from the land surface continues to be compromised.

Nutrient status

18. The NEA states that changes in the nutrient status and pH of waters and soils in recent decades have had a significant impact on the delivery of regulating and provisioning ecosystem services. The enrichment of terrestrial and aquatic habitats with nitrogen, through fertiliser use, has resulted in substantial changes in plant productivity, plant species diversity and composition, the composition of soil communities, and accelerated rates of nitrogen cycling.

Contamination

19. The definition of a soil contaminant is beyond the scope of this response, however harmful substances or agents that have accumulated in the soil, often as a result of industrial activity, are a threat to biodiversity, can make soil non-productive and pollute groundwater[4]. Contaminants can be inorganic (such as arsenic, copper, lead, sulphur) and organic (acetone, benzene, DDT).[18]

20. High traffic volume and coal burning have been responsible for raising contaminant levels in the urban environment, and non-ferrous mineralisation and associated mining activities are a significant contributor to high levels of many inorganic contaminants in soil.[19]

Climate Change

21. Soil condition is both impacted by climate change, and important for resilience to it.[20] Predicted

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[15] Guo, Lanbin B., and Gifford, R. M. (2002) *Soil carbon stocks and land use change: a meta analysis.* Global change biology 8.4: 345-360.
[16] Ogle, Stephen M., F. Jay Breidt, and Keith Paustian. (2005) *Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions*. Biogeochemistry 72.1: 87-121.
[17] Parliamentary Office of Science and Technology (2013) *Postnote 448 :Urban Green Infrastructure*
[18] For a list of priority contaminants see Martin I, Cowie C (2008) Compilation of data for priority organic pollutants for derivation of soil guideline values**,** Environment Agency, UK
[19] Ander, E. Louise, et al. (2013) *Methodology for the determination of normal background concentrations of contaminants in English soil.* Science of the Total Environment 454: 604-618.
[20] De Vries, F.T. and R.D. Bardgett (2015) Climate change effects on soil biota in the UK. Terrestrial Biodiversity Climate change Impacts Report Card Technical paper. Bodsey Ecology Limited, Huntingdon, UK.

hotter, drier summers and warmer, wetter winters will increase the risk of wind erosion and soil drought in the summer, and the risk of soil erosion by water in the winter.[21] Conditions in areas where upland peat is found will probably be rarer in the UK under climate change, and there may be indirect effects on soil associated with climate-induced changes in land use.[17]

22. There is no current consensus on the impacts of climate change on soil carbon.[22,23]

What measures are currently in place to ensure that good soil health is promoted?

International Soil Policy

23. 2015 was the UN International Year of Soils, which aimed to raise awareness of the importance of soil health amongst the public, civil society and decision-makers. Soil condition is promoted in Target 15.3 of the UN Sustainable Development Goals, which aims by 2030 to "combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world".

Soil Policy in the EU

24. There is no specific EU legislation on soil, with a proposed Soil Framework Directive withdrawn in 2014 after sustained opposition from Member States, including the UK. The European Commission states that measures contained within the Common Agricultural Policy, Water Framework Directive and other legislation "are not sufficient to ensure an adequate level of protection for all soils in Europe".[24]

25. The EU's Seventh Environmental Action Plan (2013) states that soil should be adequately protected by 2020, and calls on the Union and Member States to reflect on "how soil quality issues could be addressed using a targeted and proportionate risk-based approach within a binding legal framework".[25]

Soil Policy in England[26]

26. *'Safeguarding our Soils: A Strategy for England'*[27], introduced by the Labour Government in 2009, established the goal that "by 2030, all England's soils will be managed sustainably and degradation threats tackled successfully". This goal was reiterated in the Coalition's 2011 Natural Environment White Paper[28] (NEWP), which also established commitments to undertake a significant research programme on soil health and to reduce peat use to zero by 2030. In 2015, the Committee on Climate Change recommended the creation of a comprehensive action plan by the end of 2016 to deliver these policy aspirations.[29]

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[21] Natural England, 2015, *Summary of Evidence: Soils*.
[22] Davidson, E. A., and Janssens, I.A., (2006) *Temperature sensitivity of soil carbon decomposition and feedbacks to climate change*. Nature 440.7081: 165-173.
[23] Barraclough, D., Smith, P., Worrall, F., Black, H.I.J. and Bhogal, A. (2015) *Is there an impact of climate change on soil carbon content in England and Wales?*, European Journal of Soil Science, 66 (3):451-462.
[24] http://ec.europa.eu/environment/soil/index_en.htm
[25] DECISION No 1386/2013/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 November 2013 on a General Union Environment Action Programme to 2020 '*Living well, within the limits of our planet'*
[26] Soil policy is a devolve issue, and in our response we focus primarily on the English context.
[27] Defra (2009) *Safeguarding our Soils: A Strategy for England*
[28] HM Government (2011) *The Natural Choice: Securing the value of nature*

27. While there is no specific legislation protecting soil in England, it is protected indirectly through laws governing the control of pollution and management of contaminated land, and via conservation legislation.

Agriculture

28. Under the CAP, farmers in England must adhere to three Good Agricultural and Environmental Condition (GAEC) requirements in order to receive Basic Payment Scheme payments. Farmers must:
- ensure minimum soil cover (vegetation, cover crops, trees, stubble or crop residues) unless there is a valid agronomic justification (e.g. pest, disease or weed control; heathland restoration; outdoor pig or poultry production) (GAEC 4);
- manage land to minimise soil erosion through appropriate cropping practices and structures, livestock management, and appropriate use of machinery (GAEC 5);
- maintain levels of organic matter in soil by avoiding burning stubble and crop residues (GAEC 6).

29. No regulations or guidance are provided on other aspects of soil health such as soil fauna, microbiodiversity and structure. The guidance on soil standards provided to farmers by Defra has been significantly reduced the last five years, with just 16 pages of guidance for the 2015 CAP[30] compared to 76 pages in 2010.[31]

Planning and construction

30. The National Planning Policy Framework provides only minimal guidance on promoting soil health, stating that the planning system should protect and enhance soils, and prevent the adverse effects of unacceptable levels of pollution.[32] Planning authorities "should not identify new sites or extensions to existing sites for peat extraction". There is no specific policy framework for urban soils, despite the importance of their health in delivering vital ecosystem services including flood mitigation.[13] Defra has published a voluntary "code of practice" on the sustainable use of soils on construction sites.[33]

Peat

31. The NEWP established a goal to limit peatland degradation by reducing peat use to zero by 2030, and created the Sustainable Growing Media Task Force to advise on this process. The Task Force published its road map in 2011[34], and in response, the Government outlined a number of steps to support the horticultural sector in this transition.[35] This policy was due for review in 2015; however, it appears that this has not yet taken place.

32. Peatlands were identified in Defra's Payment for Ecosystem Services Action Plan (2013)[36] as a potential test case for PES, and Government supported the IUCN in developing the UK Peatlands

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[29] Committee on Climate Change (2015) *Reducing emissions and preparing for climate change: 2015 Progress Report to Parliamen.t*
[30] Defra (2015) *Cross compliance in England: soil protection standards*
[31] Defra / Rural Payments Agency (2010) *Single payment scheme: Cross Compliance Guidance for Soil Management*
[32] The 2009 soil strategy proposed producing a toolkit for planning authorities to better account for soil function; however, this has not been produced.
[33] Defra (2009) *Construction Code of Practice for the Sustainable Use of Soils on Construction Sites.*
[34] Knight, A. (2012) *Towards Sustainable Growing Media: Chairman's Report and Road Map*, Sustainable Growing Media Taskforce
[35] Defra (2013) *Government Response to the Sustainable Growing Media Task Force*

Carbon Code to facilitate business investment in peatland restoration.[37] A number of collaborative projects, for example the Moors for the Future Partnership are working locally to restore peat soils.[38]

How could soil health best be measured and monitored?

33. A wide range of measures exist that can indicate the physical, chemical and biological condition of the soil. It is important to distinguish between indicators that are sensitive to land management (for example, certain groups of nematodes) and indicators that have an established, mechanistic link with soil functioning (for example, nitrifying bacteria). What constitutes a healthy soil depends on the service required; productive agricultural land will have different optimal chemical, physical and biological properties to soils supporting woodland, peatlands, meadows, or urban environments.

34. A good indicator of soil condition should exhibit several properties:

- Strong correlation with the outcome measure of interest (i.e. the process or function associated with the desired land use. See Appendix I);
- sensitivity to variations in land management practices and climate;[39]
- temporal robustness (i.e. minimal fluctuations over short timescales);
- comparability across scales;
- a standardised sampling methodology;
- complementarity to other indicators;
- ease of interpretation for scientific and policy audiences;[40]
- cost efficiency.

35. Indicators of soil condition can be categorised as physical, chemical and biological, and a monitoring programme designed to obtain a comprehensive picture of soil health should integrate all three types. **There is no single indicator suitable for all outcome measures of soil condition.**

Physical indicators

36. Physical indicators include a range of measures of the soil's texture, degree of compaction and response to physical stresses. The physical properties of soil, including aggregate stability and density, can be a key determinant of soil condition.

37. These analyses of the physical structure of soil provide an indication of its ability to resist erosion, hold or filter water and its suitability as a habitat for microorganisms and plant growth. Physical structure is a particularly good indicator for healthy agricultural soils, can be a proxy for several other processes or properties, and is relatively simple to evaluate.

Chemical indicators

38. The soil's physical, chemical, and biological properties have wide ranging impacts on chemical indicators such as soil nutrient content and pH level, as well as plant growth. In agricultural soils, pH level has a strong correlation with the nutrition, growth and yields of the crops grown. Levels of heavy metals are an indicator of soil contamination.

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[36] Defra (2013) *Developing the potential for Payments for Ecosystem Services: an Action Plan*
[37] IUCN UK National Committee Peatland Programme (2015) *Peatland Code*
[38] http://www.moorsforthefuture.org.uk/
[39] Doran, J. W. & Zeiss, M. R. (2000) Doran, J. W., & Zeiss, M. R. (2000). *Soil health and sustainability: managing the biotic component of soil quality*. Applied Soil Ecology, 15(1), 3-11.
[40] Bispo, A. et al (2009) *Indicators for Monitoring Soil Biodiversity*. Integr. Environ. Assess. Manag. 5, 717

Biological indicators

39. Biological indicators include assessments of the abundance and diversity within certain taxonomic groups such as earthworms, mites or mycorrhizal fungi; the quantification of biomass in total or within such groups; and measures of enzyme activity. These measures indicate the processes taking place within the soil and the overall state of the soil ecosystem. For example, individual groups of soil organisms and the interactions between these groups have been shown to link to processes of carbon and nitrogen cycling.[41] New tools such as DNA-metabarcoding[42] and complex network analysis, can not only monitor biodiversity in soils, but also better understand how organisms interact and affect ecosystem functioning.

40. Soil carbon, assessed through soil organic matter content (SOM) holds soil together, and supports soil fertility and biodiversity. Organic matter is highly variable across soil types, but a decline in content over time is often a useful indicator of damage to soils. Many of the biological indicators listed above, such as species abundance and biomass, are closely correlated with organic matter content. Organic carbon underlies soil physical structure and chemical composition.

41. There are two main methods for estimating soil organic matter. The Walkley Black[43] technique uses an oxidising agent, potassium dichromate, to react with the organic matter in the soil, whilst in the Loss on Ignition (LOI) approach, mass is estimated as organic matter is burned off under controlled conditions.[44]

42. Research on floodplain meadows suggests that vegetation could be used as a proxy for this type of soil structure, since characterising the hydrological requirements of plant species largely reflects the porosity of the underlying soil.[45,46,47,48] Palmer and Holman demonstrated that soil structure was the most powerful predictor of vegetation type out of an array of environmental factors.[49] Further development is required to identify the best method and most appropriate indicator species, but an indicative list has been developed through the Floodplain Meadows Partnership – further information is available at this website.[50] 'Ellenberg vegetation values', which reflect the ecological behaviour of plant species, have also been used to summarise complex environmental factors including soil moisture content for many years.[51]

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[41] De Vries et al. (2013) *Soil food web properties explain ecosystem services across European land use systems*. PNAS 110:14296-14301

[42] Taberlet, Pierre, et al. (2012) *Towards next-generation biodiversity assessment using DNA metabarcoding*. Molecular Ecology 21.8 (2012): 2045-2050.

[43] Walkley, A. and Armstrong Black, I. (1934) *An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method,* Soil Science, 37 (1), pp29-38

[44] For a comparison of methods, see Wang, X., Wang, J. and Zhang, J. (2012) *Comparisons of Three Methods for Organic and Inorganic Carbon in Calcareous Soils of Northwestern China*, PLoS ONE 7(8).

[45] Araya, Y.N., Silvertown J., Gowing, D.J.G., McConway K.J., Linder H.P. and Midgley, G. (2011) *A fundamental, eco-hydrological basis for niche segregation in plant communities*. New Phytologist, 189, 253-258

[46] Gowing, D.J.G., Lawson, C.S., Youngs, E.G., Barber, K.R., Prosser, M.V., Wallace, H., Rodwell, J.S., Mountford, J.O. and Spoor, G. (2002). *The water-regime requirements and the response to hydrological change of grassland plant communities*. Final report to DEFRA (Conservation Management Division,) London. Project BD1310.

[47] Silvertown, J., Dodd, M.E., Gowing, D.J.G. and Mountford J.O. (1999). *Hydrologically-defined niches reveal a basis for species richness in plant communities*. Nature, 400,

[48] Silvertown, J., Araya, Y. N. & Gowing, D. J. (2015) *Hydrological niches in terrestrial plant communities: a review*. Journal of Ecology, 103, 93–108

[49] Palmer, R.C. and Holman, I.P. (2002) *Soil survey of the Lower Derwent ings*. National Soil Resources Institute Study no. SR9058V,Cranfield University, York.

[50] http://www.floodplainmeadows.org.uk/

[51] Schaffers, André P., and Karlè V. Sýkora. (2000) *Reliability of Ellenberg indicator values for moisture, nitrogen and soil reaction: a comparison with field measurements*. Journal of Vegetation science: 225-244.

43. Faber *et al*[52] present a number of criteria by which the usefulness of biological indicators could be assessed. These include the extent to which specialist skills and equipment are required; cost efficiency; policy relevance and ease of comprehension; sensitivity to soil type, land use and disturbance; and standardisation. An extensive list of potential physical, chemical and biological indicators of soil health is provided in Appendix I.

Existing monitoring systems

44. There are 52 known soil monitoring programmes worldwide.[53] Chemical indicators of soil condition are most commonly used, including measures of nutrient content, especially copper, iron and zinc (40 programmes), soil pH (36 programmes), and different measures of nitrogen (20 programmes). Physical indicators include particle size analysis, soil water characteristics, soil moisture and aggregate stability (29 programmes). Biological indicators are less common, used across 19 programmes, with indicators including abundance or biodiversity of fauna at different scales. 5 programmes measure enzymatic activity. The Biological Indicator of Soil Quality (BISQ) used in the Netherlands' nationwide soil monitoring system is deemed amongst the most advanced soil monitoring systems.[38,54]

45. There are numerous existing research projects in the UK that offer a wealth of data and expertise on soil, including at the NERC UK Soil Observatory,[55] Rothamsted,[56] the James Hutton Institute,[57] Centre for Ecology and Hydrology,[58] and within the University sector. The NERC Soil Security programme currently funds consortium projects, fellowships and PhD studentships, and aims to "deliver improved forecasts of the response of the soils system to changes in climate, vegetation or management at scales of analysis which match the scale of decision making".[59] BBSRC's SARISA programme aims to improve understanding of agricultural soil and rhizosphere interactions to underpin the development of agricultural ecosystems.[60]

46. Several recent EU funded projects have focussed on understanding the role of soil biodiversity in ecosystem function and developing bioindicators. For example, EcoFINDERS,[61] which included 23 partners from European 10 countries, aimed to increase knowledge of soil biodiversity and its role in ecosystem services across different soils, climate types and land uses; to standardise methods and operating procedures for characterising soil biodiversity and functioning, and to develop of bioindicators.[62]

How could the Government develop a strategy for tracking soil health? And what further measures should the Government and other organisations consider in order to secure soil health?

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52 Faber, Jack H., et al. (2013) The practicalities and pitfalls of establishing a policy-relevant and cost-effective soil biological monitoring scheme. *Integrated environmental assessment and management* 9.2: 276-284.
53 Government of Alberta, A. A. and F. P. and E. S. E. S. D. E. S. and R. B. Soil Quality Monitoring Programs: A Literature Review - Results and Discussion. at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/aesa8536
54 BISQ takes measurements across 300 randomly selected locations, stratified by land use and soil type, across a 6-year cycle. It measures environmental information such as land use and climate, bacterial community biodiversity and functions, and monitoring of species groups such as mites and earthworms. The scheme aims to establish the abundance and diversity of soil organisms across different soil types and land uses, estimate the impact of land management, and establish reference states of healthy soils.
55 http://www.ukso.org/
56 http://www.rothamsted.ac.uk/sustainable-soils-and-grassland-systems
57 http://www.hutton.ac.uk/category/area-interest/soil-research
58 https://www.ceh.ac.uk/our-science/science-areas/soil
59 http://www.nerc.ac.uk/research/funded/programmes/soilsecurity/
60 http://www.bbsrc.ac.uk/funding/opportunities/2013/2013-gfs-sarisa/
61 http://esdac.jrc.ec.europa.eu/projects/ecoFinders
62 See recent special issue of *Applied Soil Ecology* (2016), 97, pp1-134.

47. The role of soil in the delivery of many vital societal benefits requires a commitment from Government akin to that for water and air. A soil strategy, linked to Government's 25-year plans for the environment, and food and farming, which includes sampling of a determined suite of nationwide sites at an appropriate temporal scale, is recommended.

48. An effective strategy should:
- incorporate both urban and agricultural soils;
- establish baseline data on soil condition;
- have a long term commitment to monitoring and securing soil condition;
- include training provision and awareness raising;
- be incorporated into decision-making processes.

Baseline data

49. The strategy should first ascertain a robust baseline of soil data, from which to establish how and where soil changes over time. The Countryside Survey[63] (the continuation of which Defra funding is not currently in place) provides historical data that should be incorporated where possible, in addition to the Environmental Change Network data and existing projects mentioned in paragraph 45. We recommend that a strategy for tracking soil health begins by bringing existing research initiatives and datasets together, and expanding on them. The BES is well placed to provide access to individuals with expertise in this regard.

50. Comprehensive data collection would also shed light on the extent of soil contamination in the UK, and guidance on what the 'normal' levels of contaminant concentrations in English soils should be has already been developed by the British Geological Survey.[64] Monitoring should also identify especially unique, threatened or valuable soils that require particular protection.

Long Term Commitment

51. An effective strategy requires a long-term commitment from Government to monitor and address how soils change over time. The biggest factors influencing soil change occur through climate change, land use change, urbanisation and invasive species. The UK NEA states that there is insufficient knowledge regarding the recovery of soils under a changing climate, with competing explanations for changes in and vulnerability of the UK's soil carbon stocks, and soil's role in water purification. Further research is needed to understand the dynamics of soil water, how it is influenced by drivers such as climate change, and the impacts on nutrient and carbon cycling.

52. To understand the drivers and implications of soil change, a holistic approach to both research and monitoring is needed over a sustained time period. The Government's 25-year plans for the environment, and food and farming provide a timely framework from which to incorporate this approach.

Training Provision & Awareness Raising

53. A soil strategy which includes training provision for ecologists, land users and citizens to monitor and measure soil condition would enable more frequent data collection at a range of sites across the UK. Relatively simple training on the visual aspects of soil structure and colour is a cost effective way of ascertaining soil condition data at the local level, helping to flag changes in soil in a timely way. A range of tools can be used for this type of training; for instance, the James Hutton Institute has

[63] http://www.countrysidesurvey.org.uk/science-and-research/work-packages/soils
[64] http://www.bgs.ac.uk/gbase/NBCDefraProject.html

produced an app for Scottish soils that allows organic carbon assessment via an uploaded smartphone photograph.[65]

54. Greater awareness of the importance soils and the role they play in delivering societal benefits would bolster the strategy, through education, and public engagement and stakeholder activities.

Decision-making

55. An effective strategy for soil health integrates soils into decision making across government departments, including land use and planning and agricultural policy. This could include the bolstering of guidance for promoting good soil health in the National Planning Policy Framework, and a specific policy framework for planning and urban soils. Existing guidance such as the Defra voluntary "code of practice" on the sustainable use of soils on construction sites could also be made more robust, with more incentives for implementation of best practice.

56. Implementation of the strategy should align with existing policies such as the Scottish Soil Framework,[66] and soil policy within the Natural Resources policy statement in Wales.

Measures to improve soil health

57. There is a growing body of research on interventions that can be used to improve soil health and be included in the strategy;
    - The addition of organic matter to arable soils to increase soil carbon content.[67,68,69,70] This can be achieved through addition of plant material; the processing and reintroducing organic wastes;[71] and reversion of arable grassland to wildflower grasslands, which have higher carbon content due to different rooting lengths[72] and a greater mass of roots.
    - Changes in stock management to reduce the compaction of soils, and changes in crop management such as longer crop rotations, reduced tillage and cover crops.[4]
    - Tree planting to retain soil structure and reduce flooding.
    - Remediation of severely contaminated soils. Current methods can be expensive; however, there are innovative opportunities to pioneer new soil decontamination techniques.
    - Particular mention should be made of interventions to restore peat soils, due to their importance in terms of carbon storage and flood resilience. There is widespread degradation to UK peatland soils by drying through loss of Sphagnum, gripping, erosion, gullying and burning (both managed and wildfire).[73] The Scottish Assembly has committed funding for peatland restoration[74] over a 5-year period; similar commitments would be welcome from the other UK nations, and would accompany business funding via the IUCN Peatland code.

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[65] http://sifss.hutton.ac.uk/

[66] http://www.gov.scot/Publications/2009/05/20145602/0

[67] WRAP, DC-Agri project. http://www.wrap.org.uk/content/digestate-compost-agriculture

[68] Walsh, J. J., Jones, D. L., Edwards-Jones, G., & Williams, A. P. (2012). *Replacing inorganic fertilizer with anaerobic digestate may maintain agricultural productivity at less environmental cost.* Journal of Plant Nutrition and Soil Science, *175*(6), 840-845.

[69] Roig, N., Sierra, J., Martí, E., Nadal, M., Schuhmacher, M., & Domingo, J. L. (2012). *Long-term amendment of Spanish soils with sewage sludge: Effects on soil functioning*. Agriculture, ecosystems & environment, 158, 41-48.

[70] Institute of Organic Training & Advice: Research Review: Compost: the effect on nutrients, soil health and crop quantity and quality (This Review was undertaken by IOTA under the PACA Res project OFO347, funded by Defra)

[71] http://www.robustdurham.org.uk/

[72] Carbon storage by habitat: Review of the evidence of the impacts of management decisions and condition of carbon stores and sources (NERR043). Natural England 29 May 2012.

[73] Bain, C.G., Bonn, A., Stoneman, R., et al. (2011) IUCN UK Commission of Inquiry on Peatlands. IUCN UK Peatland Programme, Edinburgh.

[74] http://www.snh.gov.uk/climate-change/taking-action/carbon-management/peatland-action/

What role (if any) should soil health play in the Government's upcoming 25-year plan for the natural environment?

58. Identifying solutions to mitigate the threats of soil degradation is inherently interdisciplinary, and solutions must be assessed in the light of other concerns with which soil is interwoven, such as water and biodiversity.[75] The Government's 25-year plan for the environment provides an opportunity to incorporate soil health policy and practice in an ecosystems approach, and the inclusion of soil health in the plan is essential. In response to the Natural Capital Committee report, Government responded that a 25-year plan will initially look to address outstanding natural capital monitoring and data issues[76] providing further opportunity to link with the monitoring and data availability and analysis within a soil monitoring programme.

59. Furthermore, soil should play an integral role in the Government's 25-year plan for food and farming. Given that these two plans are being developed separately, it is essential to ensure that soil management is joined up, and given due prominence across each strategy. Secretary of State for the Environment, Food & Rural Affairs, Liz Truss stated *'I want us to be making more integrated decisions at the levels of catchments and landscapes, not single species or natural features'.*[77] The 25-year plans provide an ideal opportunity for integrated decision-making, particularly given our knowledge of the importance of soil structure in resilience to flooding events and catchment management.

Further information

The BES is happy for our response to be made available publicly. If you have any questions about the content of this response or about the work of the BES, please contact Jackie Caine, Policy Manager on policy@britishecologicalsociety.org or 0207 685 2510.

January 2016

[75] http://www.cisl.cam.ac.uk/news/blog/why-doesnt-soil-get-same-attention-climate-change#sthash.y5zZmxvS.dpuf

[76] Defra (2015) *The government's response to the Natural Capital Committee's third State of Natural Capital report*.

[77] Open Environment speech by Elizabeth Truss, Delivered on: 14 October 2015 (Transcript of the speech, exactly as it was delivered) https://www.gov.uk/government/speeches/open-environment-speech-by-elizabeth-truss

Appendix I

Potential indicators of Soil Health

Type	**Variable**	**Soil condition/process indicated**
Physical		
	Aggregate stability	Erosion, compaction
	Available water capacity	Suitability for plant growth, leaching of nutrients
	Bulk density	Structural support, water and solute movement, and soil aeration.
	Infiltration	Ability to allow water movement into and through the soil profile.
	Slaking	Stability of soil aggregates, resistance to erosion, suggests how well soil can maintain its structure to provide water and air for plants and soil biota when it is rapidly wetted.
	Soil crusts	Crust indicates poor infiltration, a problematical seedbed, and reduced air exchange between the soil and atmosphere. It can also indicate that a soil has a high sodium content that increases soil dispersion when it is wetted by rainfall or irrigation.
	Soil structure and macropores	Important soil functions related to soil structure are: sustaining biological productivity, regulating and partitioning water and solute flow, and cycling and storing nutrients. Soil structure and macropores are vital to each of these functions based on their influence on water and air exchange, plant root exploration and habitat for soil organisms.
Chemical		
	Soil pH	Wide ranging influences on soil's physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth, and yields of most crops decrease where pH is low and increase as pH rises to an optimum level
	Heavy metals: identify and quantify	Pollutants
	Nutrients (e.g. N, P, K, S, NH_4, Mg, Ca): identify and quantify, and distinguished between total stocks of C, N, P and available fractions.	Nutrient content of soils is strongly associated with land use and habitat type. Agricultural land requires high levels of nutrients whilst low nutrient levels encourage species rich plant communities
Biological		
	Nematodes: abundance, community	Recycling of nutrients (nitrogen cycling and decomposition). Maturity indices respond to a variety of land management techniques

	composition, diversity, maturity index	
	Earthworms (annelida): abundance, diversity, functional diversity	Modify the physical structure of soils by producing new aggregates and pores, which improves soil tilth, aeration, infiltration, and drainage. Participate in plant residue decomposition, nutrient cycling, and redistribution of nutrients in the soil profile
	Mites: abundance, community composition, diversity	Recycling of nutrients. Community structure strongly correlates with land use type
	Protists: community composition	Sensitivity to nitrogen content, heavy metals, land use
	Collembola: taxonomic and functional diversity	Predominant species' reflect pH, water level capacity and organic matter content
	Mycorrhizal macrofungi: taxonomic and functional diversity	Nutrient cycling (N, P, water) and heavy metal uptake
	Enchytraeids, abundance, diversity at each trophic level	Formation of soil structure, decomposition of organic material
	Soil Organic Matter (SOM)	Indicative of soil structure, aggregation, water retention, soil biodiversity, absorption and retention of pollutants, buffering capacity, and the cycling and storage of plant nutrients. Sensitive indicator of changes in soil quality due to changes in vegetation growth. SOM positively correlates with soil fertility.
	Bacteria, archaea, and fungi: abundance, diversity, Microbial Biomass Carbon (MBC), fungal: bacterial biomass ratio.	Soil microorganisms are involved in several processes that influence soil quality (e.g. respiration, release of nitrogen) and microbial biomass changes rapidly in response to changes in soil properties (e.g. rainfall, management practices). Fungal:bacterial biomass ratio is related increased efficiency of carbon and nitrogen cycling.
	Fluorescein diacetate hydrolase (FDA)	As a measure of the microbial activity in soil, FDA indicates processes contributing to available nitrogen and carbon. Sensitive indicator of soil quality change due to climatic variation.
	Mycelium hyphae: biomass	Formation of soil structure
	Ammonia-oxidising bacteria and Archaea, ammonium production (NH4+)	Ammonification, accessibility of a critical nutrient for plant growth
	Nitrifying bacteria: nitrate production (NO3-)	Nitrification, accessibility of a crucial nutrient for plant growth

Written evidence submitted by Mr. S. Cowell, farmer

I am a no-till arable farmer in Essex and have been using biological methods and making my own compost to improve my soils health, and therefore fertility, for about fifteen years. Soil tests show that I have increased Organic Matter Percentages, drainage water tests taken by my local water authority show that I am not leaching nutrients (nitrates, phosphate, etc.) or soil particulates into the river system and I have reduced fertiliser and pesticide applications quite considerably without reducing yields.

