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Identification of soil quality indicators for maguey mezcalero (*Agave angustifolia* Haw.) plantations in Southern Mexico

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Maguey mezcalero (*Agave angustifolia* Haw.) is an industrial crop grown in the highlands of Oaxaca State (Southern Mexico), a semi-arid area. A previous study focusing on soil properties provided a reference for the selection of the soil quality indicators in this study. The objective of this work was to identify the appropriate soil parameters for soil quality assessment in cultivated *A. angustifolia* plantations using three tillage systems: disk ploughing (DP), animal-drawn ploughing (ADP) and minimum tillage (MT). Each tillage system was associated with a specific topographic condition (valley, hill and mountain, respectively). Principal component analysis identified soil organic carbon, pH, soil microbial biomass carbon, and exchangeable Mg\(^{2+}\) as potential indicators for a minimum data set for soil quality assessment in *A. angustifolia* plantations. Soil organic carbon was the most sensitive indicator for separating the sites and their associated tillage systems.

**Key words:** *Agave angustifolia*, semi-arid soils, soil organic carbon.

INTRODUCTION

Soil degradation is a global concern (Trasar-Cepeda et al., 1998). Approximately 60% of rural communities in the tropics and subtropics are persistently affected by a decline in house-hold production (Stocking, 2003a), for multiple reasons including non-replenished excessive nutrient off-take by crops, pests and diseases, and the increasing prevalence of climate-change-induced drought (Stocking, 2003b). In Mexico, more than 17.8% of arable soil has suffered some degree of chemical degradation as consequence of a reduction in soil fertility (Secretaría de Medio Ambiente and Recursos Naturales, 2008). Consequently, the establishment of a reliable assessment of soil quality (SQ) is imperative. SQ has been defined in terms of sustainability as “the capacity of a

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in semi-arid regions (Imaz et al., 2010) and small hold farming systems (Mairura et al., 2008). In semi-arid areas of Oaxaca State in Southern Mexico, approximately 15,000 ha are cropped with maguey mezcalero (Agave angustifolia Haw.) with land tenure corresponding to small land holders (Chagoya-Méndez, 2004). A. angustifolia is used as a basic ingredient in the production of “mezcal”, a traditional alcoholic beverage (Bautista-Cruz et al., 2007). According to the landholders, this plant species has been cropped in highlands of Tlacolula (Oaxaca) for more than 100 years. Continuous cultivation on hill and mountain slopes may increase the probability of soil degradation. However, in a recent soil fertility study, Bautista-Cruz et al. (2007) found that the soil organic carbon (SOC), available nitrogen, and soil microbial biomass contents were higher in mountain sites than valley and hill sites, the opposite what was expected. In addition, farmers apply little or no fertilizer into soil, which may lead to depletion of soil fertility over long periods of time. Information about the quality of soils cropped with A. angustifolia is crucial in order to begin an evaluation of the sustainability of current agricultural practices. The aim of this study was to identify SQ indicators in A. angustifolia plantations under three topographic conditions (valley, hill, and mountain) associated with three tillage systems (disk ploughing (DP), animal-drawn ploughing (ADP) and minimum tillage (MT) respectively). The PCA method was employed to identify these indicators, using soil properties previously reported by Bautista-Cruz et al. (2007).

MATERIALS AND METHODS

Study sites and cropping techniques

Tlacolula District, located in Oaxaca, Mexico, was established as the study area. Study sites were Tlacolula (19°54’N and 96°54’W), San Baltazar Guelavila (19° 80’N and 96° 29’W) and Soledad Salinas (19°40’N and 96°01’W). Main soil types in these locations are Regosols and Leptosols, at an altitude of 1,060 to 1,700 m (Comisión Nacional de Biodiversidad, 2004). Parent material is limestone rock with black lutite from the lower Creataceous (Castillo and Castro, 1996). Average annual rainfall ranges from 547 to 726 mm, and average annual temperatures range from 28 to 32°C. Climate is temperate-semiarid (Comisión Nacional de Biodiversidad, 2004), with a dry deciduous lowland forest vegetation type (Lorenze and García-Mendoza, 1989). An extensive area of the original forest has been cut down and burned and the land cleared to allow A. angustifolia cropping. Soil has been used in continuous cropping of A. angustifolia for 20, 30, and 21 years, in sampling sites in Tlacolula, San Baltazars Guelavila and Soledad Salinas, respectively. Soil topography determines the agricultural practices in this highland area. Consequently, three tillage systems are used in A. angustifolia production: MT is practiced in the mountainous zone (12 to 70% slope); ADP in the hills (4 to 65% slope); and DP in the valleys (0.5 to 11% slope) (Sánchez-López, 2005). For each study site, three A. angustifolia plantations were selected with the following plant age classes: class 1 (1.5 to 3.5 years), class 2 (3.6 to 5.5 years) and class 3 (5.6 to 7.5 years). Every age class was present in each study site. Landholders collaborated in this research by assisting in soil sampling efforts and providing information about the management of A. angustifolia systems.

