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Chemical soil quality indicators in productive systems of the Colombian Piedmont Eastern Plains

Indicadores químicos de calidad de suelos en sistemas productivos del Piedemonte de los Llanos Orientales de Colombia

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Abstract

In production systems in the piedemont of the Eastern Plains of Colombia several indicators were evaluated to determine the quality of the soils of the region. Random sampling of eleven systems were included, and on each of those, five samples of soil were taken in order to evaluate all its properties; and in the selection of those which can be included as indicators. The results of the full characterization were analyzed by principal component analysis (PCA). Due to its importance the following properties were prioritized as quality indicators: organic carbon, pH, exchangeable acidity, exchangeable calcium and magnesium and iron. With these indicators, a classification of the chemical quality of the soils of the piedmont plains is proposed; which can be useful when implementing a monitoring system which allows assessing the degradation of these soil properties over time due to changes in the systems.

Key words: Oxisol, sampling, principal component analysis, classification.

Resumen

En sistemas productivos del Piedemonte de los Llanos Orientales de Colombia se evaluaron varios indicadores para determinar la calidad de los suelos de la región. Para el efecto, en un muestreo aleatorio se incluyeron once sistemas y en cada uno de ellos se tomaron cinco muestras de suelo para evaluar las propiedades principales y seleccionar aquellas con posibilidades para ser incluidas como indicadores de calidad. Los resultados de la caracterización completa fueron analizados mediante componentes principales (ACP). Por su importancia fueron priorizadas como indicadores de calidad las propiedades siguientes: carbono orgánico, pH, acidez intercambiable, calcio y magnesio intercambiable y hierro. Con estos indicadores se propone una clasificación de la calidad química de los suelos de la región, que puede ser de gran utilidad en la implementación de sistemas de monitoreo que permitan la evaluación de la degradación de los suelos a través del tiempo debidos a cambios en los sistemas de uso.

Palabras clave: Oxisol, muestreo, análisis de componentes principales, clasificación.

Introduction

Degradation of soils is a problem caused mainly by changes in their use and the adoption of practices of each crop production system. The assessment of farming effects on the soil indicates the required parameters to estimate the environmental impact caused by production systems. It entails to decision-making processes focused on conservation, sustainability and productivity. To achieve this goal it is necessary to know the quality of the soil by defining indicators. Soil quality can be defined as the ability of the soil to function (Karlen *et al.*, 1997) in order to be used (Larson and Pierce, 1994).

Although the soil is a resource that supports the development of crops, just recently it has been recognized its susceptibility to degradation and consequent reduction on crop productivity. In Colombia, specifically in the region of the eastern plains, for several years it has been making a great effort by private and public entities like the Colombian Corporation for Agricultural Research (CORPOICA), the National University of Colombia, CIAT and Universidad del Llano, among others, to develop research aimed at understanding the processes, conditions and dynamics of the soils, and the classification of their quality in this important region (Rubiano, 2005;. Phiri et al., 2001; Basamba et al, 2006; Amézquita et al, 2004). However, it is necessary to generate information in order to define chemical indicators, from which it is possible to assess the impacts caused by changes in soil use and adopted management practices.

The chemical quality indicators are useful for assessing the degree of vulnerability of the soils in order to propose corrective actions in accordance with the production system. The indicators also allow monitoring for early warning, which helps to prevent or mitigate process of degradation. Considering the above, the aim of this study was to develop chemical indicators of soil quality in production systems of the Eastern Piedmont Plains of Colombia.

Materials and methods

Area of study

The research was conducted at the research center of the Colombian Corporation for Agricultural Research (CORPOICA) la Libertad, located 4° 03` 30" north latitude and 73 ° 28` 5" West longitude approximately, at 336 MASL, in the town of Villavicencio - Meta, 25 Km via Villavicencio-Puerto López. The tropical climate is characterized by an average temperature of 26°C, 2700 mm annual precipitation and relative humidity of 85% average.

