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RELATIONSHIP BETWEEN PHYSICAL PROPERTIES AND THE MAGNETIC SUSCEPTIBILITY FOR TWO AGRICULTURAL SOILS OF VALLE DEL CAUCA

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Keywords: Soil quality, sugar cane cultivation, soil diagnosis, magnetism.

ABSTRACT

This study aimed to investigate the potential use of magnetic susceptibility (MS) as a property to characterize the soil state in two lots under cultivation of sugar cane. The MS is a property that determines the degree of magnetization of a material, and it has a potential use in the diagnosis of agricultural soils due to its measurement versatility. Soil samples were collected, and subjected to laboratory analysis from two lots named Chondular (55.3 ha) and Santa Rosa (98.3 ha), in order to measure the MS and compare it with the conventional physic properties. Data were submitted to descriptive statistics by calculating the mean and the coefficient of variation. In order to investigate the relation of the MS with other soil physical properties it was made a correlation matrix. The results shown that MS, in both sugarcane lots, has statistical correlation with physical soil properties. For lot Chondular, it was noticed a similar behavior of relationship between MS, and the content of clay and sand. The lot Santa Rosa shows high, and direct relation with other properties such as field capacity, bulk density, and total pore space. The use of MS parameter in soil diagnostic allows inferring with high assertiveness the general physical condition of agricultural soils located in the flat area of Valle del Cauca, Colombia, reducing significantly processing times, environmental impact (due to the chemical reagents used), and costs in conventional laboratory tests.

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RELACIÓN ENTRE PROPIEDADES FÍSICAS Y LA SUSCEPTIBILIDAD MAGNÉTICA PARA DOS SUELOS AGRÍCOLAS DEL VALLE DEL CAUCA

Palabras clave: *Calidad del suelo, cultivo de caña de azúcar, diagnóstico del suelo, magnetismo*

RESUMEN

Este estudio tuvo como objetivo investigar el uso potencial de la susceptibilidad magnética (SM) como una propiedad para caracterizar el estado del suelo en dos lotes cultivados con caña de azúcar. La SM es una propiedad que determina el grado de magnetización de un material y tiene un uso potencial en el diagnóstico de los suelos agrícolas debido a su versatilidad de medición. Se recogieron muestras de suelo y se sometieron a análisis de laboratorio a partir de dos lotes llamados Chondular (55.3 ha) y Santa Rosa (98.3 ha) con el fin de medir la SM y compararla con las propiedades físicas convencionales. Los datos fueron sometidos a estadística descriptiva mediante el cálculo de la media y el coeficiente de variación. Con el fin de investigar la relación de la SM con propiedades físicas del suelo se hizo una matriz de correlación. Los resultados muestran que la SM, en los dos lotes de caña de azúcar, tiene correlación estadística con las propiedades físicas del suelo. Para el lote Chondular, se observó un comportamiento similar en la relación entre la SM y el contenido de arcilla y arena. El lote Santa Rosa mostró una relación alta y directa con otras propiedades tales como la capacidad de campo, densidad aparente, y el espacio total de poros. El uso del parámetro de diagnóstico de SM en el suelo permite inferir con alta asertividad la condición física general de los suelos agrícolas ubicados en la zona plana del Valle del Cauca, Colombia, reduciendo significativamente los tiempos de procesamiento, el impacto ambiental (debido a los reactivos químicos utilizados) y los costos de las pruebas convencionales de laboratorio.

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INTRODUCTION

The evaluation of agricultural soils plays a key role in crop production, and mapping the spatial variability of soil properties is of great importance for planning sustainable agricultural practices (Barbieri et al., 2008); however, due to the high costs and time-required associated to soil sampling, testing, and analysis its use in agriculture is poorly implemented. In order to contribute to the solution of this issue, it is fundamental to study new soil parameter that can be both inexpensive and of rapid measurement, in order to provide useful information about the state of the soil. Some authors have proposed the use of pedotransfer functions, which are increasingly used in modern agriculture to indirectly estimate soil properties simply and rapidly. According McBratney et al. (2002) pedotransfer functions can be defined as mathematical models used to estimate the soil parameters from other parameters measured with greater ease and low cost.

