European Commission

Science for Environment Policy

03 May 2018
Issue 507

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Source: Viscarra Rossel, R. A., Lobsey, C. R., Sharman, C. *et al*. (2017). Novel proximal sensing for monitoring soil organic C stocks and condition. *Environmental Science & Technology*, 51: 5630–5641. DOI: 10.1021/acs.est.7b00889.

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New soil-sensing method enables more detailed, rapid and efficient environmental monitoring of soil carbon stocks and condition

In-depth soil information is increasingly required to achieve an array of environmental and economic goals. In particular, accurate estimates of soil carbon stocks are necessary to guide land-management practices and climate-related policymaking. To help meet this need, Australian scientists have developed a new sensing method to analyse cylindrical soil samples (soil cores), known as the Soil Condition ANalysis System (SCANS). By integrating a novel automated soil-core sensing system (CSS) with advanced statistical analytics and modelling, the SCANS provides a level of detail that is difficult to achieve with existing alternatives. SCANS is not only rapid, accurate and inexpensive[1], but is likely to be a useful tool for farmers, land managers and policymakers, as the improved assessment of soil functions, structures and carbon stocks will facilitate more informed, sustainable decision-making.

Soil information occupies an increasingly important role in environmental monitoring, and is required to inform current policymaking on issues such as land degradation, climate change, and food, water and energy securities. In order to better understand soil and its role in Earth's ecosystems, scientists need to assess and monitor its physical, biochemical and mineralogical properties. To date, researchers have typically taken soil samples to be analysed in the laboratory. However, this is a time-consuming, expensive process and does not meet current needs for highly detailed, quantitative soil information.

Proximal soil sensing (whereby sensors are placed in contact with, or close to, the soil being characterised) is a promising alternative to laboratory-based methods. It enables researchers to use sensors to characterise soil cores while still in the field, without needing to take samples away. This means that soil attributes can be measured more rapidly, accurately, and cheaply, in real time. Moreover, since more measurements can be made at different times and depths, it allows for more accurate characterisation of the ways in which different soil properties vary over time and area.

Now, a team of Australian scientists has developed a novel soil-core sensing method known as the SCANS, which integrates proximal soil-sensing technologies with statistical analytics and modelling to enable more comprehensive, efficient and accurate soil surveys. First, a portable CSS, which analyses soil cores in real time using an array of sensors, is deployed to the fieldsite. These include a γ-ray attenuation densitometer — a system that measures the reduction in radiation beams going through the soil core to infer the bulk density of the soil; digital cameras that image the soil being measured; a visible-near-infrared spectrometer that measures iron oxides, and clay mineralogy.

The core-sensing system of SCANS is mounted on a trailer, so its operation is dependent on the situation and the local needs. It can, for example, be parked next to a field for near real time measurements, or, if weather is hot/cold it can be taken inside a shed and a 'runner' transports the soil cores to it for measurement; or it can be in an analytical lab.

Continued on next page.

1. For information on the cost advantage of SCANS application over other SOC measurement/estimation practices see: Rossel, R.A.& Brus D.J. (2017). The cost-efficiency and reliability of two methods for soil organic C accounting. *Land Degrad Dev*. 2018;1–15.

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New soil-sensing method enables more detailed, rapid and efficient environmental monitoring of soil carbon stocks and condition *(continued)*

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The platform collects and senses soil cores at the depth intervals and resolution required by the user. The SCANS can work with a wide range of soils, provided soil coring is performed using practices and equipment appropriate to the soil type. While the SCANS has not yet been tested with very sandy soil or soil with soft or weak consistency, testing has found it to be effective for use in soil with gravel layers. However, it is worth noting that this approach is not well-suited to very dry or hard-setting soil due to penetration difficulties.

Once the soil cores have been collected, spectroscopic modelling is used to estimate a range of measurements — including total soil organic carbon, particulate, humus, resistant organic carbon, clay content, cation exchange capacity (the soil's ability to hold positively charged ions), pH, volumetric water content and available water capacity — and their uncertainties. Finally, the measurements of bulk density and organic carbon are combined to estimate carbon stocks, and a complete soil-property profile is created using Kalman smoothing (an algorithm that allows the uncertainty in the sensor measurements to be incorporated into the process). The accuracy of these spectroscopic estimates depends on the model used and how it was derived. When available, 'local' or site-specific data should be used to generate the most accurate predictions. Failing this, 'global' models can be created using existing soil-spectral libraries, so long as they contain spectra from soil samples that are similar in composition to those in the area being studied.

The SCANS is able to simultaneously sense multiple soil properties and so provide continuous, extremely detailed soil information in a way that is rapid, inexpensive and spatially precise. As such, it represents a powerful new tool for improving understanding of soil, and is suited to a variety of environmental applications. For example, it can be used to monitor soil organic carbon for accounting purposes, to model organic carbon sequestration for future soil-carbon storage projects, and to assess and monitor soil contamination by heavy metals and other pollutants. The system can make as many measurements as necessary during a day's soil monitoring — for example, 30 measurements can be made on a 1 m soil core in around 30 minutes[2].

The SCANS is also useful in agronomic applications as it could be used, for example, to improve understanding of nutrient mineralisation or to inform strategies for enhancing the water-holding capacity and infiltration of soil. Notably, the information gained using the SCANS can help to determine whether the condition of soil, its functions and its productivity are changing over time — and so can be used to promote sustainable soil and environmental management, refine the sustainability of farming practices to boost food production[3], and sequester carbon.

2. For more information and a comparison between SCANS and other soil monitoring techniques see England, J. & Rossel, R.A. (2018) Proximal sensing for soil carbon accounting. *SOIL Discuss*. https://doi.org/10.5194/soil-2017-36, in review, 2018. https://www.soil-discuss.net/soil-2017-36/

3. The SCANS system would be too expensive for a small farmer. It is currently being licensed in Australia to large farming enterprises, farmers' cooperatives, or regional consultants by the Commonwealth Scientific and Industrial Research Organisation (CSIRO).