A. angustifolia reaches sexual maturity between 7 and 10 years after being planted. Farmers in all study sites reported sowing maize (Zea mays L.) as an associated crop during the first two or three years of the plant cycle (age class 1). During the harvest process, the plant leaves are cut off, chopped up, and left on the field; they are eventually mixed with the topsoil. Fallow periods are not frequently employed. Agrochemicals (herbicides and fertilizers) have not been applied to any of the plantations sampled in this study. However, distillery effluents are normally incorporated into the soil.

Soil sampling, processing and analysis

Soil was sampled from representative field surfaces (4,000 m²) at each site for each plantation age class during the spring of 2005. Five points were selected for sampling: the first was field-centred, and the remaining four were set at a distance of 25 m from the central point, following the four cardinal directions (Dick et al., 1996; Petersen and Calvin; 1996; Boone et al., 1999). Soil indicators were calculated from data obtained for 0 to 20 cm soil layer, as this soil layer is mostly affected by disturbance due to plant cultivation and has the greatest impact on erosion control, water infiltration, and nutrient conservation (Franzluebbers, 2002).

Air-dried and sieved (< 2 mm) soil samples were used for chemical and physical soil characterization. For soil microbial biomass carbon (SMBC) determination, fresh soil sub-samples were sieved (< 0.76 mm) and stored at 4°C as suggested by Lee et al. (2007). In order to determine bulk density (Db), core samples were taken using a 50 mm diameter soil auger (three replicates). Soil characterization was carried out as follows: the extractable P, SOC, mineral N (the sum of inorganic NO₃ and NH₄⁺), exchangeable Ca²⁺, Mg²⁺, K⁺ and Na⁺, soil pH, and Db were determined using standard chemical and physical methods for soil analysis (Bautista-Cruz et al., 2007). SMBC was estimated by the fumigation-incubation method described by Jenkinson and POWLSON (1976). Throughout the soil analyses, 10% of the samples were randomly replicated for quality control. Chemical analysis for Ca²⁺, Mg²⁺, K⁺ and Na⁺ was performed using calibration curves determined from standards prepared with certified stock solutions (Sigma Aldrich). Sample blanks were analyzed to determine any matrix effects.

Identification of soil properties as soil quality indicators

Identification of soil properties for use as SQ indicators was performed using PCA with the PRINCOMP subroutine of SAS (SAS Institute, 1990, v. 6.0), following the procedure reported by Bredia et al. (2000); Sparling and Schipper (2002), and Mandal et al. (2008). In order to eliminate the effects of the different units of soil variables, the mean was subtracted from each of the measured soil properties, so that each variable had mean = zero and variance = 1. Principal components (PCs) are linear combinations of variables that account for the maximum variance within the dataset. These linear combinations describe the vectors of closest fit to the n observations in p-dimensional space, subject to being orthogonal to another (Dunteman, 1989). PCs receiving high eigenvalues and containing variables with high factor loading were found to be the variables that best represented the system attributes. Therefore, only PCs with eigenvalues ≥ 1 were selected (Bredia et al., 2000).

The assessment of loading significance in PCA was based on scaling the eigenvectors to Pearson product moment correlations between the PC scores and the original variables. Such scaling was obtained by multiplying the eigenvectors by the square root of their associated eigenvalues, correlation values ≥ 70% were considered...
to be significant (Jackson, 1991). Following this procedure, variables with highly weighted factor loading were included in the PC, as they explain the greatest proportion of the total variability given by the sites and their associated tillage systems; these variables were retained for the MDS of indicators.