One parameter that provides ease of measurement and can be used to indirectly determine soil properties is the magnetic susceptibility (MS) (Bautista et al., 2014; Grimley & Vepraskas, 2000). MS is the result of the translation and rotation of the electrons, which constitute some minerals that are present in soils, sediments and rocks (Luque, 2008); MS may also be defined as the degree of magnetization of a material in response to an applied magnetic field. The materials may have different five types of magnetic behavior: ferromagnetic, ferrimagnetic, antiferromagnetic, paramagnetic and diamagnetic (Coey, 1988).

Kanu et al. (2014) affirm that magnetic minerals present in soils may either be obtained from the parent rocks (lithogenic origin), during pedogenesis or as a result of anthropogenic activities. The same author concludes that magnetic mineral content of the soil can broadly be expressed by its MS. One important example relies in the content of iron oxides in soils. Iron oxides are the most abundant metal oxides on the soil (Schwertmann & Taylor, 1989), and they are used as indicators of pedogenetic processes (Schwertmann, 1993), because they are virtually in all soils in varying amounts with a mean interval of 0.5 to 5 % (Bodek et al., 1988; Acevedo-Sandoval et al., 2004). Iron oxides influences soil's color, its aggregation, cation exchange capacity, phosphorus retention and the plant nutrition (Schwertmann, 1993; Shewertmann & Taylor, 1989; Acevedo-Sandoval et al., 2004).

The MS parameter became popular in soil-related studies including paleoclimatic field studies (An et al., 1991; Huang et al., 2006; Torrent et al., 2010; Urcia et al 2012; Xiao et al., 1995), soil surveys (Blundell et al., 2009; Dearing et al., 1996; Marques et al., 2014; Mathé & Lévêque, 2003), and soil erosion (de Jong et al., 1998; Jordanova et al., 2014; Rahimi et al., 2013; Royall, 2001). It also has been used to identify heavy metals and soil contamination (Magiera 1998; Pedroso 2013; Petrovsky 1999; Petrovsky 2000), with few studies to support its application in agricultural soils.

The magnetic measurement methods have the advantage of revealing properties of materials in a rapid manner (Grimley et al., 2004; Hu et al., 2007; Lecoanet et al., 2003). Magnetic minerals help reveal the environmental conditions of soil formation, and are, also indicators of pollution. Soil studies based on magnetic measurements have reveal details not seen in other more general pedological analyzes related to the appearance of anthropogenic origin materials in soils (Hanesch & Petersen, 1999).

The advantages of environmental magnetism, compared to other analytical methods, is largely based on its low cost, fast measurements and non-destructive nature, which allows the reuse of samples in other analysis (*i.e.* chemical testing). The sample preparation for magnetic study is relatively simple, and fast. According to Mathé et al. (2006) the magnetic minerals can be considered as micro markers of the soil properties, since the crystallographic properties of these minerals reflect the factors and processes of soil formation, which are specific for each location. In this regard, it can be affirmed that the MS has several advantages in contrast with other conventional laboratory tests. First, with the MS analysis it can be utilized a large number of samples in a short period; second, magnetic measurements are highly sensitive, enabling even slight variations less than 1% of magnetic material present in the sample (Bautista et al., 2014); third, no additional chemical reagents are required to prepare the samples, and four, the amount necessary to make magnetic measurements is very small (20 to 25 g), so it does not require large spaces for storing samples. Those advantages can be explored in the agricultural sciences, particularly in soil study.

Some work related to soils in agriculture could be referred by Bautista et al. (2013), who determined that the magnetic properties of soil along its profile are associated to texture, and organic carbon. Similarly, Lopez (2010), indicated important relationships between MS and physical properties of the soil. In order of importance: bulk density, porosity and moisture. Furthermore, some authors such as Bartel et al. (2005), and Barragan (2010) verified changes in MS within soil depth.

Peluco et al. (2013), studied the potential use of MS as pedotransfer function to predict soil parameters under two sugarcane harvesting management systems in Brazil, and concludes that MS can be indicated as a promising alternative parameter to assist in the indirect quantification of soil properties that have magnetic expression. Cortez et al. (2011) studied the qualitative and quantitative potential of the soil for the cultivation of oranges by using MS on Brazilian soils with promising results.