- How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

Soil health can only be measured by quantifying the diversity and amount of life that it contains. This means identifying bacteria (aerobic and anaerobic), fungi (beneficial and pathogenic), nematodes, protozoa, arthropods, insects and earthworms; and assessing how many of each. A soil described as unhealthy or dead would contain very few, if any of these. The only way that farmers are able to do this is by getting a Soil Biology Report done by a lab using methods pioneered by Dr Elaine Ingham of Soil Foodweb Inc, http://www.soilfoodweb.com/Home_Page.html. This is a visual assessment by microscope which is time consuming and expensive. A cheaper and more repeatable test is the Phospholipid Fatty Acid Test (PLFA) but it is not commercially available in the UK although there are many labs in the USA that offer this service. If a British based lab could be persuaded to set up the PLFA test, a data base of soil health under different management regimes could soon be accumulated, and changes easily monitored.

- What are the benefits that healthy soils can provide to society?

Healthy soils with plenty of organic matter in them act as a carbon filter, holding onto soluble nutrients and applied chemicals and preventing them entering the water system, thereby saving water authorities the expense of cleaning them out. Active soil bacteria and fungi produce glues that stick soil particles together and prevent fine sediments leaching out which cause rivers and streams to run “yellow” rather than clear. This is the main cause of soil erosion rather than the more visible soil wash from the surface often seen after high rainfall, and is where most of the silt comes from, which needs dredging out to keep rivers running at full capacity.

- What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

Of the ninety or more elements on the Periodic Table, up to sixty five are present in all living plants and animals. Plant nutritionists only talk about seventeen of these because they are deemed essential for life, but the rest are there for a reason and are what give plants, and the animals that feed on them, true health and vitality. Hydroponic farming, where crops grow in water, amended with the seventeen nutrients, do not produce truly nutritious, healthy food. For example, tomatoes grown under this system look like the fruit we would expect, but they neither taste nor contain the full complement of nutrients that a soil grown tomato does. The only way for plants to access the full set of nutrients is by way of soil biology making them available to plant roots. It is sometimes said that if everyone only ate properly balanced, nutritious food, the NHS would be redundant. Obviously an exaggeration, but there is huge scope to reduce many of today’s illnesses by growing our food in healthy living soils.

Nearly all arable farmers will tell you that their yields have not risen for the last 15 years, in fact, although most will not admit it, they are now falling. This is because the fertility of their soils has been used up, or to put it another way, a large percentage of the organic matter has been burnt by excessive cultivations and fertiliser applications. All farms are different, but it can be assumed that many will only produce harvestable crops for one more generation, and their arable rotations may become financially unviable in an even shorter time. The only solution to feeding our population in the future without relying on dubious imported food is to reverse this soil fertility decline. Organic Farming as generally practiced in this country is not the answer either because it is so reliant on multiple cultivations for weed control and involves an inevitable halving of yields. Ploughing and subsequent seed bed preparation used on organic farms oxidises organic matter, releasing nutrients, some of which are taken up by the plants, but most are either leached away or lost to the atmosphere. These cultivations are also literally killing large quantities of soil life, particularly essential fungi and earthworms and so this farming system is not as healthy for the soil as they would have us believe.

- What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Agricultural universities and colleges are falling behind with regard to their teaching of soil biology to future farmers, they do not seem to know that there is a revolution going on in the commercial farming world. I am a member of a growing community of farmers in this country who are pioneering soil friendly methods by working together and sharing information. We have not received any help from official bodies, but have made contacts with likeminded farmers from across the world, many of whom are well ahead of us. Some of us have travelled to see like minded farmers in Denmark, Germany and France, as well as farther afield, Australia, New Zealand, North and South America. We also have regular meetings and seminars where speakers are invited to talk from all over the world and have farm walks where we can all get together and share our experiences. There seems to be a general mind set among most conventional farmers and academics that the present system has always worked so well, (look how yields have increased dramatically since the 1960s, they say) and so refuse to believe that an alternative way could possibly be an improvement.

The beauty of moving to a system of zero soil movement and less fertiliser and chemical use is that it is self-funding. Costs are so much lower and, although yields may dip a little in the transitional years, they should go on rising in the long term. What this means is that there is no need for government financial incentive, all that is required is education and encouragement. While the number of farmers in this country using these methods is still below 5%, they are increasing every year as can be seen by the year on year increase in direct drills being sold.

- What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

In recent years there has been a move to encourage farmers to take land out of production and give it over to natural areas under government sponsored environment schemes, with the assumption that yields will continue to rise to offset the fall in acreage. British farmers are now only producing half of all the food consumed in this country and their yields, having reached a plateau, are now falling, so it would now be better if the government encouraged a more environmentally friendly system of farming where soil life, insects, birds and all the rest can live side by side with sustainable food production.

If any members of the committee would like to come and visit my farm and see, feel and even smell healthy soil which is growing a wide range of high yielding crops, they are most welcome.

January 2016

Written Evidence submitted by Prof Paul Hallett, Prof Graeme Paton and Prof Pete Smith, University of Aberdeen

The University of Aberdeen offers the only dedicated MSc Soil Science in the UK and retains a strong group of scientists who were ranked top overall in the UK in REF2014 for Agriculture, Veterinary and Food Science.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

Decades ago 'soil health' was considered at the field scale and described using Land Capability for Agriculture and other metrics that compiled soil survey, meteorological, topographic and other regional data to categorise land on a scale from excellent (Class 1) to poor (Class 7). We now have much better technologies available and appropriate resolution, but the UK is data poor for the spatial characterization of soil properties. Information on the capacity of soils to transport or store water, support the weight of machinery, sustainably cycle nutrients for delivery to plants, support biodiversity, attenuate greenhouse gas production and retain carbon is patchy and sometimes derived from models constrained by the quality of the input data. Much could be learnt from Scotland's follow-on soil survey that revisited a subset of sites to measure changes over time, using a combination of traditional soil survey methods (soil type, drainage, structure) and more in-depth analysis (water retention, microbial diversity, carbon properties etc.).

A catch-all classification of 'soil health' is not feasible. Indicators are needed to measure 'soil health' for a specific purpose, whether it be food production, flood prevention, natural heritage, greenhouse gases or a range of other purposes.

A very long list of potential soil health measures could be provided here, but they are described in numerous reports. There is a need to explore methods that use specific indicators in greater depth. Promise has been shown in using biology (macro and micro biodiversity, bioindicators (earthworms, nematode species)) and soil organic matter content as indicators, but coupled measurements of chemical (pollutants, nutrients, pH) and physical (pore structure, drainage, strength) properties are needed. Techniques to monitor 'soil health' that have been deployed extensively in some European countries have not been adequately applied in the UK (e.g. compaction risk and damage). Some data have been over-extrapolated with poorly parameterized, qualitative models to generate maps of soil status or risks. This presents a significant challenge to developing and implementing government policies based on a strong evidence base.

At the level of a farm, forest operation, natural area, parkland or industrial site, a range of 'soil health' metrics are deployed. Industrial site 'soil health' can be parameterized by pollutant levels, although there remains a poor understanding of pollutant availability and potential degradation over time. In natural areas and parklands, focus will be on biodiversity and drainage capacity of soils. Farm soil health requires integrated information of a range of physical, chemical and biological properties. The measures deployed are limited by cost, reliability and often variability over space and time. Investment in developing and implementing new approaches (in-field sensors, rapid assays, new laboratory technologies, remote sensing) is helping to address these challenges.

What are the benefits that healthy soils can provide to society?

This is summarised succinctly in soil protection strategies as:

• greater food and biomass production;
• controlling and regulating environmental interactions: regulating water flow and quality;
• storing carbon and maintaining the balance of gases in the air;
• providing valued habitats and sustaining biodiversity;
• preserving cultural and archaeological heritage.

Degraded soils make food/timber production more expensive with a greater environmental footprint. Degraded soils increase greenhouse emissions, exacerbate flood risk and lead to erosion. Landscape value as defined by monetary or carbon value, by habitat or natural resource is lost.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

See above.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

See Section 2.9 of the Defra 'Safeguarding our Soils' document for a list of measures. Implementing GAEC has been challenging as qualitative descriptors to protect soil health are provided, which is difficult to assess on the farm. Moreover, catch-all risks and management suggestions pertaining to all of Europe that may be less relevant to UK conditions are included.

AHDB and organisations such as LEAF promote good soil management to farmers. AHDB investment in scientific research exploring favourable soil management options will provide some measures that can be used to assess 'soil health' impacts of agriculture. This investment provides evidence that levy payers appreciate the benefits of healthy and productive soils. The UK government needs a strategy to bridge the gap between strategic research on soil behaviour funded by RCUK, and more practical research with immediate relevance to farming, forestry and water industries.

A soil protection strategy is required. Considerable effort was put into the EU Soil Framework Directive and implementing such a policy would protect farming interests. 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

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

As described above and in Defra's 'Safeguarding our Soil' document, soil is an underpinning feature of the natural environment so the maintenance of its 'health' should play a major role in the 25 year plan. Inclusion of soils in ongoing efforts to quantify Natural Capital is essential. Given winter 2015/2016 flooding, the capacity to store and transport water needs

greater measurement so that risks can be better understood. Likewise, sequestering carbon in soil and decreasing soil emissions of greenhouse gases contributes to reaching COP21 targets.
There should also be consideration of the international impacts of soil degradation. Recent UK government investment in soil research via the Newton Fund is very welcome as it addresses such challenges directly. Food production from soil alone produces 20-30% of global greenhouse gases, consumes 70% of abstracted freshwater reserves and has degraded almost 25% of the vegetated land on earth.

January 2016

Written evidence submitted by Wildlife and Countryside Link

Executive Summary

The benefits and ecosystem services provided by healthy soils are huge and the consequences of not protecting healthy soils are extremely damaging to the economy, society and the environment resulting in reduced agricultural production, biodiversity and water quality and increased flooding to name just a few.

In seeking to promote soil health the government should use a combination of better regulation, advice and appropriate implementation and enforcement. We are concerned that recent budget cuts may weaken enforcement efforts.

We have previously urged the Government to introduce a set of basic rules as part of Good Agricultural and Environmental Condition (GAEC) standards 4 and 5. We believe that the GAECs as written fail to provide adequate protection for soils.

We consider that measures to improve soil health should form part of the Government's new 25 year plan for food and farming. This plan should be developed in collaboration with the 25 year plan for the environment to ensure consistent messaging and deliverable actions to address the challenges of soil health. However, soil health should not be limited to these plans but needs to be incorporated into the wider Government agenda.

Introduction

1. This document has been submitted by the Agriculture and Blueprint for Water Working Groups on behalf of the Wildlife & Countryside Link (Link). Wildlife and Countryside Link brings together 47 voluntary organisations concerned with the conservation and protection of wildlife, countryside and the marine environment. Our members practise and advocate environmentally sensitive land management, and encourage respect for and enjoyment of natural landscapes and features, the historic and marine environment and biodiversity. Taken together our members have the support of over eight million people in the UK and manage over 750,000 hectares of land. More information is available at http://www.wcl.org.uk/.

2. Link has set out our shared vision for more sustainable agriculture in our publication 'Farming Fit for the Future' (www.farmingfitforthefuture.org.uk) and our vision for the water environment in 'Water Matters' (www.blueprintforwater.org.uk). Our aspirations include farmers who are supported through advice and other mechanisms to renew soil health and halt soil erosion and pollution.

This consultation response is supported by the following 13 organisations:

- Amphibian and Reptile Conservation
- Angling Trust
- Butterfly Conservation
- Buglife - The Invertebrate Conservation Trust
- CPRE
- Institute of Fisheries Management
- RSPB
- Salmon & Trout Conservation UK
- The Rivers Trust
- The Woodland Trust
- The Wildlife Trusts
- Wildfowl & Wetlands Trust
- WWF UK

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

1. Monitoring of soil health is very important. A first step is to define what soil health is and what a strategy hopes to achieve. The monitoring regime needs to accurately measure appropriate indicators such as those listed below. Monitoring results will vary according to time of year and weather which will need to be taken into account.

2. Measuring soil health should include the following components:
   - Soil organic matter to be measured annually – soil organic matter is fundamental to a healthy soil food web and consequently to above ground wildlife.
   - Infiltration rates
   - Soil biota - Soil biodiversity plays an important role in the functioning and the physical properties of soil. There is a need for more research to better understand how this contributes to crop health, productivity and resilience.
   - Soil carbon - The importance of soil carbon both for climate change and in the context of fertility is increasingly recognised. There is a strong argument for ceasing arable production on the most carbon rich soils – deep peat to ensure that carbon remains locked in those soils.
   - Physical structure - The physical structure of soils is important for productivity, stability and water retention. This is important both for farming and flood prevention and should include factors such as soil compaction and soil erosion.

3. A strategy for soil health should take account of the elements listed above and include:
   - A clear definition of and standardised measure(s) for soil health.
   - Compulsory testing and reporting on organic matter
   - If soil health is shown to be decreasing the land manager to work with the appropriate agency to create a plan to protect and improve their soil.

4. The 25 year plans need to link closely with any Government soil strategy, or to require a Government soil strategy if one has not already been announced and should include targets to improve soil health based on the measures listed above to ensure that England's soils improve over time benefiting both productivity and the natural environment.

What are the benefits that healthy soils can provide to society?

5. Benefits include:
   - A sustainable farming economy - productive capacity, underpinning our agriculture industry,
   - Carbon storage – restoring humus should be central to improving soil health,
   - Contribution to flood alleviation and water purification, detoxification of pollutants,
   - Reservoir of biodiversity,
   - Attenuation of soil-dwelling pests and pathogens[1]; reduction in need for pesticide and herbicide use,
   - Improved human health. Healthy soils results in nutritionally dense crops and livestock. Plants grown in fields with high fungicide use have reduced nutrient uptake through symbiotic relationships. Vegetables grown in fields devoid of nutrients lack minerals and vitamins. Between 1940 and 1992 vegetables have lost 49% of their Sodium content, 46% of their Calcium content and 76% of their Copper content http://www.mineralresourcesint.co.uk/pdf/mineral_deplet.pdf,

6. Case Study on the benefits of healthy soils: National Trust Wimpole Estate
   The Natural Capital Committee working with a consortium of Eftec, RSPB and PwC developed a framework for organisations to take better account of the natural capital they own, depend on or for which they are responsible - corporate natural capital accounting (CNCA).

7. As part of the CNCA pilot the National Trust Wimpole Estate, Cambridgeshire, applied the approach to investigate a new way of recording what natural assets are owned by the Trust and the relative costs and benefits that flow from their management.

8. The range of estate benefits included farm income, visitor revenue, recreation, wildlife and carbon sequestration. Given the multiple benefits of natural capital, the challenge for CNCA was to identify, value and present them in a format that provided an overall understanding of the state of natural capital for the site.

9. Wimpole is a 1,200 ha historic estate and an important visitor attraction consisting of parkland, farmland and semi-ancient SSSI woodland. Due to poor soil quality, the lowland arable farm had recently undergone changes in farming practices, moving from conventional arable farming, to organic cropping and Higher Level Stewardship (HLS).

[1] UK National Ecosystem Assessment (2011) Chapter 14: regulating services http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=XPPBQJuWlzk%3d&tabid=82

10. The CNCA framework was used to measure and report the overall change in natural capital value arising from this change in management regime. Natural Capital refers to the stock of natural assets upon which our societies and economies are built. It includes all habitats, their benefits and all abiotic resources like minerals. The concept regards natural resources as important productive assets. It is common sense to preserve the value of any productive capital; understanding its value encourages the sustainable management of that capital.

11. The CNCA is like a balance sheet that shows the asset values (multiple benefits provided by natural capital) and liabilities (costs of investing in natural capital). Comparing the previous intensive arable practice to the current organic regime demonstrated that, despite the reduction in crop yields, the overall income was about the same, due to a combination of lower fertiliser costs, higher HLS grant income and a slight price premium for organic produce.

12. There were significant benefits through increases in soil carbon sequestration, higher recreational benefits and improvements to biodiversity. Taking these additional benefits into account meant that the overall return on investment was much greater than recognised in conventional financial accounts.

13. Link: http://www.naturalcapitalcommittee.org/corporate-natural-capital-accounting.html - Through the same link, you can also view a testimonial by the National Trust team who managed the CNCA pilot.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

14. Ultimately without healthy soils we cannot have a viable or sustainable agricultural economy. All the benefits listed above will be compromised.

15. Soil degradation in England and Wales costs farmers and wider society an estimated £1.2 billion[2] per year in lost productivity, flood damage, reduced water quality and other costs. Healthy soils are vital for food security. The Government's ambition is to 'grow more, sell more, buy more' British food – this will be impossible if we do not look after our soils.

16. A failure to protect soil health can result in a loss of nutrients and organic carbon. Edmonson *et al*. (2014)[3] found that small-scale urban food production can occur without the penalty of soil degradation seen in conventional agriculture, highlighting the need to manage our rural soils better.

17. Unstable soils can lead to increased diffuse pollution due to run-off of sediment and particulate pollutants attached to sediment (including pesticides, nutrients and faecal microbes) into waterways.

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[2] Defra/Cranfield University (2011) Cost of soil degradation in England and Wales, SID 5 Research Project Final Report
[3] http://onlinelibrary.wiley.com/doi/10.1111/1365-2664.12254/full

18. Sediment runoff can negatively impact aquatic biodiversity - it can reduce light penetration and plant and algal growth. Globally endangered species such as the freshwater pearl mussel are extinct from many rivers with many surviving populations unable to successfully reproduce because sediment deposition prevents the conditions needed for juvenile mussels to survive. If sediment settles on gravel beds it can inhibit fish from spawning. Other impacts on fish in particular can be found in the Salmon & Trout Association briefing paper http://www.salmon-trout.org/pdf/Briefing%20Paper%20Sediment%20New%203.pdf.

19. It is thought that 75% of sediments polluting water bodies have derived from farming http://www.foodsecurity.ac.uk/assets/pdfs/agriculture-water-quality-report.pdf. Sediment fingerprinting research indicated 61% of the sediment load of the River Tweed in Scotland was derived from arable and pasture topsoils (Owens *et al*., 2000).

20. Around a third of water pollution problems can be traced back to agriculture and rural land use. See Environment Agency (2013) England's Waters: Challenges and Choices. Critically soil runoff prevents a number of Natura 2000 protected areas from meeting their conservation objectives. Consequently the UK is unable to meet its obligations under both the Water Framework Directive and nature directives.

21. Increased flooding – healthy soils hold more water than intensively managed soils; some land management such as maize cultivation can result in increased sediment run-off into rivers which can exacerbate flooding. Soil erosion, diffuse source pollution and sediment problems associated with maize cultivation in England.

22. Degraded soil means loss of a carbon sink and release of stored carbon to the atmosphere.

23. Increased water treatment requirements - excess sediment and particulate pollutants attached to it, pollute drinking water sources; runoff from degraded peat soils also negatively affects water quality. Increased silt in rivers can also negatively impact in-river structures including energy turbines.

24. Faecal microbes from grazing livestock are transported to coastal waters attached to sediment impacting upon bathing water quality. In severe cases such pollution can lead to marine dead zones.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

25. In seeking to promote soil health the government should use a combination of better regulation, incentives, advice and appropriate enforcement. We are concerned that recent budget cuts may weaken enforcement efforts.

26. Cross compliance is a key policy tool but is currently inadequate in how the rules are designed and enforced. See:

- Link response to cross compliance consultation
- Link response to further consultation on soil GAECs
- Link response to new basic measures consultation
- WWF report on compliance rates with measures to prevent diffuse pollution

27. Evidence and experience to date shows that the quality of information and advice received by farmers is key in determining uptake and success of schemes designed to change behaviours (for example Dwyer and Blackstock (2007) Understanding and influencing positive behaviour change in farmers and land managers; Rural Economy and Land Use Programme (2012) Improving the success of agri-environment initiatives). Experience suggests that for advice to be effective, it has to be provided by a trusted source, indicating the need for continuity. Given this, we are deeply concerned about cuts to the government agencies responsible for providing advice.

28. The recent Defra consultation on new basic rules for farmers in England to tackle diffuse water pollution from agriculture included a number of actions relevant to soil health. For example: *Take action to prevent soil erosion and run-off from tramlines, rows, irrigation and high risk sloping lands or those lands highly connected to surface water. (Compliance achieved if already meeting GAECs 4 & 5).* As we stated in response we do not believe that meeting GAECs 4 and 5 is enough to achieve the desired environmental outcomes of these rules. The GAECs are not currently sufficient to protect soils and water (see Link's informal cross compliance consultation response on soil GAECs (2014)).

29. The GAECs do not prevent inappropriate land management practices: for example they allow soils to be left under maize stubble over winter and ploughing up and down slopes. GAEC 4 includes a list of "acceptable agronomic reasons for not providing cover" which provide a broad loophole to avoid having to meet the standard. Compliance with GAEC 5 is determined by whether an inspector observes signs of soil erosion, which given the low rate of inspection means a lot of bad practice is likely to be missed, and only picked up once the damage has been done. Furthermore, erosion is only considered 'significant' if it is over a single area greater than 1 hectare, or 20m x 2m along a water course.

30. LINK consider that the new basic rules should be redrafted, drawing on evidence and expert opinion as needed, to address the significant shortcomings of the existing cross compliance standards. New measures might include something similar to the Scottish General Binding Rules which states that no land should be tilled within two metres of a surface water body or wetland and five meters of a well, spring, borehole used for human consumption.

31. As a minimum:
    - The list of acceptable types of winter cover should be amended to exclude land uses which are known to leave soil vulnerable to erosion (e.g. maize stubble)
    - Definitions drawn up of 'high risk lands' (based on features such as soil type and depth, slope, rainfall), high risk land uses and management practices. High risk practices should be forbidden on high risk lands.

- Any erosion within 5m of surface waters, or which adversely affects the growth, quality or diversity of natural or semi-natural vegetation, should be considered ‘significant’.

32. Work commissioned by WWF (Investigating Agricultural Compliance Rates, Alex Inman Consulting (2014)) identified ten key measures to address diffuse pollution. Those relevant to soil health include:
    - Take steps to address and repair soil compaction
    - Increase Soil Organic Matter

33. Geographically targeted legislation might be a suitable approach to address some of these issues. Improved guidance on best practice is also needed.

34. Organic farming prioritises soil health. The UK government could do more to promote and support organic farming.

35. UK government and industry should give more priority to research funding and knowledge exchange to farming practices that maintain and enhance soil health.
    - Useful reference: Natural England summary of evidence on soils

36. Incentives could be developed to play a bigger role in re-building soil health. For example using a high rate of compost whilst still growing winter wheat which will allow current rates of farming production to continue. Monitoring would be vital and provide evidence that fertility was not being over exploited.

37. Government should work with leaders in sustainability within the farming community to embed good soil management.

38. **Restoration of upland peat soils -** Upland peat soils like other soils when in good condition can perform important functions. These include underpinning internationally important habitats which support internationally important species, providing carbon storage and water management and purification. Yet upland peat soils have been severely degraded over the past century through over grazing, over burning and over drainage. In recent years multiple initiatives have been initiated in order to halt the erosion and begin to restore these important functions. More information can be found at IUCN Peatland Programme. Issues remain around tackling conflicting land use issues e.g. burning for grouse moor management.

39. **Restoration of lowland peat soils -** The UK’s lowland peatland soils are strategically important from a carbon perspective. For example approximately 330MT of carbon is stored in the lowland Fens – equating to around 60% of all the soil carbon in peat in England, and around 1.2 billion tonnes of CO_2. Ongoing cultivations of these soils is slowly releasing this stored carbon through erosion and mineralisation. Emissions from drained soils accounts for 5.5MT of CO_2 per year in the UK’s Greenhouse Gas Inventory. A number of initiatives are beginning to be taken forward to safeguard these soils but urgent action is needed to take the last remaining deep peat soils out of production.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

40. Soil health should be a key feature in both the 25 year plan for the Natural Environment and also crucially the 25 Year Plan for Food and Farming. However, soil health should not be limited to these plans but needs to be incorporated into the wider Government agenda through agricultural, flooding and health policies.

41. This should include recognition of the importance of effective regulation which is well designed and enforced to ensure strong protection of the natural environment. Link's vision Farming Fit for the Future sets out how environment and farming must be improved in a holistic way to benefit people and the environment – soil health is key to this.

42. The two plans should be co-ordinated to ensure they provide effective leadership in safeguarding the natural environment and guiding the development of the food and farming industry to ensure its sustainability.

January 2016

Written evidence submitted by the Soil Association

Executive Summary

- UK soils are deteriorating, reducing our long-term capacity to grow food and releasing significant amounts of greenhouse gases in the process. The UK government (with others) stopped EU action to protect soils, and instead it has said it will ensure that our soils are in good condition by 2030.

- No action has been taken to implement this pledge. The Soil Association is calling for three actions which would signal a determination to reverse decades of neglect of British soils. If the Committee's important investigation is to break this long period of neglect urgent action is required in these three areas.