**RESULTS AND DISCUSSION**

Only the first two PCs in the PCA had eigenvalues ≥ 1; they explained approximately 72% of the total variance of the observations, providing a good synthesis of the original set of variables (Table 1). The highest loadings of PC1 (44.74% of total variance), in decreasing order of loading scores, were SOC, pH, SMBC, and exchangeable Mg$^{2+}$. Exchangeable Ca$^{2+}$ and K$^+$ were the only significant factors in PC2 (27.06% of total variance). PC1 was the component that best separated the soil properties from the different sites and their associated tillage systems (Figure 1). Three soil groups were discernible, according to PC1: (a) valley soil under DP, (b) hill soil under ADP, and (c) mountain soil under MT. The highest SOC and SMBC values for PC1 were found in mountain soils (MT). This may be attributable to the fact that this soil type undergoes less perturbation than hill and valley soils. Consequently, the soil organic matter oxidation rate is lower (Reicosky et al., 1995), providing a greater availability of substrate for soil microbial activity. The mountain soil displayed the lowest soil pH value; in contrast, hill and valley soils had higher, more similar soil pH values. SOC had the highest loading in PC1 (Table 1); this indicator was therefore the most sensitive for separating the sites and their associated tillage systems. Soil organic matter has been considered the most important indicator of SQ and agronomic sustainability for arable soils as a result of its impact on other physical, chemical, and biological indicators of SQ (Reeves, 1997). Previous SQ studies which used PCA (Bredja et al., 2000; Sparling and Schipper, 2002; Imaz et al., 2010) reported that SOC and total nitrogen contributed in differentiating soils.

SMBC had a high loading in PC1. In fact, of the biological soil properties used to assess SQ, SMBC has been considered one of the most reliable (Gil-Sotres et al., 2005). PC2 showed differences between sites in terms of soil properties that are not often associated with the tillage system employed (Figure 1). In particular, PC2 showed that the valley soil (DP) had the highest exchangeable K$^+$ content, followed by the mountain soil (MT) and the hill soil (ADP). Exchangeable Ca$^{2+}$ was higher in hill soil than in valley and mountain soil (Bautista-Cruz et al., 2007).

In the present study, exchangeable Mg$^{2+}$ was found to be a major indicator in SQ assessment; this may be due to these soils were cultivated for long-term with *A. angustifolia* and maize, and significant quantities of nutrients have been released from the soil reserves in response to crop uptake. Pennock and Van Kessel (1997) have reported exchangeable Mg$^{2+}$ as a SQ indicator in forest ecosystems. However, care must be taken before including exchangeable Mg$^{2+}$ as a consistent SQ indicator. Further research is needed to confirm that variations in the exchangeable Mg$^{2+}$ concentration were not caused by differences in soil mineralogy.

According to the PCA, soil properties such as SOC, pH, SMBC, exchangeable Mg$^{2+}$, Ca$^{2+}$, and K$^+$ had highly weighted factor loadings in their corresponding PCs, as they explained the majority of the total variability in soil properties given by the sites and their associated tillage systems.
Figure 1. Principal components 1 and 2. Values in parentheses indicate plant age classes: class 1 (1.5 to 3.5 year), class 2 (3.6 to 5.5 year) and class 3 (5.6 to 7.5 year). ADP, animal-drawn ploughing; DP, disk ploughing; MT, minimum tillage.

several authors of previous studies have used the PCA method to identify the most appropriate soil properties to be used as SQ indicators. Campos et al. (2007) selected C, N, Mg$^{2+}$, effective cation exchange capacity, total porosity, bulk density, microbial biomass-C ($C_m$)/C, Al, inorganic nitrogen, and $C_m$ as potential indicators for long-term SQ monitoring in an elevation transect of the Cofre de Perote volcano (Mexico). Mandal et al. (2008) identified electrical conductivity, fluorescein diacetate enzymatic activity, exchangeable Na$^+$, apparent steady state saturated hydraulic conductivity, and available P as the most important indicators to be included in a MDS for SQ evaluation in farmlands in the Bet She’an Valley (Israel). Sinha et al. (2009) employed a PCA to derive a rhizosphere soil microbial index (RSMI) and found that dehydrogenase activity, basal soil respiration/$C_m$, $C_m$/soil organic carbon, electrical conductivity, phenol oxidase, and active $C_m$ were the most critical properties to include in the RSMI. Imaz et al. (2010) identified penetration resistance, particulate organic matter, total organic matter, and aggregate stability as the most sensitive SQ indicators in semi-arid soils in the Mediterranean basin.

Results of the present study agree with those of previous studies in confirming that PCA is a useful tool for selecting appropriate SQ indicators.

Conclusions

Principal component analysis was found to be a practical tool in the selection of appropriate soil quality indicators in A. angustifolia plantations in Oaxaca, Mexico. Soil organic carbon, pH, soil microbial biomass carbon, exchangeable Mg$^{2+}$, Ca$^{2+}$, and K$^+$ proved to be the most critical soil quality indicators for the studied agrosystem. Of these soil quality indicators, soil organic carbon was the most sensitive for separating the sites and their associated tillage systems.

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REFERENCES


