Cultivos Tropicales, 2017, vol. 38, no. 1, pp. 50-56 january-march

ISSN impreso: 0258-5936
ISSN digital: 1819-4087

Ministerio de Educación Superior. Cuba
Instituto Nacional de Ciencias Agrícolas
http://ediciones.inca.edu.cu

VARIATIONS IN SOME SOIL PROPERTIES BECAUSE OF THE LAND USE CHANGE IN THE MIDDLE AND LOW PARTS OF THE MEMBRILLO MICRO-WATERSHED, MANABI, ECUADOR

Variaciones en algunas propiedades del suelo por el cambio de uso de la tierra, en las partes media y baja de la microcuenca Membrillo, Manabí, Ecuador

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ABSTRACT. The land use change, principally the change from forest lands to cultivated ones, is one of the practices that have the highest impact in soil degradation in the World and, besides, provoke a great deal of CO_2 emission to the atmosphere. So that is necessary to evaluate theses changes that occur in soils properties in different ecosystems, to take the appropriate conservation measures and improve soil management. In this paper, for a first time, the change of some soil properties due to land use change is studied, from the lowest and middle part of Membrillo micro-watershed in Manabí province, Ecuador. This micro-watershed has a hilly to premountian relief where primary and secondary forests, cocoa plantations and lands under maize cultivation are predominant, in the lowest part. The soils are Phaeozems, Cambisols and Fluvisols. In this paper we present the results obtained related to changes on soil morphological characteristics (color, structure and the A y B horizon thickness), organic carbon lost and the change on volume density, provoked by land use change.

Key words: soil degradation, organic carbon

RESUMEN. El cambio de uso de la tierra, sobre todo el de tierras forestales a tierras cultivadas, es una de las prácticas que mayor impacto ha tenido en la degradación de los suelos en el Mundo y que ha provocado en gran parte la emisión de CO_2 a la atmósfera. Por esto se hace necesario evaluar las transformaciones que ocurren en las propiedades edafológicas, por el cambio de uso de los suelos, en los diferentes ecosistemas para de esta forma tomar las medidas adecuadas para su mejoramiento y conservación. En este trabajo, se estudian las variaciones de algunas propiedades de los suelos de las partes medias y bajas de la microcuenca Membrillo (provincia Manabí, Ecuador). Esta microcuenca presenta un relieve alomado, premontañoso, en la cual predominan bosques primarios y secundarios y plantaciones de cacao, pastizales y cultivos como el maíz en su parte baja. Los suelos son Feozems, Cambisoles y Fluvisoles y se presentan los resultados sobre cambios en sus características morfológicas (color, tipo de estructura, espesor de los horizontes A y B), las pérdidas de carbono orgánico y en la densidad aparente del suelo, provocado por el cambio de uso de la tierra.

Palabras clave: degradación del suelo, carbono orgánico

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INTRODUCTION

It is shown that with man's activity in food production, soils change in their properties. The emergence and development of agriculture and its increase with the application of irrigation, mechanization and chemo, causes the change of soil properties. These changes, often silent, mean that the soil degrades and loses the capacity to produce food (agroproductivity), being more pronounced in the rippling regions and accompanied by the emergence of the erosion process.

With the emergence of the Green Revolution in Agriculture after World War II, these processes of soil degradation increased. It was shown that soils in the world have declined by 17 % in the period 1945-1990, compared to only 6 % in the period 1900-1945 (1). From this stand the concepts of sustainable agriculture, organic agriculture, etc.

In recent years, the following classification of anthropogenic soil changes ordered by the degree of transformation has been proposed (2):

- ♦Transformation of the topsoil
- ♦Change of some soil horizons
- ♦Change of the taxonomic level of the soil
- ♦Deep profile disruption
- ♦Training of anthropogenic parent material
- ♦Total landscape change

The agricultural influence in the transformations of the properties of the soils must be considered today as one of the main causes of the transformations that occur in the soils (3). Recently, the variations occurring in the properties of the Red Ferralitic leachates formed from myocene hard limestone rock, by the action of the continued cultivation for many years, and even their possible synergy with climate change are shown (4, 5).

