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Prediction of chemical and biological variables of soil in grazing areas with visible- and near-infrared spectroscopy

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ABSTRACT

Grazing is one of most important agricultural activities in mountainous and semi-mountainous regions in the Basque Country and a sustainable use, based on soil properties monitorization, is necessary for the conservation of grassland ecosystems. Visible- and near-infrared reflectance spectroscopy (VNIRS) has been reported to be a relevant alternative for monitoring soil properties, given that it rapidly provides a large number of measurements at low cost. The present work aimed at evaluating the feasibility of NIRS to predict usual chemical and biological soil properties. Soil spectra of VNIRS (350–2500 nm) of 147 samples from representative grassland sites of the most common combinations of management practices and altitudes ranges in the Basque Country (Northern Spain) were acquired to predict chemical and biological soil properties (pH, soil organic matter (SOM), total nitrogen (TN), Olsen phosphorus (P Olsen), extractable potassium (K) and basal respiration (BR)). Furthermore, differences were analyzed among a homogenization gradient of soil sample presentations (0–10 cm topsoil fresh core cylinders; fresh and crumbled; and air-dried ground and sieved to ≤ 2 mm) which were respectively acquired with three different probes (contact; sample turn table (STT); muglight). The partial least squares regression (PLSR) method was applied to develop prediction models. With the contact probe and fresh core presentation, the best prediction models were for pH and BR (RPD = 2.67 and RPD = 2.77 respectively; RPD: ratio of prediction to deviation). For fresh samples, spectra recorded with the STT probe provided better prediction accuracy, i.e. RPD = 2.81 and 3.03 for pH and BR respectively. With sample presentation homogenization, calibration models improved for processed samples to a RPD = 3.59 and 3.23 for pH and BR respectively together with SOM (RPD = 4.01). Conversely, P and K were the variables with the poorest models for all cases, with RPD values ≤ 1.82 and ≤ 1.48 respectively. The sample processing effort for soil homogenization related to the used probe improved significantly model quality. Altogether, VNIRS can be considered a useful method for monitoring grasslands soil properties for management purposes.

1. Introduction

Conservation of mountainous and semi-mountainous grazing areas is vital for mountain livestock farming. The preservation of these agroecosystems is closely related to traditional grazing management based on regular grazing (Galvánek and Janák, 2008) and summer livestock grazing (Hopkins, 2011). In the Basque Country (northern Spain), approximately 85% of the land surface are mountainous areas, grazing being one of the most important economic activity in those areas since the Neolithic era (Barandiaran and Manterola, 2000). The use of mountain pastures through a system of valley-mountain movement is one of the characteristics of the traditional production systems of the Basque Country (Oregui et al., 1997). Currently, it is under threat from progressive abandonment of grazing activities due to economic factors and lack of generational replacement (Lasanta-Martínez et al., 2005). Furthermore, some management practices in these areas such as under and over-grazing, excessive fertilization or intensive use of herbicides can negatively affect the conservation of these agro-ecosystems (Wakelin et al., 2009).

In a more general context, the population increase throughout the world tends to generate high impacts on soil quality making physico-chemical and biological indicators of paramount importance in soil

Abbreviations: VNIRS, visible- and near-infrared spectroscopy; NIRS, near-infrared spectroscopy; NIR, near-infrared; STT, sample turn table; SOM, soil organic matter; TN, total nitrogen; BR, basal respiration; PLSR, partial least squares regression; RPD, ratio of prediction to deviation; PCA, Principal Component Analysis; SNV, Standard Normal Variate; MSC, Multiplicative Scatter Correction; RMSEC, Root Mean Square Error of Calibration; SECV, standard error of cross validation; SEP, standard error of prediction; R^2, coefficient of determination for calibration; r^2, coefficient of determination for prediction

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quality assessment (Bastida et al., 2008). The monitoring of soil properties might help in the decision making process for sustainable use. Therefore, an alternative technique providing large numbers of measurements at low cost in a short period of time would be useful. Visible- and near-infrared reflectance spectroscopy (VNIRS) has been reported to be a relevant alternative for assessing and monitoring soil quality (Askari et al., 2015a; Gras et al., 2014; Viscarra Rossel et al., 2016). This rapid technique is cost effective and lacking of hazardous chemicals requirement. Moreover, it can be used in the field, and several soil properties can be measured from a single scan (Viscarra Rossel et al., 2006).

Near-infrared spectroscopy (NIRS) applied to agriculture and food science increased in the 1980s, but it was not until the end of 1990s when its application in soil science flourished (Bellon-Maurel et al., 2010). The prediction of soil properties is possible either by direct interaction with specific absorbance bonds or by indirect correlation with soil properties that are directly linked to soil spectra (Askari et al., 2015b; Soriano-Disla et al., 2014). Near-infrared (NIR) reflectance signals are produced by flexural and longitudinal vibrations in bonds between C, N, H, O, P and S atoms, and provide information about the quantity of each element in the analyzed material (Brunet et al., 2007; Zornoza et al., 2008). However, this technique requires chemometric analyses to relate spectral information to sample parameters measured by conventional methods.