The research center has 1342 hectares of alluvial terraces with slightly flat topography. Soils are predominantly kaolinite clays and quartz, coming from sediments of the recent Pleistocene to the old Holocene period. These natural pastures predominate in this soils, which are strongly acidic (pH <4.5), with high aluminum saturation (> 70%) and low base saturation (<25%). They have low phosphorus (1 ppm), calcium, magnesium and potassium availability, and minor elements deficiency, with exception of iron (Rincón and Caicedo, 2010). The natural vegetation is from the tropical Rainforest (IGAC, 2004) as classified by Holdridge (1967), but a large percentage have been eliminated due to the establishment of different agricultural systems.

Production systems from the upper terrace: oil palm (*Elaeis guineensis*) 18 years of age, pineapple Golden (*Ananas sativus*), sweet sorghum (Sorghum vulgare), maize (*Zea mays*), soybean (*Glycine* max) and Valencia orange (*Citrus sinensis* (L.) Osbeck).

Production systems from the middle terrace: rubber (*Hevea brasiliensis*), grass cultivar (cv.) Llanero (Brachiaria dictyoneura) associated with peanut forage (*Arachis pintoi*), only grass cv. Llanero, oil palm (*Elaeis guineensis*) 30 years old, Acacia (*Acacia mangium*), yopo (*Anadenanthera peregrina*) and melina (*Gmelina arborea*).

In the recent alluvial terrace, the degraded pasture of Brachiaria system (*B. decumbens*) was selected.

Analysis of response variables

The chemical properties were analyzed from soil samples taken to the Laboratory of Soils, College of Agricultural Sciences, National University of Colombia in Bogotá, and included: pH (1:1) with potentiometer; oxidizable organic carbon (CO) (Walkley and Black, 1934); available phosphorus (P) (Bray II, 1945); calcium (Ca); potassium (K); magnesium (Mg); sodium (Na); cation exchange capacity (CEC) (extraction with 1M ammonium acetate, pH 7, atomic absorption); exchangeable acidity (extraction with 1N KCl); copper (Cu); iron (Fe); manganese

(Mn) and zinc (Zn) (DTPA extraction, atomic absorption) and boron (B) (mono-calcium phosphate extraction).

Processing of the statistical information

Data were analyzed using the statistical package SAS and ADE-4 (Thioulouse *et al.,* 1997). The principal components were grouped (PCA), reducing the number of original variables to a minimum data set (MDS). Variables were selected according to the contribution to the creation of components (Factor 1 and Factor 2 of the PCA).

For the selection of the main variables, it was consider the contribution of each to the construction of the first two components of the PCA. Then, the highest value was divided in two, and the variables with the same or higher values remained the same when comparing with the result. The following are the selected variables that represent the highest variability as possible indicators of soil quality due to their sensitivity by changes in production systems and land use. Finally, a proposed approach to the classification of the chemical quality of Oxisols of Piedemonte of the Eastern Plains of Colombia was made. The resulting data from the degraded pasture of Brachiaria were used as reference, besides the ranges of the chemical properties of soils in the region (Rincón *et al*., 2010), the levels of standard interpretation for agricultural soils and classification soil fertility by level for acid-tolerant plants (Salinas and García, 1985, adapted by Rincón *et al.,* 2010).

Table 1. Contribution of each chemical variable to the construction of factors 1 and 2. Oxisoles the Piedmont Eastern Plains of Colombia.

