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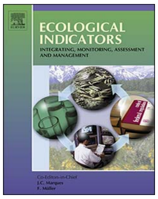

Original Articles

Infrared spectroscopy as a tool for the assessment of soil biological quality in agricultural soils under contrasting management practices

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ABSTRACT

Soil quality estimation is one of the most important means of evaluating changes in soil resulting from management. However, there is still no unanimity about what parameters should be included in soil quality assessment. Although there is a consensus on the inclusion of biological variables, mainly because they are robust and tend to show a short-term response after disturbances, their measurement is usually expensive and time consuming. This study explored the feasibility of using infrared spectroscopy for estimating biological parameters in olive grove soils under organic and conventional management. Four types of soils in two areas with contrasting parent material (marls and colluvial limestones) in southern Spain were selected. Biological status was established by measuring soil enzyme activities related to nutrient cycling (acid phosphatase, alkaline phosphatase, β-glucosidase, arylsulfatase and dehydrogenase) and potential nitrification rate, and calculating their geometric mean as the GMea index.

The infrared spectroscopic signature of the soil proved to be sensitive to biological status, and discriminated the different types of soil, which had quite different biological activity, relatively well (sensitivity and specificity over 97%), but did not discriminate different soil management practices quite as well (sensitivity and specificity over 75%). In addition, the results acceptably predicted the biological GMea index (RPD ≈ 2) from near infrared (NIR) spectra by means of partial least squares (PLS) regression. These results demonstrate the applicability of infrared spectroscopy as a fast and efficient technique for estimating biological soil quality, as well as for discriminating between soils with differing biological quality.

1. Introduction

It is well known that one of the most significant human alterations of the global environment is the intensification of agriculture (Matson et al., 1997; Vitousek, 1994). Sensitive to these issues, the European Commission has been a motor of environmentally-friendly agricultural policies (European Union, Council Regulation (EEC), 1992), promoting crop management practices, such as organic farming, that optimize yields while preserving soil health and protecting the environment.

One explicit goal of organic farming is to maintain and eventually improve soil quality (often used synonymously with soil fertility or soil health) through management practices that preserve the soil's functionality and biological potential. Around 30% of organic farming in the region of Andalusia (southern Spain) is in olive groves. Olive oil production is of enormous economic and social importance in this region, and olive groves are the dominant landscape in more than two million hectares. Therefore, the demand for suitable soil quality indicators for evaluating and monitoring the impact and measuring the success of specific agricultural practices has increased. Indeed, the development of monitoring programs is of fundamental importance for the precise definition of policy-relevant end points.

This makes research in soil science focus increasingly on the search for soil quality quantification indicators, even though the concept itself is not well-established (Bastida et al., 2008), since no single or combined biological or physicochemical variable is able to reflect the many interacting processes responsible for soil quality (Puglisi et al., 2006). Physical and chemical properties have been used extensively to measure soil quality (Miralles et al., 2007). However, these properties usually change on too long a time scale (decades) to be practicable for management. On the contrary, soil properties based on biological and biochemical activities, such as soil enzymes, have been shown to respond to small changes in soil conditions, thus providing information sensitive to subtle alterations in soil quality (García-Ruiz et al., 2008; Pascual et al., 2000). However, determination of these soil quality

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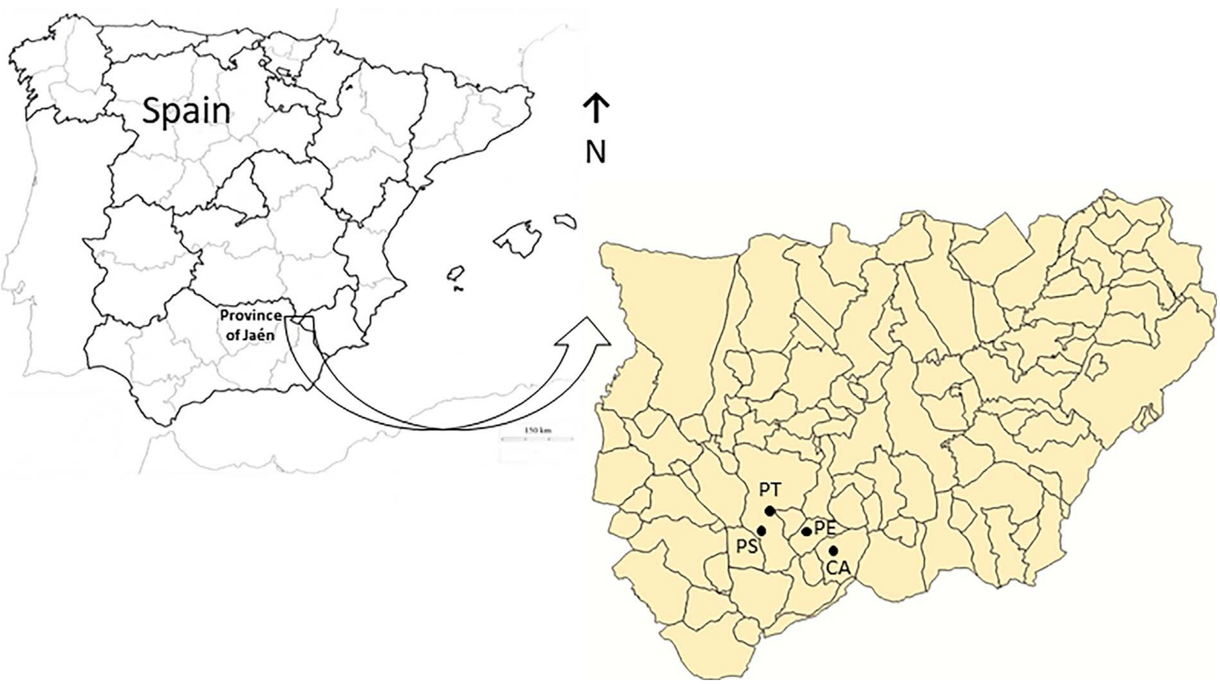

