Food and Agriculture Organization of the United Nations

ITPS | SOIL LETTERS

INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

4

September 2021

SPECTROSCOPY: TOWARDS ECO AND HUMAN FRIENDLY SOIL ANALYSES

This letter aims to show how spectroscopy can offer a fast, reliable, and environmental-friendly method to provide the large soil information databases necessary for decision making in sustainable agricultural systems.

Soils are primarily heterogeneous, and naturally exhibit both horizontal and vertical variability, as well as varying over time. Intensive agricultural practices like crop rotation, fertiliser and lime application and degradation processes, such as nutrient mining by crops, nutrient leaching and erosion/deposition can further increase soil variability. A spatially dense soil analysis is often required to comprehensively understand these variations and prepare spatial distribution maps of the soil properties. Once completed, such maps become an invaluable tool when obtaining global estimates of given properties, as well as enabling precision farming and site-specific nutrient management (SSNM).

Building knowledge about soil health[1] is imperative when formulating an efficient and sustainable production system. At the present time, a large number of laboratory analyses and soil samples are required to generate information on soil spatial/temporal variability and soil health. However, such analyses are time-consuming, labour intensive, often not environmentally friendly, and can be harmful to human health. A study conducted by the FAO Global Soil Laboratory Network (GLOSOLAN) showed that most standard chemical analyses have medium or high risks to human health and can contribute to environmental pollution[2]. Additionally, complete soil analyses are often costly, requiring a range of different equipment and chemicals. However, these issues can mostly be avoided through the development of quicker and less expensive detection methods.

Soil spectroscopy, or dry chemistry, is an evolving technology for rapid, cost-effective and non-destructive characterisation of soil properties based on the interaction of electromagnetic energy with matter (Nocita *et al.*, 2015). Here, electromagnetic spectra of soils are correlated with the conventional laboratory-measured soil properties of interest to develop mathematical prediction models. After the satisfactory validation of the prediction models with an independent dataset, the prediction models are used for quantitative prediction of soil properties. This technique opens up new possibilities for its application in SSNM, monitoring soil quality in landscapes and digital soil mapping. One of the advantages of soil spectroscopy is that it is able to simultaneously retrieve various soil properties from a single spectrum. However, the accuracy of the spectroscopic technique depends on the accuracy of the conventional laboratory methods used to analyse different soil properties and the multivariate statistical procedures

1 http://www.fao.org/documents/card/en/c/cb1110en

2 http://www.fao.org/global-soil-partnership/glosolan/soil-analysis/standard-operating-procedures/en/

NIR spectrometer with fiber optics and a tungsten halogen lamp in a fixed geometry analyzing a rotating comparably large sample

itps INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

GLOBAL SOIL PARTNERSHIP

VIS-NIR portable spectrometer

followed in the development of prediction models. Thus, basic analytical capabilities of laboratories need to be improved and much research is needed in different soils and environments, mainly in the less developed regions of the globe.

The indisputable advantages of spectroscopic methods for studying soils in comparison with the routine laboratory chemical methods are:

- speed;
- low cost of analysis (wherever a large database is available);
- minimum environmental hazard;
- minimum risk to human health;
- no need to purchase chemicals and utensils;
- possibility of a non-destructive method of soil analysis (currently only possible for soil surface surveys); and
- equipment portability.

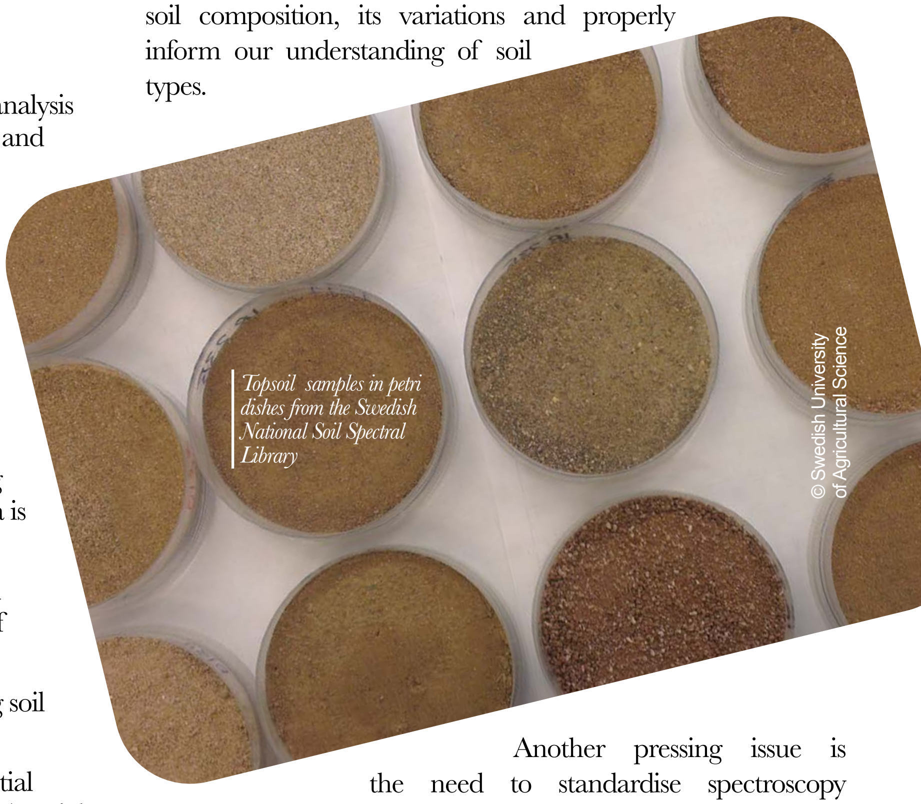
Nevertheless, spectroscopic methods also have some limitations.

