Food and Agriculture Organization of the United Nations

GLOBAL SOIL PARTNERSHIP

A Global Soil Spectral Calibration Library and Estimation Service

A Concept Note of the Global Soil Partnership

Prepared by the Steering Committee on Soil Spectroscopy
in the framework of the Global Soil Laboratory Network (GLOSOLAN)

Background

Many studies have demonstrated the potential of soil diffuse reflectance spectroscopy as a rapid and low-cost method for soil characterization (Janik et al., 1998; McBratney et al. 2006; Shepherd et al., 2007; Nocita et al. 2015). Numerous soil properties can be calibrated to near- and mid-infrared spectra owing to the fact that soil spectra respond to soils mineral and organic composition (Soriano-Disla et al. 2014; Wijewardane et al. 2018). However, a major constraint for wider uptake of soil spectroscopy is the lack of spectral calibration libraries for different soil types. Building spectral calibrations requires reference soil property data with matching spectral data for the diversity of soils in a region of interest.

The biggest challenge to developing good calibrations in many countries is the large variation in the quality and consistency in the measurement of soil properties used for calibration (reference data). To illustrate the severity of the problem, Figure 1 below shows the results of a global ring test conducted in 2019 by the Global Soil Laboratory Network (GLOSOLAN[1]) of the Global Soil Partnership (GSP), FAO. A set of control soil samples were sent out to 100 laboratories around the world together with a standard operating procedure (SOP) for conducting the soil test. The extreme variability in the results is disturbing.

[1] GLOSOLAN was established in 2017 with the purpose of harmonizing global soil data and laboratory methods of analysis. The network facilitates networking and capacity development through cooperation and information sharing between soil laboratories with different levels of experience. The network aims to improve evidence-based decision making towards the achievement of sustainable soil management, food security and nutrition and Agenda 2030.

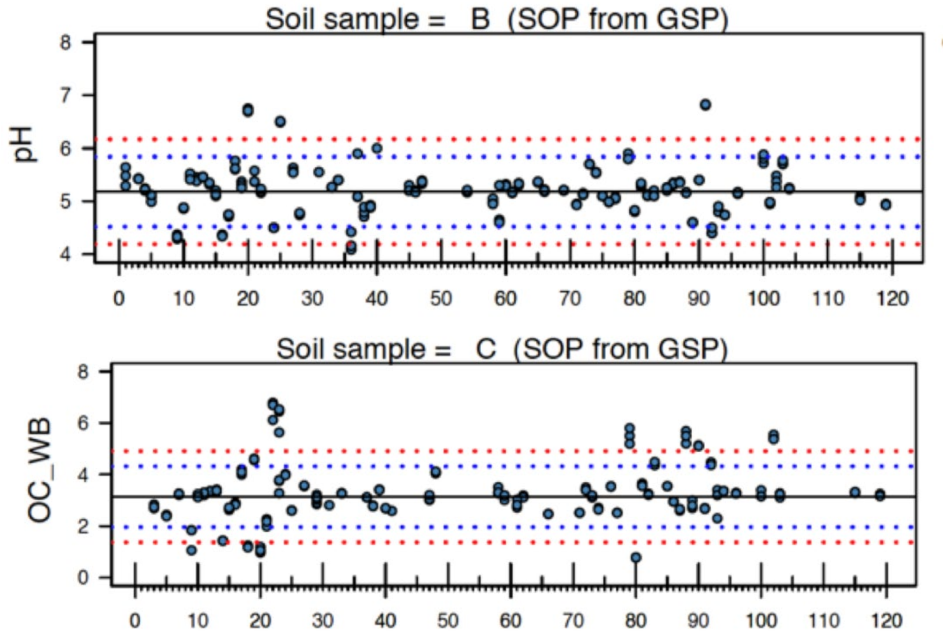

Figure 1. Results of triplicate analysis of control samples returned by 82 participating laboratories using the same standard operating procedure for soil pH (mean 5.2, SD 0.25) and organic carbon by the Walkley-Black method. Source: C Hartmann, N Suvannang and L Caon, GLOSOLAN.