- **First**, the UK government should adopt a target of increasing Soil Organic Matter in UK arable soils overall by 20% over the next 20 years. This would reduce greenhouse gas emissions, help protect against flooding and droughts, and start to rebuild the capacity of British soils to produce our food into the future.

- **Second**, drained English and Welsh lowland fens, around 40% of which are the East Anglian Fens, contain the equivalent of 1.2 billion tonnes of CO_2, and are responsible for massive emissions of greenhouse gases - at least 5.2 Mt of CO_2 per annum - which is the same as the total emissions from the UK chemical industry and more than the emissions from all UK railways or from all buses in the UK.

- The Government should set up a special climate and soil protection area covering the 20,000 hectares of remaining deep peat in The Fens, with a target of reducing greenhouse gas emissions from the area by 80% by 2050 (the UK's legally binding target), by introducing a mix of measures, including: further management of land for the public and wildlife; farming systems to conserve rather than degrade peat; and alterations in the drainage systems to help safeguard peat soils.

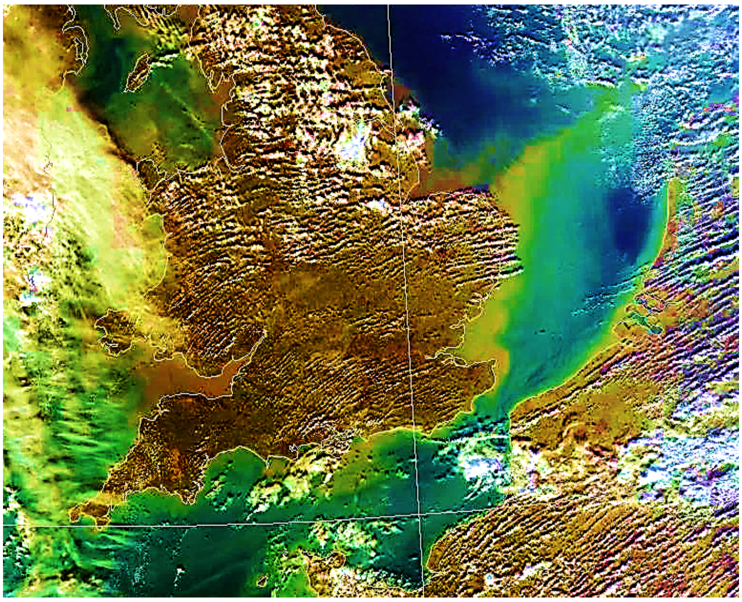
- **Third**, the Government must act to halt the dramatic rise in the area of farmland being used to grow maize for Anaerobic Digestion (AD). Maize is probably the fastest expanding arable crop in the UK (up from 8,000 in 1973 to 186,000 hectares in 2015), and one of the most damaging to soils. In 2014 researchers found that 75% of late-harvested sites in South West England showed high or severe levels of soil degradation.

- Maize for AD is a threat to food production - the area of farmland projected for new maize crops for AD would be sufficient to produce 2 billion loaves of wholemeal bread, or enough potatoes for 6 billion bags of chips.

- Maize grown for AD is subsidised twice by the taxpayer, first through CAP subsidies to farmers growing maize, and secondly through renewable energy subsidies to the AD operators.

- The Government should end this double subsidy, not allow maize to be grown as part of the 'greening' requirements of the CAP, and remove all renewable energy subsidies for crops grown specifically for AD production.

Political background



A photograph taken on 16.02.14 shows soil flooding out of England's rivers. Photograph from Dundee Satellite Receiving Station via The Guardian: http://bit.ly/1m26MPJ

1. Our soils have been neglected for far too long. The reasons for this neglect include the unrealistic assumption that we can manipulate soils with inputs of chemicals in ways that make natural processes redundant, and the absence of clear evidence about the degree of soil losses and their impact on our ability to produce food in future. Similar lack of precise scientific evidence applies to our understanding of the impact of greenhouse gas (ghg) emissions from UK soils, and, to a lesser extent, our understanding of the capacity that soils have to sequester carbon. These uncertainties, and the need for more scientific research, provide no excuse for continuing inaction.

2. The UK government was one of the Member States insisting that no action should be taken at EU level to protect our soils, to compliment EU action already being taken to protect freshwater, inland seas and air from unacceptable pollution and other negative impacts. The UK said that EU action was unnecessary, as safeguarding soils could safely be left to national governments. The Government are committed to ensuring that all soils are sustainably managed by 2030, but they have not said how they will achieve this.

3. With that in mind, we have focused our evidence on three specific areas, one general policy objective, one specific regional area of catastrophic soil loss and ghg emissions, and one extremely damaging and rapidly growing farming practice. All demand urgent action from the UK Government to ensure that all soils are sustainably managed by 2030.

4. If the Environmental Audit Select Committee's important investigation is to break decades of neglect of UK soils we believe as a minimum that action in these three areas is vital.

Scientific background

5. Scientific evidence suggests that soils in the UK – in particular arable and horticultural soils – are suffering from declining soil organic matter levels. As a result of this and other factors, compaction, increased surface run off and erosion are serious problems on many farms. This evidence does not focus on the scale of the problem, or the need for more and better data and more research, as we assume others will cover these points. We have concentrated on setting out three areas requiring urgent action.

1. Commit to increasing soil organic matter levels in UK cropland by 20% in 20 years

6. While there are difficulties in pinning down a specific target for soil health, soil organic matter (SOM) is the best proxy. Good levels of SOM are crucial to everything from long-term yields and the quality of food grown, to resilience to extreme weather and soil erosion, and a vital store of soil carbon (and with bad management, a major source of ghg emissions).

7. Based on the widespread evidence from organic farming, we are calling for the UK Government to commit to increasing SOM levels by 20% in the next 20 years in arable soils – a relative increase of just 1% a year. This is similar to the French Government's 4/1000 - '4 pour mille' initiative, announced at the Paris climate summit - a plan to increase global levels of soil organic carbon in all soils by 0.4% each year, in order to make a significant contribution to the offsetting of ghg emissions (a '4 per thousand' target).

8. For the UK, a 20% increase in SOM in the next 20 years is a realistic target that would have profound impacts on UK food security, soil erosion, water quality, water storage, resilience to floods and droughts, and carbon sequestration. For example, for carbon, based on figures for organic farms, meeting this target could result in carbon sequestration equivalent to that achieved by planting forest three-quarters the size of Wales.

9. Although there is much we do not know about soils, we do know how to increase SOM, and we have identified seven ways to safeguard soils:

Seven ways to safeguard soils:	**Practical steps for farmers:**	**Government should act to:**
1. Increase the amount of plant and animal matter going back onto fields	Use legumes, composts and composted animal wastes instead of nitrogen fertilisers where possible	Increase farmer awareness of the broader benefits of manure and composts
2. Improve soil health monitoring across the UK	Monitor soil organic matter levels	Make soil health monitoring part of cross-compliance under Pillar 1 of CAP ensuring farmers do this on a representative sample of their farm
3. Encourage soil organisms	Consider the impact of multiple agrochemicals on soil life	Invest in research on the role of soil biology in securing crop productivity and carbon and water storage, and how agrochemicals affect this

4. Cover bare soil with continuous plant cover	Use green winter cover crops	Ensure this through cross-compliance
5. Bring more trees onto farmland	Increase understanding on the value of trees	Commit to increasing agroforestry in the UK (as proposed by the Climate Change Committee) through agri-environment schemes under Pillar 2 of the CAP
6. Reduce soil compaction from machinery and livestock	Use deeper rooted crops and reduce risks through visual assessments and remedial action	Make avoiding and treatment of soil compaction a cross-compliance requirement
7. Design crop rotations to improve soil health	Diversify rotations and use grass leys and clover	Encourage landlords to ensure that soil organic matter is maintained or enhanced (depending on the soils) throughout a tenancy

2. The need for action to save the lowland drained peat soils of the East Anglian Fens

10. The drained Fens of East Anglia are strategically important from a carbon perspective. Approximately 330 Mt of carbon is stored in all the lowland Fens – around 60% of all the soil carbon in peat in England, and around 1.2 billion tonnes of CO_2. Emissions from the oxidation and erosion of these drained soils account for 5.2 Mt of CO_2 per year in the UK's Greenhouse Gas Inventory.

11. This is the same as the total emissions from the UK chemical industry and more than the emissions from all UK railways, or from all buses in the UK.

12. Calculating exact emissions figures from lowland fens is difficult, and the current estimate of 5.2 Mt of CO_2 per year is likely to be an underestimate. Scientists are currently recalculating emissions, and a provisional estimate is 11.8 Mt of CO_2 per year.

13. The communities in and around The Fens are reliant on agriculture – either directly or indirectly, and while peat is complex to farm, this land is generally more profitable per hectare and carries a significantly higher land value than most arable soils.

14. We are highlighting the very significant soil losses and release of ghgs from the East Anglian Fens, in part because the impact on our climate from just this one area of UK soils is so significant, but also because it illustrates the absence of action, from the Government or farming industry, in saving these fragile soils and in reducing the ghg emissions they are responsible for.

15. In The Fens there are ambitions to expand the area of land that is already managed primarily for wildlife. Restoration to wetlands and wet pastures brings about an estimated net societal benefit of around £130 per hectare per year.

16. Changing current land management will be a long-term process, requiring a mix of land management in future. To ensure continuing food production, and to support the local economy, there is a need for land management practices that help conserve peat that fall between intensive arable farming and management for nature.

Action needed

17. It is impossible completely to halt the loss of these peat soils, but there are a number of actions that would dramatically reduce soil losses and ghg emissions. In other areas where farming has had an unacceptable impact on the environment and public interests, EU legislation has ensured that coordinated, often geographically defined action has to be taken, for example in Nitrate Vulnerable Zones or in implementing the Water Framework Directive through Catchment Sensitive Farming. The Government should set up a zone of special climate and soil action, covering the remaining areas of deep peat in The Fens (around 20,000 hectares of deep peat).

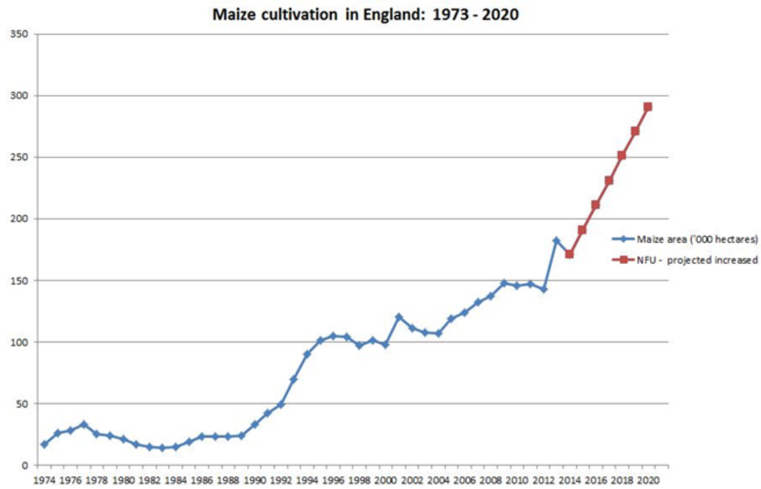
18. All interested parties, including farmers, landowners, local authorities, nature conservation bodies, drainage interests, soil scientists and others should be brought together to agree a plan of action to meet clear targets, including the UK's legally binding target of cutting greenhouse gas emissions by 80% by 2050. This will provide an effective baseline against which progress can be judged.

19. Initiatives that could be taken in The Fens special climate and soil action zone include:

- expanding current plans for extending the areas of re-wetted peat managed for extensive livestock production, wildlife and people
- encouraging more organic farming, to ensure roughly half of farmland is under grass, more organic matter is returned to the soil, and to encourage the return of extensive livestock farming
- incentivise agroforestry which increases productivity, improves soil structure through deep tree roots, and maintains cover to prevent wind and water erosion (wind erosion in The Fens is estimated to cause a loss of 3 tonnes of soil per hectare per year)
- investigate opportunities for high value cropping based on farming in wet soils
- change the remit of the Internal Drainage Boards from draining The Fens for productivity (and to manage flood risks) to include a duty to protect the soil and to improve its quality
- encourage good farming practice, including keeping soil covered, growing green Winter cover crops, and switching to livestock grazing on permanent or temporary grassland
- trials of new land management techniques and demonstration projects on farms to encourage innovative ways of safeguarding peat soils.

3. Maize for anaerobic digestion

20. A large increase in maize cultivation has occurred in the UK in the last four decades, with a rapid increase since the early 1990s.



The figures in red illustrate the additional area of maize required by the National Farmers' Union's (NFU) stated ambition to increase the number of on-farm anaerobic digestion plants in the UK to 1,000 by 2020

The problem

21. Maize is now probably the most rapidly expanding crop in the UK – up from just 8,000 hectares in England in 1973 to 186,000 hectares in 2015. Most maize is used as a livestock feed, but an increasing proportion – currently around 20% - is cultivated as a feedstock for anaerobic digestion (AD). Maize is not native to northern Europe, and despite the development of more resilient varieties, remains a difficult crop to grow in our maritime climate without a high degree of artificial inputs. Maize is strongly associated with causing severe damage to soils and rivers, and with increasing the risk of flooding.

22. Maize grows in wide rows and matures slowly, leaving soil exposed throughout the growing season. It is harvested late in the year, sometimes into late November depending on weather, when the ground is often sodden. Maize harvest requires heavy machinery, and repeated heavy tractor movements on wet soil can cause severe compaction and rutting. Many farmers aim to follow good practice, harvesting earlier and establishing a winter cover crop, but often this is not possible.

23. During periods of heavy rain, on many maize fields, rainwater contaminated by slurries, pesticides, fertilisers and soil washes off fields, resulting in flooding, pollution and damage to rivers.

Wye and Usk Foundation

24. A study conducted in 2014 found that 75% of late-harvested sites in South West England showed high or severe levels of soil degradation. One of the study's authors estimated that during the floods over the winter of 2013/14, every 10 hectare block of land under maize stubbles produced 375 million litres of enhanced runoff.

25. The public subsidies available for biogas from AD that have encouraged expansion of maize crops have also led to significant increases in rent for arable land, a huge problem for tenant farmers, placing struggling farmers under even greater pressure.

26. The double subsidies available to maize grown for AD – through the basic farm payment under CAP and again through renewable energy incentives, such as the Feed-in Tariff for biogas – must end. In 2015 the total amount paid to farmers growing maize for all purposes amounted to almost £33 million. In addition, 'renewable' energy subsidies for maize used in AD plants cost British energy consumers up to £50 million per year. The National Farmers' Union have called for an expansion of the crop-fuelled AD industry, requiring an additional 100 – 125,000 hectares of maize to be grown.

27. This increase would represent a clear risk to the environment, and a significant loss of high quality agricultural land, reducing our capacity to produce food. The 125,000 hectares ear-marked for maize could produce enough wheat to make 2 billion loaves of wholemeal bread, or enough potatoes for 6 billion bags of chips. Given the pressure to feed an increasing population, we cannot sacrifice valuable agricultural land to a technology as specious as producing fuels from purpose grown crops. Of dubious benefit from a climate change perspective, there is compelling evidence that biogas from maize in particular is negative in terms of its overall environmental impact.

28. For all other maize cultivation, the Government should recognise the severe harm that can be caused by poor maize management, and introduce robust criteria for best practice, and enforcement mechanisms for non-compliance. The Government missed an opportunity to introduce best practice criteria for maize for AD following its recent consultation on the Feed-in Tariff. Maize should be removed as a qualifying crop under the EU's greening requirement under CAP.

Action needed

29. To implement the Government's commitment to improve and safeguard British soils by 2030, the Soil Association is calling for:

- saving up to £50 million per year by stopping all the subsidies available for AD digesters fuelled in whole or partly by maize, and increasing the support for biogas from waste
- removal of maize as a qualifying crop under the greening requirements for 30% of the new Common Agriculture Policy's Basic Farm Payment
- the EU to remove the Basic Farm Payment for fields growing maize for AD
- the introduction of strict measures for management of maize crops under cross-compliance (requirements for farmers to be eligible for the Basic Farm Payment) – mandating compliance with officially recognised best practice.

The Soil Association

32. The Soil Association was founded in 1946 by farmers, scientists, doctors and nutritionists to promote the connection between the health of the soil, food, animals, people and the environment. We have taken a close interest in the health of our soils for the last 70 years. Today the Soil Association is the UK's leading membership charity campaigning for healthy, humane and sustainable food, farming and land use. We have always been concerned about agricultural soil health and it's overlooked, yet central importance to farming, our environment and our own health.

January 2016

Written evidence submitted by academics engaged in research and teaching in soil science at Newcastle University

Summary

- Soil health is the soil's ability to perform functions essential for human society: regulating water and air quality; maintaining plant and animal productivity, filtering and buffering pollutants; storing and cycling nutrients and providing mechanical support (and resources) for human infrastructure.
- The loose concept of 'soil health' provides a basis for a wide range of stakeholders to engage in productive and pragmatic debate on best practice soil management for particular situations.
- Outside the established legal framework for assessment of contaminated land, the assessment of soil health is difficult, not only because of the inherent complexity of the medium (including considerable spatial and temporal heterogeneity) but also because of the multiple uses to which soil is put and the multiple functions required of it, often simultaneously.
- A major challenge is to agree a set of soil properties that are sufficiently simple and robust for routine use, yet provide information that can be interpreted to give meaningful insights into the state of a soil and whether or not it is deteriorating or improving. These should include dynamic physical, chemical and biological indicators that have been shown to have strong links to soil function.
- A range of diverse approaches have been developed to assess soil health by government agencies, the UK scientific community, land owners-managers and the public .Any Government strategy should be developed and delivered as a partnership between these stakeholders.
- Any monitoring scheme (at whatever scale or for whatever purpose) should use carefully selected standardised methods and a carefully designed sampling scheme (including consideration of scale and replicability). Such a scheme could then be enhanced through citizen science.
- It is essential that soil health is explicitly recognised and is a central element in the 25 year plan for the Natural Environment. Maintaining effective soil function is critical for the delivery of almost all the wider biodiversity and landscape benefits that the plan will identify.
- Newcastle University would highlight that, given the diversity of land uses, soils and systems, provision of information, guidance and education is most likely to deliver benefit in terms of practical initiatives to maintain and improve soil health in the short to medium term (5-15 years).
- Biodiversity, water and air are covered by substantial European legislation, transposed into English law. We urgently need a similar framework for soils. This would help secure the required commitment to protect and improve the health of our soils.

Soil Science at Newcastle University

Newcastle University puts academic knowledge, creativity and expertise to work by supporting student learning and also producing innovations and solutions that tackle societal challenges. Newcastle University has always had a focus on applied science and plays a leading role in education and research in areas such as agriculture, geology and medicine. Currently, soil science capability is spread across three collaborating academic schools (Agriculture, Food and Rural Development, Civil Engineering and Geosciences, Biology) within Newcastle University). On-going research (Soil@Newcastle) is co-ordinated through Newcastle Institute for Research on Environment and Sustainability. There are more than 20 academics supported by a range of research assistants and students leading research in many aspects of soil science, including:

- soil survey, classification and mapping;
- soil mechanics;
- soil hydrology; irrigation and drainage;
- soil mineralogy and fertilising materials;
- soil acidity and fertility; carbon and nutrient cycling (including C sequestration, fertiliser availability and losses);
- soil microbial dynamics and processes (including application of next–generation sequencing);
- soil-plant-microbe interactions (focused on small scale rhizosphere dynamics);
- soil ecology (including plant-pathogen interactions);
- impacts of soil management on soil properties and processes;
- precision management approaches to soil and input management;
- on-farm tools to assess soil quality;
- interactions and co-impacts in agricultural, semi-natural systems and urban systems;
- empirical and process-based modelling of soil-plant-environment interactions.

How could soil health best be measured and monitored?

Definition

- Soils are the site-specific outcome of interactions between climate, geology, topography, vegetation and management over millennia; there is a huge diversity of soil types (series) and large ranges in soil properties (depth, stoniness, pH, texture…) across the UK and often across a single field.
- Before considering how soil health can be measured it is important to consider how, and indeed whether, soil health can be clearly defined.
- The USDA has defined soil health as the soil's ability to perform the essential functions: regulating water and air quality; maintaining plant and animal productivity, filtering and buffering pollutants; storing and cycling nutrients and providing mechanical support (and resources) for human infrastructure. This capacity of soil is also known as 'soil quality'. Use of the term soil health stresses the role of biological systems in delivering soil function.
- The term soil health has widespread resonance; it is understood to be a "good thing" by farmers, gardeners, conservationists and the general public. In communication with the general public about the importance of soil and

the critical importance of soil function to human health and well-being – the term soil health can be used as a general concept without fear of misunderstanding.

- The concept of soil health does not refer simply to a static set of soil characteristics (texture, mineralogy, microbiology) or emergent properties (water holding capacity, capacity to degrade pollutants). Soil health also requires consideration of the capacity of the soil to sustain function in the face of changing environmental conditions or management impacts. The ecological concepts of resistance and resilience interpreted in terms of capacity to resist change to soil function and/or to quickly restore function when it is disrupted are also critical. The functional fragility of soils, and more importantly the site-specific options available to improve soil health must be part of any assessment.
- Whether or not the **concept** of soil health can be clearly defined, the **term** is so attractive to non-specialists that it is necessary for it to be used in a meaningful way, accepting that it is a scientific and a social construct. The general concept should allow a wide range of stakeholders to engage in productive and pragmatic debate on definitions of best practice soil management for particular situations.

Measurement

- Soil health/quality is usually characterised by measurement of combinations of soil properties (physical, chemical, biological); no one property can provide a sole indicator of soil health.
- The clear legal frameworks for air and water quality set targets in relation to maximum concentrations of particular pollutants. With water or air it is possible to define a 'normal' condition in which these materials are relatively pure in a chemical or biological sense. This cannot be achieved so readily for soil.
- There are clear legal frameworks governing the assessment of soil properties for contaminated land. Any remediation work seeks to ensure a standard (often measured by levels of pollutants in soils or percolating waters), which indicates that the land is "suitable for use".
- Outside this narrow framework, the assessment of soil health is more complex, not only because of the inherent complexity of the medium (including considerable spatial and temporal heterogeneity) but also because of the multiple uses and functions required of soil, often simultaneously.
- Various soil parameters have been proposed as indicators of soil health. Although there would be some agreement amongst scientists and other stakeholders on an essential dataset, this is not fully determined and proposed parameters are not always well linked to function.
- A major challenge is to agree a set of soil properties that are sufficiently simple and robust for routine use, yet provide information that can be interpreted to give insight into whether or not soil health is deteriorating or improving. In particular, positive aspects may be more difficult to envisage conceptually, particularly those soil properties, which support effective performance of particular functions (e.g. biodiversity, structural resilience), rather than those that are the direct cause of the function (e.g. rhizobia for N fixation).

- Inherent soil properties (those resulting from the operation of soil-forming factors) can be distinguished from dynamic soil properties, which are most affected by management. We suggest that the dynamic properties e.g. structural stability, soil organic matter, soil microbial community function should be the focus of soil health measurements where the aim is to promote sustainable management of soils rather than simply identify soils most suited to particular uses. Site factors will also need to be quantified if soil health data are to be used to compare sites or seasons.
- Spatial and temporal scales must be considered explicitly. Temporal and spatial integrity of data can also be difficult to achieve, and for measurements to be both appropriately accurate and practical some trade-offs will be required.
- New remote sensing methods are providing a range of exciting possibilities to measure indicators of soil properties rapidly and non-invasively (hence more cheaply); however, this work is not yet widely ground-truthed against classical measures of soil properties or considered in relation to soil function. Over the next decade it is likely that these measurement methods will become part of routine soil monitoring.
- Increasingly, soil health frameworks, that are more analogous to the way in which human health is assessed, are being developed for particular uses. We consider that soil health should be assessed holistically by measuring a number of indicator parameters that are then compared to optimal ranges and/or critical limits.

Monitoring

- Land quality, and the fitness of land for different uses, is routinely assessed in land use planning. Land use capability approaches (ALC in England) use some inherent soil properties in site assessment. Hence ALC could be adapted to provide the background description of site and inherent soil factors against which soil health can be considered.
- There is a wealth of publicly-funded soil data for the UK collected and collated by the Soil Survey of England and Wales. This is not particularly cast in terms of soil health, but provides important background information on soil variability at landscape scale. The 1:250,000 scale maps, which cover the whole of the country, although excellent in providing information about soil groupings (associations), are necessarily broad brush. Detailed soil mapping at 1:25,000 scale represents the major soil and land-use landscapes. However, the National Soil Inventory is only accessible at a cost.
- For agriculture – there are a number of well-established approaches in other countries e.g. Cornell Soil Health Assessment, New Zealand Visual Soil Health Assessment, soilquality.org.au. In the UK, there have also been a number of approaches developed to allow farmers to assess soil health e.g. LEAF Simply Sustainable Soils, AHDB Healthy Grassland Soils, and to take steps to improve it.
- Separately there are a range of approaches that have been/are in use to assess and monitor soil health as part of national surveys. Such approaches will be described in detail elsewhere by those organisations who have deployed them e.g. Countryside Survey, Representative Soil Sampling Scheme.

- Citizen science has also been mobilised to collect focussed data on soil properties e.g. the worm survey within the Open Air Laboratory programme (OPAL).
- These diverse approaches have value at the scale and for the purpose for which they have been developed and hence any new Government strategy should be developed and delivered as a partnership between these existing stakeholders: government agencies, the UK scientific community, land owners-managers and NGOs.
- We recommend that any monitoring scheme (at whatever scale or for whatever purpose) should use carefully selected standardised methods and a carefully designed sampling scheme (including consideration of scale and replicability). Such a scheme could then be enhanced through the integration of citizen science.

What are the benefits that healthy soils can provide to society?

- Lists of critical soil functions vary slightly, but Newcastle University would stress:
  - Foundation for buildings, roads or pipelines
  - Production of agricultural, horticultural or forestry products
  - Regulation of water quantity and quality (e.g. nitrate, phosphate, pesticides, metals, microorganisms)
  - Regulation of atmospheric composition (e.g. nitrous oxide, methane, carbon dioxide)
  - Reservoir of biodiversity
  - Cycling of elements (e.g. C, N, P, S)
  - Waste disposal pathway – detoxification of pollutants
- Even taking a strictly utilitarian perspective, the value of these goods and services to society is significant. Approximately 80% of the total value of ecosystem services ($33.3 trillion per year in 1992, Constanza *et al.* 1997) can be linked to soil functions, and consequently human welfare can be directly linked to the efficient and effective functioning of soil. For many stakeholders, the ability of soils to carry out this essential and multi-functional role is what the concept of soil health describes.
- Recent research work at Newcastle University has highlighted the important role of soil in urban environments as a dynamic store of carbon to offset carbon emissions. Soil engineering approaches integrate building waste rich in calcium or magnesium. Soils with portlandite from concrete and calcite have been shown to absorb and stabilise 85 tonnes of CO_2 per hectare, removing even more carbon than growing woodlands on agricultural land.