- Reliable regional calibration data has to be collected in addition to the existing global spectral libraries or soil libraries from other countries and regions.
- The accuracy of measurements will keep being refined for as long as additional calibration data is made available. There is no end point.
- For more accurate results, the soil samples need drying and grinding, slowing down the speed of analysis.
- A detailed protocol for preparing and analysing soil samples is necessary.
- Suitably trained personnel together with the initial investment in the spectrometers and laboratory (special conditions for more precise data) limit the number of facilities with the capacity to analyse, process and store the data in the soil libraries.

The soil properties predicted with the highest accuracy using spectroscopic techniques are organic and inorganic carbon, total carbon, total nitrogen, granulometric fractions, especially clay, cation exchange capacity, and pH (Soriano-Disla *et al.*, 2014). The available nutrients can also be predicted with acceptable accuracy once a good regional soil spectral library is available.

The initial work on IR spectroscopy was carried out mainly in the near-infrared (NIR) range as instruments working in that range were readily available (Stenberg *et al.*, 2010). However, technological advancements in the mid-infrared (MIR) regions over the last twenty years have made its use in soil spectroscopy much more attractive. The technique utilises diffuse reflectance Fourier transform mid-IR spectroscopy (DRIFTS) using grounded but non-KBr diluted samples. In soil spectroscopy, a minimal pre-treatment of soil samples i.e. drying and grinding of soil samples to < 0.5 mm size, is also required.

As previously mentioned, one of the major constraints for the wider application of soil spectroscopy is the lack of universal spectral calibration libraries for different soil types. The development of robust spectral calibrations require a large volume of laboratory-analysed soil data with corresponding spectral signatures to cover the diversity of soils in each region of interest. This means that all the leading laboratories worldwide need to collaborate and share their spectral database, in order to develop and validate more robust and accurate prediction models for soil characterisation on a large scale, across a wide range of soil environments. Only then can the global soil spectral library effectively describe global soil composition, its variations and properly inform our understanding of soil types.



Topsoil samples in petri dishes from the Swedish National Soil Spectral Library

Another pressing issue is the need to standardise spectroscopy instruments and the conventional procedures used to analyse the soil samples. Once fully developed, the soil spectral libraries will provide the basis for the development of robust chemometric models. Combining the models with pedotransfer functions or with the remote sensing-based platform will also help to develop a soil database on a spatial scale. To this end, an international standard for collecting laboratory spectra and the inclusion of spectra of reference materials should be developed to reduce the costs linked with the collection of new samples. Looking forward, developing a common standard procedure for collecting spectral signatures and retrieving soil properties from spectra through chemometric analyses is likely to give rise to new applications for spatial scale analysis of soil attributes.

There are several international and national soil spectral libraries covering many parts of the world. The most geographically diverse is the Vis-NIR international library collected under the leadership of R. Viscarra-Rossel (Viscarra Rossel *et al.*, 2016). The USDA-NRCS Kellogg Survey Laboratory has scanned over 80,000 soil samples in the MIR range. The LUCAS has about 20,000 topsoil samples scanned in the Vis-NIR range (Stevens *et al.*, 2013). The Brazilian soil spectral library has about 40,000 soil samples scanned in the Vis-NIR range (Demattê *et al.*, 2019), although the number of samples in some regions such as the Amazon is still scarce. The AfSIS soil spectral library maintained by ICRAF, Nairobi, contains ~18,500 samples of African soils scanned in MIR spectrum (Vågen *et al.*, 2020).