Fig. 1. Location of the study area: Cambil (CA) and Pegalajar (PE) in Sierra Mágina; Puente Tablas (PT) and Puente de la Sierra (PS) in Jaén.

Table 1
Climatic, soil type and some landscape features of the sites.

Location	Management	n	Altitude (m.a.s.l.)	Slope (%)	Orientation	MAR (mm)	MAT (°C)	Geological substrate	Soil type[a]
PT	Conventional	14	923	9	SW	559	16.9	marls	Haplic cambisol
PT	Organic	19	923	7	SW	559	16.9	marls	Haplic cambisol
PS	Conventional	15	1012	11	SE	559	16.9	marls	Haplic regosoll
PS	Organic	12	1012	13	SE	559	16.9	marls	Haplic regosol
PE	Conventional	12	825	5	N	553	15.3	Colluvial limestones	Cutanic Luvisol
PE	Organic	12	825	7	N	553	15.3	Colluvial limestones	Cutanic Luvisol
CA	Conventional	38	874	12	SW	553	15.3	Mix of marls and colluvial limestones	Haplic cambisol
CA	Organic	35	874	14	SW	553	15.3	Mix of marls and colluvial limestones	Haplic cambisol

PT: Puente Tablas; PS: Puente Sierra; PE: Pegalajar; CA: Cambil..
MAR: mean annual rainfall; MAT: mean annual temperature.
[a] FAO (2006).

indicators is usually quite time consuming. To be of practical use in assessing soil quality, bioindicators should be easily measured by standardized methods, and reflect changes in management within a relevant time frame, e.g., by providing early warning of potential threats to soil quality.

Infrared spectroscopy has been proposed as an alternative method for determining soil quality (Paz-Ferreiro and Fu, 2016). Over the past decade, this technique, particularly in the form of reflectance measurements in the near infrared region (NIR), has rapidly developed into a fast robust analytical method for many agricultural, and food products (Blanco and Villarroya, 2002). In soil science, infrared spectroscopy has been used for assessing properties related to moisture and organic matter content, including carbon and nitrogen, and cation exchange capacity (Chodak et al., 2004), as well as for predicting physical and physicochemical variables (Bellino et al., 2016; Soriano-Disla et al., 2014) The effectiveness of NIR reflectance spectroscopy has also been shown for estimating soil nutrients (Cozzolino and Morón, 2003; Islam et al., 2003), physical characteristics (Sørensen et al., 2005) and some biochemical properties (Cohen et al., 2005; Reeves et al., 2000). Total and particulate organic carbon and charcoal carbon were appropriately estimated by infrared spectroscopy (Janik et al., 2007). Soil organic carbon content was unbiased predicted by reflectance spectroscopy of 20000 soil samples from 23 countries (Stevens et al., 2013).

The advantages of using NIR reflectance spectroscopy include simple sample pretreatment (sieving), lack of chemical reagents and its non-destructive nature, and analysis is rapid, inexpensive and accurate.

For soil quality, infrared spectroscopy has already proved to be effective in discriminating between types of soils and management (Aranda et al., 2014). However, the few attempts made at predicting biological variables have shown rather discrepant results (Dick et al., 2013; Heinze et al., 2013).

The aim of this study was to assess the capability of NIR infrared spectroscopy to discriminate among soils under contrasting management practices (conventional *versus* organic) and to predict both individual (specific soil enzymes) and combined (GMea) soil biological indicators.

2. Materials and methods

2.1. Study site and soil sampling

Two pedoclimatic areas, Sierra Mágina and Jaén were studied. Both areas have a semi-arid Mediterranean climate, with low precipitation and mean temperatures of around 16 °C. Soils at the sites, which were chosen to include different soil characteristics, were Cambil (CA) and Pegalajar (PE) in Sierra Mágina, and Puente Tablas (PT) and Puente de

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