What are the consequences of failing to protect soil health?

- These are largely the converse of the benefits discussed above.
- Recent work at Newcastle University is investigating how contaminated soil can be managed to prevent chronic disease. Contaminants from industry are often found bound to the soil and have the potential to cause disease in humans. Primary Biliary Cirrhosis (PBC) is a rare disease that affects the liver, especially in post-menopausal women. Ongoing work is investigating

the environmental triggers for PBC which are thought to be linked to low but persistent levels of contaminants in the soil.

- Another focus is the potentially damaging impact of climate change and management on peatland systems. The decomposition of peat removes one of the most efficient carbon sinks on the planet and has massive implications for feedbacks to the global climate system. Our work is focussed on developing early warning indicators of peatland change so that management approaches can be developed to minimise further catastrophic peatland loss.

What measures are already in place to ensure that good soil health is promoted? What further measures should the Government and other organisations consider?

Current measures

- Biodiversity, water and air are covered by substantial European legislation, transposed into English law. We urgently need a similar framework for soils. This would help secure the required commitment to protect and improve the health of our soils.
- A strategy for soil protection in England ‘Safeguarding our soils’ was developed (Defra, 2009) and was maintained as a key commitment in the Natural Environment White Paper, ‘The Natural Choice’ (Defra, 2011), with research focused on exploring how soil degradation affects a soil’s ability to support vital ecosystem services. ‘The Natural Choice’ set a goal that by 2030 all soils in England should be managed sustainably and degradation threats tackled successfully, in order to improve the quality of soils and to safeguard their ability to provide essential ecosystem services and functions for future generations (Defra, 2011). We consider that ‘The Natural Choice’ continues to provide a sensible basis for developing an updated strategy for soil health.
- The foresty and construction sectors have developed best practice guidance to minimise impacts on soil and loss of soil to watercourses during operations.
- In agriculture, the compliance requirements to maintain soil in ‘Good Agricultural and Environmental Condition’ set standards for soil management. Agronomists are required to have basic soil science understanding (FACTS/ BASIS accreditation) and there are a number of initiatives underway to develop a soil health module for these schemes. There are also a range of voluntary initiatives in agriculture (often in partnerships with NDPBs such as Natural England) that incorporate some consideration of soil function e.g. Catchment Sensitive Farming.

Future measures.

- The links between soil properties, processes, management practices and key soil functions need to be understood and explicitly incorporated into the models used to describe and manage environmental impacts.
- There is a role for the better incorporation of soil information, and particularly the emerging information on managing risks to soil function into spatial planning. We can identify situations where maintaining one soil function will be incompatible with another, and a compromise or a decision on priorities will be required. Hence there is a key role for Local Planning

Authorities in discussions on the development of a strategy for soil health and its protection.

- For many soils and farming systems already, we can identify “best practice” management approaches that minimise impacts on soil health, particularly for productivity and direct impacts on air and water quality. For example, major impacts on and off-site on soil health often can be linked to particular crops / soil type combinations e.g. maize, late harvested vegetables. This can be used to refine guidance on best (or least worst) management approaches and policy frameworks supporting them in order to optimise the delivery of all ecosystem services in the landscape.
- Whilst the development of frameworks for monitoring soil heath at national scale are a laudable aim, which should not be overlooked, Newcastle University would highlight that, given the diversity of land uses, soils and systems, provision of information, guidance and education is most likely to deliver benefit in terms of practical initiatives to maintain and improve soil health in the short to medium term (5-15 years).

What role (if any) should soil health play in the Government’s upcoming 25 year plan for the natural environment?

- It is essential that soil health is explicitly recognised and is a central element in the 25 year plan for the Natural Environment. Maintaining effective soil function is critical for the delivery of almost all the wider biodiversity and landscape benefits that the plan will identify.
- However, it is equally critical that with reference to soil health (and other areas) there is recognition and alignment of the plan for the natural environment with that for food and farming and with the Planning Policy Frameworks.

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January 2016

Written evidence submitted by Dr Tancredi Caruso, Institute for Global Food Security, Queen's University Belfast

The Institute for Global Food Security (IGFS) is one of the four Queen's University Belfast flagship Global Research Institute. REF 2014 ranked IGFS number one for research intensity in the UK for agriculture and veterinary science. One of the key research foci of IGFS is plant and soil.

Soil is tremendously threatened by human activity and global change. Soil health means that soil can deliver fundamental ecosystem level services such as provision of clean water, physical and biochemical support to grow food, and support for all the biodiversity we rely on.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

Soil health can be measured through a range of indicators. In the past, these indicators have typically focused on physical and chemical properties of soil such as carbon, nitrogen and pH. There is now overwhelming evidence that the future generations of soil health metrics should be multivariate with a focus on biological properties. Soil is in fact a biological reactor and a phenomenal reservoir of biodiversity, which is ultimately responsible for all soil functions. For example, the bioavailability of nutrients and pollutants also and critically depends on the biotic interactions happening at the plant-root interface and not just on soil chemistry. These interactions happen, in the first instance, at very local scales but eventually scale up to the landscape. Indicators of soil health should then account for the multiple scales at which soil processes occur. Soil biota can also be harnessed to change soil health as desired. Mycorrhizal fungi, which play a pivotal role in plant soil interactions, are a perfect example of a group of organisms for which there is already experience in terms of manipulating soil biota to build fertility and there are currently funded research programmes working in this direction. The take-home message is that soil biota must become a central point of concern for the future strategy of soil health monitoring. We have mentioned spatial scales, which range from the single plant soil interface to the entire landscape. Explicit reference to temporal scales is also essential here. Plants and soil interact at scales ranging from minutes to millennia. Soil health assessment programmes cannot deal with this whole range of scales but should certainly have a component of seasonal fluctuations plus a decade perspective. Seasonal fluctuations are essential to global change dynamics, given the increasing unpredictability of disastrous weather events, which are putting usual soil cycles at risks. Decade perspectives are necessary for longer term plans, especially important for the depletion on P and N. Again, soil biota plays a pivotal role because the life cycle of organisms is seasonally regulated while soil biota activity ultimately determines how plants can access P and N. It is now clear that we will be able to resolve crisis such as the P-crisis by monitoring and protecting the biological mechanisms through which plants and crops access P.

A valuable outcome of a successful monitoring programme of soil health should be the provision of digitized soil maps that include explicit biological information. Some critical areas should be covered by maps updated at regular intervals of time, and the spatial and temporal scale of the maps should match the scales at which soil management strategies are implemented.

What are the benefits that healthy soils can provide to society?

There is a broad range of direct and indirect benefits that healthy soil provide to society but we believe the most important are:

i) Food security, to be understood both in terms of quantity and quality. Quantity because soil is the basis to produce food and only the protection of soil will allow the delivery of enough food for an increasingly growing population. Quality because healthy soil improves nutrient efficiency. Good examples of that are the cases of iodine and selenium deficiency.

ii) Food safety, which is part of security but specifically refers to issues such as contamination and pollution. A good example is Arsenic in rice, which is a global issue.

iii) Clean water. Soil is part of the Earth Critical Zone being deeper than the organic layers usually considered in this context. Peatland areas in the UK are a perfect example of the key role of soil for the water cycle.

iv) Support of aboveground life via the ecological interactions that link soil biota to plants.

v) Global change dynamics. Soil is the major active pool of organic C and humans are running the risk to turn soil into a source of C to the atmosphere. This is a major point of concern for UK soils.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The consequences of failing to protect soil health are easily understandable in terms of the five key benefits soils provide to us and also have clear economical implications if we consider that, for example, UK figures in terms of annual income or loss directly related to soil management range from £1 to £5 billion. Specifically, the failure could lead to

i) Inability to provide the population with right amount and quality of food, especially in terms of nutrient efficiency. Locally, this will also determine a failure to meet future global market demands.
ii) Unsafe food, mostly because of environmental contamination (PAHs, metals) not buffered by functional soils.
iii) Significant issues with supplying water at acceptable health standards. In some cases, significant issues with supplying water at all.
iv) Degraded aboveground biodiversity
v) Unpredictable global change dynamics.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?
The best example of measures that are relevant to soil health is CAP, that directly determines the management of agricultural land but only very indirectly refers to soil. It is a global problem not just a UK one: soil is not formally recognised as a key element of land management strategies. In the UK there are policy documents that have made clear the importance of soil in this context but the implementation of the policies is lagging behind. The nodal point is soil biota. Future policy documents and management must recognise that soil has an ecosystem level complexity and soil biodiversity is central to that complexity. The key questions to ask when a management policy is to be implemented should be: how is this action going to affect soil biota and how these effects will feedback to the aboveground system?

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?
Food security, clean water, landscape protection (e.g., floods) and global change dynamics are part of long-term governmental plans for the environment. Strong scientific evidence demonstrates that soil is central to the future dynamics of all these key factors while soil has been underappreciated for a long time. The government should therefore have a clear long-term plan for supporting the science that underpins our understanding of soil dynamics and translating this science into policies and practices.

January 2016

Written evidence submitted by James Warne, Soil First Farming

How could soil health best be measured and monitored?
Soil physical health can be assessed and monitored in the field by practitioners with suitable knowledge and experience using simple equipment and techniques.

Soil chemical & micro-biological health can be measured by taking representative samples to a laboratory which is leading to confusion. However there are now many different assays and soil test 'suites' on offer to the farmer. Soil macro-biological health maybe assessed in the field.

How could the Government develop a strategy for tracking soil health?
By engaging with current practitioners and advisers in discussions along with researchers, scientists etc. In our opinion mass change will not come easily. There is considerable resistance to change within the farming community, especially enforced change. At present there is a small but dedicated number of farmers across the country who are experimenting and developing systems upon their farms which put soil health at the heart of their business. But there is also a similar or greater number of farmers who are also trying to change but for differing reasons such as trying to reduce cost.

The government therefore has to encourage and motivate people along the transition from a situation of high input, intensive, segregated agriculture to a more targeted input but still intensive but more integrated approach. This may involve encouraging the return of livestock to many areas. There may also be considerable resistance to change from the agricultural service sectors who may view such ideas with considerable skepticism. But to re-iterate there are many farmers in all areas of the UK who are enabling positive change to the state of their soils

What are the benefits that healthy soils can provide to society?
It is our belief a healthy soil may contribute many benefits to society. Many of these benefits maybe considered to be anecdotal, but we at Soil First Farming see many of these benefits on the farms we advise upon.

On a local level and national level, improved soil health may contribute;

- Benefits to water quality
- Reduced diffuse pollution
- Improved health in the population
- Reduced fertiliser inputs
- Reduced run-off
- Increased infiltration rates
- Reduced flooding

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

- Continued soil loss

- Ever increasing inputs (fertilisers, pesticides diesel & steel) to maintain yield
- Increased diffuse pollution
- Ever greater threat to biodiversity
- Potential for increased health problems within the population

What measures are currently in place to ensure that good soil health is promoted? Very little. Schemes such as Higher Level Stewardship and the more recent Countryside Stewardship try to promote better on-farm soil management (scheme options such as SW3 - Over winter cover crops) but in my experience uptake is minimal. Also the scheme does not try to address soil management holistically, but rather minor soil issues in isolation.

Thankfully the totally ineffective 'Soil Protection Review' has been dropped from the new Basic Payment Scheme. I don't believe this contributed any single benefit to soil management. Forcing farmers to complete a paper form which involved identifying possible physical soil issues and then suggesting mechanical remedies simply addresses the symptom, not the cause.

The 'Greening Rules' within the BPS may lead, in some circumstances, to greater crop diversity within a rotation and this may lead to some minor improvements in soil quality. But again this is one measure in isolation when the situation really needs to be considered in its entirety. Soils will benefit from greater diversity with the rotation and continuous soil cover combined with much reduced tillage.

And what further measures should the Government and other organizations consider in order to secure soil health?

Consider adopting the basic principles of Conservation Agriculture, they are;

- Minimal soil disturbance
- Continuous soil cover
- Diverse crop rotation

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

A University of Sheffield report (published 2014) highlighted that soil in urban areas is considerably 'healthier' than its rural farmed counterpart. The Sheffield report also suggested that if nothing changes then there may only be 100 more harvests available before our topsoil is totally degraded.

Soil health should be given a very high regard within the Government's 25 year plan. However once within the plan, action needs to be taken to incentivise farmers, and therein lies the problem. If the government were to legislate or force change (through BPS rules for instance) then resistance is met and many will be resentful about this.

Far better will be to allow farmer led change through organisations such as BASE-UK.   This is a farmer operated and financed organisation (open to all) which exists to allow the transfer of knowledge between like-minded farmers.

January 2016

Written evidence submitted by the National Trust

Executive summary

- Soil provides vital 'supporting' and 'regulating' ecosystem services, whose level of importance for agricultural production and wider society is not sufficiently recognised.
- Despite the importance of good soil health, it is being lost faster than it is being created.
- Achieving the necessary step-change in management practices will involve more people understanding the threats to soils, knowing what constitutes land at high risk of soil damage or loss and understanding how different land uses and practices can raise or lower that risk. This should lead to more people reviewing whether their land use is appropriate in light of its characteristics and capability.
- Supporting this type of change will require better, more readily available data and practical decision making tools. We also need to re-double efforts to find mechanisms that incentivise appropriate management (e.g. new markets for ecosystem services) and to be far less tolerant of agronomic or other justifications that lead to soil damage without mitigating action.
- We should use the opportunity afforded by the Government's two 25 year plans for Food and Farming and for the Natural Environment to develop a sustainable and integrated approach to soil management. We have ideas to share and are interested in working in partnership with others to build a smarter approach.

1 Introduction

1.1 We are pleased that the Committee has chosen to examine the issue of soil health and the role that Government and other organisations should have in improving the current situation.

1.2 Comments in this response focus on what we see as the long term threats that make improving soil health a priority, our experience (of soil compaction, soil erosion and loss of soil organic matter and nutrients) and our developing ideas about what can be done differently in order to improve soil health.

1.3 The National Trust exists to look after special places for ever, for everyone. We are Europe's largest single conservation charity with 4.5 million members and the UK's largest private landowner and farmer with some 247,000 hectares of land and 2,000 agricultural tenancies. We are committed to working across our estate and beyond our boundaries to develop innovative ways of managing land on a scale which are good for farmers, good for the economy and good for the environment.

1.4 Our new strategy recognises the many benefits that nature provides as well as threats it faces. Like most farmers, we and our tenants use our land to produce food and make a living, but business-as-usual is not an option. We recognise the need to feed a growing population but agricultural soil, on which so much of the UK's farm productivity depends, is being lost faster than it is being created[1]. We are also seeing growing problems such as poor soil structure and low levels of

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[1] Verheijen et al., 2009. F.G.A. Verheijen, R.J.A. Jones, R.J. Rickson, C.J. Smith **Tolerable versus actual soil erosion rates in Europe** Earth-Science Reviews, 94 (1–4) (2009), pp. 23–38.

soil organic carbon and soil nutrients when compared to their counterpoints in natural ecosystems[2]. To achieve our vision for the natural environment, by which we mean land that it is healthy, beautiful, rich in nature and in culture, enjoyed and productive, we all need to improve the health of our soils. This will require changing how land management decisions are made and we are committed to working with our tenants, other stakeholders and the Government to achieve this.

1.5 While recognising efforts made to date, we believe a renewed effort is needed, from Government and from a wide range of organisations and stakeholders, including ourselves. In particular, there is an important role for the forthcoming Government's two 25 year plans for Food and Farming and for the Natural Environment to highlight the supporting and regulating ecosystems services delivered by soils and their essential contribution to provisioning services such as food production. Soil should be an integrating theme, and measures included to secure its long-term health and track progress towards that end.

2 How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

2.1 The measurement of soil health needs to be at a sufficient resolution to be useful without incurring prohibitive costs. Visual monitoring of soil surface condition can detect obvious issues. Stable soils are characterised by factors including an absence of erosion, compaction and run-off whilst poor soil condition can be indicated by livestock poaching, waterlogging caused by compaction, traffic damage, and soil wash from surface erosion – rill, sheet, gullying and wind erosion. Remote sensing could have a role to play in assessing some of these factors. This should be in addition to encouraging farmers to assess and then monitor the health of their own soils, as this is likely to be more effective at increasing understanding and providing the motivation for change.

2.2 Biological assessment (most simply earthworm biomass), chemical analyses (nutrients and organic carbon) and physical examination of the soil profile are all possible at field level using soil samples. Repeating the sampling approach adopted by Countryside Survey with soil samples taken from randomly assigned 1km squares, could have the benefit of contributing new information to an existing series of data.

2.3 Developing a successful strategy for tracking soil health is likely to require collaboration by a range of stakeholders including academics, applied soil scientists, biologists, agronomists, farmers, remote sensing specialists and soil laboratory specialists. The role for Government is to provide the mandate for this work and could also set standards for the gathering and sharing of resulting data.

3 What are the benefits that healthy soils can provide society?

3.1 Soil, the processes that drive its formation, the cycling of nutrients and the fixation of carbon by soil biota are interrelated and usually considered to be 'supporting' services, underpinning the delivery of all other ecosystem services. According to the UK National Ecosystem Assessment, 'supporting' services

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[2] Agricultural soils contain 25% to 75% less SOC than their counterparts in undisturbed or natural ecosystems

Lal, R. 2004a. **Soil carbon sequestration impacts on global climate change and food security**. Science 204: 1623-1627.

provide the basic infrastructure of life, but differ from other ecosystem services in that their impacts on human well-being are indirect and mostly long-term in nature. Soils also deliver important ‘regulating’ services, e.g. regulating climate by locking up carbon and regulating the transfer of water, nutrients and pollutants from land into river systems.

3.2 Soil provides a medium for a wide variety of soil biota – the importance of which is still imperfectly understood, is an essential base of most habitat types and land uses, including farming and forestry; and is a repository of zoological and botanical remains and of archaeological artefacts.

4 What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

4.1 There are three main soil issues that give rise to negative consequences for society:

- **Soil compaction** – results in damage to soil structure which leads to reduced performance as a growing medium and, due to a reduced capacity to absorb water, can lead to surface water run-off and surface water flooding. As the ability of soil to regulate the movement of water is reduced, so water enters river systems more quickly than would otherwise be the case. Depending on catchment hydrology, this may contribute to peak flows occurring quickly after a rainfall event, and the risk of flooding. Archaeological deposits and artefacts are also at risk of damage from soil compaction and from measures taken to deal with poor soil structure (e.g. archaeological deposits in subsoil horizons may be damaged or destroyed by agricultural practices such as deep ploughing or subsoiling and artefacts may be removed from their historic context).

- **Soil erosion** – from exposure to wind and water, resulting in losses of the soil resource from fields and deposition elsewhere. This causes public nuisance on highways and paths, and when deposited into drains and watercourses, it can, over time, exacerbate the tendency of watercourses to flood and negatively affect water quality, smother fish breeding grounds and reduce biological diversity in riverbed gravels.

- **Loss of soil organic matter and other soil biota** – results in a reduced capacity to capture, cycle and store nutrients and carbon, with the consequence that soil becomes a contributor to carbon emissions and crop production requires increased (often artificial) nutrient inputs.

4.2 Machinery and techniques have made it possible and profitable to convert what would once have been marginal into more productive agricultural land, but some of this is proving vulnerable to the abovementioned issues. Resolving this may require a re-evaluation of what is an appropriate crop type given the land’s characteristics. For example, in Northern Ireland, at our Mount Stewart property, we are currently phasing out potato production on fields at high risk of soil damage, replacing this with cereals and ley grassland. At our Stackpole Estate in Wales, recent management changes have included the introduction of legume-rich ley grasslands allied to rotational grazing, in order to stabilise fragile soils.

4.3 We face the issues that confront many farmers, whereby systems of farm management that are highly (or at least sufficiently) productive, in terms of crop yields achieved and profits generated, can also have the effect of locking in practices that are costly in terms of inputs (fertilisers, agrochemicals and amount of tillage) and damaging to soil structure, soil biota and the ability of the soil to store carbon. The experience from our Wimpole estate in Cambridgeshire is that it is possible to make significant changes, to better protect the land and secure the value of the ecosystem services it delivers, whilst maintaining profitability. Such an approach does require a considerable commitment from the farm manager and staff, as well as access to good data and advisory support.

4.4 We have properties where soil lost from fields has accumulated as silt in our lakes, reservoirs and rivers, leading to gradual reductions in open water and changes to river flows, to their chemical composition and ecological quality. In addition to threatening their ecology, and in some cases amenity value, restoring their condition (e.g. through dredging) can be both prohibitively expensive and create new challenges, such as finding appropriate places to safely dispose of the resulting material.

4.5 Peat (especially upland deep peat) is another soil whose health determines whether it is a carbon sink or store, and where practices (e.g. drainage or burning) designed to increase its productivity for particular enterprises, can have unintended consequences. For example, eroding peat soils will lead to sediment in watercourses and discolouration, the latter requiring costly treatment before being used as drinking water. The United Utilities-led SCaMP projects are beginning to demonstrate the multiple benefits that can be achieved from management designed to restore the hydrological function of peat soils. Through our own projects, such as the High Peak Moors Vision, we are also restoring the condition of upland peat.

4.6 Soil issues can arise from recreational uses as well as from farming operations and commercial developments. Our ranger teams put considerable time and resource into ensuring that countryside paths are well maintained and suitable for the volume and type of use they experience. Initiatives such as the Lake District's 'Fix the Fells' partnership has repaired paths in order to prevent damage across fragile upland soils and enable continued visitor enjoyment.

5 What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

5.1 The soil protection standards within the list of requirements for Good Agricultural and Environmental Condition (GAEC), specifically GAEC 4 (minimum soil cover), GAEC 5 (minimising soil erosion) and GAEC 6 (maintaining organic matter in soil), combined with GAEC 1 (2m buffer strips along watercourses) and the accompanying guidance note, offer minimal protection. For example, the acceptable agronomic reasons for not complying with GAEC 4 are broadly cast. The intention to reduce the number of Common Agricultural Policy (CAP) inspections may further limit their effectiveness. Advisory support can support change and advice is available to farmers and land managers who recognise the need to take action to manage their soil, from Government (e.g. via Catchment Sensitive Farming) from industry (e.g. Campaign for the Farmed Environment, LEAF, Soil Association) and from research institutions (e.g. Cranfield University).

5.2 Despite some successes in minimising the effects of normal farming operations, this has not been on a scale sufficient to tackle all the issues noted above. The fact that this situation has consequences over the medium to long term (e.g. we may have as little as 60 years of topsoil left[3]) strongly suggests that further action is needed.

5.3 We believe that more work is needed in the following areas:

- effective communication of the conservation challenges facing our soils, what can be done to improve the situation and the consequences for farming and for society of not tackling the issues. This will require publicly accessible data (e.g. on pesticide residues in soil and the effects on biota and water quality) and timely advice so that new knowledge from research can be translated quickly into results in the field;

- much greater consideration and profile given to what constitutes land at high risk of soil damage or loss and to the high risk of problems arising from certain crops and practices; this understanding leading to more assessments of whether the capability of the land is appropriate for the enterprises being pursued; and

- re-doubling efforts to find mechanisms that incentivise appropriate soil management (e.g. finding new markets for ecosystem services) and being prepared to be less tolerant of agronomic or other justifications that lead to soil damage without mitigating action.

5.4 The necessary step-change in soil management must involve more people reviewing whether their land use, on a field-basis and at the enterprise-level, is appropriate in light of the characteristics and capability of that land, the knowledge, skills and interests of those managing the land, and what we understand about likely effects on land of a changing climate. In particular, we do need to move to a situation where crops that present a high risk of damage to soils are not grown in places where soils are vulnerable (e.g. maize should only be grown in low risk locations). Soils at high risk of loss, such as thin soils over limestone geology, also merit greater conservation effort.

5.5 The National Trust is about to trial a new tool, *Land Choices*, to help us improve land condition in line with our strategic ambitions for the natural environment. This will provide a structured way to pursue our vision for land, to gather information about its current condition and potential, to review options and develop recommendations for future management that are in keeping with the land's capability. We would be happy to share our experiences of the development and use of this tool.

6 What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

6.1 The conservation and wise use of soil must be common to *both* 25-year plans. Those areas where Government support for soil health, via inclusion in the plans, would have greatest effect include:

- encouraging bold thinking and innovation that helps realise new economic solutions to incentivise better protection and management of soil health;

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[3] Comment attributed to Maria-Helena Semedo of the FAO at a World Soil Day Forum, December 2014: http://www.scientificamerican.com/article/only-60-years-of-farming-left-if-soil-degradation-continues/

- supporting practical testing, scaling-up and dissemination of promising new approaches – including help to overcoming existing barriers; and

- supporting the gathering of data and information and the carrying out of research, to build understanding and track progress.

The Government should also examine, as part of the 25 year plan for Food and Farming, whether CAP simplification and other deregulatory pressures are pushing us in the wrong direction on soil. We believe that the approach to CAP under that plan must adopt the principles of the 25 year plan for the Natural Environment, especially as the Natural Capital Committee recommended a focus should be made on improving the environmental performance of farming.

6.2 The National Trust is approaching both plans on the basis of our own strategy, which aligns well with the Government's own environmental ambitions. We know that to achieve this will require a change in how land management decisions are made. To play our part, we will:

- Explore how our approach to Land Condition Assessment, Land Choices, citizen-science initiatives and natural capital accounting can help build understanding;

- Use our estate to test new approaches to working at landscape scale and develop market-based solutions to support sustainable land management;

- Support a smart re-deployment of existing public funds and removal of barriers to fast-track and scale-up these new approaches; and

- Investigate new and innovative ways we can promote nature to and engage with our 4.5 million members and the public in order to build understanding and support for the vital role that nature (including soil) plays.

6.3 Finding ways to better incentivise more sustainable practices through ecosystem services and natural capital approaches is where the Government will have a strong interest and where we believe we have something to contribute. Given the supporting and regulating functions of soil, such approaches must include ways of improving standards of soil management. For example, we are supportive of plans to establish the new Natural Capital Committee and are keen to continue working closely with it, building on our Wimpole natural capital accounting pilot (covering soil).

January 2016

Written evidence submitted by Wardell Armstrong LLP

About us

We are environmental consultants working for Wardell Armstrong LLP, international environmental and engineering consultancy with headquarters in Stoke on Trent and offices throughout the UK, from Edinburgh to Truro; we are based in Newcastle upon Tyne. Our main areas of expertise are environmental management and impact assessment, and within it, soils, agricultural land, hydrology, and peatlands. We would like to submit the evidence because we are passionate about soil and we think that soil health is one of the foundations of healthy and prosperous society, but it has been often overlooked.

EXECUTIVE SUMMARY

The term ‘soil health’ or ‘quality’ may have many definitions so it is important that it is defined first. The definition must consider what ecosystem services or benefits soil provides. The indicators chosen to measure soil health will also depend on the type of land use and habitat supported. There is a multitude of properties that can be used to assess soil health, such as structure, organic matter content and soil microbial biomass. Soil health could also be assessed through proxies, such as plant health. There has been numerous projects and research papers published on soil monitoring which could be used to design and implement UK-wide regular monitoring programme effectively and efficiently.