However, many countries possessing a large proportion of soil resources have a very limited or no soil spectral library. In order to promote and facilitate the introduction of this method worldwide, Global Soil Partnership (GSP) and its GLOSOLAN network have launched the soil spectroscopy initiative mainly focused on country capacity building. This includes training on the creation of national/regional soil spectral laboratories, developing national/regional soil spectral libraries with its estimation service, and the provision of advisory services on suitable instrumentation. The objective of this development is to allow countries access to more soil data using a time- and cost-effective analytical method. Ultimately, national/regional soil maps can be improved and used to facilitate sustainable soil management. This initiative will also support the development of a globally representative soil spectral library, the harmonisation of soil spectroscopic methods and the development of standardised protocols for sampling and measurements.

Spectroscopy offers a safe, quick and cost-effective way to analyse soils. How soon it becomes commonplace will depend on the willingness for close cooperation and database-sharing between institutions worldwide, such as those participating in GLOSOLAN, combined with support for the development of collaborative research in countries lacking laboratory facilities or trained personnel.

REFERENCES

Demattê, J.A.M., Dotto, A.C., Paiva, A.F.S., Sato, M.V., Dalmolin, R.S.D., de Araújo, M. do S.B., da Silva, E.B. *et al.* 2019. The Brazilian Soil Spectral Library (BSSL): A general view, application and challenges. *Geoderma*, 354: 113793. https://doi.org/10.1016/j.geoderma.2019.05.043

Nocita, M., Stevens, A., van Wesemael, B., Aitkenhead, M., Bachmann, M., Barthès, B., Ben Dor, E. *et al.* 2015. Chapter Four - Soil Spectroscopy: An Alternative to Wet Chemistry for Soil Monitoring. *In* D.L. Sparks, ed. *Advances in Agronomy*, pp. 139–159. Academic Press. https://doi.org/10.1016/bs.agron.2015.02.002

Soriano-Disla, J.M., Janik, L.J., Viscarra Rossel, R.A., Macdonald, L.M. & McLaughlin, M.J. 2014. The Performance of Visible, Near-, and Mid-Infrared Reflectance Spectroscopy for Prediction of Soil Physical, Chemical, and Biological Properties. *Applied Spectroscopy Reviews*, 49(2): 139–186. https://doi.org/10.1080/05704928.2013.811081

Stenberg, B., Viscarra Rossel, R.A., Mouazen, A.M. & Wetterlind, J. 2010. Chapter Five - Visible and Near Infrared Spectroscopy in Soil Science. *In* D.L. Sparks, ed. *Advances in Agronomy*, pp. 163–215. Academic Press. https://doi.org/10.1016/S0065-2113%2810%2907005-7

Stevens, A., Nocita, M., Tóth, G., Montanarella, L. & van Wesemael, B. 2013. Prediction of Soil Organic Carbon at the European Scale by Visible and Near InfraRed Reflectance Spectroscopy. *PLoS ONE*, 8(6): e66409. https://doi.org/10.1371/journal.pone.0066409

Vågen, T.-G., Winowiecki, L.A., Desta, L., Tondoh, E.J., Weullow, E., Shepherd, K. & Sila, A. 2020. Mid-Infrared Spectra (MIRS) from ICRAF Soil and Plant Spectroscopy Laboratory: Africa Soil Information Service (AfSIS) Phase I 2009-2013. World Agroforestry - Research Data Repository. [Cited 7 September 2021]. https://data.worldagroforestry.org/citation?persistentId=doi:10.34725/DVN/QXCWP1

Viscarra Rossel, R.A., Behrens, T., Ben-Dor, E., Brown, D.J., Demattê, J.A.M., Shepherd, K.D., Shi, Z. *et al.* 2016. A global spectral library to characterize the world's soil. *Earth-Science Reviews*, 155: 198–230. https://doi.org/10.1016/j.earscirev.2016.01.012

Analysis of topsoil samples with a Contact Probe

© Swedish University of Agricultural Sciences

INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

The Intergovernmental Technical Panel on Soils (ITPS) is composed of 27 top soil experts representing all the regions of the world. ITPS members have a 3-year mandate and provide scientific and technical advice and guidance on global soil issues to the Global Soil Partnership primarily and to specific requests submitted by global or regional institutions. Created in 2013 at the first Plenary Assembly of the Global Soil Partnership held at FAO Headquarters, the ITPS advocates for addressing sustainable soil management in the different sustainable development agendas.