Variables	Factor 1	Factor 2	Variables	Factor 1	Factor 2
pH	1185	1651	C.I.C.	237	158
Organic carbon	465	1781	Phosphorus	714	0
Calcium	2002	143	Copper	30	418
Potassium	138	160	Iron	6	2696
Magnesium	2093	50	Manganese	3	1058
Sodium	52	150	Zinc	513	1165
Exchangeable acidity	1673	272	Boron	882	291

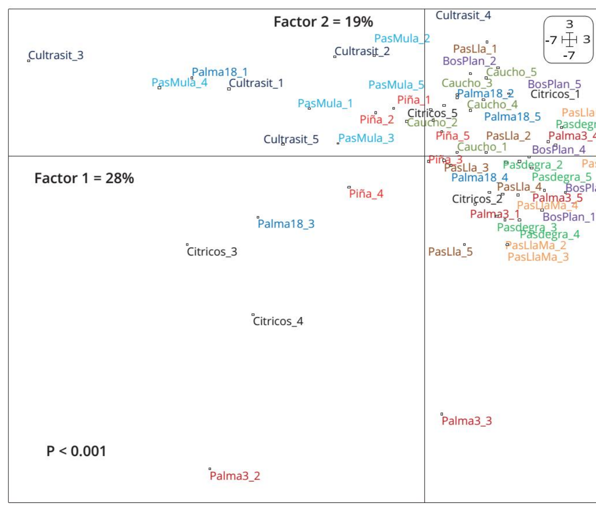

Figure 1. Distribution of the evaluated places in relation to the amount of the chemical variables and the formation of Factors 1 and 2. Oxisols of the Piedmont of the Eastern Plains of Colombia.

Results and discussion

Selection of soil chemical quality indicators

The selection of chemical indicators was followed by the contribution of each variable to the formation of Factors 1 and 2 of the ACP (Table 1). Figures 1 and 2 show the results of the multivariate analysis or principal component analysis (ACP) with differences according to sampling sites (P <0.001). The first two components explain the 47% of the data variability, distributed in 28% for the first factor and 19% for the second. The first factor separated the sites due to their content of Ca, Mg, P, B, pH and exchangeable acidity (Ac.I); while the second factor separates the sites due to their contents of Fe, Mn, organic C and mainly K (Figure 2). The pH and exchangeable acidity were opposite variables.

The low variance included in Factors 1 and 2 (<50%) was due to the chemical variability of soil, which is related to the different uses and agronomic management of crops. The main factors are the implementation of amendments as dolomite lime to correct acidity and increase the base saturation. Furthermore, the increase of P content in order to have higher availability in the soil.

The first component established differences in sites with higher values of pH, Ca and Mg, that corresponds to the crops of *Brachiaria* cv. Mulato II, palm-18 and transitory crops. On the other hand, the systems with high values of exchangeable acidity corresponding to Brachiaria cv. Ranger, cultivated forest, degraded pasture grass cv. Ranger associated with perennial peanut did not have differences. In the second factor, the sites were separated by levels of Fe, Mn, organic C, and K, differentiating the high content of these elements like with grass cv. Llanero Llanero, grass cv. Ranger associated with perennial peanut, palm-30, citrus and degraded pasture. The low nutrient contents were present on rubber, pineapple, grass cv. Mulato and seasonal crops (Figures 2 and 3).

The chemical variables within the same system are very heterogeneous (Figures 1 and 3). This variability may be due to the management of fertilizers, especially when it is applied around the plant. Moreover, although amendments such as dolomite lime are uniformly applied the crop area, the plants only uptake Ca and Mg cations that are close to the root system. Thus, cations that are outside the root system are not absorbed and therefore have higher values of these elements. It should be mentioned that some of the evaluated sites in the same production system had a different soil series, such as cv. Llanero which is associated with forage peanut and palm -30 cultivation.