Healthy soils are foundation of ecosystems which provide multiple benefits to humans, such as food, clean air and water, flood regulation, and nutrient cycling. Those benefits are directly related to the constituents of human well-being: security, basic material for good life, health, and good social relations, which underpin our freedom of choice and action. The consequence of failing to protect soil health is loss of those important soil functions. Agricultural land in the UK is currently under high development pressure. To ensure that where developments need to be located on agricultural land poorer quality land is used, local authorities should be required to carry out reconnaissance agricultural land classification surveys in order to be able to compare potential development sites to be included in local plans. Currently data available to councils is incomplete and they have to rely on provisional, small scale, maps which do not allow for such comparisons to be made.

As with question one, this depends on the land use. Most legal or policy measures do not explicitly address soils, although soil health protection is to some extent included in measures associated with the application of waste to land; protection of waterbodies and wildlife habitats; and contaminated land regulations. Effects of developments on soil and soil health should be better addressed and explicitly promoted within the planning policy.

Soil health should be included in the Government's upcoming 25 year plan for the natural environment. The government should actively seek involvement of scientific institutions and other stakeholders to effectively protect soils through the plan.

1 HOW COULD SOIL HEALTH BEST BE MEASURED AND MONITORED? HOW COULD THE GOVERNMENT DEVELOP A STRATEGY FOR TRACKING SOIL HEALTH?

1.1.1 We agree with another consultee, Dr Oliver Knox, that to measure and monitor soil health, first this term needs to be properly defined. Also, as another consultee, Prof. Mark Hodson identifies, this definition will depend on what services provided by the soil are being considered. We would like to add that the definition of soil health and therefore the set of indicators used to measure it, will depend on factors such as land use, habitat and soil type, to name but a few. For example a very strongly acidic soil pH 4 would not be considered healthy for soils in agricultural use, as it would substantially reduce yields and the range of crops that can be grown; however a soil pH 3.5 is normal for a sphagnum moss peat, which plays an important role in carbon storage and regulation. Therefore, while some indicators of soil health may have the same desired ranges across a variety of different soil types and land uses, most will need to be interpreted differently depending on the situation.

1.1.2 The term ‘soil health’ is often used interchangeably with the term ‘soil quality’. Soil quality can be defined as "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, sustaining biological productivity, to promote the quality of air and water environment, and to maintain plant, animal and human health" (Doran & Safley, 1997). Soil quality can be assessed using a multitude of abiotic and biotic properties and processes, including, but not limited to, pH, cation exchange capacity, soil organic matter content, macro- and micro-nutrients concentrations, soil respiration, nitrogen transformations and soil microbial biomass.

1.1.3 In order to determine and track a soil's quality/health, monitoring of multiple (carefully chosen) soil quality parameters is required over a period of time. This has been comprehensively covered in Dr Oliver Knox’s response to the inquiry, so is not repeated here.

1.1.4 An alternative to the multi-parameter assessment of soil quality, is the use of proxies such as plant health monitoring, organic matter content (as perfectly explained by another consultee, Prof. Mark Kibblewhite), as well as the visual assessment of key parameters such as root abundance/development, presence of earthworms or presence of waterlogging. Although the use of proxies means that specific information cannot easily be retrieved, these could still be used to determine how healthy a soil is.

1.1.5 A new government strategy to track (and improve) soil health should account for the use of specific soil physical/chemical and biological parameters as suggested above. As this will enable the use of pre-defined values to determine soil health. These parameters can also be complemented by the use of proxies as demonstrated in the GREATsoils 'Which tests to use to assess the health of your soil?' report (Organic Research Centre, 2015)

1.1.6 It may seem a daunting and prohibitively expensive task to implement UK-wide soil monitoring programme, however there are readily available, well-researched, solutions to this problem even on the European scale. The monitoring could be implemented by using a tiered approach, where the monitoring network density varies depending on, for example the indicator type, as not every soil property has to be monitored with the same density and intensity (Kibblewhite *et al*., 2008). Given the UK's strong history of soil science and still strong research capacity, there clearly are no insurmountable obstacles to the effective implementation of a soil health monitoring programme.

2 WHAT ARE THE BENEFITS THAT HEALTHY SOILS CAN PROVIDE TO SOCIETY?

2.1.1 Soil health is intrinsically linked to the contribution of soils to ecosystem services: provisioning, supporting, regulating and cultural. Ecosystem services are benefits and advantages humans derive from ecosystems. Ecosystem services link in multiple ways to the constituents of well-being: security, basic material for good life, health, and good social relations, which in turn are the foundation of our freedom of choice and action. Security is provided by soils through provisioning of food, fibre, regulation of climate, flood, disease, and water purification, among others. Soils have a major role in providing basic material for good life, such as sufficient nutritious food by their role in supporting primary production and nutrient cycling, climate regulation and provisioning. Healthy soils contribute to human health by water and climate regulation, provision of healthy food, and healthy environments for recreation. Finally soils contribute to good social relations by being a foundation for cultural ecosystem services, which can be further categorised as aesthetic, spiritual, educational and recreational benefits.

3 WHAT ARE THE CONSEQUENCES OF FAILING TO PROTECT SOIL HEALTH FOR THE ENVIRONMENT, PUBLIC HEALTH, FOOD SECURITY, AND OTHER AREAS?

3.1.1 The main consequence is loss of the essential benefits and advantages the healthy soils provide, as summarised in the answer to question 2.

3.1.2 One of the threats to soils is built development, which reduces soil function to a mere support for buildings. We would like to notice that currently there is no coherent UK or local policy and, what's more important, a long-term strategy that would adequately protect healthy soils from irreversible developments. The safeguards in this respect are weak and consideration of alternative sites to avoid better quality agricultural land, often insufficient. For example councils often rely on incomplete data when preparing local development plans, e.g. they use 1:250,000 provisional agricultural land classification maps, which give little information for a meaningful comparison between the sites. A new campaign of surveys on land under high development pressure, similar to one carried in the 90's by ADAS, is needed to inform local development strategies. Without the knowledge about the extent of 'best and most versatile' (BMV) agricultural land, requirement of National Planning Policy Framework to "seek to use areas of poorer quality land in preference to that of a higher quality" cannot be met. This is not soil health issue per se, but loss of most of the ecosystem functions soil provides due to surface sealing under built developments is the most serious and irreversible form of soil degradation.

3.1.3 Additionally, the need to balance both the need to produce food for an ever expanding population and the need to maintain land for amenity/conservation value as well as non-food crops, may become more prominent if soil health degrades dramatically. For example a reduction in areas able to provide a substantial crop yield for food production may lead to non-food use areas being converted to arable crop production, including non-designated areas of high conservation value.

4 WHAT MEASURES ARE CURRENTLY IN PLACE TO ENSURE THAT GOOD SOIL HEALTH IS PROMOTED? AND WHAT FURTHER MEASURES SHOULD THE GOVERNMENT AND OTHER ORGANISATIONS CONSIDER IN ORDER TO SECURE SOIL HEALTH?

4.1.1 As with question one, this depends on the land use. Most legal or policy measures do not explicitly address soils, although soil health protection is to some extent included in measures associated with the application of waste to land; protection of waterbodies and wildlife habitats; and contaminated land regulations.

4.1.2 In the context of developments where soils are temporarily (e.g. quarries) or permanently (e.g. housing) displaced, soil health is protected to a varying degree, mostly through implementation of best practice industry guidance e.g. Defra Guidance for Successful Reclamation of Mineral and Waste Sites (2004) and Construction Code of

Practice for the Sustainable use of Soils on Construction Sites (2009). However, again, there are no legally binding requirements for the promotion of soil health in such situations. The protection of soils is largely based on other environmental and social considerations, such as the need to restore a quarry site to acceptable afteruse or the need to provide healthy and pleasant public green spaces within a residential estate.

4.1.3 Within the planning system, consideration of soil protection is solely focussed on agricultural land use, with the exception of specifically protected habitats or designated sites. There are no requirements for the promotion and maximisation of soil health within urban or semi-rural environments e.g. there is no consideration of measures to minimise the area of sealed soil and enhance carbon sequestration. We believe that there is a need for explicit, legally binding measures to promote soil health (for example by including requirements for such considerations to be included within environmental impact assessment documents). Especially as there are readily available, cost-effective solutions that could significantly improve soil health in those contexts. Since soils are crucial in the provision of ecosystem services, the promotion of ecosystem services approach in strategic and local planning, as well as environmental impact assessment, could potentially lead to soil loss and soil health being better addressed.

5 WHAT ROLE (IF ANY) SHOULD SOIL HEALTH PLAY IN THE GOVERNMENT'S UPCOMING 25 YEAR PLAN FOR THE NATURAL ENVIRONMENT?

5.1.1 Soil health should be included in the 25 year plan, as good soil quality underpins a successful natural and anthropogenic environment which is the basis for most benefits derived from ecosystems. The role of both agricultural and non-agricultural land in maintaining and improving soil health should be made prominent, particularly as non-agricultural soils in semi-natural or natural ecosystems can easily function in supporting these ecosystems. Currently the emphasis is on the agricultural potential of soils, while other functions are neglected or only partially considered. To effectively protect soils in the plan, implement it, and achieve its goals, the Government should seek involvement of scientific societies (e.g. British Society of Soil Science), universities, research institutes, and NGOs.

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January 2016

Written evidence submitted by the White Rose Sustainable Agriculture Consortium of the Universities of Leeds, Sheffield and York

Our interdisciplinary consortium is running field and laboratory experiments funded by the BBSRC GFS-SARISA programme (Global- Food Security, Soil and Rhizosphere Interactions for Sustainable Agri-ecosystems), and NERC (Soil Security Programme) to investigate ways of improving the sustainability of UK agriculture. Our major focus is on developing crops and management systems that restore soil quality and functioning in arable fields and grasslands, using Leeds University Farm, a commercially run, conventional arable farm as a test-bed for sustainable soil and crop management.

How could soil health best be measured and monitored?

Main recommendation: There is a critical need to establish and maintain a comprehensive 5-yearly national assessment of topsoil health measuring bulk density, soil organic carbon, earthworm species abundance and soil nutrient status. Subsoil measurements need to be made on at least a decadal frequency and include bulk density, structure assessment and soil organic carbon concentrations. Soil depth and soil losses to erosion or volume shrinkage through compaction also need to be monitored.

To provide such national assessments of soil health, and how it is changing over time under different land uses and management, and in response to climate change urgently requires the repeated collection of data from a very large number of representative sites across the UK at regular time intervals (typically every 5 years) using standardized methodologies. To achieve the high-spatial resolution data required to make meaningful assessments at the national scale necessitates the measuring of a targeted set of indicator variables that encompass the most important components of soil functioning. **These functions are crop production, carbon, nutrient and water storage, and hydrological services such as good drainage and recharge of groundwater with unpolluted water.**

The key components of soil health underpinning these functions, in order of importance include (**a**) nutrients and pH; (**b**) organic carbon content; (**c**) soil structure, (**d**) biological activities, and (**e**) chemical pollution- particularly in the context of urban soils and soils that have been exposed to heavy industries and mining activities etc. Soil texture (the proportion of particles that are sand, silt or clay) plays a major role in soil functioning but does not change over decadal time-spans so does not require routine monitoring. Soil texture, however, must be known to understand and interpret data on the other soil components.

Nutrients (N, P, K, and micronutrients) and pH are the most commonly measured soil variables on most farms as they are used to target fertilizer and lime application rates, and the costs of analysis are typically repaid by ensuring appropriate applications and reducing wastage and pollution. However, this data is not nationally managed and its full potential unrealized with respect to evaluation of soil health from field to region to the national scale. *In situ* sensing is developing at a fast pace, with wireless sensing supported at relatively low-cost, uploading data to local hubs for national use. Sensor costs are falling too, allowing for greater spatial coverage, with increasingly realistic prospects for cost-effective investment in an effective national-scale monitoring network for key nutrients and pH, potentially reducing or complementing soil testing by conventional sampling and analysis. Furthermore, in-field sensor technologies have the potential to provide real-time assessments of soil water and nutrient status to inform better management.

Organic carbon monitoring requires both the concentration of organic carbon (mass per unit mass of soil) and bulk density (mass of soil per unit volume) need to be determined in order to establish whether soil is maintaining, gaining or losing carbon. The accuracy of current national soil carbon inventory estimates are currently constrained by a lack of data and rely on assumptions, some of which, for example applied to urban areas, have proved to be highly inaccurate and to have systematically underestimated the true stocks (Edmondson *et al.,* 2012; *Scientific Reports* DOI:10.1038 /srep00963). The Countryside Survey has provided the most recent (2007) national data measuring soil organic matter stocks to 15 cm depth (using bulk density cores) from nearly 600 squares 1 Km from across the UK. But this sampling is insufficient in depth and in spatial replication to determine long-term changes in carbon stocks, much of which is present below 15 cm.

Whilst good yields can sometimes still occur on UK soils that have been intensively managed for many years and in which the organic matter content is far below that which is normally considered optimal (see for example the submission to this inquiry by Rothamstead Research in relation to recent yields at the Broadbalk experiment), it is important not to be misled into thinking that the loss of organic matter is inconsequential for yields or other soil functions. The exception does not prove the rule. In the UK average wheat yields have plateaued at about 7-8 tonnes per hectare for the past decade (Knight *et al.,* 2012, Home Grown Cereals Authority Report HGCA 502), and the breeders indicate that it is soil not genetics that now constrains yields in most cases. When there is sufficient rainfall at the right time, and nutrients can be added as demanded by the crop then we can grow good wheat crops on soils of sub-optimal organic matter content and get yields of 11-14 tonnes per hectare- but this is uncommon. The real problem lies in the fact that most years don't provide the optimal water supply at the right time, and many farmers now are constrained in the amounts of fertilizer they can add because of the Water Frame Work Directive and the need to prevent nitrate contamination of surface runoff and groundwater.

<u>The fertilizer company YARA suggest that an increase in arable soil organic matter by 1% of the soil mass would increase the water storage capacity of the soil by 187,000 litres per hectare or the equivalent of nearly 1.9 cm of rain.</u> The White Rose Sustainable Agriculture

Consortium has shown that arable farming on a typical conventional Yorkshire farm where wheat was grown for 60% of the time in land under continuous arable cultivation for more than 20 years has depleted soil organic matter from the 4% value found under adjacent woodland to 1.5% of the topsoil weight, resulting in a 33% decrease in water-holding capacity per unit mass of soil. This is one of many reasons why restoring soil organic matter in arable soils is so important. The recent flooding incidents highlight the fact that if we degrade the organic matter content of soils, their water storage capacity and rates of drainage (for example by depleting earthworm populations), the consequences extend beyond just the drought and flood susceptibility of crop yields- but have potentially devastating effects down-stream to property, livelihoods and the economy. Furthermore, flooding is often extremely damaging to soil resulting in erosion and losses of clays and organic matter (the physically light and buoyant fractions that are vital for soil water and nutrient storage and soil structure), and when eroded these components take decades to millennia to regenerate.

Structure has been degraded in many soils due to intensive tillage or livestock trampling causing reduction in soil pore space, impairing drainage and increasing physical resistance to root growth (penetrometer resistance). These effects are manifested in higher bulk density, lower water-holding capacity, reduced infiltration rates, and loss of water-stable macroaggregates >1mm diameter in which carbon and nutrients are stored. Loss of water and nutrient storage capacity has profound economic consequences with respect to the resilience of cropping systems to drought and waterlogging, nutrient and chemical losses to the wider environment- leading to water pollution, and soil erosion leading to silting up of watercourses, and flooding leading to property damage and threat to human health and safety. In arable soils loss of organic matter is a major factor in degradation of soil structure and loss of water and nutrient storage capacity. Bulk density, or the closely related variable air-filled pore space at field capacity (Griffiths *et al.,* 2015 *Soil Use and Management* **31** 491–503), are arguably the most useful single variables for measuring and monitoring soil structure over space and time. <u>Since bulk density is also required to determine soil organic carbon stocks there is a strong case for prioritizing its measurement in national soil health assessments.</u>

Biological activities present unique challenges for soil health monitoring due to the huge diversity of organisms and the spatial and temporal variability in their activities. DNA and RNA analysis tools allow characterisation of soil microbial communities but the quantities of data produced is overwhelming with respect to national monitoring, and as large numbers of microorganisms in soils are unculturable and of unknown function there is limited value in untargeted microbial community analyses. No single measure can capture or represent biological health of a soil, but there are some relatively simple bioindicators that are widely recognized to be associated with healthy soils with good functioning- amongst which **earthworms**, which are soil ecosystem engineers are arguably the best. Their functional roles are well established and farmers and gardeners alike know that soils with high earthworm numbers tend to be fertile, productive and rich in organic matter. Earthworms can account for over 90% of faunal biomass in permanent grassland. Their burrows create preferential flow pathways for surface drainage enhancing water infiltration rates- by over 60% in one study. Where earthworms have been experimentally removed from grassland, soil bulk density increased, soil organic carbon greatly decreased and soil water holding capacity and infiltration rates declined (Clements *et al.,* 1991 *Agric Ecosyst Environ* **36**:75-85)- all factors that lead to serious loss of soil functioning and increase risks of soil erosion and flooding. However, biological records for earthworm species in the UK is lamentably piecemeal. It is not possible to meaningfully assess the condition of our soils and in particular monitor whether they are changing without a far more substantial base-line dataset for such critical components as these.

How could the Government develop a strategy for tracking soil health?

Main recommendation: There is an urgent need to establish a national database of soil measurements referenced to exact locations and with sample dates, and to repeat these measurements every 5 years for topsoil and every decade for subsoil. The key measurements required are listed above (a-e). Management practices that maintain and improve soil health need to be implemented and the effects verified and rewarded. Practices that lead to soil degradation, and particularly those that lead to long-term soil loss or impaired functioning such as reduced organic matter content should be prevented, rigorously policed and strongly sanctioned against as the highest priority.

Better use of existing data: Currently there is a huge amount of soil analysis undertaken for farmers by commercial laboratories but this data is not then fed into national assessments of soil health. One commercial analyst, Lancrop laboratories, for example over the past 20 years have analysed over 1.6 million UK soil samples. Requiring and / or paying a contribution towards the submitting of data generated using standard protocols in accredited laboratories to a central data bank would be an extremely cost-effective way of capitalizing on existing efforts. This will need to be supplemented by additional nationally coordinated field sampling in areas where current sampling regimes are infrequent spatially and temporally, possibly subcontracted to commercial laboratories or by investing in developing a high-throughput cost efficient central facility run by a Research Council or government agency (e.g. British Geological Survey).

Changes in soil mass need to be measured. If soil is sampled from the surface but the soil is gradually eroding or shrinking due to compaction or oxidation of subsoil carbon then the loss of soil volume may go unnoticed and undetected until it is very substantial. Given that the time to form arable topsoil is hundreds to thousands of years per cm of soil substantial and very serious losses that will take many generations to be regenerated can easily occur in a single growing season. There is a critical need to install a network of permanent soil depth markers that can be used to accurately measure ongoing changes in soil depth. There is also a need to more closely monitor soil losses to rivers and to the sea. The so called '*silting up of the drains and rivers*' leading from the Somerset Levels, for example, represents loss of topsoil that needs to go back on the land not be washed into the Bristol Channel where it will be useless for farmers!

The critical importance of soil organic matter monitoring and management. We recommend the re-instatement of Soil Protection Reviews in the single farm payment system, including requiring organic matter concentrations and bulk density (to at least 50 cm depth) to be an essential part the assessment soil health in arable fields on a 5-yearly basis. A recent report by Lancrop laboratories indicates that over 70% of the samples they have analysed for organic matter content contain less than the optimal 4% value, and out of over 15,000 samples of arable and grassland soils the most frequent concentration of organic carbon in arable soils was 2.5%, and in grassland was 7.5%. They concluded in 2013 "over 50% of UK soils are lacking in organic matter"- in other words these soils have generally been managed in ways that have degraded their organic matter content and as a result this has compromised their functioning.

What are the benefits that healthy soils can provide to society?

Healthy soils provide multiple services and benefits directly and indirectly. They filter and store water, provide us with food, fibre and fuel, and support biodiverse ecosystems, increase resilience to flooding and drought, store carbon, immobilize and transform greenhouse gasses into more benign by-products, retain and degrade organic pollutants such as pesticides, provide structural underpinning to buildings infrastructure and resist erosion. Ultimately soils provide the essential life support system for humans. Over 90% of our food is dependent on soil for its production.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The supply of water and nutrients from soil to crops in an area of 15.6 million km^2 of arable land (approximately 7800 km^3 of topsoil to 0.5 m) globally is what now sustains 7.2 billion humans- and the whole of the global economy that runs from their activities. In the future this global volume of topsoil (equivalent to a cube of 20 x 20 x 20 km) will probably have to support a population of over 10 billion humans. For every person on the planet an average of five tonnes of soil is eroded every year – a total of around 35 billion tonnes of soil. At rates of soil formation in agricultural fields it would require 10 ha of land per person to balance this loss- there are only 1.9 ha of land per person in the world (Rees 2003, *Nature* **421**: 898), of which only 0.2 ha are arable land. Average annual rates of soil erosion in the EU 28 countries are nearly 3 tonnes per hectare from arable land, rising to nearly 10 tonnes per hectare for land under continuous cultivation (http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_erosion). This ongoing soil loss has profound implications both for national and international food security. With climate change and increasing global food demand resilience in UK food security will require less rather than more dependence on international food markets and will need to ensure dependable yields from within our own land. The consequences of managing soil only for short-term farm yields (both of crops and animals) has been soil degradation that has then impacted on flood risk, water quality etc. with major economic costs and risks to public health.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Main recommendation: Soil protection has been a low priority in society and in government for a long time and this is reflected in the absence of effective measures to ensure that soil is properly valued, protected and cared for. We identify a number of priority areas for future policies:

Promoting reduced / no-tillage agriculture. Incentives are needed to change from conventional inversion ploughing and to access the most effective new combined minimal tillage-seed drills that are lightweight and minimise soil damage and reduce fuel use. These provide multiple soil and environmental benefits.

Promoting the use of leys in crop rotations. The use of grass in crop rotations on arable land traditionally played a crucial role in restoring soil macroaggregates, rebuilding soil structure, soil organic carbon storage, and earthworm populations. Leys are not being used on arable farms because they do not deliver the short- term financial rewards of repeated cropping. More research is needed into optimal management systems using leys followed by herbicides and reduced tillage systems.

Rewards for good soil stewardship leading to improved soil health. Providing proper financial incentives for good soil stewardship and management, underpinned by national monitoring and measurements of soil health indicators to verify success are long overdue. If we value soils at all we need to properly value the work of farmers who look after the soil.

Farming incomes and sustainable farm futures. Sustainable soil management critically depends on providing farmers with reasonable incomes, providing the financial security to focus on long-term sustainability and soil management rather than being critically dependent on short-term returns irrespective of the longer-term consequences. We cannot continue to expect our farmers to protect the soil resource for the future as a free service for the nation. The financial rewards for UK farmers are appalling compared to their contribution to the nation's well-being. Farmers comprise less than 1% of the UK population yet they provide 60% of the food we eat- but the farm-gate economic value of their produce is only 0.5% of GDP and the average age of a UK farm holder is 58 years. These data from DEFRA reveal why soil has been such a low priority- when our dairy farmers are often paid less for milk than it cost to produce it, do they have the time or resources to be concerned about soil health?

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

To deliver long-term soil sustainability and reverse the historical soil degradation through decades of oversight and neglect requires that the protection and improvement of soil health nationally must be integral to government environmental plans and policies. The UK's 25 year natural environment plan and the 25-year food and farming plan need to place soil health amongst the priority areas needing most urgent evaluation and future protection.

January 2016

Written evidence submitted by the NERC Centre for Ecology and Hydrology

NERC Centre for Ecology & Hydrology (CEH) with input from:

Prof Bridget Emmett, CEH Science Area Lead for Soils Research

Dr David Robinson (Soil Scientist)

Dr Rob Griffiths (Soil Ecologist)

Dr Aidan Keith

Janet Moxley (Soil Ecologist Carbon Scientist)

Who has contributed to this input?

Prof. Bernard Cosby (Hydrogeochemist)

Purpose for responding

CEH wishes to highlight the importance of our soil resources in supporting important sectors of the UK economy and contributing significantly to national well-being, and to draw attention to the need for effective and comprehensive monitoring and protection of this resource to enhance UK soil health and security.

Key messages to highlight in response:

(Main focus of response, main points for executive summary)

- There is no commitment to an ongoing national soil monitoring programme or framework for soil protection for the UK.
- Devolved administrations and England have developed their own solutions to this gap which could be rolled out at a UK scale funded through the RDP (as in Wales).
- Soil health indicators should include biological and physical indicators as well as the traditional chemical metrics (e.g. nutrients, carbon, acidity) as together they are more indicative of change in soil health (as in Wales).
- Future programmes should link to existing long-term data (e.g. 30 year GB-scale soil health trend data 1978 – 2007) if future outcomes of policy change are to be objectively assessed against past successes and/or failures and should be part of an integrated ecosystems approach.
- Current schemes are focussed on the countryside and do not capture the state of soils in sub-urban and urban environments.

Written evidence submitted by the NERC Centre for Ecology and Hydrology

- Evidence of the wide-ranging benefits of improved soil protection has been thoroughly

The following evidence for the above inquiry is submitted on behalf of the Centre for Ecology & Hydrology (CEH), a Natural Environment Research Council (NERC) research centre reporting to Government through BIS. CEH is the UK's centre of excellence for integrated research on terrestrial and freshwater ecosystems and their interaction with the atmosphere. CEH science is organised into nine Science Areas: Biosphere – Atmosphere Interactions; Ecological Processes & Resilience; Natural Capital; Natural Hazards; Pollution & Environmental Risk; **Soil**; Sustainable Land Management; and Water Resources underpinned by Monitoring & Observation Systems and an overarching programme for data and information, Environmental Informatics. Together, these deliver cross-disciplinary monitoring, survey and hypothesis-led experimental investigation, providing data and knowledge to the wider science, policy and innovation communities.

documented in a range of studies. Modelling provides valuable tools for exploring possible future scenarios.

- Estimates of the costs of current soil degradation are available and are significant to the UK economy (ca. £1.2 billion).

- We emphasise that soil is one of our natural assets which underwrites and supports important components of the UK economy and contributes significantly to national well-being.

Consultation/inquiry questions:

Introduction/Background

CEH welcomes the opportunity to make a submission to this inquiry. Our views are submitted under the **specific questions** requested in the call for evidence.

Question 1: How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

How could soil health best be measurement and monitored?

Although it takes hundreds of years for a soil to fully develop, soils can change very rapidly in response to pressures such as land use change, management, pollution and climate change. It is imperative that we understand how soils are changing on policy relevant timescales (5-10yrs), a task requiring the collection and assessment of reliable soil change data (Robinson et al., 2015; Panagos et al. 2015).