Combining spectral libraries from different laboratories is further complicated by the number of different soil analysis methods and equipment used for the same soil property and even different variations of the same method in different laboratories (Terhoeven-Urselmans et al., 2010; Viscarra Rossel et al. 2016). Additionally, the date of measurement of the reference and of the spectral data can be different, introducing error due to change in soil properties during storage. If the current status continues, soil spectroscopy will provide variable results, be prone to estimation failure and result in loss of confidence among potential users. Furthermore, countries with limited laboratory resources, those who stand to benefit the most from spectral technology, will find it difficult to develop their own calibrations.

The USDA-NSSC Kellogg Soil Survey Laboratory (KSSL) has demonstrated excellent mid-infrared (MIR) spectral calibrations for key soil properties across a very wide range of soil types across the continental USA (Figure 2). The foundation for the high performance of the calibrations is the excellence in reference analytical quality of the laboratory sustained over many years. In addition, the existing calibration library of over 80,000 soil samples represents a significant coverage, perhaps more than 60%, of global soil variation, including 292 globally distributed samples from ISRIC. KSSL has more than 200,000 additional characterized samples, including international samples, still to be scanned using MIR. **This proposal is to build on the KSSL's excellent reference quality analytical capability and its existing extensive calibration library to provide a freely available, global soil spectral calibration library and estimation service under the Global Soil Partnership, implemented through GLOSOLAN**.

Property	n	R^2
Physical indicators		
Water retention (1/3 bar)	10996	0.83
Water retention (15 bar)	27116	0.94
Bulk density (clod)	10553	0.81
Bulk density (core)	7003	0.80
Sand	34912	0.96
Silt	34913	0.92
Clay	34913	0.96
Aggregate Stability	1912	0.71
Al (DCB extract)	22892	0.97
Fe (NH4OAc extract)	21318	0.81
Chemical indicators		
Cation exchange capacity	39600	0.98
Exchangeable Ca	38068	0.94
Exchangeable Mg	38122	0.88
Exchangeable K	37702	0.83
Exchangeable Na	16259	0.94
Base saturation	14658	0.86
EC (paste)	6400	0.82
EC (water)	614	0.84
pH (water)	37123	0.88
CaCO3	19171	0.98
Biological indicators		
Organic carbon	53673	1.00
Total nitrogen	51641	0.97
Plant available nutrients		
P (Bray-1)	3527	0.74
P (Olsen)	10000	0.72
P (Mehlich3)	19139	0.70
K (Mehlich3)	952	0.72

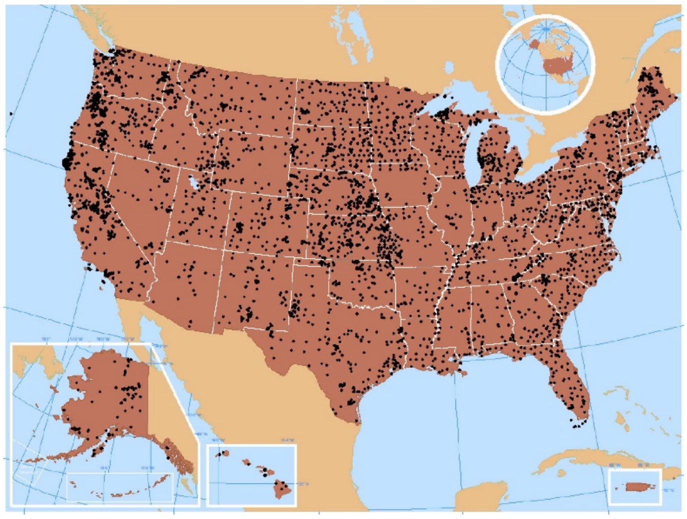

Figure 2. R-square values for spectrally estimated versus reference soil properties for a 20% hold-out validation set from the KSSL laboratory using mid-infrared spectroscopy and memory-based learning for a diverse set of soils from the USA (Dangal et al. 2019, Sanderman et al. 2020).

