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A simple apparatus to measure soil spectral information in the field under stable conditions☆

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ABSTRACT

A new assembly for measuring surface reflectance in the field was developed and built to fill the gap between laboratory and field spectral measurements of the soil surface. This device, named SoilPRO (Soil field PRObe), can be connected to any field spectrometer fiber tip and used to measure representative and undisturbed surfaces of different soil types, low grass and artificial materials. Here, the SoilPRO is presented and compared to reflectance-measurement methods that are commonly used in the laboratory (dark box configuration and the ASD® contact probe) and the field (bare fiber handheld by pistol grip and ASD contact probe). The SoilPRO's performance was evaluated by conducting continuous tests in the laboratory and outdoors with soil samples, and in the field with five different surface types as test targets. The SoilPRO's reflectance products in the field were very similar to those of commonly used methods under optimal conditions, while eliminating most of their associated errors. The device provides a new approach to spectral data acquisition in the field that enables measuring undisturbed soil surfaces while maintaining constant and stable environmental and operational conditions. The SoilPRO measures the reflectance of a representative target's footprint across the spectrometer's full range of sensitivity. The measurement is not dependent on the sun's radiation or atmospheric variations, or on operator stability or measurement geometry, and it does not disturb the surface being measured. Reflectance is an inherent property, and the assembly provides superb reflectance accuracy for the surface area in question.

1. Introduction

In recent decades, there has been increasing recognition of the opportunities provided by the field of hyperspectral remote sensing. In particular, spectral-based remote sensing of soil is gaining workers' attention, and soil-related applications are being continuously developed. Soil spectral information, obtained mainly in the laboratory, has demonstrated the promising capability of providing quantitative information on many soil attributes (Ben-Dor and Banin, 1995; Viscarra Rossel et al., 2016). Slowly but surely, quantitative analysis of soils is also entering the spectral imaging domain using field and/or airborne sensors, as end users become more aware of its potential (Ben-Dor et al., 2008; Chabrillat et al., 2002; Hedley et al., 2015; Lagacherie et al., 2008).

The quantitative analysis of soil spectral information is strongly dependent upon the measurement protocol and especially sample preparation. For laboratory purposes, this problem has been solved by each laboratory establishing a consistent protocol, and in recent years, by use of Internal Soil Standard (ISS) methods (Ben Dor et al., 2015). However, field conditions for soil spectral measurements do not match those in the laboratory, and the two domains' measurements cannot be simply interchanged (Lagacherie et al., 2008). Moreover, in the field, maintenance of a strict protocol is very complicated due to changing conditions, e.g., in illumination, atmospheric attenuation and measurement geometry. Furthermore, some field targets are not transferable to the laboratory, while others may not retain their original spectral properties after sampling.

Whereas in rock and mineral analyses, spectral position, shape and assignment of diagnostic features are important for classification (apparent part of the refraction index), in soils, spectral intensity and position, as well as shape, are important (both real and apparent parts of the refraction index representing the scattering and absorbance intensities, respectively) (Baumgardner et al., 1985; Ben-Dor and Banin, 1995).

Soil reflectance measurements in the field lack stability, reproducibility, accuracy and transferability (Chang et al., 2005; Milton and Goetz, 1997). This is because these measurements are traditionally performed with a fore optic pointed at the target (Milton et al., 2009),

☆ Soil field PRObe (SoilPRO®: a portable accessory to measure reflectance of undisturbed soil in the field under all conditions).

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which is strongly affected by atmospheric attenuation, changes in the sun's elevation, user stability and experience, spectral protocol configuration, surface variations, and measurement geometry and calibration scheme (e.g., use of a white reference [WR]). These effects require frequent calibration, resulting in a high volume of measurements for a given target to eliminate these nonsystematic errors, together with extensive documentation of the environmental conditions during the spectral acquisition. In general, these nonsystematic effects hinder accurate comparisons between spectra and further, do not allow quantitative analysis of the acquired spectral information.

Today, field measurements are performed mostly with a bare fiber (BF) fore optic, which suffers from all of the above-listed problems. Another option is to measure soil reflectance in the field using a contact probe (CP) device (Gomez et al., 2008; Wenjun et al., 2014) that is commonly used in the laboratory. This last option suffers from poor representative area (measurement of a small spot size) and poor contact with irregular surfaces. Moreover, it can harm the real surface's structure through the required physical contact thereby losing the natural surface representation, as in the case of a physical soil crust or a thin layer of dust accumulation.

In general, a standard method for measuring soil surface reflectance in the field should be robust, representative and as reproducible as measurements performed in the laboratory (i.e., enabling extraction of the same spectrum over the same area with no change in its nature). Accordingly, an alternative method and protocol for measuring soil spectral information in the field is needed. This method has to represent the soil surface exactly as it is seen remotely ("a natural surface"), cover a large representative area and overcome all of the other aforementioned problems, i.e., user effect, geometry stability, atmospheric attenuation (plus clouds) and changes in illumination with time.