Identifying change at a national level requires a comprehensive monitoring strategy that ideally captures both ongoing trends in all major habitat types together with more detailed assessment information in areas of high risk. This sampling strategy should:

- sample both top soil (0-15cm) and soil at depth (ideally 1m);
- cover all major land class types i.e. not just agriculture but forestry, conservation land,

Written evidence submitted by the NERC Centre for Ecology and Hydrology

peatland, urban and coast;

- include physical and biological indicators as well as the more commonly reported chemical metrics (e.g. nutrients, carbon and acidity), and include indicators of both good (e.g. carbon) and poor (e.g. high level of metals/metalloids, recalcitrant organic chemicals, agri-chemicals) soil health. The UK Soil Indicators Consortium started work in this area but needs to be revisited as data and technology has moved on, e.g. automation of analysis methods, improved capacity to analyse soil biodiversity using DNA analysis, advances in environmental information management and validation of potential high-throughput/rapid proxy metrics of soil health e.g. spectroscopy, image analysis.
- link to past soil sampling schemes to ensure continuity of data and thus provide evidence of the effects of any new policies or incentive schemes on the rates of change in soil health.
- maintain continuous monitoring of imported soil for pests and disease, e.g. importation of plants in their native soils by the horticulture/landscape industry poses a potential high risk of both plant **and** soil pest and disease outbreaks.

In the past, several soil monitoring schemes have provided us with valuable information either for GB as a whole (Countryside Survey; Emmett et al 2010), England and Wales (National Soil Inventory), and Scotland (National Soil Inventory Scotland). To our knowledge, none have secured funding to continue into the future. In addition, a range of public bodies are responsible for monitoring specific aspects of soil health. There is country level monitoring of acidity, heavy metals and polyaromatic hydrocarbons (PAHs) on agricultural land where sewage sludge and other organic wastes have been applied, and maintaining good soil quality is part of the assessment of Good Agricultural and Environmental Condition (GAEC) of land eligible for Common Agricultural Policy (CAP) payments, and local authorities are responsible for soils at sites which have contaminated land. Currently, only an EU level soil monitoring programme (LUCAS) is active within the UK as a whole. However, the LUCAS sampling strategy is too sparse and has an inappropriate sampling structure to provide meaningful change data at the UK level.

Looking forward, a team of leading UK soil scientists involved in soil monitoring identified the most statistically efficient (and thus cost effective) approach as one with a sampling structure that ensures sampling effort covers as many land types as possible (Black et al. 2012). Combining this stratified sampling approach with multi-purpose surveys (e.g. of vegetation and water) can also increase cost efficiency as it provides data relevant to a wide range of national and international environmental commitments as well as their inter-dependencies (e.g. has change in land management or plant species composition been observed where soil health has changed?). This approach recognises that soils do not act in isolation but are closely connected and impacted by land management and vegetation change. This is the approach taken by the monitoring programme, Countryside Survey, which has reported on change in GB top soil condition between surveys in 1978, 1998 to 2007 (Emmett et al., 2010; Reynolds et al., 2013) and national distributions of soil microbial diversity (Griffith et al. 2011), trace elements (Spurgeon et al. 2008) and organic pollutants (Heywood et al. 2006).

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This CS approach has now been adopted by Wales as the basis for a rolling annual monitoring programme of soil (and other natural resources), the Glastir Monitoring and Evaluation Programme (GMEP). Ongoing change is tracked relative to change over the last 30 years for land inside and outside the Glastir agri-environment scheme providing both national-scale reporting and objective assessments of the Glastir scheme benefits for soil health. A new pilot scheme in 2016 will extend this to include additional sampling in the National Parks to assess if soil health (and other natural resources) inside the Parks are better protected relative to ongoing national trends.

Funding for the GMEP was secured from the EU Rural Development Programme (RDP) and the Welsh Government. GMEP ensures compliance with the recommended guidance from the EU for *ca.* 2% of the RDP to be used to assess the success / outcomes of payments to farmers. This multi-purpose survey approach and funding model could potentially be rolled across the UK providing a valuable national framework for a wide range of *ad hoc* evidence-based surveys relating to a range of policy initiatives such as agri-environment schemes, designations, etc.

How could the Government develop a strategy for tracking soil health?

Guidance on this issue is available from international sources. For example, the first United Nations Intergovernmental Technical Panel on Soils report on the Status of World Soil Resources was published in December 2015 (FAO and ITPS. 2015). The key elements of this are pertinent to the development of a UK Government Strategy for tracking soil health, i.e.:

1. Define soil health and communicate with all stakeholders.
2. Develop a tiered national monitoring system which builds upon existing networks to determine the current state and trend of soil condition.
3. Implement a flexible approach to soil monitoring data which can incorporate data from both structured national surveys (e.g. Countryside Survey; NSI) and unstructured sampling (e.g. farm measurements).
4. Provide support to evaluate the ‘Normal operating range’ of soils using existing data and consolidate a benchmarking system for appropriate land use and soil types.
5. Encourage better integration between environmental and health research and support further interdisciplinary programmes across Research Councils (e.g. Joint Environmental and Human Health programme)

The UN report recognised that opportunities now exist to better link soil monitoring with the state of the economy through frameworks like the United Nations System of Environmental Economic Accounting, SEEA (2015). The SEEA proposes a comprehensive accounting framework for natural resources, including soils, to supplement economic indicators like GDP. This needs to be aligned with efforts by the UK’s Natural Capital Committee. The Natural Capital Committee is an independent

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advisory body, set up in 2012. It provides advice to the government on the state of England's natural capital - that is, our natural assets includes forests, rivers, land, minerals and oceans. Soil must be recognised as an independent asset, as they are in the SEEA.

Question 2: What are the benefits that healthy soils can provide to society?

Soils underpin the provision of food, fibre and clean water, and provide a range of other services of value to society. Blum (2005) summarized these services under six broad categories as:

Biomass production: e.g. food, feed, fibre, fuel production. 'The food and drink supply chain is the UK's single largest manufacturing sector and accounts for 7% of GDP, employs 3.7M people and is worth £80Bn per year.' (Food Matters, 2008).

Protection for humans and the environment: e.g. soil can remove pollutants from the environment e.g. by filtering water or hosting micro-organisms which can break them down. It can also recycle waste such as compost, sewage sludge and other organic materials into soil organic matter. However, without good management, soil can be a source of pollution e.g. water companies spend large amounts of money annually cleaning water for domestic use.

Gene reservoir: e.g. many antibiotics and medicines are extracted from soil exemplified by the 2015 Nobel Prize for medicine. The antibiotics to treat TB also were extracted from soil (Nobel Prize 1952).

Physical basis for human activities: supporting our infrastructure. 'The change in the amount and distribution of rainfall, as a result of climate change, will lead to a significant increase in the damage done by the shrinking and swelling behaviour of clay soils. The Association of British Insurers predicts that subsidence (downward movement of the ground surface) claims will reach £600 million a year by 2050.' (BGS, 2012).

Raw material: topsoil, turfgrass, and sports turf. 'Each year, British Sugar receives over 300,000 tonnes of soil, with the 7.5 million tonnes of sugar beet it purchases from UK farmers.' (British Sugar, 2015). This produces the British Standard topsoil product.

Preserver of cultural heritage: e.g. Lindow man found in a bog in Cheshire.

In addition, and not mentioned by Blum:

Climate Regulation Soils store large amounts of carbon. It is estimated that 9.8 billion tonnes of carbon is stored in soils in Great Britain (Dawson and Smith, 2007). Increasing carbon sequestration in soils can help to tackle climate change, but poor management of high carbon soils could release large amounts of carbon dioxide. Soils can also be sources and sinks for methane and sources of the powerful greenhouse gas nitrous oxide.

Regulating water flow as part of sustainable catchment management. Well managed soils can retain

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and gradually release water reducing flood risk and increasing resilience to droughts.

Question 3: What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

The EU has undertaken substantial work on identifying soil threats in support of its last attempt to develop a Soil Framework Directive in 2006 including economic implications (e.g. Kuhlman et al,. 2010).The UN has published a standard set of accounting methods to link the state and change of environmental assets to economic indicators like GDP; this effort comes under the system of environmental economic accounts (SEEA).

Some UK-focussed examples of the consequence of failure to protect soil resources include:

- Recent work on soil economic value (Robinson et al., 2014) indicated that the median price of a tonne of topsoil in the UK is £30. The estimated loss of 2.2 million tonnes of top soil per year results in a replacement cost of £66 million annually in the UK. If this soil is ending up in water courses it can cause major damage, for example by covering spawning gravels used by fish and inhibit drainage systems with both social and economic cost.
- Degradation of the soil genome may mean the loss of organisms that may be the future potential cure for a range of human and animal diseases (e.g. identification of the new soil cultured antibiotic teixobactin earlier this year by Ling et al. 2015). 50% of current antibiotics have been derived from soil organisms.
- Damage to soil by pollution (e.g. acidic deposition, reactive nitrogen, heavy metals, radionuclides, persistent organic pollutants) from a range of sources may reduce soil functions and the ability to sustain ecosystems and fulfil important functions like waste recycling. The presence of legacy pollutant in soil is a significant restriction on the use of brownfield land for urban development, which provides a significant temporal and financial restriction on the multifunctional use of past industrial sites. Pollutions concerns are not limited to brown field sites in urban centres as atmospheric processes have transported contaminants to some of our most rural locations impacting on soil health with potential consequences for water, biodiversity and in some cases human health. For some pollutants, areas most at risk have been mapped using the critical load / level approach and found to exceed 50% (Critical Load Modelling and Mapping Focal Centre http://www.cldm.ceh.ac.uk/uk-national-focal-centre) - monitoring by the British Geological Survey (BGS) using G-BASE (2014) helps to establish the context on background levels of heavy metals across the UK. Countryside Survey also reported on heavy metal levels in UK surface soil and with the Environment Agency Soil and Herbage Survey, provided an initial picture of the distribution of some persistent organic pollutants in topsoil at a national scale. The small price we pay for monitoring our environment is a good investment compared to the consequences of contaminants affecting soil multifunctional use and entering natural and human food chains.
- Small losses of soil organic carbon contribute to major greenhouse gas emissions. A Defra report from 2008 suggested a 1% loss of soil organic carbon was equivalent to UK GHG

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emissions from all sources for a year (Defra, 2008).

- Loss of organic matter reduces the ability of soils to infiltrate rainfall and store soil moisture. This has several potential consequences: increased shrink swell on vulnerable soils and more damage to engineered infrastructure (Harrison et al., 2012); enhanced overland flow and runoff may contribute to local flood risk (Marshall et al. 2014); increases the need for irrigation; results in a reduction in river flow during dry periods; increases the likelihood of more intense heatwaves (Seneviratne et al., 2005); results in greater reliance on oil based fertiliser products reducing our resilience and making us susceptible to oil price volatility.

Some agricultural practices (e.g. harvesting in wet conditions, leaving fields bare after harvest, excessive trampling by livestock) result in large volumes of productive topsoil being compacted and degraded.

Question 4: What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

There are a range of agricultural controls and incentives in individual countries linked to the Single Farm Payment / Cross Compliance schemes and relating GAEC. These are important to soils for 'damage limitation' but are significantly inadequate if soil health is to be positively promoted to the same degree as water and biodiversity. For Scotland, the Code of Good Practice for Prevention of Environmental Pollution From Agriculture (Scottish Executive, 2005) gives guidance on good practice related to soil management required for compliance with GAEC.

Managing Authorities (Devolved Administrations and Defra for England) also have higher level agri-environment schemes which promote more positive actions for soils such as reduction in soil erosion (Environmental Stewardship, England); fertiliser reductions and peatland restoration (Glastir, Wales); securing carbon storage in soils (Agri-Environment Climate Scheme, Scotland). However, these programs only relate to agriculture whilst soil under all land uses needs to be considered (e.g. urban, forest conservation areas) together with all threats – not just land management (e.g. air pollution, climate change). Other control programs include the Biosolid application rate controls (1989) which aim to limit any build-up of soil contaminants, and controls of sulphur and nitrogen gaseous and particulate emissions which limits the acidification and eutrophication rate of soils.

Forest and Soil Guidelines (Forestry Commission, 2011) support the UK Forestry Standard and provide guidance on the sustainable management of forest soils.

Various Industry Boards (e.g. AHDB), NGOs and third sector organisations (e.g. The Soil Association) and Learned Societies (British Soil Science Society; the Microbiological Society; Society of Biology)

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promote better understanding and management of our soils, e.g. the Fertiliser Manual RB209 as well as a range of local initiatives.

Dissemination of data and encouragement of crowd sourcing / citizen science also has an important role to play. For example, recent efforts to consolidate legacy data in the UK have been undertaken by the soils community supported by NERC, which now presents more than 100 soil data layers through the UK Soil Observatory (Lawley et al., 2014). This is complimented by the mySoil app which allows the public to submit photos, soil pH and soil texture information to enhance the national soil picture (Shelley et al, 2013).

Further measures to be explored could include;

- A greater focus on improved soil management incentives potentially using the "Payment for Ecosystem Services (PES)" approach.
- Self-monitoring options by farmers to encourage greater ownership and recognition of 'good practice'.
- Support of new EU legislation for a revised Soil Framework Directive which provides similar protection to soil as to water, air and biodiversity (without undue costs for the restoration of all contaminated land which may not be best use of resources).
- Greater consideration of soils in the planning system including consideration of soil carbon, soil sealing and soil biodiversity.
- Incentives for peatland restoration.
- Research on emerging threats and opportunities to soils, e.g. effect of pesticides and veterinary medicines and their residues of soil micro-organisms; effect of biochar application on soils.
- A coordinated UK soil monitoring network

Question 5: What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soils should be central to the 25-year plan and the Government should adopt a balanced approach to monitoring all of the UK's natural resources and their change upon them. This is needed to provide the evidence base for coherent environmental and economic policy, with monitoring being be a centrally important part of the programme. The 25 year plan should offer an integrated monitoring strategy that includes an efficient, robust monitoring design, preferably joined up as far as possible across the UK and potentially linked to Europe, emphasising indicators that help us understand important environmental changes and ensuring good links to historical data. The UK soils community are well positioned to do this if funding sources can be pooled to provide smarter and more integrated monitoring across the soil, water, and biodiversity sectors.

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It is also worth pointing out that each devolved administration has its own plan for the natural environment. For example, Wales has a its 'Well Being of Future Generations Act', a cross Government legislative programme which critically already included a soil quality indicator as one its high level impact indicators alongside social, economic and other environmental indicators. Perhaps the Inquiry can encourage England and Scotland to agree on a common set of soil health indicators which are consistent across the UK for monitoring, analysis and reporting?

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Written evidence submitted by the NERC Centre for Ecology and Hydrology

January 2016

Written evidence submitted by Sophie Webb, Reading Agricultural Consultants Ltd.

Executive Summary

- Soil health is a dynamic concept that needs to consider the context and specific function of a soil before the criteria for effective evaluation can be defined.
- For a nation-wide programme of measurement and monitoring of soil health indicators to be successful, it must be simple to implement on the ground.
- The benefits of maintaining healthy soils are far reaching and extend beyond economics.
- It is imperative that society begins to consider soil as an important entity in its own right if the national soil resource is to be protected from long term damage and degradation.
- There is a lot to be learned from mainland Europe regarding the protection of soils from development projects, more specifically in relation to compensation schemes to help offset adverse impacts on soils.
- Soil is essentially a non-renewable resource and must play a significant and central role in any 25 year plan for the natural environment, particularly as soil currently does not have equal legislative protection as that presently afforded to air and water.

1. How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

1.1. Different criteria would need to be considered depending upon the scenario in which the soil exists. For example, healthy agricultural soil would have relatively high nutrient content and good drainage, whilst a meadow or wetland would be much healthier in its own context with low nutrients or poor drainage respectively.

1.2. An enormous range of measureable soil properties can be evaluated to give various indications of soil health. These can be divided into physical, chemical and biological properties. The decision to be made is then how many of which properties to evaluate, by whom, and on what scales.

1.3. For bulk data collection in an agricultural and woodland context, the key to any successful programme for the measurement and monitoring of soil health indicators will be simplicity. Qualitative measurements of physical, chemical and biological properties could be easily made in the field on an annual basis and recorded with little training required by the assessor. Physical factors, for example topsoil depth, structure and colour could be afforded a score based upon comparisons with standardised, high quality photographs and colour scales, whilst smell could be matched against a description, eg. 'earthy' or putrid. Chemical factors such as pH could be quickly estimated using pH test strips, whilst levels of major nutrients will be frequently available to farmers anyway due to regular agronomic soil testing. Possibly the easiest and most useful biological factor to measure is earthworm activity, again affording the soil a score based upon how many earthworms are present within a given volume of soil.

1.4. Totalling scores and comparing with pre-determined thresholds for indicators of soil health would provide instant feedback to the assessor on the relative state of their soil, providing the impetus to either improve the soil if needed, or continue to manage effectively if the state is good.

1.5. Where applied on agricultural land, tying such a scheme in with the basic payment system would ensure it was universal, and by making the evaluation simple and quick, individual land managers and farmers are more likely to partake. Supplementing these measurements with, for example, 5-yearly laboratory analysis of microbial activity, organic matter and nutrient content etc, and collating with the ground data, would result in a valuable database of the state of intensively-managed soils, including those in parks, open areas and woodland within an urban setting as well as agricultural land, on a national scale.

1.6. However, different criteria would be required for extensively-managed soils, for example across wetland, heathland and peatland where the primary soil functions may be the support for biodiversity, and the storage of water and carbon rather than the production of food and biomass. The same concept of simplicity must be applied to the assessment process, which should be made possible without requiring specialist training or equipment. Criteria may be more centred toward biodiversity surveys, measuring the depths of peat layers, and estimating water content based on simple, descriptive classifications, whilst factors such as structure, smell or colour become less important.

2. What are the benefits that healthy soils can provide to society?

2.1. Healthy soils provide many benefits to society but, to the absolute detriment of soil, the focus is typically on economics and food production. In this context, put very simply, healthy soils result in higher crop yields, providing economic benefit to society. Unhealthy soils result in compaction and erosion, which result in economic loss. Even the Government White Paper, 'The Natural Choice: securing the value of nature', has a significant economic undertone throughout.

2.2. The National Planning Policy Framework (NPPF) refers to "the economic and other benefits of the best and most versatile agricultural land". Best and most versatile agricultural land is classified as such due to its capability to consistently produce a given yield and range of crops, i.e. to produce the highest economic return. The soil will be able to do this due to having what would be considered relatively good health: good structure, drainage, ideal pH, free of contaminants etc. However the 'other' benefits of the best and most versatile land are limited or less clear; for example, high grade agricultural land can produce vast monocultures which are not highly valuable for biodiversity, and the regular removal of fibre is not conducive to organic matter or nutrient accumulation.

2.3. On the other hand, poorer quality agricultural land, in which the soils for example may be waterlogged for much of any given year, considered indicative of *unhealthy* soil, and which has no obvious direct economic return, is afforded no specific protection in the NPPF. But their 'other' benefits are huge: water filtration and storage, gas exchange, biodiversity and carbon storage to name but a few. 'Healthy' soil is not necessarily good soil, and 'unhealthy' soil is not necessarily bad: the definition of each being entirely dependent on a soil's context and function.

2.4. The difficulty is that society needs to move away from this immediate association between a soil and its direct economic value or lack thereof. It is difficult to understand the benefits when they are not immediately obvious, directly affecting, or which have never even been comprehended by most. How do you value the ability of a soil to prevent flooding of houses some distance away, in most but maybe not all years? It's not absolute and it's not consistent. Soil is dynamic and its abilities and attributes change. But what doesn't change is an outright benefit not just to society, but which is much wider reaching in the environment. We should not be protecting soil for the purposes of preserving the benefits it directly provides to society, but because soil is its own entity that deserves protecting.

3. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

3.1. It is widely accepted that soil is essentially a non-renewable resource and therefore the question shouldn't be of protecting soil *health*, but of protecting soil full stop. The consequences of failure are already evident. In a socio-economic context, building in floodplains and disturbing and/or sealing commonly waterlogged soils, thus failing to protect them, is undoubtedly a contributing factor to more frequent and intense local flood events. Consequences on food security are fairly obvious: if a soil is damaged and unable to produce a crop, the UK's reliance on imports will increase.

3.2. In environmental terms, if a soil is not kept healthy, importantly, *in its own context*, and such processes as nutrient cycling, carbon sequestration and water filtration are upset, the negative impacts will be further reaching than the soil environment, extending to air and water quality also.

4. What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

4.1. Environmental stewardship schemes provide some initiative but more could be done. There are lessons to be learned from Europe as regards protecting soil health through reducing sealing and limiting use of greenfield land for development. Compensation payments are applied in several countries across Europe whereby if greenfield land is to be developed, the developer must pay compensation for each square metre of soil disturbed. The payments are then used for soil protection and quality monitoring elsewhere. Alternatively, as in Dresden, the compensation for sealing land in one development area relates to de-sealing land elsewhere, reinstating soil health.

4.2. Initiating a compensation scheme in the UK would, although still be considering the value of soil in monetary terms, at least get society thinking about soil as a resource and get the topic talked about.

4.3. There should be more active encouragement, assistance and initiative to utilise brownfield land for developments as when using greenfield land, once the soil is disturbed, moved, stockpiled and replaced, restoring the health and functions of that soil is a lengthy process.

5. What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

5.1. Soil health and soil generally should be attributed a significant and central role in the 25 year plan. The influences of soil are so far reaching, directly affecting air quality and water quality, which currently have much more protection through legislation than does soil. That soil is essentially non-renewable should further promote its importance in any plan for the natural environment. It is vitally important that soil health is considered much beyond the socio-economic context and understood that the 'worst' soils can often be the 'best' in fulfilling the various functions of soil.

January 2016

Written evidence submitted by the Microbiology Society

1. The Microbiology Society is a membership organisation for scientists who work in all areas of microbiology. It is the largest learned microbiological society in Europe, with a worldwide membership based in universities, industry, hospitals, research institutes and schools. The Society publishes key academic journals, organises international scientific conferences, and provides an international forum for communication among microbiologists and supports their professional development. The Society promotes the understanding of microbiology to a diverse range of stakeholders, including policy-makers, students, teachers, journalists and the wider public, through a comprehensive framework of communication activities and resources.

Introduction

2. Soils are estimated to hold a quarter of the world's biodiversity. This biodiversity, of which micro-organisms are a major component, is essential for terrestrial life and the ecosystem services which human society relies upon[1,2]. Typically, one gram of soil contains over a billion bacterial cells and over 10,000 species of bacteria, as well as numerous viruses, fungi, archaea and protozoa.
3. These micro-organisms are important for the formation, fertility, structure and stability of soils, and help deliver numerous essential ecosystem services, including: nutrient cycling and climate regulation; plant growth and agricultural production; water purification and regulation; and pollutant and contaminant. Soil micro-organisms are an important resource that can be harnessed to improve the health of soils (e.g. biofertilisation, pathogen suppression, bioremediation) and for other societal benefits (e.g. pharmaceuticals). Consequently failing to protect soil health, including microbial biodiversity, can impact the ability of soils to deliver these vital ecosystem services.
4. The Microbiology Society recently published two briefings[3,4] and a topical issue of *Microbiology Today*[5], which summarise the importance of, and issues relating to, soil microbiology and microbiological research in this area.
5. Measuring and monitoring microbial indicators of soil health is important because of the intrinsic role soil micro-organisms play in soil formation and maintenance, and the delivery of key ecosystem services. Different microbiological measures may, for example, provide an

[1] Turbé, A. *et al.* (2010). *Soil biodiversity: functions, threats and tools for policy makers.* Bio Intelligence Service, IRD, and NIOO, Report for European Commission (DG Environment). Link last accessed: 28/01/2016.

[2] Bardgett, R. D. & van der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. *Nature* **515**, 505-511.

[3] Microbiology Society (2015). *Briefing: Food Security from the Soil Microbiome*. http://www.microbiologysociety.org/policy/briefings.cfm/publication/food-security-from-the-soil-microbiome.

[4] Microbiology Society (2015). *Briefing: Microbiology and Climate Change*. http://www.microbiologysociety.org/policy/briefings.cfm/publication/microbiology-and-climate-change.

[5] Microbiology Society (2015). *Microbiology Today: Soil. Microbiology Today* 42:2. http://www.microbiologysociety.org/publications/microbiology-today/past-issues.cfm/publication/soil.

indication of the capacity of soils to recycle nutrients, store organic matter, release greenhouse gases, degrade pollutants, and affect crop yields. Some microbiological indicators can also help us to understand physiochemical properties of soils that can be difficult to measure directly or over longer periods. Such microbiological evidence is important to inform policy, and to develop and optimise soil management practices and biotechnologies to improve soil health and ecosystem service provision.

6. Universally defining and measuring soil health is challenging. While soil must be fit for purpose, from both a microbiological and broader perspective, what is considered 'healthy' varies extensively by soil type, function of interest, and from the perspective of different users. For example, a soil considered healthy for wheat cultivation might not be considered healthy for forestry, grazing or bioremediation. A well-fertilised soil might be good for crop growth but considered unhealthy with regards to fertiliser pollution. A range of microbial, and other, soil health indicators and baselines are needed, which are specific to different soil types and functions.

7. Our evidence focuses on soil microbiology and the importance of microbiological science. However, it is important to understand that soil health is determined by interactions between biological, physical and chemical components, including microbes and larger life forms that make up soil biodiversity. Indeed, the biodiversity and activity of soil microbial communities relies on interactions with other organisms and the local physiochemical environment. Soil monitoring and management strategies must utilise multiple indicators of, and seek to protect, all of the components of healthy soils. An interdisciplinary approach to soil research and management is vital.

Benefits of soil microbiology to society and resulting consequences of failing to protect soil health

Nutrient cycling and climate change

8. Soil micro-organisms play a fundamental role in cycling nutrients, including carbon, nitrogen and phosphorus, which are essential for plant growth, and therefore terrestrial life[4,6]. Decomposing soil bacteria and fungi play a key role in the formation, maintenance and breakdown of soil organic matter. The biomass of micro-organisms in soils is itself an important component of the total carbon stored in soils[1]. Soil micro-organisms also convert nutrients, including nitrogen and phosphorus, into forms that are usable by plants and other organisms.

9. Nutrient-cycling micro-organisms naturally use and emit key greenhouse gases, notably carbon dioxide, nitrous oxide and methane. There is evidence that soil degradation and disturbance (e.g. land use change; some intensive farming practices) can enhance microbial decomposition of soil organic matter and consequently the release of carbon dioxide and

[6] Singh, B. K. *et al*. (2010). Microorganisms and climate change: terrestrial feedbacks and mitigation options. *Nature* **8**: 779–790.

methane from microbial respiration. Climate change could also potentially enhance microbial respiration in some soils[4,6]. Understanding how soil micro-organisms will respond to land use pressures and climate change is a complex and important research challenge.

10. An important global issue is the release of nitrous oxide from agricultural soils, as a consequence of enhanced microbial nitrification and denitrification, driven by the inefficient application of nitrogenous fertilisers[4,6,7]. Agriculture is estimated to contribute 84% of UK nitrous oxide emissions[8]. Microbial nitrification also produces nitrates, which can leach or run off into water courses causing environmental damage through eutrophication.