Other authors (Chevrier & Mathé, 2007; Torrent et al., 2007) also report on the relationship of MS with mineralogical parameters. Kämpf & Curi (2000), indicate that iron oxides are important indicators of environmental conditions. These minerals are abundant in tropical soils and have strong expression in the magnetic behavior. MS shows up as a promising measure qualitative and quantitative mapping to assist in specific areas of management in certain agricultural areas of Valle del Cauca Department in Colombia. The MS parameter in soil testing, complemented with computational tools such as GIS software, can permit the location of possible problem areas, with the objective to establish corrective actions on suitable soils for agriculture.

The aim of this research is to assess the relationship of the MS with conventional physic properties for two soils of southern Valle del Cauca, Colombia, in order to evaluate its implementation as an efficient parameter for soil physical testing.

METHODOLOGY

The study areas are located in the south of the department of Valle del Cauca, Colombia, in the municipalities of Palmira and Candelaria. Measurements were made in two soils under cultivation of sugar cane, located specifically in two lots: Santa Rosa and Chondular. The Santa Rosa lot is located in Palmira, with geographical coordinates 3º35’05’’N, and 76°15’16’’W, altitude 1060 m.a.s.l., and average temperature of 23.5°C. The Chondular lot is located in Candelaria, with geographical coordinates 3°26’35’’, and 76°22’45’’, 967 altitude m.a.s.l., and average temperature of 23.5°C (Figure 1).

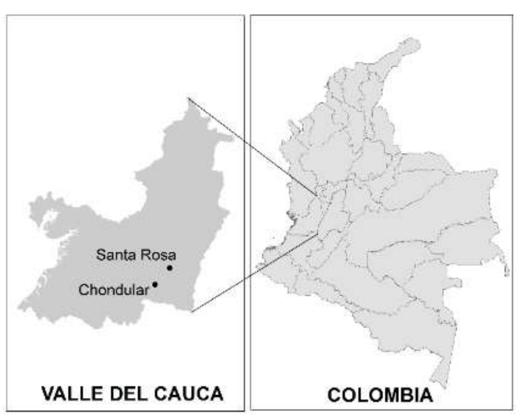

Figure 1. Location areas

According to the study of soils conducted by IGAC - CVC, (2004), in the Santa Rosa lot dominates the Pachic Haplustolls Consociation family, with fine texture, isohyperthermic, with loamy PL symbol belonging to the Palmira complex soils. While in the Chondular lot, predominates the Consociation of Haplustolls Cumulic family, fine texture, isohyperthermic, with loamy MN symbol of a complex of Manuelita soils. Altered and unaltered soil samples were collected at a depth of 0.00-0.30 m for physical analysis. Every point of sampling was geo-referenced with GPS with the objective of obtain boundaries of areas of the sugar cane lots, for a total area of approximately 98.3 hectares for lot Santa Rosa, and 55.3 hectares for lot Chondular. 45 and 28 reference-sampling points were distributed, respectively, for lot Santa Rosa and Chondular with a density of 1 point per 2 hectares (Figure 2).

The disturbed samples were taken with a Dutch auger-hole, extracting four sub-samples within a radius of 10 meters around the georeferenced point for the representative sample mixture. For the undisturbed samples three repetitions per sampling point were taken, using a core auger-hole. The samples were taken to characterize physical properties and measurements of soil magnetic susceptibility in the Environmental Physics Laboratory at the Universidad del Valle.