Generally, soil samples need to be processed to analyze many of soil properties but VNIRS measurements can be made on wet soil avoiding the need for sample drying and grinding, which streamlines the procedure and reduces time and costs. Nevertheless, it is important to take into account the influence of sample presentation on the development of the calibration equations. Some authors (Brunet et al., 2007; Stenberg et al., 2010) demonstrated that model quality increase for more homogeneous samples. That is because non-processed samples are influenced by conditions such as soil moisture, structure and particle size, among others (Gras et al., 2014), which mean difficulties in the process to build robust models (Niederberger et al., 2015).

Following the previous reason, nowadays, there is a clear need to make progress in the development of VNIRS field methods in order to address the soil threats related to agricultural practices (Askari et al., 2015b). Large databases of soil spectra are being developed to help meet the growing demand for soil information, used for the assessment and monitoring of soil at a range of scales (Viscarra Rossel et al., 2016). The implementation of VNIRS methodology will further allow for the design and implementation of innovative management practices and policy aimed at sustainable development (Viscarra Rossel and Bouma, 2016). In grassland management, the rapidity and accuracy of this technique to monitor certain soil properties could help farmers and land managers to implement a sustainable management in order to ensure the conservation of these habitats.

The aims of the present study were (i) to evaluate the feasibility of VNIRS to predict certain chemical and biological soil properties, and (ii) to analyze the effect of sample presentation in a homogenization gradient (0–10 cm topsoil fresh core cylinders of 2.5 cm diameter; fresh and crumbled; and air-dried ground and sieved to ≤ 2 mm) and correspondent probes used (contact; sample turn table (STT) and muglight) on the calibration development.

2. Materials and methods

2.1. Study area and sample collection

The study was conducted in the Gorbeia Natural Park (Basque Country, northern Spain, latitude 43° 07′ N and longitude 2° 51′ W) and its nearby surroundings, which are principally characterized by its long-standing pastoral tradition (Zapata et al., 2004). The grassland areas are mainly formed by habitats of community interest (Habitats Directive 92/43) such as “alpine and sub-alpine calcareous grasslands” (6170), “grassland in mountain areas” (6230) and “acidophic dry heaths” (4030). The climate is humid temperate, with an annual mean temperature of 10.1 °C and a mean precipitation of 2000 mm.

Currently, grassland management practices included those related to the grass management (year-round grazed pastures, mixed-grazed and harvested- and harvested non-grazed sites), the fertilizer treatment applied (organic fertilization with manure, mineral NPK-fertilized and liming) and mechanical fern control.

Sample sites were selected taking into account all the practices numbered above and the valley-mountain movement previously mentioned, in order to collect the greatest variability and representativeness. From each site, soil samples were collected during 2012–2013 and a total of 147 samples were used for this study. Topsoil from 0 to 10 cm was collected using a core soil sampler (2.5 cm diameter), air-dried at ambient temperature and sieved to ≤ 2 mm before measuring physicochemical properties. Conversely, for measuring basal respiration soils were fresh stored at 4 °C for a maximum of 2 months prior to analysis.

2.2. Chemical analysis and biological soil properties

With the aim of studying the impact of most common practices in grassland agroecosystems management, in previous studies a collection of soil properties were established for agroecosystem health cards application (Anza et al., 2015; Lanzén et al., 2015). Among these properties, those with potential for being measured by VNIR spectroscopy were used in this study.

Chemical parameters were analyzed following the standard methods (MAPA, 1994). The soil pH was determined with a pH meter in a soil solution of 1:2.5 in water. Soil organic matter was determined through the Walkley-Black method (Nelson and Sommers, 1996). Total nitrogen content was measured following the Kjeldahl method (Bremmer and Mulvaney, 1982), available phosphorus according to the Olsen method (Olsen et al., 1954) and extractable potassium with ammonium acetate (Pratt, 1965).

Basal respiration (indicating total belowground activity) was measured according to an adaptation of ISO standard 16072:2002 (Anza et al., 2015; ISO, 2002; Lanzén et al., 2015), by which CO_2 emission rate from soil was measured in a hermetic jar incubated for 3 days at 30 °C and quantified by means of NaOH-titration. The measurement of soil basal respiration has been applied across a variety of research studies and is commonly accepted as a key biological indicator for measuring changes to soil quality and frequently used to quantify changes in the activity of the soil microbial community (Creamer et al., 2014).

2.3. VNIRS scanning

Spectroscopic measurements were acquired with a portable NIR reflectance instrument (LabSpec 5000 NIR; ASD, USA) using three different probes, contact probe for non-processed samples (fresh soil core cylinder sections), sample turn table (STT) for semi-processed samples (fresh and crumbled) and the muglight probe (halogen light source integrated in a stable power system equipped with a quartz window on the top) for processed samples (air-dried ground and sieved to ≤ 2 mm). First, 0–10 cm fresh soil core cylinders of 2.5 cm diameter were cut in 5 transversal sections and spectra were acquired on top sides for each section with the contact probe. Then, the resulting cores were crumbled and STT was used for spectra acquisition. Finally, the samples were dried and sieved (≤ 2 mm) and spectra were acquired with the muglight probe.

The spectral devices were calibrated with a white Spectralon© tile before the spectral acquisition of each sample. All spectra were measured with a single NIR spectrometer and using three different probes. Each spectral sample was composed by two spectral replicates according to Terhoeven-Urselmans et al. (2008), Gogé et al. (2012) and Gras et al. (2014). Considering scan acquisition effort and samples