11. Managing soil microbial biodiversity and activity, through better soil management, is therefore critical to contribute to climate change mitigation and resilience[4,6,7,8]. For example, it is important that farms monitor nitrogen use and utilise management plans[8]. Microbiologists are also investigating how to improve the efficiency of nitrogen use and reduce the need for synthetic fertiliser inputs[4]. One area is optimising the use in cropping systems of legumes, which supply nitrogen biologically through symbiotic relationships with nitrogen-fixing bacteria. Microbiologists are investigating how crops associate with and affect communities of soil micro-organisms. Harnessing this knowledge could, for example, enable us to develop crop varieties that produce good yields under lower nitrogen input conditions, or that biologically inhibit denitrification.

Food security and agriculture

12. Micro-organisms are vital for agricultural production[3,9]. Microbes that form associations with plant roots and free-living soil microbes can contribute to crop growth and soil health by:

    - Cycling nutrients that are essential for plant growth (e.g. nitrogen, phosphorus and sulphur).
    - Improving soil structure and organic matter content, which are important for fertility, water retention and minimising soil loss to erosion.
    - Conferring disease resistance to crops by outcompeting pathogenic microbes and stimulating biochemical plant defences.
    - Improving the resilience of plants to environmental stresses, such as fluctuations in temperature and moisture.
    - Enhancing root growth and nutrient uptake.

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[7] Reay, D. S. et al. (2012). Global agriculture and nitrous oxide emissions. *Nature Climate Change* **2**: 410-416.

[8] Parliamentary Office for Science and Technology (2015). *POSTNote 486: Emissions from Crops*.

[9] Microbiology Society (2011). *Position Statement on Food Security and Safety*. http://www.microbiologysociety.org/publications/policy-docs.cfm/publication/2011-food-security-and-safety.

13. Unsustainable intensive farming methods (e.g. high tillage and continuous cropping), and the selection of crop varieties that are less able to associate with beneficial soil micro-organisms, such as arbuscular mycorrhiza fungi, may negatively affect, and underutilise, soil microbial biodiversity and the services it provides; this may impact agricultural productivity and could contribute to related issues such as soil loss to erosion and reduced water and nutrient retention[3].
14. For example, practices that affect microbial soil biodiversity can increase the susceptibility of crops to soil-borne diseases[3]. The build-up of soil-borne pathogens under intensive cropping regimes is thought to be a driver of oilseed rape yield decline, which can cause 6-25% declines in annual yield. Take-all is a serious fungal root disease of wheat, which appears in the second or third year of continuous cropping. It is estimated to affect half of UK wheat crops, reducing yields by an average of 5–20%, costing tens of millions of pounds each year.
15. Microbiologists are investigating potential approaches that farmers could use to harness the soil microbiome as a tool to suppress pathogens and enhance crop growth[3,9]. Research themes include: understanding what microbes are present, what their function is, and how they interact with plants; promoting crop-microbe associations through inoculating soils with beneficial micro-organisms or developing crop varieties that better associate with soil micro-organisms; and investigating optimal soil management regimes (e.g. crop rotation, intercropping and reduced-tillage) that promote beneficial microbial biodiversity.

Water purification and regulation

16. Soil micro-organisms play an important role in water purification and the regulation of soil water uptake and storage[1,10], which is important for agriculture and mitigating flooding risks. Fungal mycelia and microbial compounds help to stabilise soil aggregates contributing to drainage, but can also affect soil water repellency. Interactions between roots and mycorrhizal fungi, and also root pathogens, can affect water uptake by plants.

Bioremediation and geomicrobiology

17. Micro-organisms play an important role in degrading soil and groundwater pollutants and contaminants into non-toxic molecules[1]. Bioremediation methods, which stimulate these microbial processes to treat contaminated soils (e.g. hydrocarbon and metal pollution from industrial activity) in situ or ex situ, have been used, and continue to be researched and developed[10,11].
18. Soils play an important role in supporting urban infrastructure, for example providing structural support of buildings, and acting as buffers against flooding and contamination. Soil micro-organisms may contribute to soil stability and permeability by facilitating geochemical processes such as the precipitation of minerals. The potential to harness this

[10] Rillig, M. C. *et al.* (2010). Mycelium of arbuscular mycorrhizal fungi increases soil water repellency and is sufficient to maintain water-stable soil aggregates. *Soil Biology and Biochemistry* **42**: 1189-1191.

[11] DEFRA (2010). *Defra Research Project Final Report SP1001: Contaminated Land Remediation*.

geomicrobiology to increase the load bearing capability and liquefaction resistance of soils, and ground water flow control is beginning to be explored[12].

Human Health

19. Human health is benefitted by soil microbial biodiversity in a number of ways[1,13], including supporting ecosystem services such as food production and water cycling, and suppressing soil borne human pathogens.

20. Environmental and land use change, and poor soil management can impede the ability of the soil microbiome to support these services[1,12]. For example, a report by the European Commission Joint Research Council[14] highlighted that more research was needed into soil-borne human diseases, including how land management, land use change and climate change could affect their incidence.

21. Soil is a well-validated habitat for identifying a wide range of micro-organisms that produce bioactive metabolites (secondary metabolites) with important applications in human and veterinary medicine. For example, 60% of clinically important antibiotics are derived from Actinobacteria. Recent research in the USA used a new approach to isolate previously unculturable soil bacteria, which resulted in the discovery of a new antibiotic called Teixobactin[15]. The Microbiology Society Small World Initiative science engagement project is providing the general public, students and educators in the UK and Ireland the opportunity to work with scientists as part of a global initiative to discover new antibiotics from soil bacteria.

22. Antimicrobial drug resistance has emerged a key national and global public health policy issue, which also links in part with agricultural and environmental policy[16]. Environmental levels of drug-resistant bacteria have been increasing due to antibiotic use in humans and animals. Therefore, an important area of research relating to soil microbiology and soil health is detecting and monitoring environmental reservoirs and transmission routes of antimicrobial drug-resistant micro-organisms.

Measuring and monitoring microbial indicators of soil health

23. Microbiological indicators of soil health include measuring microbial taxonomic diversity and abundance (biodiversity), microbial biomass, and measuring indicators of microbial function

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[12] DeJong, J.T. *et al.* (2010). Bio-mediated soil improvement. *Ecological Engineering* 197-210.

[13] Wall, D. H. *et al.* (2015). Soil biodiversity and human health. *Nature* **528** 69-76.

[14] Jeffery, S. & van der Putten, W. H. (2011). *JRC Scientific and Technical Report: Soil Borne Human Diseases*. European Union.

[15] Ling, L. L. *et al.* (2015). A new antibiotic kills pathogens without detectable resistance. *Nature* **517**, 455-459.

[16] Parliamentary Office of Science and Technology (2013). POSTnote 446: Antibiotic Resistance in the Environment.

(e.g. respiration; nitrification). Measures of microbial diversity and activity might be considered in relation to:

- Specific organisms, such as plant pathogens, biocontrol agents and plant growth-promoting rhizobacteria, that perform specific functions (desirable or undesirable), often in association with specific plants.
- Functional microbial groups that perform broader soil functions, such as ammonia oxidisers, nitrate oxidisers and degraders of specific pollutants.
- The 'total' soil microbial community or 'soil microbiome' for a particular environment, which encompasses a wide diversity of potential indicators, many of which are likely to be, as yet, uncharacterised.

24. Advances in high-throughput sequencing have revolutionised the ability of microbiologists to characterise soil microbial communities through a technique called metagenomics. Total microbial DNA can be extracted from a soil sample and the taxonomic diversity and abundance of different micro-organisms can be assessed using methods including high-throughput DNA sequencing, quantitative polymerase chain reaction and bioinformatics. Measuring the presence and abundance of known functional gene sequences or RNA (e.g. sequences related to nitrification) can provide an indication of microbial activity and function. Such measures may also help us to understand physio-chemical properties of soils that can be difficult to measure directly or over longer periods.

25. In the same way metagenomics and molecular characterisation done on the human microbiome project is revealing how human health is related to the associated microbial community, it is likely that understanding the soil microbiome will lead to greater understanding of soil health and yield new ways of managing our soils for healthier and more sustainable natural and productive ecosystems.

26. Another way of assessing abundance and activity is to measure the release of carbon dioxide from soils due to microbial respiration; this can also potentially be used to monitor rates of decomposition of soil organic matter. A full-spectrum of other gases released by microbial processes (e.g. methane, nitrous oxide and other trace gases) may provide assessments of the abundance and/or activity of particular functional groups of micro-organisms.

27. Efforts have been made to identify microbial indicators, and other biological indicators, of soil composition and health, which could be employed in standardised soil monitoring programmes[17,18,19]. Some national-scale surveys of soil microbial biodiversity have also been carried out in the UK[20,21]. For example, molecular approaches have been applied to soils

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[17] Black, H. I. J. *et al.* (2011). *Scoping biological indicators of soil quality Phase II. Defra Final Contract Report SP0534*. Defra.

[18] Ritz, K. *et al.* (2009). Selecting biological indicators for monitoring soils: a framework for balancing scientific opinion to assist policy development. *Ecological Indicators* **9**: 1212−1221.

[19] Stone, D. *et al.* (2016). Selection of biological indicators appropriate for European soil monitoring. *Applied Soil Ecology* **97**: 12−22.

collected from the Countryside Survey to reveal the first map of bacterial distributions across Britain[21]. This study revealed how microbial communities are strongly affected by both natural geological and climatic factors as well as land use change.

28. More broadly, DNA- and RNA-based methods, and other approaches, for measuring soil microbial biodiversity and function are widely used in fundamental and applied research into understanding soil microbiology in relation to specific environments, ecosystem services and issues. Some examples of UK research involving Microbiology Society members include:

    - Research into understanding agricultural soil microbiomes and how to manipulate them through soil management or biotechnology to improve crop yields[3].
    - Investigating soil microbial diversity dynamics in relation to upland peat restoration in the Southern Pennines, an approach that could help inform future restoration projects[22].
    - International research investigating the potential impacts of climate change on soil respiration and soil carbon stocks[23].
    - Research showing that environmental antibiotic resistance gene abundances can correlate geochemical soil conditions, which suggests a potential broader use for soil geochemical data monitoring to inform epidemiological risk studies related to AMR transmission from the environment[24].

29. Despite advances in measuring and monitoring microbial biodiversity and function, particularly from advances in genomics, there are several challenges and needs that continue to be addressed with regards to understanding and monitoring microbial soil health:

    - Standardised indicators and methods for monitoring microbial soil health are required. The extensive microbial diversity of soils makes it difficult to identify standard biomarkers (e.g. genetic markers) and correlate them with different soil types, water content and vegetation. Extensive variation in soils and their uses means that a variety of indicators must be developed and used.
    - Monitoring programmes will require different baselines of microbial biodiversity and function to be established for different soil environments (e.g. different urban, agricultural and natural soils) and uses, so that a defined healthy and well-functioning

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[20] Yao, H. *et al.* (2013) Multi-factorial drivers of ammonia oxidizer communities: evidence from a national soil survey. *Environmental Microbiology* **15**: 2545−2556.

[21] Griffiths, R. I. *et al.* (2011). The bacterial biogeography of British soils. *Environmental Microbiology* **13**: 1642–1654.

[22] Elliott, D. R. *et al.* (2015). Bacterial and Fungal Communities in a Degraded Ombrotrophic Peatland Undergoing Natural and Managed Re-Vegetation. *PLoS One* DOI: 10.1371/journal.pone.0124726.

[23] Karhu, K. *et al.* (2014). Temperature sensitivity of soil respiration rates enhanced by microbial community response. *Nature* **513**: 81−84.

[24] Knapp, C. W. (2011). Antibiotic Resistance Gene Abundances Correlate with Metal and Geochemical Conditions in Archived Scottish Soils. *PLoS One* **11**: e27300.

soil microbial community for a given environment can be compared with any monitored sites. Continued research is needed to establish baseline data and standardised statistical approaches for mapping monitoring sites against baseline data.

- Linking change in soil biodiversity with change in soil function, and thus ecosystem services, remains a key challenge due to the complexity of soil ecosystems and methodological constraints. Continued research is needed to examine in more detail which specific micro-organisms are responsive to environmental change in different soil habitats, and determine how this context-specific change in diversity affects soil function.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Policy

30. Current UK and EU policy relating to soil health has been effectively summarised in a recent POSTnote[25]. The current lack of a UK-wide soil monitoring scheme, no specific EU legislation on soils, and the importance of biological soil quality indicators was noted.
31. Existing Government policy documents regarding soils already recognise the need to protect UK soils and undertake research and action to address this[26,27]. It is important that measures suggested are taken forward and implemented in new Government strategies. Management of soils to retain and increase organic matter content, for example, would likely benefit microbial biodiversity, biomass and function, and associated ecosystem services.
32. The Food and Agriculture Organization of the United Nations recently published its *Status of World Soil Resources* report[28], which highlights the global importance of, and threats to, soils, and includes recommendations for policy-makers. A European Union report[1] summarises issues and tools for policy-makers that specifically relate to soil biodiversity.

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[25] Parliamentary Office of Science and Technology (2015). *POSTnote 502: Securing UK Soil Health*.

[26] Defra (2009). *Safeguarding our Soils: A Strategy for England*.

[27] HM Government (2011). The Natural Choice: securing the value of nature.

[28] Food and Agriculture Organization of the United Nations (2015). *Status of the World's Soil Resources Technical Summary*. http://www.fao.org/documents/card/en/c/39bc9f2b-7493-4ab6-b024-feeaf49d4d01/.

Research and development

33. Fundamental and applied microbiological research can make an important contribution to understanding, monitoring and securing the health of UK soils. As illustrated by the diversity of examples provided above, soil microbiology research can increase our understanding of the biodiversity and function of soil microbiota and how these may be affected by human activities and climate change; inform management methods and policies to improve soil health and productivity; and potentially aid the development of biotechnologies to improve soil health.

34. Scientific skills and capabilities relating to microbiology, soil science, food security and agriculture have been identified as being vulnerable[9,29,30]. For example, given the importance of new molecular methods now and in the future, bioinformatics is still a limiting skill and discipline that is needed to develop better understanding of the highly complex soil microbiome. Any strategy to secure UK soil health needs to consider the importance of continuing to improve and support the capabilities, sustainability and translation of UK soil science. Recently introduced government-funded research and training initiatives, including the Soil Security Research Programme, Soil and rhizosphere interactions for sustainable agri-ecosystems (GFS-SARISA) funding call, and the Soil Training and Research Studentships are examples of good practice in the respect. Investment in research and the next generation of soil microbiologists needs to be long-term and available to all institutes to expand and develop this area into the future as new challenges emerge.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil health policy should feature prominently in the Government's natural environment plan due to the intrinsic role of soils as a part of, and in sustaining, the natural environment and the ecosystem services they provide. Better understanding, protection and sustainable harnessing of UK soils will be important for resilience to challenges such as climate change, food security and antimicrobial resistance. The broad importance and complexity of soil health means that it is important that the Government engages a broad range of stakeholders, across science, agriculture, industry and the wider public, when developing and implementing policies for soil health.

January 2016

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[29] BBSC (2015). *BBSRC and MRC review of vulnerable skills and capabilities report*. http://www.bbsrc.ac.uk/about/policies/reviews/consultations/1501-vulnerable-capabilities-report/.

[30] *Joint response from the Society for General Microbiology and the Society for Applied Microbiology to the BBSRC/MRC Vulnerable Skills Consultation.* http://www.microbiologysociety.org/policy/consultation-responses.cfm/year/2014/.

Written evidence submitted by Agriculture and Horticulture Development Board (AHDB)

1. AHDB is a statutory levy board, funded by farmers, growers and others in the supply chain. Our purpose is to equip levy payers with independent, evidence-based information and tools to grow, become more competitive and sustainable. We cover the six sectors of Pig meat in England; Beef and Lamb in England; Commercial Horticulture in Great Britain; Milk in Great Britain; Potatoes in Great Britain and Cereals and Oilseeds in the UK.

2. Soil provides many ecosystem services and focus of the AHDB response relates to arable crop and livestock production and horticultural use.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

3. Soils in E&W have been affected by declines in organic matter, with implications for their biological productivity, resilience and mechanical stability during crop and animal production. Soil Health measurement and monitoring requires indicators that will establish sound baseline information and measure change over the medium to long-term. Scale is also important and needs to reflect national, regional (catchment), and farm and field levels. The tools should be readily available and cost effective.

4. A consolidated approach is required; at present there are different requirements for different needs, e.g. relating to soil classification and land use, water framework requirements or catchment management. Consideration needs to be given to the common soil health requirements for meeting these needs and a co-ordinated approach developed for measuring and monitoring. There can be ‘read across’ of the outcomes and, of interventions measured against agreed criteria. The data from the monitoring exercises, should (subject to appropriate confidentiality and anonymity) be open access and able to be interrogated by the engaged parties.

5. The indicators used may be chemical, physical and biological, and components relating to soil structure could be measured – drainage, water retention, compaction and soil organic matter. Soil biodiversity, using total biomass may be useful, but how the structure and size of the soil microbial, animal and plant community interact to maintain and improve soil health needs to be better understood.

6. Crop and animal performance could be considered as a measure of the productivity of healthy soils but there are many confounding variables, around weather and production economics that make this a challenging metric.

7. These elements come together in two of the recommendations from the report that AHDB contributed on ‘Feeding the Future[1]’
    - Use systems-based approaches to better understand and manage interactions between soil, water and crop/animal processes
    - Develop evidence-based approaches to value eco-system service delivery by land users and incorporate these approaches into effective decision support systems at the enterprise or grouped enterprise level

[1] http://feedingthefuture.info/report-launch/research-priorities/

8. From a grower/producer perspective the focus needs to be on practical measures that engender positive change.

What are the benefits that healthy soils can provide to society?

9. A crucial national benefit provided by healthy soils is improved security of production of safe food. A more resilient soil will potentially improve services in relation to water storage, with reduced erosion of particulates and nutrients; improved Integrated Pest Management systems exploiting beneficial micro-organisms with the potential to reduce crop protection product usage; irrigation capability to maintain productivity and avoid soil/crop stress; better nutrient recycling; greater carbon storage to reduce GHG emissions from arable land.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

10. The opposite of the above, e.g. risks to the food supply chain, with potentially more expensive or environmentally damaging sourcing.

11. Less healthy and resilient soils are at greater risk of compaction in both crop and livestock production systems and this has consequences on efficiency of crop production and animal health.

12. Poor water holding capability in soils could lead to greater flooding and soil erosion risk, a scenario likely to increase with current climate change projections.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organizations consider in order to secure soil health?

13. There are a number of current initiatives that generate and deliver information relating to improvements in soil health. These are badged under a wide range of initiatives e.g. Rural Economy and Land Use (RELU) Landbridge knowledge exchange network[2], Catchment Sensitive Farming (CSF) initiatives and case studies[3], research council funded programmes e.g. NERC Soil Security or Sustainable Arable Research and Innovation Club (SARIC) where outputs are promoted through research conferences and Knowledge Transfer Networks.

14. AHDB recognises that the need to develop and maintain, resilient bio-diverse soils is central in meeting the demand for food and alternative fuels, particularly because of the combined pressures facing agriculture to reduce environmental impact and adapt to climate change[4]. A range of resources are available for example to help levy payers assess soil structure and health, and manage cultivations, examples include Soil management for potatoes[5] and Healthy grassland soils guide[6]

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[2] http://www.relu.ac.uk/landbridge/
[3] http://publications.naturalengland.org.uk/category/13001
[4] http://www.ahdb.org.uk/projects/Soils.aspx
[5] http://potatoes.ahdb.org.uk/sites/default/files/publication_upload/Soil%20Management%20for%20Potatoes%20updated%202013.pdf
[6] http://dairy.ahdb.org.uk/resources-library/technical-information/grass-management/healthy-grassland-soils-guide/#.VpZ5KcsnzZ4

15. Although these all generate valuable knowledge and outputs, navigating a way through the plethora of research projects and advisory literature is daunting for growers and advisors. There is a challenge in consolidating the most relevant information for a particular location where individual site specific management decisions need to be taken.

16. Going forward it is crucial to take a holistic view of soils and not to consider soil health in isolation.
    - There is a need to consider water management, in particular relating to catchments; and consequences of climate change.
    - Investment in soils R&D and support for translational activities to improve knowledge by advisors and practitioners.
    - There is a need for co-ordination of outputs and consistency in messaging.
    - The evidence provided by research and an ongoing critical evaluation of outcomes can support the development of frameworks (policy) for improvement of soil health but specific management decisions will need to be taken on an individual field basis (advisory).

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

17. Soil health is key in nearly all areas relating to crop and grassland productivity, due to the processes of decomposition of organic matter and nutrient cycling. Plus, soil-borne pathogens can cause yield losses, while beneficial organisms can promote plant growth or suppress disease. Soils health (biology) is interlinked with soil physics and chemistry and all play a role in maintaining productive agricultural and horticultural systems. As a national resource, it is crucial that soils are adequately protected and where possible quality enhanced to improve delivery of a wide range of ecosystem services and, from an agriculture and horticulture perspective, improve resilience in production systems to be better able to cope with economic and environmental challenges.

January 2016

Written evidence submitted by Dr Arwyn Jones

1. Executive Summary

- Soils are a key national resource that provide critical economic, social and environmental benefits.
- Soils are under pressure due to increased competition for land. Soil degradation will be exacerbated by the effects of climate change.
- UK should ensure the development of current and policy-relevant knowledge-base on the state of soils, the pressures on them, trend in soil functions and the impact of change on the supply of soil-based ecosystem services.
- UK should develop targeted and integrated research programme leading to a better understanding of the spatial variability of soil functions, their value as natural capital and the economic consequences of soil degradation.
- UK should address the provision of tools and supporting services for land users to ensure sustainable soil management and reduction in the extent and intensity of soil degradation processes.
- The development of a multi-stakeholder awareness raising programme is the key to highlight the value of soils to society.
- Greater awareness should be underpinned by increased emphasis on the value of soil in all education streams.
- Recent international agreements and initiatives (SDG, COP21, food security) place significant emphasis and targets on healthy soils.

2. Details of submitter

Dr. Arwyn Jones is from the European Commission's Directorate-General Joint Research Centre (EC JRC), located in Ispra, Italy. I am responsible for coordinating the provision of relevant evidence base knowledge and data to support of soil related European Union policies. As the Commission's science service, the JRC[1] provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle. I authored the soil assessment of the 2010 State of the European Environment Report (SOER)[2], the JRC Reference Report on the State of Soil in Europe[3] and with the European Environment Agency, coauthored the Soil Chapter in the 2015 SOER[4]. I chaired the Working Group responsible for developing the Plan of Action for investment, technical cooperation, policy, education, awareness and extension[5] in relation to the UN Food and Agriculture Organization's Global Soil Partnership initiative and active in the development of the European Regional Soil Partnership. I am also responsible for the JRC's Soil Atlas Series and am currently coordinating the development of the first ever Global Soil Biodiversity Atlas in support of the Global Soil Biodiversity Initiative (https://globalsoilbiodiversity.org). Finally, I am responsible for the Commission's European Soil Data Centre (ESDAC)[6]. The footnotes indicated in this section provide a wealth of highly background information of relevance to the submission.

1 https://ec.europa.eu/jrc/
2 www.eea.europa.eu/soer/europe/soil
3 http://esdac.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/EUR25186.pdf
4 http://www.eea.europa.eu/soer-2015/europe/soil
5 http://www.fao.org/globalsoilpartnership/the-5-pillars-of-action/2-awareness/en/

3. Relevance of soil as natural capital

Soil is a keystone natural resource that provides life critical ecosystem services. Soils underpin almost all food, production, animal forage, as well as all natural fibres and plant biomass (timber, biofuels, etc.). Soils regulate global nutrient cycles and greenhouse gas fluxes. They mitigate flood events and help purify water supplies. They store, buffer and transform pollutants. A habitat in its own right, soils underpin aboveground ecosystems and are increasingly recognized as a critical genetic store. Soils preserve our cultural heritage and are the core elements of landscape that support tourism and leisure. Soils are at the heart of green economy.

Despite their fundamental role for the ecosystem and the economy, soil functions are taken for granted and perceived to be in abundance.

Soils are spatially diverse as they reflect local conditions of geological substrate, climate, position in the landscape, vegetation, human activity and time. Consequently, soil is an extremely complex and variable medium where its properties, the functions that they deliver and their responses to management practice vary. This has implications on policy development.

The EU Soil Thematic Strategy (COM(2006)231 final) outlines the arguments to protect soil while using it sustainably, through the prevention of further degradation, the preservation of soil function and the restoration of degraded soils.

Several human activities put pressure on soils which can lead to a loss of function or in extreme cases, a loss of the soil body. recognises soil erosion (by wind and water), soil sealing (also known as land take), contamination (both by local industrial activities and by diffuse emissions), landslides, a decline in organic matter, compaction and salinization as the major threats to soil across the EU. Apart from the build of salts, all of these threats are evident to a greater or lesser extent in the soils of the UK.

Increasing competition on land and soils is putting increased pressure on soils. Increased land take, often affecting the most productive soils, results in increased stress on more marginal soils or result in indirect soil pressure (i.e. in other countries or regions).

Soil degradation affects the ability of the soil to deliver key soil based ecosystem services and functions.

As it is a relatively slow process, soil degradation generally goes unnoticed.

An increasing urban society lacks awareness of the value and relevance of soil, which in turn is reflected in a low political priority. Addressing this at a societal scale is challenging. As a contribution to the establishment of the European Soil Partnership, the JRC is coordinating efforts to develop a range of material and best practices on soil awareness. A key element is greater emphasis on soil at all levels of education. There has been a significant decline in tertiary level soil science teaching in the UK. This could lead to a lack of critical mass to develop the necessary scientific knowledge base to support UK soil based policy development, implementation and monitoring.

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[6] http://esdac.jrc.ec.europa.eu/

Soil processes are strongly evident in the targets of the recently adopted Sustainable Development Goals and are highly evident in the outcomes of the COP21 in mitigating the effects of climate change (UK Government has acknowledged the 4/00 initiative for soil carbon sequestration and peatland restoration schemes).

4. Key areas of action for UK soils

- Development of current and policy-relevant knowledge-base

  The collection of systematic Information on the state of soil is a key mechanism to assess the impacts of policies on soil functions and also underpins the development of modelling frameworks and scenario analysis. UK should invest in coherent and systematic soil monitoring programme with emphasis on assessment of soil functions and key drivers (e.g. soil microfauna, soil organic carbon stocks).

- Targeted and integrated research programme leading to a better understanding of the spatial variability of soil functions, their value as natural capital and the economic consequences of soil degradation.

  While there is a wealth of basic soil research, there are still significant gaps in our understanding of the supply of soil functions, their resilience to pressure (especially climate change) and their intrinsic value. Much more research is required to address and understand the economic and environmental consequences of soil degradation, including indirect land use change. Conversely, research should demonstrate the secondary benefits of sustainable soil management.

