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A new soil quality index based on morpho-pedological indicators as a site-specific web service applied to olive groves in the Province of Jaen (South Spain)

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ABSTRACT

Soil quality has become a fundamental concept in soil science and agriculture, but it can be difficult to apply its theoretical and experimental approaches to poorly surveyed zones where precision techniques are far from being applied. In this paper, we propose a new technique that enables little-used qualitative morpho-pedological data to be managed and integrated into a single Field Soil Quality Index (FSQI). Nonlinear Principal Component Analysis (NLPCA), a technique able to handle categorical data, is applied here to deal with morpho-pedological indicators. When categorical values are transformed, they can be properly analyzed and interpreted. This procedure requires less expert knowledge, so it can help soil quality assessments by non-experts. We applied the FSQI protocol to soils in the most important olive-growing area in the world, Jaen Province (Southern Spain), which has serious problems with soil degradation and erosion. First, a soil database for the study area was compiled, including 18 morphological attributes for 131 surface horizons belonging to eight Land Use Types. Secondly, the NLPCA provides optimal scalings and attribute weights that transform and integrate morphological indicators into a simple weighted additive index (FSQI). Thirdly, the scaling functions and weights found were applied to the same attributes of an evaluation set comparing two soil management types (conventional *vs.* organic) in olive groves. The FSQI means for the first (conventional) were significantly lower than in the organic groves (0.278 *vs.* 0.463, $P < .05$), which supports the validity of the index. A site-specific FSQI web service has been created to assist in decision-making in the study area, whose methodology can be generalized to other zones and crops.

1. Introduction

Soil quality is the capacity of soils to support ecosystems functions (Larson and Pierce, 1991). Soil quality can be assessed from a set of parameters, the soil quality indicators, which accurately summarize soil functions. Any negative impact affecting soil quality indicators would be related, through these functions, with a loss of the economic or ecological value of the ecosystems. Agriculture is probably the global activity that most affects soil quality, mainly causing the destruction of the structure and loss of soil organic matter (Lal, 1998). Knowledge of soil quality is valuable for decision making process in many aspects of agriculture, such as assessing soil for precision agriculture (Vitharana et al., 2008) and consolidating land in fragmented parcels (Gajendra and Gopal, 2005). Awareness of soil quality can be determinant to ensuring the success of new or reconverted production areas.

As in other fields of environmental sciences, in soil science efforts have been made to make quantitative assessments from heterogeneous datasets (Harden, 1982), which are either qualitative or measured using scales difficult to compare. This is the case of soil quality assessment (Seybold et al., 1998), where soil quality indices, integrating the most relevant soil indicators of each system into a single numerical measurement, have proven to be a suitable way to deal with soil quality (Velasquez et al., 2007; Bastida et al., 2008). Prior to their integration in an index, these indicators must be normalized by means of mathematical and logical functions (scoring functions) to relate the physical value of the indicator with a standardized soil quality scale. This may be the key step in soil quality index development (Andrews et al., 2002). Scoring functions may be more or less complicated (linear, nonlinear, etc.), but all have several adjustable parameters which must be set heuristically for different places and conditions, based on

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previous knowledge of the soil (Andrews et al., 2004).

Field morphological soil properties are among the most important pedological properties for genesis and classification. They can be found easily and economically, are included in virtually all soil databases, and can be readily applied by growers. However, as they are non-numerical, their quantitative use in soil quality creates significant difficulties (MacEwan and Fiztpatrick, 1996). Thus there are few antecedents for the calculation of soil quality indexes on the basis of pedo-morphological indicators, which were established only through knowledge-based decision rules (Onweremadu et al., 2008; Pulido-Moncada et al., 2014). However, numerical techniques can make categorical variables provided by users manageable. Nonlinear Principal Component Analysis NLPCA (Gifi, 1990) enables an object to be fitted into a multi-dimensional space given by principal components, which are linear combinations of a set of attributes with which the system can be characterized. This is the same as classical or linear principal component analysis (PCA), except that non-numerical (ordinal or nominal) variables can be included in the initial set of attributes and transformed into a numerical scale by optimal scalings. The method optimizes the correlations between the transformed variables and the principal components, which in essence means that the correlational structure among the variables is represented as clearly as possible, for the particular dataset analyzed. NLPCA is highly efficient in systems based on qualitative information, such as pedometrics (Calero et al., 2005, 2008; Sánchez-Marañón et al., 2011).

Olive groves are one of the main crops in southern Spain, where they strongly influence the landscape and culture. Furthermore, olive groves are vital to its economy, particularly in Jaen Province, which accounts for more than 21% of world production. This explains the high impact of this crop on soil quality (Gómez et al., 2009), and the growing interest of European land managers to adopt strategies (*i.e.*, the “greening” policy) to deal with soil degradation, mainly soil erosion (COM (2012) 46 final; RD (2014) 1078). So given the critical levels of soil degradation, it is urgent to advance in the regional impact of agricultural practices on soil quality beyond just the plot or the farm. Nevertheless, there are very few studies dealing with soil quality indexes in olive groves and those are based on analytical indicators (Gómez et al., 2009; García-Ruiz et al., 2012).