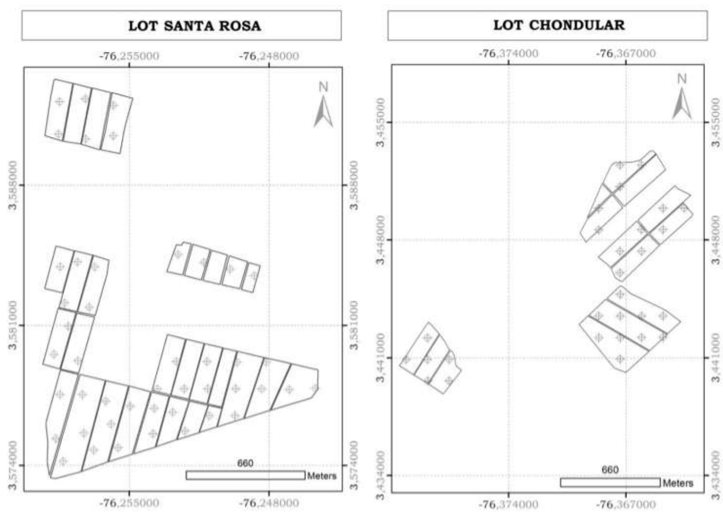

Figure 2. Distribution of sampling points for lots Santa Rosa (left) and Chondular (right)

Physical soil analysis included the determination of percentages of sand (A), loam (l) and clay (Ar), bulk density (Da), field capacity (Cc), drainable porosity (Pd), total pore space, and thermal conductivity (Ct) of every soil sample with a sampling density of one point every two hectares. For SM determining, was used the PCSM Pike Agri-lab supplies equipment with a µCGS measuring system (Table 1).

To determine the MS, the samples were dried in the oven Quincy Lab. 40GC at 50 °C for 12 hours, then passed through a sieve of 2 mm size to separate the fraction of soil. It was weighed 25 grams of every soil sample, and deposited in plastic containers. The MS measurements were performed with the PCSM Pike Agri-Lab Supplies equipment, using a µCGS measuring system and dimensionless units.

Table 1. *Physical properties of soil analyzed*

No.	Properties	Simbol	Units	Method
1	Sands	A	%	Hydrometer
2	Clays	Ar	%	Hydrometer
3	Field capacity	Cc	%	Gravimetric (NTC 5167)

4	Thermal conductivity	Ct	Cal/cm·s·°C	Zúñiga & Reyes*
5	Bulk density	Da	g/cm^3	Gravimetric (NTC 5167)
6	Total pore space	EPT	%	Gravimetric (NTC 5167)
7	Loam	L	%	Hydrometer
8	Drainable porosity	Pd	%	Gravimetric (NTC 5167)
9	Magnetic susceptibility	Sm	CGS	

* European patent No. 20030228. Zuniga, O. & Reyes A. Universidad del Valle (2007)

Data were statistically analyzed, obtaining the average and coefficient of variation. The information obtained from the analysis of soil was processed by using software ArcGis 10.1. Initially a general descriptive statistical analysis was run, followed by a geostatistical analysis that included checking normality of the data. Semivariograms were analyzed for each property in order to obtain parameters necessary for ordinary Kriging interpolation method for the generation of raster files type. Finally, it was obtained the spatial correlation matrix between the set of physical properties analyzed and the SM parameter.

RESULTS AND DISCUSSION

By implementing a GIS, it was found high spatial correlations between analyzed properties of the order of 0.9, -0.88, -0.54, -0.76, 0.61, -0.69, 0.48, with A, Ar, Cc, Ct, Da, Ept and L, respectively, for Chondular lot, and in the order of 0.59 and -0.65 with A and Ar for Santa Rosa Lot.

Descriptive analyzes (Table 2) showed high variability for the MS for both study lots, with values of 44.9 and 42.8%, respectively, for lots Santa Rosa and Chondular. For the other hand, it was found that properties such as Ept and Da had little variability within the study areas.

Maps presented in the figure 2 show the spatial distribution of the MS (left map) in contrast to clay content (center map) and sand content (right map), with which one can identify a reverse and forward ratio, respectively was obtained, appreciating similarity between high susceptibility areas and areas of high sand content and vice-versa.