- Provision of tools for land users to ensure sustainable soil management and reduction in the extent and intensity of soil degradation processes

  Ultimately, soil management is in the hands of land users, predominantly farmers. They should be supported through outreach and extension programmes to adopt sustainable soil management practices. The development of farm-scale ICT solutions to soil management (e.g. cropping systems for increase carbon sequestration)

- Multi-stakeholder awareness raising programme
  UK should address the general lack of societal awareness of the importance of soil in people's lives and the well-being of the planet. In many cases, deficiency in education is the specific underlying cause of unsustainable land management practices, of the general lack of investment (both in education and physical measures to protect soil) and of the widespread political reluctance to adopt short- and long-term measures to preserve and enhance soil conditions. This can be done through brief and vivid messages as part of a sustained long-term outreach and engagement programme. The UK Government should foresee a significant increase in investments to support such actions.

- Greater emphasis on the value of soil in all education streams (i.e. primary, tertiary, 3rd age)

  Education in soil sciences is important and needs to be taken into account by other disciplines. The current soil science community should strive to show synergies with other domains to demonstrate its relevance. Pressure should be brought at all levels to halt the decline in soil science teaching at tertiary level, while boosting professional technical qualifications and support to educationalists, so that soils and agriculture can be more appealing for the younger generations.

4. Current and upcoming challenges

Land use. Increasing competition for land, increased demand for food and fuel crops, will all lead to increased land use and potential soil degradation. At the same time, extreme weather events linked to climate change, together with land take for urbanisation and infrastructure development will exacerbate this trend. This matters to the UK because competition for land and water resources has economic, social and environmental implications not only in the UK but also across the world. Increasing global population and demands of developing economies are key factors to consider. econ. In addition, land degradation leads to a decrease in the amount of multi-functional land, which could lead to the UK being even more dependent in future on its finite land resources – which include some of the most productive soils in the world[7] – and on their sustainable use.

Preservation of soil organic matter. Intensive and continuous arable production can lead to a decline of soil organic matter. The historical drainage and conversion of peatlands has major implications for national soil organic stocks. However, with appropriate management practices, soil organic matter can be maintained and even increased. Apart from peatlands, particular attention should be paid to the preservation of permanent pastures and the agricultural soils as a contribution to the fulfilment of present and future emission reduction commitments of the EU.

A more efficient use of resources. Agriculture is highly dependent on soil fertility and nutrients availability. A mechanism should be developed to address security of supply of soil nutrients, improvements in soil conditions and limiting pollution.

Soil biology is increasingly recognized as the key driver for many soil functions. While our understanding of specific communities is increasing, the relevance of the interaction between them as part of the soil food web, their geographic and temporal variations and response to pressures are unknown.

There is an Increasing explosion in localized soil data collection, predominantly driven by precision agriculture. This information, coupled with crowd sourced data, the myriad of observations provided by earth observation sensors (e.g. the Sentinel systems of the EU's Copernicus Programme[8]) and 'big data' technologies will greatly improve risk assessment scenarios and modelling framework to help maximize soil functions whilst minimising degradation processes.

January 2016

[7] http://www.fwi.co.uk/arable/wheat-yield-world-record-shattered-in-lincolnshire.htm
[8] http://ec.europa.eu/growth/sectors/space/copernicus/index_en.htm

Written evidence submitted by the University of Reading

On 18th November, 2015, the University of Reading hosted an event on 'Soil Health', attended by 90 people from industry (consultancy and farmers), policy, conservation charities and Universities. Organisations represented included: ADAS, British Geological Survey, Carbon Gold, CCRI, Centre for Ecology and Hydrology, Defra, East Malling Research. Edaphos, Environment Agency, Estrells Education, Hampshire and Isle of Wight Wildlife Trust, Henan Polytechnic University, Institute for Environmental Analytics, Natural England, Natural History Museum, Natural Resource Intelligence & Innovation, Nepal Agriculture Research Council, Padjadjaran University, P.T. Hosier & Son, Penn Croft Farm, Rothamsted Research, Soil Association, Soil Bio Lab, STRI, Treework Environmental Practice, University of Bristol, University of Gloucestershire, University of Nottingham, University of Reading, Velcourt, Wexcombe Farming Co, Yara UK, Yatesbury House Farm, A summary of the key outcomes has been prepared by Dr Joanna Clark. The full workshop report will be published online:
https://www.reading.ac.uk/soil-research-centre/NewsEvents/src-stakeholder-event-2015.aspx

Executive summary

a. Demand for simple indicators to measure and monitor soil health across a range of sectors is high; people want to know if management strategies to improve soil health are working. However, the diversity of soil types and uses means that there is no one single measure that 'fits all'. The UK has the capability to develop a suite of tools across all sectors; we now need the leadership and resource to do this.
b. The UK has a wealth of soil data collected by public, private and third sectors that could be more fully utilised once barriers to data access and integration have been overcome. The UK Soil Observatory is an example of a platform that could be expanded further to broaden access and sharing of soil health data.
c. Government needs to bring consistency and alignment across all policies that directly and indirectly affect soils, to avoid conflicting advice presented to land managers and practitioners and conflicting outcomes.

How could soil health best be measured and monitored? How could the Government develop a strategy for tracking soil health?

1. Demand for a monitoring system to track soil health is high across all sectors; but the evidence base is not yet in place to move forward. Need to track long-term benefits from different environmental improvement measures were identified for use under trees, abandoned mine reclamation, conservation agriculture and impacts of anaerobic digestate on soils.
2. Data sharing is a priority. We need to make better use of the information we already have. Access to the national soil survey data and the detailed measurements of soil chemical and physical properties is limited to those who can pay for it. This is a major barrier to monitoring soil health. Awareness of tools, such as the UK Soil Observatory (http://www.ukso.org/), that provide access to soil maps need to be widely publicised across sectors, and beyond academia, so that people who need information know where to find it.
3. Data integration is a priority. Information about soil health is held in many different locations, from Universities, research institutes, consultancies to the farm office and garden shed. We need to pool data sources together to make better use of information available through platforms like the UK Soil Observatory.
4. The simple problems is that we have no specific definition of what soil health means in terms of quantitative indicators. Definitions depend on the intended user/industry (e.g. farmer, forester, golf course manager, conservationist) and the specific functions we want soils to be able to do (e.g. provide food, mitigate flooding and climate change). A question arose about whether we should measure soil health directly, or other indirect measures that act as an indicator of 'health' e.g. ability to support a crop; or ability to buffer again environmental stressors like drought or flooding.
5. Another challenge is whether we can define universal indicators that cover the diverse range of soils we have in the UK (and globally). For instance, a healthy agricultural soil may have high nitrogen content, whereas a high nitrogen content in a peatland is associated with poor health of that particular system.
6. Farmers and land managers noted that monitoring the direction of travel (improving or degrading) was more important than quantify the exact values of a specific indicator, e.g. soil organic matter or nitrogen content. They need to know if their management practices are actually improving soil health or not.

7. Delegates stressed the need for simple tools; particularly the need to improve the evidence base supporting the efficacy of rapid low-cost visual assessments. Although a range of measures are available, academics do not yet have the evidence to make a recommendation about the utility of a single tool. We have a good knowledge of soil physical and chemical properties, our understanding of soil biology is less well developed and currently a key frontier in research.

What are the benefits that healthy soils can provide to society? What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

8. Healthy soils are essential to support human life, from the most obvious things like food production to less obvious things like drinking water purification, climate change regulation, flood mitigation and cultural heritage; and the things we perhaps take for granted like turf to support recreation and the sports industry. Unhealthy soils will provide less of the things we need; critical issues as demand from a growing population increases.
9. One critical driver for interest in soil health from the farming community is the yield plateau; why have wheat yields not increased over the last 20 years in spite of advances in science and technology supporting food production? Many are concerned that declining soil health has had a role to play. Some people noted that perhaps there is an overreliance on technological solutions rather than integrating knowledge about managing fertility through crop-rotations, for instance.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

10. Many examples of good practice, motivated by a desire across sectors to 'do good' by our soils.
11. As noted above, we need a better evidence base to enable us to understand the benefits of different management strategies and simple tools to enable us to track soil health and provide the demonstrable benefits to persuade others to change practice and/or behaviour. For instance, many of the benefits of agri-environment measures for the full range of ecosystem services, including flood mitigation and water purification, provided by different types of soils has yet to be fully quantified and captured.
12. We need to put people at the heart of soil health. Soil science has traditionally focused on the soil itself, rather than the relationship between people and the soil/natural environment. Bringing the social dimension in earlier is more productive, rather than in crisis such as in response to flooding or a pollution incident.
13. Government and organisations need to consider is how to bring together the many fragmented measures. We need a whole systems approach to measurement, data collection, analysis and sharing.
14. Another key issue identified was one of land tenure. Tenants who don't own the land may not feel long-term responsibility or obligation to protect 'soil health'.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

15. Government needs to bring together all stakeholders to build a shared understanding of what soil health is and co-ordinate programmes to evaluate utility of different indicators across a range of soil types. We have national capability to do this work within and outside research institutions; what is need is leadership and resource to make this happen.
16. Government needs to bring consistency and alignment across current policies that directly and indirectly affect soils and the services they provide to people. At present, fragmented policy can present itself as apparently conflicting advice to farmers and land managers. Integration between air pollution, climate change, biodiversity, food and water policy is needed.
17. Government needs to develop cross-theme initiatives between soil health and tree health. Government has invested heavily in tree health and plant biosecurity research in recent years – efforts need to be coordinated.
18. Government needs to ensure there is alignment between policy targets and what is feasible in practice on-farm, in forests, gardens, sports turfs etc.

January 2016

Written submitted by the Sustainable Food Trust

Summary

- There is scientific consensus that soil health is essential for future food security, but also impacts on a wide range of other issues of national concern and global concern, including climate change, flooding, water quality, biodiversity, natural capital and non-renewable resource depletion and the health and well-being of society. However there is inadequate implementation of appropriate management practises.

- UK soils have predominantly been managed and assessed for well over half a century in terms of their physical and chemical properties only. Soil biological life is central to sustaining the health and productivity of soils, to improving their ability to sequester and store atmospheric carbon permanently and to achieving their full potential as a methane sink.

- Biologically active soils are also important for climate change mitigation and adaptation, flood prevention and drought tolerance, water quality improvement and the avoidance of potentially untreatable crop diseases.

- One of our central concerns is that some attempts to reduce UK greenhouse gas emissions are in fact worsening the problem of soil degradation. One example of this is the decreased consumption of UK produced red meat, which has reduced UK methane emissions, but led to increased consumption of chicken. This has resulted in the conversion of grassland to crop production in the UK, with resultant losses of organic matter and increased importation of soya from South America, where its production is linked to the progressive degradation of recently virgin land. As such we feel policies need to be developed which address these two serious challenges in a coordinated way.

- We also feel the Government should recognise the paramount and unique role of grass and species-rich grassland in particular for the production of high quality and low carbon beef, generating income for farmers and at the same time as improving soil health and simultaneously addressing a wide range of related biodiversity and other issues. As such, policies are needed to save the UK's traditional grazing livestock sector from economic collapse and prevent this being replaced by more intensive systems with greater use of grain, a trend which is already underway.

- There is a theoretical case and a limited amount evidence, that increasing extremes of acidity and alkalinity in UK soils, the prolonged use of ammonium-based fertilisers and glyphosate, and the build up of cadmium, a contaminant of phosphate fertilisers and elsewhere (which can replace zinc in plant tissues), could be reducing the availability of important micronutrients such as selenium, zinc and copper, and this could be reflected in lower levels in typical human diets, with implications for diseases such as cancer where studies have found that dietary zinc reduces cancer rates.

- Appling the internationally agreed precautionary principle means that appropriate research and implementation is needed on how to better manage soils to help address a wide range of environmental and human health issues.

1. Introduction

1.1 The Sustainable Food Trust (SFT) is a UK-based charity with a global remit to help accelerate the transition to more sustainable food systems globally. We work collaboratively with a wide range of academic and other non-government organisations in the UK and other countries. Our evidence is based on our analysis of issues, supported by published research. We will not address parts of two points in the terms of reference as we have little evidence to present on these aspects.

2. How could the Government develop a strategy for tracking soil health?

2.1 The Government should openly acknowledge that soil health is of equal importance to climate change for the longterm wellbeing of the human race. Consumers, retailers, food producers and others need to be made aware of the problem in order to give the Government sufficient political support for the extensive programme of action and change needed to address the problem.

2.2 The Government should establish a task force to assess and advise on whether current agricultural practices are appropriate and adequate to address the wide range of inter-related food security, environmental sustainability and diet-health related issues we face. Addressing the issue of soil health should be one integral aspect of the task force's work.

3. What are the benefits that healthy soils can provide to society?

3.1 Remaining healthy English soils contain:

- Substantial amounts of carbon and nitrogen, as key components of soil organic matter,
- Beneficial bacteria, including methanotrophs, which use methane as their energy source – and constitute the soil methane sink[1,2],
- Multitudes of insects and other invertebrates, such as spiders, many of which are beneficial in that they predate agricultural pests such as aphids.
- Over 1,000 species of ground beetles, which predate agricultural pests such as slugs,
- Large numbers of other bacteria and fungi with natural antibiotic properties – some with potential as new therapeutic agents, - only 3% have so far been studied[3].

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[1] **Tate, K.R., (2015)**. *Soil methane oxidation and land-use change e from process to mitigation*. Soil Biology & Biochemistry, 80, 260-272

[2] **Nazaries, L., Murrell, J.C., Millard, P., Baggs, L., Singh, B.K., (2013).** *Methane, microbes and models: fundamental understanding of the soil methane cycle for future prediction*. Environmental Microbiology, 15, 2395-2417

[3] **Vakhlu, J., Ambardar, S., Johri, B.N (2012)**. *Metagenomics: A Relief Road to Novel Microbial Genes and Genomes*. In: Microorganisms in Sustainable Agriculture and Biotechnology. Springer Netherlands, 263-294.

3.2 Healthy soils also have enhanced ability to absorb heavy rainfall, reducing the risk of flooding due to heavy rain and also making crops less prone to drought. Extensively managed grassland dramatically slows the runoff of heavy rain to watercourses, compared with over-stocked grassland and cropland[4]. Scientific opinion varies on how much moisture can be absorbed by humus – the most stable form of organic matter, but estimates vary from 4 to 20 times its own weight. Healthy soils, and especially those under appropriately stocked grassland, are also very important for water quality. Soils under remaining semi-natural grassland also contribute to the provision of clean groundwater through the absorption of the reactive atmospheric[5].

3.3 Current high levels of atmospheric CH_4 pose a very serious threat and healthy soils represent its only biological sink. Methane emissions reduction takes place in well-aerated and extensively managed soils, where low affinity and high affinity methanotrophic bacteria respectively, use CH_4 produced by methanogens in the soil and CH_4 in the atmosphere as their energy sources. Soils only break down c. 5% of global CH_4 emissions, so the soil methane sink is frequently overlooked, but with atmospheric concentrations increasing at only 0.1% p.a. over the last decade, small changes in the sink have the potential to increase or reduce total concentrations. Changes to land management, specifically the conversion of forest and natural grassland to crop production and the use of ammonium-based fertilisers, have seriously damaged the soil methane sink. Because of this, grassland soils tend to oxidise CH_4 at a higher rate than cropland soil (6 and 3 kg CH4/ha/year respectively), and therefore play an important role in helping to balance GHGs emissions[6,7].

4. What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

4.1 Healthy soils are essential for the survival of all societies. There are many examples of civilisations that have flourished for centuries on fertile soils, which eventually disappeared into the sand and dust created by their own land mismanagement. These include the Sumerians in Mesopotamia; to a certain extent, the Roman Empire's exploitation of the once highly fertile soils of North Africa; parts of ancient Greece, China, India, and Central America.

4.2 Yet despite our far greater knowledge, we are mismanaging soils just as badly as many past civilisations. When soils were exhausted, those societies were often able to migrate to new regions with fertile soils and develop new communities. We no longer have that option because we depend on a global food system and soil degradation already affects more than half (52%) of all farmland. There are also pressing ecosystem

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[4] **Bullock, James M., et al. (2011)**. *Semi-natural grasslands*. WCMC-UNEP, Cambridge.
[5] **Phoenix, G. K., Booth, R. E., Leake, J. R., Read, D. J., Grime, J. P., & Lee, J. A. (2003)**. *Effects of enhanced nitrogen deposition and phosphorus limitation on nitrogen budgets of semi-natural grasslands*. Global Change Biology, 9, 1309-1321.

[6] **Soussana, J. F., Tallec, T., & Blanfort, V. (2010)**. *Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands*. Animal, 4, 334-350.

[7] **Nazaries, L., Murrell, J.C., Millard, P., Baggs, L., Singh, B.K., (2013).** *Methane, microbes and models: fundamental understanding of the soil methane cycle for future prediction*. Environmental Microbiology, 15, 2395-2417

and cultural reasons for preventing the conversion to crop production of the remaining areas of virgin grassland and forest.

4.3 ***Food security*** The relationship between soil degradation and decrease in agricultural productivity is well documented[8]. It is estimated that every year 12 million hectares (23 hectares a minute) of land is lost to food production. In addition, 24 billion tonnes of fertile soil is lost each year, 3.4 tonnes for every person on the planet. It is projected that soil degradation will lead to a 12% decline in global food production over the next 25 years, resulting in a 30% increase in world food prices[9]. This will occur during a period when more is demanded of soils than ever before, due to the growing global population and climate change.

4.4 The most likely reaction to this will be to encourage even greater intensification of food production, which in the medium term will only make the underlying problem worse[10] [11]. This will increase pressure for the last remaining areas of natural grassland and forest to be converted to food production with devastating consequences for wildlife and planetary ecosystems.

4.5 While currently uncollated, a large number of studies show that crops are less prone to disease and pest attack when grown in soils with high, rather than low organic matter. The recent emergence of septoria in wheat, resistant to all current fungicides, gives advanced warning that crop yields and quality in future could be reduced dramatically on land with degraded soil.

4.7 ***Climate Change*** Some of the most actively promoted measures for mitigating climate change will actually increase soil degradation, while doing little if anything to reduce emissions. One of these is the conversion of grassland to crop production in the belief that poultry production is more environmentally benign than beef and sheep-meat production. Our analysis is that methane from ruminants is responsible for 3-4% of global greenhouse gas emissions, significantly less than many people have been led to believe, that chickens are in direct competition with humans for grain, whereas ruminants can eat grass and crop residues, and that FAO's frequently cited 2013 report[12] is highly misleading because it conflated livestock emissions with land use change and then only in South America.

4.8 Between 42—78 billion tonnes of carbon have been lost from soils over the last century, mostly emitted to the atmosphere as carbon dioxide[13]. Changing the use of

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[8] **Lal, R. (2001)**. *Managing world soils for food security and environmental quality*. Advances in agronomy, *74*, 155-192.

[9] **UNCCD, (2015)**. *Desertification, Land Degradation & Drought (DLDD): some global facts and figures*. United Nations Conventions to Combat Desertification.

[10] **Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., Whitbread, A. (2012)**. *Global food security, biodiversity conservation and the future of agricultural intensification*. Biological conservation, 151(1), 53-59.

[11] **Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B. & Steinfeld, H. 2013.** *Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment.* Food and Agriculture Organization of the United Nations (FAO), Rome.

forest or natural grasslands to continuous crop production leads to the loss of a large part of this carbon to the atmosphere, where it contributes to global warming[14]. This is widely understood. Less well understood however is the fact that such land use change also leads to the loss of nitrogen from soils, predominantly in the form of nitrous oxide, which in global warming terms increases the impact of such land conversion by 50%[15]. Conversion of grassland to arable soils also results in an increase in CH_4 emission from soils[6] and leads to both loss and degradation of hedgerows and mature trees with additional implications for soil carbon sequestration, catchment management and biodiversity.

4.9 ***Economic*** Failure to protect soils has severe economic consequences. It is estimated that the value of quantifiable soil degradation in England and Wales is in the range £0.9-1.4 billion per year[16]. This is mainly linked to the loss of organic content of soil (47%), compaction (39%) and erosion (12%) and does not include the costs associated with the loss of cultural services, soil biota or soil sealing. The estimated costs of soil degradation are positively correlated with the intensity of farming. The negative impact on the global economy of soil degradation has recently been estimated at $6.3-10.6 trillion p.a.

4.10 ***Public Health*** Soil health has several direct and indirect implications for human health. Humans may acquire chemical pollutants and pathogens directly from the soil through inhalation and dermal absorption[17]. More indirectly, soil erosion, surface runoff, interflow and leaching transfer pollutants and pathogens from soils into watercourses, the plants and animals that constitute our food chain. The extensive use of antimicrobials in agriculture means that most livestock manures contain both antimicrobial residues and resistance genes.

4.11 Phosphate fertilisers contain cadmium impurities[18] and cadmium, being close to zinc in the periodic table, can replace it in plant tissues. Water-soluble phosphates also suppress soil fungal communities, including mycorrhiza, which play an essential role in plant uptake of trace elements of importance in human nutrition. Further, while the average soil pH level has changed little since the 1970s, this masks an increase in soil acidity on naturally acidic soils, due to increased crop yields and reduced use of agricultural lime, which reduces the availability of selenium; while increased alkalinity

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[13] **Lal, R., (2004)**. *Soil carbon sequestration to mitigate climate change*. Geoderma, 123, 1-22.

[14] **Guo, L.B, Gifford, R.M., (2002)**. *Soil carbon stocks and land use change*. Global Change Biology, 8, 345-360.

[15] **Vellinga, Th.V., van den Pol-van Dasselaar, A., Kuikman, P.J., (2004)** *The impact of grassland ploughing on CO_2 and N_2O emissions in the Netherlands.* Nutrient cycling in Agroecosystems, 70, 33-45.

[16] **Graves, A.R., Morris, J., Deeks, L.K., Rickson, R.J., Kibblewhite, M.G., Harris, J.A., Farewell, T.S., Truckle, I., (2015)**. *The total costs of soil degradation in England and Wales*. Ecological Economics, 119, 399-413.

[17] **Brevik, E. C., Sauer, T. J. (2015)**. *The past, present, and future of soils and human health studies*. Soil, 1, 35-46.

[18] **Roberts, T.L. (2014)** Cadmium and Phosphate Fertilzers: The Issues and the Science, Procedi Engineeering 83, 52-59

on limestone and chalk soils, due to increased cultivation, would be expected to reduce the availability of copper. A number of studies also implicate nitrogen fertiliser in unhealthy changes in soil microbial life, while a handful of studies claim to find that the herbicide, glyphosate, locks up (chelates) soil minerals, further reducing their availability to plants.

5. What further measures should the Government and other organisations consider in order to secure soil health?

5.1 Given the technological advances that have been made in recent years and the greater scientific understanding of the issues today, all types of soil degradation are potentially reversible, as long as there is sufficient public support, understanding and political will.

5.2 Under appropriate management soils are an infinitely renewable resource, while under inappropriate management they are effectively a very finite resource. Under natural condition it can take 500-1,000 years to form an inch of soil from parent rock. Soil organic carbon (SOC) could be increased in farming systems through the use of carefully prepared compost derived from urban waste and the replacement of nitrogen fertiliser with compost and fertility building break crops, such as clover and other legumes. Other practices with the potential to increase SOC and reduce soil degradation include cover crops, optimal fertilisation, appropriate stocking densities, the use of more productive and more nutritious grasses, deeper-rooting grasses, hedgerows and tree planting and carefully timed applications of composted livestock manure or aerated slurry. We recommend that the Government and other organisations become active in promoting those practices which treat soil as a renewable resource to be maintained and improved for the future, instead of an inert medium, through which soluble chemicals are transferred to plants.

5.3 The greater use of cover crops could help to improve soil health with multiple benefits, including protecting the soil, reducing nutrient loss, improving soil structure, fixing nitrogen, feeding soil biological life, and managing soil moisture. Cover crops are also beneficial for promoting beneficial microbes that suppress soil-borne pathogens. However, policy makers should recognise that increased planting of cover crops is unlikely to occur without policy incentives, because establishing cover crops incurs extra costs and prevents arable farmers following what are currently the most economic rotations.

5.4 Several studies show that as an alternative to conventional tillage, no-till can improve the functioning and quality of soil[19],[20],[21]. However, a meta-analysis of the

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[19] **Garcia-Franco, N., Albaladejo, J., Almagro, M., Martínez-Mena, M., (2015)**. *Beneficial effects of reduced tillage and green manure on soil aggregation and stabilization of organic carbon in a Mediterranean agroecosystem*. Soil & Tillage Research, 153, 66-75.

[20] **UNEP, (2013)**. *The Emissions Gap Report*. United Nations Environment Programme, Geneva.

[21] **Lal, R. (2012)**. *Climate Change and Soil Degradation Mitigation by Sustainable*

evidence undertaken in the UK showed that mitigation potential of no-till through soil carbon sequestration has been widely overstated, with any measurable increase in SOC in the top few inches of soil doing no more than compensating for SOC losses at greater depths[22]. The study concludes that where no-till is appropriate it can be beneficial to soil structure and resilience, but that is should not be advocated in relation to climate change mitigation. A review of 610 studies comparing no-till with conventional tillage undertaken by researchers at the University of California Davis found that while there are situations in which no-till can increase production, overall it reduced yields by 6-9%[23]. Taken together these two studies call into question the value of no-till systems for increasing SOC and crop yields. A further problem associated with no-till systems is the build up of perennial weeds such as blackgrass that are resistant to all herbicides.

5.5 In England over the last decade there has been significant conversion of grassland to cropland, driven in part by the low profitability of grazing livestock. Evidence from longterm studies at Rothamsted shows that SOC declines steadily where grassland soil is ploughed and converted to continuous arable crop production, while it increases steadily where cropland is sown to grass[24]. These studies also show that alternating crop and grassland rotations have the potential to slowly increase SOC levels, providing the correct balance is achieved between carbon building under grass and carbon exploitation under cropping.

5.6 We recommend that the Government promotes sustainable grazing livestock as a central aspect to the development of sustainable food systems, because of the paramount role of grass in preserving existing soil carbon stocks and its potential to reverse soil degradation and rebuild soil carbon and structure. Many organisations have promoted the decline in ruminant production, due to their methane emissions. But ruminants can be managed in ways which do not add to atmospheric carbon, since the carbon atoms in their methane and carbon dioxide emissions cannot exceed those which are turned into carbohydrates each year through photosynthesis, by the plants they consume. Emissions per kg of meat or litre of milk are also much lower in England than the world's drylands, due to higher productivity. As such global averages should not be used to assess policy options for the UK.

5.7 The fact that extensively managed grasslands are at least twice as effective as croplands, per hectare as a soil methane sink also needs to be recognised, since it has implications for land management choices, and policies are needed to help restore the methane sink on degraded soils.

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5.8 We also recommend that the Government and other organisations take soil biodiversity into account when assessing terrestrial ecosystems.

5.9 It is essential that these issues be better understood and that policies are developed to address two global threats of climate change and land degradation simultaneously.

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