Currently, soils transformed by man are recognized as particular taxa in almost all edaphic classifications (6, 7). For agricultural soils the classification is complicated because we must consider the indicators of the properties that the soil acquires by agrogenic formation, and then its intensity, since there may be intermediate stages. These ideas are applied in their most elaborate versions, first, the most complete in this direction, the classification of soils of Russia (8) also the classification of the World Reference Base (9), and China's (10).

Even in the recent classification of soils of Cuba 2015, agrogenic and erogenic terms are applied to separate subtypes of soils formed by anthropic action (11).

Following this line of work, it is proposed that these changes are more pronounced in tropical regions, with soil structure being one of the fastest changing properties (12). Considering these premises, the soil characteristics (Feozem, Cambisol and Fluvisol) of the mid and low regions of the Membrillo micro-watershed, Manabi province, Ecuador, were presented for the first time in a previous paper. The purpose of the present work is to show how some of the properties of the main soils of the region have changed by the continued cultivation.

MATERIALS AND METHODS

Several sites were selected in the Parish of Membrillo, under different forms of use. From these sites ten soils profiles were studied, with some samples of the 0-20 cm layer within the studied areas. The relationship of the profiles studied and their use is as follows:

- ♦ Soils under forest (primary and secondary): 2 profiles (F-5 and F-8).
- ♦ Soil under cocoa plantation (Theobroma cacao): 4 profiles (F-2, 100 years, F-3, 30 years, F-10 3 years and F-6 1 year).
- ♦ Soils under pasture (*Paspalum notatum*): 2 profiles (F-7, guinea grass over 20 years old, F-4, now natural pasture, overgrazed).
- ♦ Soils under maize cultivation for 7 years (*Zea mays*): 2 profiles (maize of 45 days with improvement and irrigation and maize with 30 days).

The soil profiles are described in each case using the World Reference Base classification (9) and the North American Soil Taxonomy (14) is also applied. Soil analyzes were carried out in the laboratory of the "Manuel Félix López" Higher Agricultural Polytechnic School of Manabí (ESPAM MFL, according to its acronyms in Spanish), using the following methods:

- ♦ Humidity through the oven, at 105 ^{o}C, to constant weight
- ♦ Density of volume by the method of the cylinders (of 100 cc) in the field
- ♦ Organic matter by the method of Walkley & Black (15).

The Upper Limit of Productive Humidity was determined in the laboratory by the Richards Press.

The carbon content is calculated by dividing the organic matter content between 1,724 and its reserves by multiplying the carbon percentage by the volume density and the horizon thickness. In this case it is determined for the 0-20, 0-50 and 0-100 cm layers so that the values are comparable.

Irrigation was done empirically, deducing the Upper Limit of Productive Humidity (LSHP, previously linked to the Field Capacity) by the current humidity and soil type, establishing as Lower Limit of Productive Humidity a 75 % of LSHP. The standards are set for 0-20, 0-50 and 0-100 cm layers of soil.

RESULTS AND DISCUSSION

Due to the natural conditions of soil formation in the region under primary forests, it is soils with a strong accumulation of organic matter (humification), which would lead to the formation of Feozems (according to the Soil Classification of the World Reference Base) or Molisols (according to the classification of the North American Soil Taxonomy) and in the formed parts of sediments of Fluvisols or Fluvents (by these classifications respectively).

However, due to anthropogenic activity some of the Feozems soils have been degraded (Table I), and in the soil profiles, three soil reference groups were found: Feozems, Cambisols and Fluvisols, also shows the classification of these soils by the two world classification systems (WRB and Soil Taxonomy).