The aim of this study was to develop and validate a new soil quality index (FSQI) based on field morphological indicators acquired from soil surveys, and apply it to the soils of the world’s largest olive-growing area. Lack of prior knowledge requires easy access to our index by growers using a web-based tool. Web-based decision support systems are emerging as effective tools for reaching a wide range of crops, including olive cultivation (Orellana et al., 2011). However, most of them require a certain amount of expertise for their effective usage. Our tool is intuitive and can serve as a low cost assessment solution for present and potential land management.

2. Material and methods

2.1. Site and crop description

Olive groves (*Olea europaea* L.) occupy over 6600 km^2 in the Jaen Province (South of Spain), the 49% of its total area. They are located mainly on level or gently sloping lands and over carbonated materials (marls, limestones and dolostones), and are strongly limited in altitude by frost (approx. 1200 m above sea level). Despite the predominance of olive trees, other crops, forestry and natural areas are also present, but limited mainly to steep or very steep slopes in mountainous reliefs and at altitudes > 1000–1200 m. The climate is Mediterranean, with summer droughts, a mean annual temperature ranging from 7 °C to 18 °C and a mean annual precipitation of around 400–570 mm (xeric soil moisture regimen). The potential vegetation is dominated by an ilex xeromorphic forest (*Quercus* sp.) to 1800–1900 m, and black pine (*Pinus nigra* subsp. *salzmanii* (Dunal) Franco) at higher altitudes.

A tendency to the intensification of olive groves in the Jaen Province by increasing fertilizers, pesticides, tree density, mechanical harvesting and irrigation, occurred in the last decades. Intensification has favored important processes of soil degradation as the loss of organic matter and accelerated erosion. In view of this situation, since 2003 successive reforms of the Common Agricultural Policy (CAP) has encouraged the farmer to adopt sustainable soil management. Currently, CAP 2014–2020 implements the Good Agricultural and Environmental Conditions (GAEC), some of them can actively promote soil quality, e.g. the GAEC 4 forces the farmer to maintain a minimum ground cover by grass strips in lanes (RD (2014) 1078). Nevertheless, the majority of soil management systems still remove the plant cover by tillage, herbicides or both. Only about a 20% of the olive groves in the Province show a temporary or permanent plant cover (MAGRAMA, 2015).

2.2. Soil data and Land Use Types (LUTs)

We compiled a soil database, explicitly designed for this work, for the olive grove region in the Province of Jaen. This was one of the most complete collections of morpho-pedological data on the study area. A total of seven 1:100,000 soil cartography sheets (Aguilar et al., 1993, 1995, 1997; Delgado et al., 1997a, 1997b, 1997c; Sierra et al., 2003) were used along with other soil studies (de Haro, 1992; Aranda, 1998; Martín-García et al., 2000; Calero et al., 2008, 2009). All of these information sources were to be observed with minimum quality criteria and georeferenced. The soil database provided a total of 131 soil profiles and the morphological and analytical properties commonly handled in pedological works. In this case, 18 field soil morphological indicators (FSMI) and 23 analytical properties were collected. Of the soil profiles, only the surface horizons (Ah and Ap), with a mean thickness of 18 cm, were used to develop the soil quality index. FSMIs were described according to the Schoeneberger et al. (1998) and FAO (2006) field guides, employing the Munsell soil color chart (Munsell Color Company, 1990) to determine color. Eight Land Use Types (LUTs) were defined in the study area soil database. LUT characterization was based on the FAO (2006) Land Use Classification Scheme, including some modifiers for crop type, human influence and vegetation class.

LUTs were described as follows: (1) Little-Disturbed Forest (LDF): small scattered and relic patches throughout the study area with the presence of holm oak (*Quercus ilex* subsp. *ballota* (Desf.) Samp.) forest, often also including other semi-deciduous and deciduous oak species (*Quercus faginea* Lam.; *Quercus pyrenaica* Will.), (2) Mediterranean Xeromorphic Woodland (MXW): holm oak, with an open community structure, more or less altered by human influence, and tending to *dehesa* (traditional forest management, subjected to extensive traditional grazing and scant firewood extraction by selective cutting), (3) Pine Plantation Forestry (PPF): areas subjected to low-intensity forestry use, mainly *Pinus* subsp. (*P. halepensis* Miller, *P. salzmanii* (Dunal) Franco, *P. pinaster* Aiton, *P. radiate* D. Don), in some cases semi-naturalized, (4) Mediterranean Xeromorphic Scrub (MXS): successional stages commonly occupying fire-disrupted MXW, including evergreen scrub such as *Quercus coccifera* L., *Rhamnus* sp., *Retama sphaerocarpa* L., etc., (5) Alpha Grass communities (AG): composed mainly of alpha grass (*Stipa Tenacissima* L.) and/or other tall and medium height Mediterranean perennial grasses with similar ecological status (*Lygeum spartum* L.), which form high-density prairies, (6) Pastures and degraded grassland (PDG), including both the earliest successional stages (short grasses and dwarf-scrubs) and those traditionally used for grazing sheep and goats, (7) Olive groves (OG), and (8) frequent, but scattered Herbaceous Annual Cultures (HC), mainly wheat and barley, and to a lesser extent, corn and cotton. From a pedological view, the soil database includes information about 11 WRB-soil groups (FAO, 2015), which summarize virtually all the soil typologies present in the study area. These include from Arenosols and Gleysols (frequencies of 1%) to Calcisols, Regosols and Leptosols (frequencies of 31, 21 and 15%, respectively).