This initiative will also support the broader GLOSOLAN project "Developing standards and capacity for soil spectroscopy". This effort is strengthened by the already ongoing efforts by GSP and its Soil Data Facility, currently hosted by ISRIC, to build a Global Soil Information System (GLOSIS) for soil (reference) data. GLOSIS is a distributed global soil information system that uses a harmonised soil data model (already under development) and facilitates standardisation of soil data using SOPs and harmonisation rules developed by GLOSOLAN. GLOSIS will consist of local, national or regional nodes that together build the database, which is accessible through one entry point, and is expected to be operational soon.

Objectives

Under the framework of GLOSOLAN, this project aims to:

1. Build a globally representative soil spectral calibration library (database) based on soil mid-infrared diffuse reflectance (MIR) spectra with accompanying soil property reference data recorded in one gold-standard reference laboratory.

2. Provide a freely available and easy-to-use soil property estimation service based on the global spectral library.

3. Support countries to contribute to the global spectral calibration library and use the soil property estimation service.

Outputs and Activities

Output 1. A global soil spectral calibration library

Activity 1.1. Establish a spectral library initiative at USDA-NSSC Kellogg Soil Survey Laboratory (KSSL) under the GSP framework and linked to GLOSIS. The partners will work together on the development of the initiative and its architecture.

Activity 2.2. Countries contribute samples of their benchmark soils (minimum of 200 g, preferably 500 g, of air-dried 2-mm sieved samples), which KSSL will characterize for a standard suite of soil properties (e.g. Figure 1) together with MIR, at no cost, and then add the data into the global calibration library. The GSP-FAO and other regional bodies like iSDA-Africa and CSIRO may assist countries in preparing and shipping the samples to the United States through the FAO country or regional offices. The KSSL will accept short-term internships for countries to send scientists along with their samples to assist with the processing and archiving of the spectral data.

Output 2. A freely available soil property estimation service

Activity 2.1 Provide a global soil property estimation service based on the MIR spectra and soil property data recorded at KSSL.

The partners will work together on the development of the best calibration algorithms and serve them up through user-friendly web-based interfaces. The best performing algorithms for calibration model development at present include machine learning techniques such as memory-based learning that create calibrations on-the-fly for each sample using a subset of the most similar spectra in the calibration library. These will require access to a high-performance computing (HPC) platform and options are already being investigated with various providers. The service would also provide alternative models, including downloadable desktop versions, for countries with limited internet connectivity. All code will be open source and FAIR (findable, accessible, interoperable and re-usable).

Anyone using compatible instrument specifications and sample preparation procedures will be able to use the estimation service. Laboratories submitting samples will also be able to use the KSSL reference measurements to benchmark or calibrate their own laboratories and as such possibly use their existing soil spectral libraries in conjunction with the estimation service.

Activity 2.2. Maintenance of the estimation service.

Uploading of spectra will be facilitated through easy-to-use interfaces with in-built quality checks and a system for flagging spectral outliers, which would alert the user to submit samples that have high value for improving the calibration. In this way the global calibration coverage will be continually improved over time in an efficient way. The calibration library will need to be versioned and spectral uploading will be linked to GLOSIS.

Activity 2.3. Targeted research to improve the calibration service, including algorithms to transform spectra from different instruments to the master instrument, and on improved modelling techniques. There is an increasing range of spectrometers and sampling accessories in use and provision of algorithms to transfer the spectra to be compatible with the KSSL master instrument will be important for extending the utility of the estimating service.

Activity 2.4. In the longer-term, a global soil property mapping service based on uploaded spectra and covariates or other Earth Observation data will be explored. The mapping resolution can depend on available point data, covariates and possibly a specified minimum accuracy. As a starting property, attention may be given to calibrating soil organic carbon concentration.

