**Resistance to perturbation in agricultural land: can we identify and fingerprint functional soil conditions across scales?**

## Objectives

The Soil Security programme seeks an improved and predictive understanding of the ability of soils to perform multiple functions in different contexts and at different scales, and their ability to resist, recover and adapt to perturbations, such as those caused by land use change and extreme climatic events. This project will address these goals by producing new large-scale data to enhance existing datasets from national soil monitoring networks and distributed field experiments, employing novel environmental modelling methods to improve mechanistic understanding, and developing and testing new tools which utilise spectral measurements for estimation of soil characteristics. It will identify important controls on soil quality indicators (SQIs) and conditions associated with biophysical resistance to perturbation under agricultural land management, and assess the utility of spectral approaches to fingerprint soil conditions that confer resistance. The following are specific objectives to meet these aims:

O1. Determine the contribution of plant composition, soil type, and land management history, in driving SQIs and biophysical soil resistance.

O2. Construct multivariate normal operating ranges for key SQIs and biophysical soil resistance, and assess whether there are differences in these between climatic/environmental zones and soil types.

O3. Derive calibrations using spectral data for the prediction of SQIs and compare approaches of increasing complexity (i.e. MIR v NIR v VIS v RGB).

O4. Test and validate spectral approaches to assess SQIs and resistant soil conditions in distributed field experiments where the agricultural ecosystem has been perturbed.

In achieving these objectives the project will generate new insight to improve understanding of the functioning and to inform the management of UK soils, complementing and extending the work of existing consortia, as well as developing novel directions within the scope of the programme.

**Summary**

Managing the land sustainably is important to nature and human wellbeing. The way that agricultural land is managed, and the plant species which are grown on it, can influence biological, physical and chemical characteristics of soil, and affect its ability to recycle nutrients, grow crops, feed grazing animals, regulate water movement and store carbon. The effects of higher management intensity over an extended period of time (e.g. continuous cropping, increased use of fertilisers, higher grazer densities) is likely to degrade soil quality and reduce its ability to sustain the various services that it provides such as food production, water and nutrient cycling. Understanding how different agricultural land management practices may impact soil conditions is therefore important so that soil quality can be maintained or improved. Poor quality soils may also be more susceptible to perturbations such as flooding and drought. Since these climatic events are becoming more frequent in the UK, it is also vital that we recognise management practices and soil conditions that confer resistance to such perturbations.

This project aims to identify the influence of plant composition, land management and soil type on soil characteristics considered as indicators of soil quality. It will use existing data from a UK-wide monitoring programme and create new data using archive soil samples to examine soil indicators (e.g. organic matter concentration) and biophysical resistance (e.g. soil aggregate stability) across the gradient from arable to semi-natural grassland management. This work will also evaluate whether combinations of soil quality indicators differ between climatic regions and soil types of the UK.

Since the measurement of soil properties with extensive sampling can often require detailed, time-consuming and expensive laboratory analyses, there has been a drive towards the development and use of proximal approaches for measuring soil properties. These approaches include the use of spectral measurements, which examine the reflectance of different wavelengths of light from soil samples, and are used to derive calibrations which can be validated and use to estimate soil properties using the spectral information. Model calibrations will be derived for three different spectral methods and digital imagery, including spatial environmental data, and the utility and predictive ability of these approaches to fingerprint soil quality indicators compared. The methods using visible spectra and digital imagery will then be applied and field-tested, across landscape gradients and in field experiments, and appraised with regard to the cost and utility for estimating soil quality indicators across scales.

This project will quantify how soil quality indicators are affected by environmental factors and how it changes across a gradient of agricultural land management, and identify conditions that determine the ability of different soils to resist and recover from perturbations. It will also test the ability of spectral measurements to fingerprint soil quality and resistance with the potential to provide a rapid evaluation of soil quality under different management practices. Overall, it will generate new scientific insight to inform the sustainable management of UK soils and provide practical tools to estimate soil functioning on agricultural land.

**Academic beneficiaries**

The Soil Security Evidence Review [1] identified areas of soils and land use research for which there was a limited evidence base. These areas included establishing envelopes of normality (or normal operating ranges) for soil quality indicators, benchmarking indicators for ecosystem services and specific soil functions, identifying indicators that can detect change in ecosystem delivery within a policy cycle (particularly those combining proximal sensing and modelling), and the assessing the practicality of different approaches such as spectroscopy to provide soil information. In specifically addressing these highlighted areas with a limited evidence base, this work detailed in this proposal and its outcomes would have clear and direct benefits for other researchers in the UK, but findings will have relevance to researchers internationally involved in soils and land use research.

It will increase understanding of the links between above and belowground systems under agricultural land management, and extend knowledge of the key controls on soil quality indicators. It will also provide information on the normal range of soil indicators expected given particular climatic and soil conditions, and researchers will be able to adopt the relevant data and modelling approach to test whether soils from their own fieldsites and experiments are outside typical conditions. High-impact journals will be targeted to publish the findings from the novel modelling components of the project so that they reach as wide an audience as possible. We will also aim to publish summary articles in national and international research magazines (e.g. Planet Earth, Impact) so that other disciplines are aware of the work.

The project will leave a legacy of large-scale datasets on key soil indicators, which are linked to existing databases of land use, plant community and soil characteristics measured since 1978 in the Countryside Survey. It will also create spectral data using visible (VIS), near-infrared (NIR) and mid-infrared (MIR) approaches and generate data for hundreds of samples taken from across a broad gradient of agricultural land use. These data have potential to contribute to further large-scale modelling and mapping, and the spectral data has the potential to be combined with Earth Observation data for improved prediction of environmental characteristics across large spatial scales e.g. [2].

The datasets and spectral libraries created by this project will be published and/or made available in suitable repositories to facilitate re-use of data. These will be publicised via the UK Soil Observatory website and the EU JRC Soils portal, and appropriately referenced in all publications deriving from the project so that other researchers are fully aware of their availability.

[1] Soil Security Programme & ADAS Ltd. 2016. 2015. Soil Security Evidence Review Defra report SP1620.
[2] Peng et al. 2015. Modeling Soil Organic Carbon at Regional Scale by Combining Multi-Spectral Images with Laboratory Spectra. PLoS One 10(11): e0142295.

**Impact Summary**

Agricultural land management controls the delivery of functions and services provided by soils. Changes in management intensity can degrade soil quality and its multifunctional capacity. It is therefore of critical importance to broaden understanding of how different agricultural land management practices may impact soil conditions and also how changes may alter the ability of the soil to resist perturbations such as flooding and drought. The research and policy community will benefit from the scientific insight generated by the project, including improved understanding of the links between above and belowground systems under agricultural land management, and extended knowledge of the key controls on soil quality indicators. It will also leave a legacy of large-scale datasets on key soil indicators and spectral data using visible (VIS), near-infrared (NIR) and mid-infrared (MIR) approaches, linked to existing co-located environmental data, across a broad gradient of agricultural land use from arable to semi-natural grassland. These data have excellent potential for re-use and contribution to further large-scale modelling and mapping is expected. The findings from the project will impact farmers and land managers by providing spatially relevant information to help with land management decisions for sustainable soil functions under changing climate. The tools developed in the project also have the potential to provide the ability for cheaper, more rapid evaluation of soil quality under different management practices, and the ability to measure these more intensively over time. The development of a smartphone app mean that such tools could be readily adopted. Together, the findings of the project inform the sustainable management of UK soils and provide the practical tools to estimate soil functioning on agricultural land.