The past few years have seen the development of assemblies that overcome some of the limitations inherent in spectral acquisition under field conditions (Milton et al., 2009). Some of these self-developed tools make use of an internal illumination source, either inside the probe as a modification of available devices (Kusumo et al., 2008) or in an isolated chamber for surface and subsurface use (Christy, 2008; Rodionov et al., 2015), to ensure stable radiation intensity without any atmospheric attenuation. However, these tools are heavy and cannot be carried by the operator; they require a tractor tow and are not suitable for field and ground truth work.

Taking into account the above constraints and the strong need for a standard protocol for soil reflectance measurements in the field, we developed an assembly that fills the above gaps and can be simply adapted to any portable spectrometer available today in the user community that contains an optical fiber. This paper describes the technical characteristics and performance of this assembly and provides examples from soil and artificial surfaces.

2. Instrument development

To establish a reliable reading of soil reflectance in the field, the following issues need to be addressed: atmospheric attenuation (including clouds), solar illumination conditions (changes in sun elevation), representative footprint under natural conditions, a constant geometry, and user independence (including unskilled personnel). Accordingly, we designed and constructed an assembly that maintains these parameters constant while providing instrument mobility and simple operation by any user using any portable spectrometer available today. The device, termed SoilPRO ("Soil field PRObe", hereafter SP), is under patent pending process (U.S. Patent Office, January 17, Serial No. 15407295).

Fig. 1 illustrates the SP. It is composed of an aluminum cylinder (painted matte "Kodak" black inside) with a diameter of 24 cm and height of 25 cm (total device weight is 1.6 kg). This assembly allows measuring reflectance from a surface of about 200 cm^2 when the bare fiber of a field spectrometer with a 25° field of view (FOV) is mounted on its side (45°) covering most of the area beneath it. The assembly dimensions were based on the dimensions of the commonly used 25 × 25 cm (10 × 10 in.) Spectralon (Labsphere®) WR panel, such that the assembly, when placed on the WR, covers most of its area without extending beyond it. The SP thus allows maximal optimization and WR procedure conditions.

On top of the cylinder, a stabilized tungsten halogen lamp uniformly illuminates the surface area beneath. To use the SP illuminator lamp in the field (Analytical Spectral Devices [ASD Inc, n.d.] ProLamp® and Ushio® bulb model JC14.5 V-50 WC), we attached a power supply adapter (12 V DC to 15 V DC and 220 V AC to 15 V DC according to the bulb specifications). The adapter provides stable input voltage to the bulb from any grid or portable power source during the operating time and indicates any power instability or battery fault. For the SP prototype, we used a lightweight portable lithium ion battery (11.1 V, 31.2 Ah, 1.98 kg), which could operate the assembly system for about 5 h and, in contrast to other commonly used CP tools, does not consume precious power from the field spectrometer's battery. To that end, the optic fiber is connected via an adapter to a mount attached to the conical aluminum side addition of the chamber to position its fore optic at a 45° angle, for maximum target area. This configuration is designed to maintain minimal specular reflection and maximal Lambertian radiation collection from the target below, as well as to simulate the geometry of the ASD Contact Probe® (ASD Inc, n.d.) apparatus and the illumination unit's operating protocol as suggested by ASD Inc (2012). In a future version, a camera that captures the measured surface will be mounted. The result is a lightweight tool that is easy to carry and simple to operate in the field for any user, and that provides stable illumination power. Fig. 1 shows the SP's design, parts and working principles.

2.1. Field spectrometer

The ASD FieldSpec® (model FSP 350-2500P) was selected to carry out all measurement in this project. The FieldSpec consists of three discrete detectors: visible–near infrared (VNIR; 350–1000 nm), shortwave infrared (SWIR1; 1001–1800 nm), and SWIR2 (1801–2500 nm), for 2151 spectral bands overall. The FieldSpec was set up to average 30 measurements for dark current, a WR and the target's spectrum. All shifts between the spectra's different regions as a result of the three spectrometric detectors were corrected using SWIR1 as the baseline.

2.2. SoilPRO performance evaluations, general

To evaluate the reliability of the SP's performance in measuring soil surface reflectance accurately while avoiding the problems described in section 1, we conducted a series of tests in which the SoilPRO spectra were compared to those obtained by the commonly used methods—CP and BF—under optimal conditions. The first stage was carried out under controlled conditions and was aimed at evaluating the degree of similarity of the SP spectra to those obtained by the other methods using a set of known soil samples and spectra; the noise level was tested based on WR spectra. The second stage was carried out in the field, where the SoilPRO spectra of five different targets were compared to those from the CP and BF methods. The two test stages are presented as discrete case studies.

3. Laboratory and outdoor measurements of test soil samples

3.1. Material and methods

As a primary stage and to evaluate the reliability of the SoilPRO products, we applied a test with a well-known group of soils. We selected five different soils from Israel that represent five different USDA orders (Table 1). All of the soils were sampled in the field from 0 to 5 cm, brought to the laboratory, air-dried and sieved to pass > 2 mm. Each soil was placed in a shallow aluminum plate painted in a matte