Table 2. *Descriptive statistics for the physical properties of soil*

	Lot Santa Rosa					**Lot Chondular**				
	MIN	MAX	MED	ST DEV	CV	MIN	MAX	MED	ST DEV	CV
A	14,4	59,3	32,9	9,9	30,1	4,1	35,0	15,1	7,4	49,0
Ar	16,1	45,4	31,2	5,8	18,7	16,9	59,8	40,3	12,0	29,8
Cc	76,7	122,5	102,2	8,7	8,5	95,9	125,0	109,5	7,0	6,4
Ct	5,6	12,5	8,3	1,5	17,6	7,3	12,6	9,6	1,0	10,9
Da	1,1	1,7	1,4	0,1	6,6	1,1	1,5	1,3	0,1	5,4
Ept	37,7	52,4	44,7	2,7	6,0	41,9	49,3	45,8	1,7	3,8
L	21,5	48,0	35,9	5,6	15,6	31,1	62,8	44,6	8,1	18,1
Pd	2,9	18,0	10,6	3,3	30,7	6,1	15,8	9,3	2,1	22,7
Sm	36,6	195,9	89,6	40,3	44,9	46,7	212,5	98,1	42,0	42,8

CV: Coefficient of variation; ST DEV: Standard deviation; MIN, MAX & MED: Minimum, maximum and medium, respectively

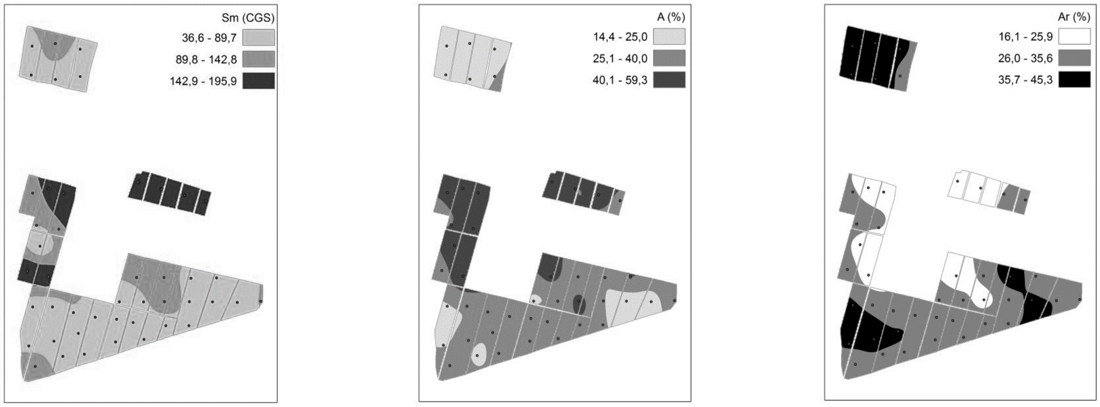

Figure 3. Map of MS, sands and clays for lot Santa Rosa

For lot Chondular, it was noticed a similar relationship between MS, the content of clay, and sand (Figure 4). The lot Santa Rosa shows a MS with high direct relation to other properties such as field capacity, bulk density, and total pore space.

The relationship between the maps of Figures 3 and 4, were quantitated through a correlation matrix (Table 3), confirming correlation values for lot Santa Rosa, of 58.7% with the sands, and - 64.8% with clays.

