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Regional-scale variability of soil properties in Western Cuba

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ABSTRACT

The soils of Artemisa and Mayabeque provinces, in western Cuba, have a historical importance in Cuban agricultural productivity and have been subject to production- oriented practices and fragile protection from degradation. Very few contemporary studies about these soils are available. As a support to near-future management decisions, the objectives of this work are: i) to characterize the variability of some physical and chemical properties in the main agricultural lands of the Cuban provinces of Mayabeque and Artemisa, and ii) to identify relevant features associated to soil property changes and their possible impacts on near future decision making. Soil samples were taken in a 116 data point stratified-random-unaligned grid at two depths: 10–15 cm and 35–40 cm. The measured properties were: sand (Sa), silt (Si) and clay (Cl) content, organic matter content (SOM), bulk density (ρ_b), particle density (ρ_s), exchangeable cation content (Na^+, K^+, Ca^{2+}, and Mg^{2+}), pH, and the macroaggregate size distribution. An exploratory analysis illustrates the most outstanding issues of the variable distribution, their dependence on the involved soil depths and types, and the correlation between measurements. Some relevant spatial features associated to the behavior of the properties are identified with kriging spatial interpolation. Calcium content is shown to be a key property in soil functioning, mainly for its effect on macroaggregation. In contrast, Cl and SOM did not affect the soil structure patterns. Analyses suggest that Cuba's most productive soils are subject to severe degradation mainly from increasing pH and compaction, and therefore the adoption of conservation practices is crucial for their sustainability on the medium and long term.

1. Introduction

Common to many underdeveloped countries, years of overuse with unsustainable land management, especially in the form of single-crop farming, have affected the productivity of Cuban soils (Febles, 2016). Continued soil degradation is one of the factors inducing the negative long term trends in agricultural yields and the marked dependence on imported food (Leitgeb et al., 2015). Soil degradation is currently considered a main environmental problem, compromising short and medium range development priorities related to food security (Ministerio de Ciencia, Tecnología y Medio Ambiente, 2011), making it a national security issue. Measures for soil conservation and improvement based on reliable data are therefore of critical importance to sustainability of Cuban agricultural activity and food security.

The soils of western Cuba, close to the capital Havana in the center of the Artemisa and Mayabeque provinces, are among the most affected by degradation problems. The southern part of these provinces is dominated by the Habana-Matanzas plain of soils of the Cuban 'Ferralíticos' class, a coastal plain strip with the most productive soils of the country which have been mainly cropped for sugarcane since the middle of the eighteenth century (Boyer, 1939). Representing only 5.2% of Cuban territory, national statistics show it to produce about 12% of all agricultural items (Oficina Nacional de Estadísticas, 2011). The region is also important for the cultivation of grass for livestock farming. It counts on the largest infrastructure for irrigation and the highest mechanization indexes.

Some plot scale studies performed in this region show that compaction (Tarawally et al., 2004; Hernández et al., 2006; Cid et al., 2011), erosion (Febles et al., 2014), loss of organic C (Hernández et al., 2006, 2013), and an increase in pH (Jaimez et al.,

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2004), are among the degradation problems caused by soil overuse and misuse. It is difficult, however, to upscale these results to the entire region so as to evaluate the actual magnitude of the problem and to adopt correcting management strategies. The nature of soil variability is itself scale-dependent because the soil forming factors and involved processes interact over many different spatial and temporal scales (Burrough, 1983; Trangmar et al., 1985; Goovaerts, 1998). The efficient assessment of soil conditions must consider the variability of the soil properties that are affected by the different forms of soil degradation (Brejda et al., 2000). Knowledge of soil spatial variability is essential to identify zones that need site-specific management for sustainable development (Schimel et al., 2000; Tesfahunegn et al., 2011).

Soil management in Cuba is hindered by a lack of good, reliable and up-to-date information about magnitude and variability of important soil properties. Restrictions associated to the collapse of the Soviet Union, a few decades ago, limited the scope of many research attempts in fields like pedology and edaphology (Maal-Bared, 2006). Distribution of information is constrained to local journals and magazines, making the available information of narrow use. Available soil maps are long standing (see Parry and Perkins, 2000, page 320) and, as a consequence, there are no standards for levels of quality regarding datasets and metadata documentation.

Geostatistics (Journel and Huijbregts, 1978; Isaaks and Srivastava, 1989) has shown to be a useful tool for detecting, estimating and mapping the spatial patterns of regional variables like the soil properties. It focuses on the modeling and interpretation of the semivariogram, quantifying the spatial relationship between sample values as a measure of dissimilarity with distance (Goovaerts, 1997). This enables the interpolation of values at unsampled locations using Kriging methods, a generic name adopted by the geostatisticians for a family of generalized least-squares regression algorithms (Webster, 1996). The geostatistical characterization of the variability of the soil properties at regional scales can lead to better management decisions aimed at correcting problems (Özgöz, 2009).

