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/statisticsexplained/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