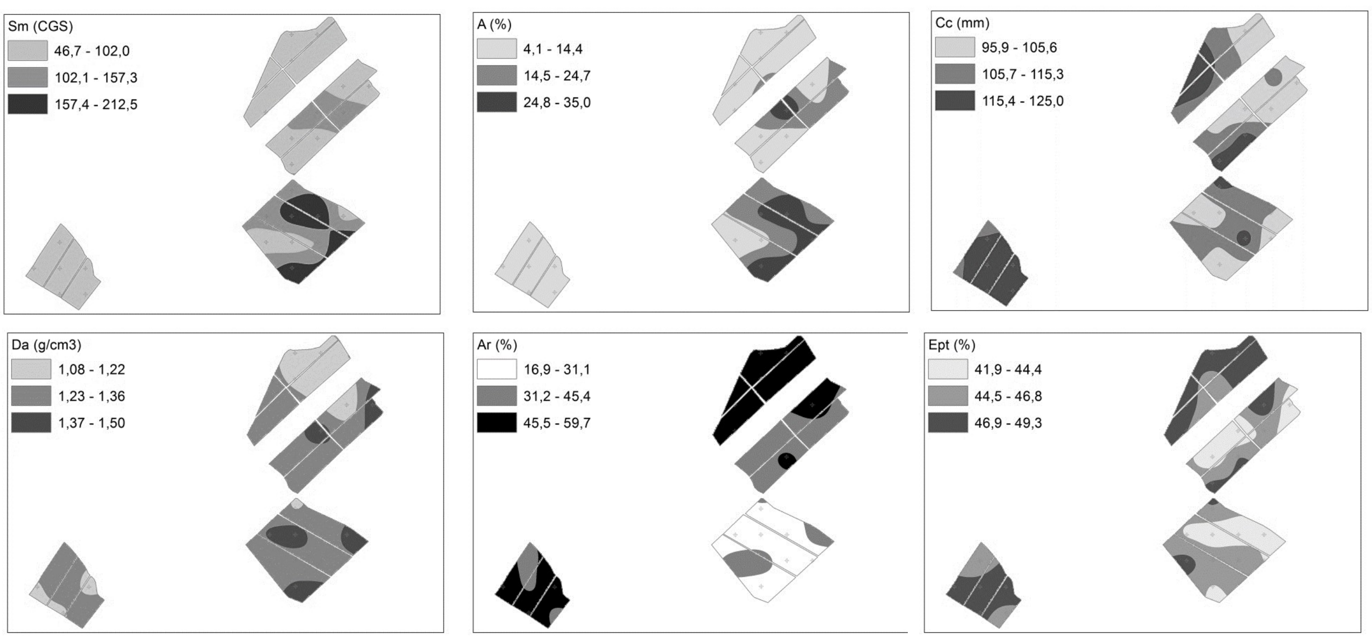

Figure 4. Map of MS, sand, clay, field capacity, bulk density and total pore space for lot Chondular

Table 3. *Coefficients of spatial correlation of physical properties with the MS*

Lot	A	Ar	Cc	Ct	Da	Ept	L	Pd
Santa Rosa	0,58795	-0,64836	-0,20422	-0,16203	0,09811	0,06013	-0,36769	0,23206
Chondular	0,89772	-0,87689	-0,5363	-0,76592	0,61007	-0,6858	0,47865	0,03381

The higher content of MS can be related, to the texture property (Williams & Cooper, 1990). Grimley et al. (2004) found MS values consistently higher in well-drained soils and lower in hydric soils at northeastern Illinois USA, reflecting anaerobic deterioration of both detrital magnetite and soil-formed ferrimagnetics. The authors indicate that the higher magnetite content and slower dissolution rate in sandy soils may explain the difference. This corroborates the findings of this study, in which the highest MS values were observed in sandy textures present in soil (Mollisols). On the other hand, Fontes et al. (2000) mentioned that the magnetic behavior is in fact more evident in soils whose clay fraction is bigger because in clay, magnetite is oxidized to maghemite, while in the sand fraction; magnetite is oxidized directly to hematite that has lower MS than magnetite in Brazilian soils (oxisols). More research is therefore required to verify and test the MS method in a variety of regions, land uses, soil types and parent materials. It is important to determine and compare critical values at several contrasting sites and to develop a database using this new technique. Highly variable critical MS values in areas of South Africa, probably a result of differing magnetite contents in soil parent materials among the sites, show the need for calibration of critical MS values on a site specific basis (Grimley et al., 2004).

CONCLUSIONS

The results of the present study showed a high correlation between the magnetic susceptibility and texture, particularly with the clay and sand fraction of the analyzed soil (Mollisol). The magnetic susceptibility could be indicated as a promising alternative parameter to assist in the indirect quantification of soil parameters that presents magnetic expression. The use of the SM parameter use in diagnostic soil allows us to infer with high assertiveness in the general physical condition of agricultural soils located in the flat area of Valle del Cauca, potentially contributing to reducing the time and cost of processing laboratory.

Notwithstanding the above stated, it is fundamental to develop more studies to expand the knowledge about the relationship between the magnetic susceptibility and the conventional characterization properties of soil in order to refine the use of magnetic susceptibility for different agro-climatic conditions.

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