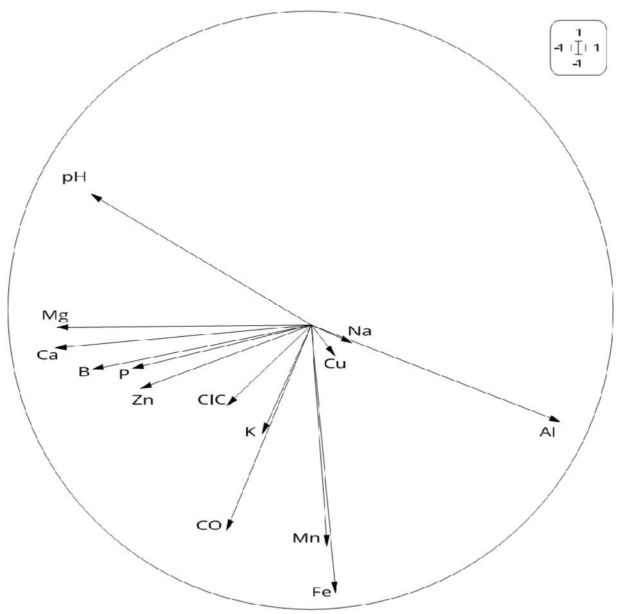

Figure 2. Correlations for chemical variables in terms of their contribution to the formation of Factors 1 and 2. Oxisols of the Piedemonte of the Eastern Plains of Colombia.

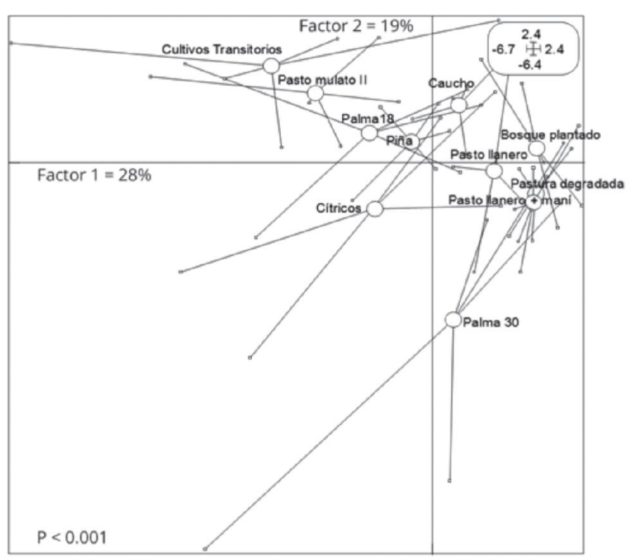

Figure 3. Grouping of the land use systems as a function of the amount of chemical variables and the formation of Factors 1 and 2, and their similarities. Oxisols of the Piedmont of the Eastern Plains of Colombia.

The heterogeneity of the variables between systems is due to the different agronomic management in each system and the geomorphologic soil position in the production systems. Figure 3 shows the first group consisting of grass cv Mulato II, seasonal crops and palm-18. This group is characterized by high values of pH, P, Ca and Mg, and lower values of exchangeable acidity and Fe. The second group consists of pineapple and rubber cultivars with slightly lower values of pH, Ca and Mg than the previous group, but with higher levels of exchangeable acidity and Fe and high levels of B and P available. The third group includes degraded pasture systems, grass cv. Llanero and grass cv. Llanero associated with forage peanut and palm-30. This group showed the highest values of organic C, exchangeable acidity and high levels of Fe and Mn. The fourth group consists of the citrus cultivation characterized by low pH, high content of available P and Zn, and a high value of organic C (except for degraded pasture and cultivation of palm-30 which have higher values for this variable). The fifth group is made up of planted forest characterized by lower content of organic C (Figures 2 and 3). The grouping of these systems was made due to their similarity in chemical properties, their geomorphologic position and management. Thus, high terrace soils have improved their chemical properties using a rotational system of seasonal crops, especially pasture cv. Mulato II and seasonal crops. Although citrus crops are in high terraces, they were not pooled with other systems because of the application of dolomite lime which is done in alternating stripes and not uniformly as it is done in pastures and other crops.

The significant differences ($P < 0.001$) by the ACP states the use of the soil influence the chemical properties of the soil. As evidenced by the fact that soils with the same geomorphological positions showed differences in their chemical components, which is indeed the result of different use of the soil.