Output 3. Countries have capacity to contribute to the global spectral calibration library and use the soil property estimation service

Activity 3.1. Disseminate standards for sample preparation, recording soil spectra, and packaging and shipping of samples. Adherence to standards will be critical to the successful building and use of the estimation service.

Activity 3.2. Provide advisory services on sample selection, implementation of the standards, and using the soil property estimation service.

Activity 3.3. Offer countries training opportunities to assist in the scanning of their samples at KSSL and to learn about the laboratory and spectral methods.

This output will support the broader GLOSOLAN project "Developing standards and capacity for soil spectroscopy".

Conclusion

The proposed Soil Spectral Calibration Library and Estimation Service, facilitated by GLOSIS under the GSP and GLOSOLAN, will generate enormous efficiencies and constitute an important global public good. Most importantly, participating laboratories will have access to high quality soil reference data and will benefit from the global soil spectral library, which may contain similar soils from other regions. The coverage and value of the global calibration library will increase over time with smart selection and addition of new samples. The capacity and competitiveness of national soil laboratories on spectroscopy will be enhanced through participation in the initiative. Developing countries with limited laboratory resources stand to gain the most from the service. Since inherent limitations in the reproducibility of laboratory reference measurements currently affects reliability everywhere, this centralized effort would result in more reliable spectral estimations and prevent enormous wastage of resources spent on sub-optimal calibrations in laboratories across the world. Access to a high-quality spectral calibration library and estimation service would support unprecedented high quality and quantity of soil data collection, which in turn would improve evidence-based decision-making in many fields including sustainable soil management, food security and nutrition, and climate adaptation and mitigation.

References

Dangal SRS, Sanderman J, Wills, S, and Ramirez-Lopez F (2019). Accurate and Precise Prediction of Soil Properties from a Large Mid-Infrared Spectral Library. *Soil Systems* Soil 3, 11.

Janik LJ, Merry RH, and Skjemstad JO. (1998). Can mid infrared diffuse reflectance analysis replace soil extractions? *Australian Journal of Experimental Agriculture* 38:681– 696.

McBratney AB, Minasny B and Viscarra Rossel R (2006). Spectral soil analysis and inference systems: A powerful combination for solving the soil data crisis. *Geoderma* 136: 272–278

Nocita M et al. (2015). Soil spectroscopy: an alternative to wet chemistry for soil monitoring. *Advances in Agron*omy 132: 139 – 159.

Sanderman J, Savage K, and Dangal SRS (2020). Mid-infrared spectroscopy for prediction of soil health indicators in the United States. *Soil Science Society of America Journal* https://doi.org/10.1002/saj2.20009

Shepherd KD and Walsh MG (2007), Infrared spectroscopy—enabling an evidence-based diagnostic surveillance approach to agricultural and environmental management in developing countries. *Journal of Near Infrared Spectroscopy* 15: 1-19.

Soriano-Disla JM, Janik LJ, Viscarra Rossel RA, Macdonald LM, and McLaughlin MJ. (2014). The performance of visible, near-, and mid-infrared reflectance spectroscopy for prediction of soil physical, chemical, and biological properties. *Applied Spectroscopy Reviews* 49:139–186.

Terhoeven-Urselmans T, Vagen T-G, Spaargaren O, and Shepherd KD. (2010). Prediction of soil fertility properties from a globally distributed soil mid-infrared spectral library. *Soil Science Society of America Jou*rnal 74:1792–1799.

Viscarra Rossel, RA et al. (2016). A global spectral library to characterize the world's soil. *Earth-Science Reviews* 155; 198-230.

Wijewardane NK, Ge Y, Wills S, and Libohova Z. (2018). Predicting physical and chemical properties of US soils with a mid-infrared reflectance spectral library. *Soil Science Society of America Jou*rnal. 82:722–731.