In line with these facts, the objectives of this work are: i) to characterize the variability of some physical and chemical properties in the main agricultural areas of the two provinces from western Cuba, Mayabeque and Artemisa, and ii) to identify relevant features associated to soil property changes and their possible impacts on near future decision making.

2. Materials and methods

2.1. Study area

This work focuses on the part of the old Cuban province of Havana (Fig. 1), since 2011 part of the provinces Artemisa and Mayabeque, where agricultural practices are predominant. This province occupied 5731 km^2, about 5 percent of the total area of Cuba, and corresponds to about 12% of the country's grain, root and horticultural crop production. It is responsible for almost 80% of the agricultural food supply to the capital Havana, with more than 2 million inhabitants. Agriculture in this region is by far the most mechanized of Cuba and includes a complete irrigation infrastructure.

The climate of the region is characterized by two well defined seasons. The rainy period, from May to October, concentrates more than 80% of the annual precipitation of about 1300 mm on average. Rainfall amount and frequency during this period have a major influence on productivity of annual crops like sugarcane and pasture, or perennial crops like mango and avocado. The dry season, from November to April, coincides with mean temperatures of about 22 °C, slightly lower than the annual average of 25 °C and therefore it is determinant for the agricultural production of crops that need relatively low temperatures during their vegetative cycle. The production of highly demanded products like tomato, lettuce or potato is practically limited to this dry and cool season and demands considerable investments, mainly in terms of irrigation.

2.2. Morphology and geomorphology in the region

The territory of the old Havana province is developed over karst rocks from the Miocene. It is divided in six main geomorphologic classes, classified according to lithology, geological structure and predominant landscape form (Iturralde-Vinent, 1985). The studied region is represented by three of these classes: the karst plain, the karst hills, and the central hills. The karst plain occupies the largest part of the studied territory. It occurs in the southern third of the territory and has a branch, extended as a polje of about 5×10 km in the center-northern area. The south plain is part of the Habana Matanzas karst southern plain, and has a width varying between 17 and 30 km. The plain has a marked lithological homogeneity. Karstification is intense to depths of at least 100 m (Iturralde-Vinent and Gutiérrez, 1999), as a result of Miocene limestones cropped at the surface (Seale et al., 2004). Groundwater is the predominant source of water; fluvial streams are very scarce. The soil composition, the groundwater upwelling, and hydrogeological structure favor the formation of a marshy zone toward the coast.

A major part of the north-south fringe of the plain between coordinates East-340 and 360 km was covered by a great lagoon during the Quaternary (Iturralde-Vinent, 1985). Posterior upland processes caused the lagoon to dry out, whereas the remaining streams dissected the plain. A small lagoon, vestige of the original great lagoon, existed there until less than 30 years ago.

Karst and Central Hills have a marked tectonic origin. Karst Hills are common in all the territory, but are most common in its center portion. They are the result of the accumulation of karst Miocene deposits, resulting in very resistant rocks with a high macroporosity, product of lithogenic and tectonic cracking (Iturralde-Vinent, 1985). They are present in the Jaruco and Picadura heights, and also in some specific zones of the Bejucal and Madruga elevations. Maximum elevations vary between 200 and 250 m.

The Central Hills are constituted by sequences of erodible carbonated-terrigenous and terrigenous material from the Eocene and Oligocene. They are typically known as the Bejucal-Madruga-Coliseo heights that extend to the east from the municipality of Bejucal to the interior of the neighboring Matanzas province. The landscape is characterized by isolated or aligned hills of low height (100–150 m) forming mountain ranges of about 10 to 15 km long. They have a karst with local, lenticular, terrigenous – carbonate drainage. However, unlike the karst hills, surface karst and cracking is uncommon in the Central Hills. They were more prone to the effects of tectonic, weathering and erosive processes during the Quaternary period, that favored the leaching of the karts rocks, and the outcrop of older non-carbonated rocks. According to Iturralde-Vinent (1985), these are low structural-tectonic, horst, horst-anticline and anticline heights.

2.3. Soil types

This study focuses on the following soil types described in the last version of the Cuban soil classification system published by the Instituto de Suelos (1999): "Ferralíticos", "Pardos", "Húmicos", "Fersialíticos", "Hidromórficos" and "Vertisuelos" (see Fig. 1a). All of these soils show high clay contents, usually above 35%. For a better comprehension we provide a brief description about the mineralogy, some specific features, as well as the correlation with the FAO World Reference Base (IUSS Working Group WRB, 2014).