Based on the results, the most representative variables are pH, organic C, exchangeable Ca, exchangeable Mg, exchangeable acidity and Fe. These properties are the most significant contributors to the explanation of variance and therefore, they can be used as indicators of soil quality. Moreover, agricultural practices lead to increased base saturation (Ca and Mg) which automatically cause an increase in pH and a decrease in exchangeable acidity and Fe availability. According to the above statement, the proposed chemical indicators are representative of the edaphic dynamics in the area and may be useful for determining the quality of these soils. Organic C is also a good indicator of soil quality as it is a reservoir of nutrients and their behavior affects other properties (USDA-NRCS, 2011). Organic matter is an important reservoir of nutrients and contributes to maintaining the physical properties of soils, water retention and erosion resistance (Gregorich *et al.*, 1994), especially when tillage is part of the management.

Ca and Mg are indicators of impact, since they cause effects on soil properties when applied. Therefore their effects are inherent in the management of soil and depend on the contribution of dolomite lime to correct the low saturation base, especially in these soils. By contrast, the pH, organic C, exchangeable acidity and Fe are indicators affected by the change in land use and management. Thus, pH and exchangeable acidity are positively affected when dolomite lime is applied. In this case the first increases while the second decreases, followed by the decrease of Al toxicity in plants. Organic C and Fe decrease with the use and management of soil and therefore they are negatively affected. In summary, the chemicals selected indicators are within the recommended by the USDA (1999), Doran and Parkin (1994) and Larson and Pierce (1994), except by the exchangeable acidity due to differences in agricultural and ecological characteristics of the study areas.

Approach to the classification of the chemical quality of Oxisols with similar land use management regarding the present study

The information presented in Table 2 is a useful tool to evaluate fertility in terms of the soils chemical quality of Piedmont, regarding the similar land use management of the studied areas. This information provides critical levels when combined with the nutrient requirements of the production systems. However, it is only applicable for soils of the study and the values and classification cannot be extrapolated to other areas of the Piedmont Eastern Plains of Colombia. Since this information only respond to climatic and soil conditions of the study area, it should only be used in areas with similar environmental characteristics and in the same order of soil sample (Oxisols). In addition, they should take into account the type of crop and nutrient requirements, so it is necessary to validate each crop in the future.

Conclusions

The soil conditions in the study area allowed the selection of the main chemical properties to determine the quality of soils in the Piedmont Eastern Plains of Colombia. They correspond to pH, organic C, exchangeable Ca, exchangeable Mg, exchangeable acidity and Fe.

Table 2. Classification of the soil chemical quality indicators. Oxisols of the Piedmont Eastern Plains of Colombia.

Indicator	Soil chemical quality			Measurement (Time)	Method	Assessment
	Low	Medium	High			
pH	<4.5	4.5 - 5	>5	Quarterly	Water: Soil (w/v) 1:1	Potenciometer
OC (%)	<1.2	1.2 - 1.7	>1.7	Annual	Walkley and Black	Colorimetry
Ca (Cmol+/kg)	<0.3	0.3 -1.5	>1.5	Biannual	Extraction with 1 M Ammonium Acetate, pH 7	Atomic absorption
Mg (Cmol+/kg)	<0.05	0.05 -0.5	>0.5	Biannual		
Fe (ppm)	<50y >182	50 - 100	100-182	Annual	Extraction with DTPA	
Ac.I (Cmol+/kg)	>3.5	1.5 -3.5	<1.5	Quarterly	Extraction with KCl 1N	Volumetric

The selected indicators as well as being useful for monitoring the effect of land use on chemical properties of soils, they may be useful in designing sustainable production systems to prevent or mitigate the negative effects (increased acidity) and maximize positive effects (contribution of nutrients) of agricultural practices in the region.

The proposed indicators are suitable for monitoring the chemical quality of the soil, they are easy to measure and sensitive to changes of the production systems

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