Table I. Classification of soils studied by the World Reference Base systems (WRB) and Soil Taxonomy

No. de Perfil	Classification according to the WRB	Classification according to Soil Taxonomy
F-1	Fluvisol mólico, vértico (éutrico, endoarcíllico)	Mollic Udifluvent
F-2	Feozem lúvico	Typic Hapludoll
F-3	Feozem lúvico (endoarcíllico)	Typic Hapludoll
F,4	Cambisol háplico (éutrico, esquelético)	Typic Haplanthrept
F-5	Feozem vértico, lúvico (endoarcíllico)	Vertic Hapludoll
F,6	Cambisol háplico (éutrico)	Typic Haplanthrept
F-7	Feozem gléyico, lúvico (ántrico, endoarcillico)	Aquic Hapludoll
F-8	Fluvisol mólico (ántrico, éutrico esquelético)	Typic Hapludoll
F-9	Fluvisol mólico (ántrico, éutrico esquelético)	Typic Udifluvent
F-10	Feozem lúvico (ántrico, endoarcíllico)	Typic Hapludoll

Regardless of the Soil Referential Group (GRS, according its acronyms in Spanish), there are variations in its properties due to the change in land use. These are mainly manifested in those properties that change in a relatively short time, such as: their morphological characteristics (soil thickness, color, structure), and other physical and chemical properties (in bulk density or volume density), in the pH and content in organic matter and the carbon reserves of the soil.

Changes in some soil morphological characteristics

The change of the morphological properties of the soils by the crop, is posed in several publications. According to several researchers (3, 12), it results from the first appreciable changes occurring in the soil properties by intensive cultivation; being more marked in the unstable reliefs (corrugated, hilly, mountainous), due to the erosive process.

Table II shows the morphological characteristics of the soil, in the different soil profiles grouped by the current use.

The cumulative upper humic horizon of any soil represents the most important part of the profile, since the great percentage of the roots of the plants are developed in this part and it is also the richest for the biodiversity that can present. In the results shown it can be observed that in Feozems soils under forests the thickness of the A horizon can reach around 80 cm, which expresses the quality of these soils alone, that if at any time they are put under cultivation or pasture search for by all means to maintain that thickness at least 50 cm.

In the case of Feozems soils under long-standing cacao plantation, the thickness of the A horizon is smaller, fluctuating around 40 cm, which could have been caused by the possible use of these soils with other types of crops as preceding cocoa, which may tend to decrease this thickness.

For the soils under a few years' cocoa (profiles F-10 and F-6), it was found that the thickness of the A horizon was reduced to 28 cm on average. This behavior could be inferred that it is because these soils in previous years were cultivated with manifestation of erosion processes, stronger in the F-6 profile that led to transforming it into Cambisol. In this case it is very appropriate to use it under cocoa since in time it can achieve to restore the depth of A horizon, even to transform the Cambisol into Feozem again.

In soils under pasture, the two profiles showed degradation, F-4 by very strong erosion and F-7 by overgrazing.

Table II. Morphological characteristics of the profiles studied in current use conditions

Land use	Group of soil	Nu. Profile	Thickness mean horiz, A+B (cm)	Loss in cm and in (%)	Color of hor. A by Munsell Table	Structure of the horizon A
Primary forest Secondary forest	Feozems	F-5 F-8	70+ 94=84	---	Black, very dark gray, very dark brown	Granular and subangular blocks that are crumbled into granular
Cocoa for many years (30-50)	Feozems	F-2 F-3	30+48= 39	45 cm (46,4 %)	Very dark brown, black	Granular, Subangular blocks that become granular
Cacao of few years (less than 19)	Feozem Cambisol	F-10 F-6	45+11= 28	56 cm (66,7 %)	Very dark brown	Subangular and angular blocks
Pastures with overgrazing	Cambisol Feozem	F-4 F-7	5+45= 25	59 cm (70,2 %)	Very dark brown to dark brown	Subangular and angular blocks
Maize	Fluvisoles	F-1 F-9	25+37= 31	53 (63,1 %)	Very dark gray, very dark brown	Granular, polyhedral, subangular blocks

In both cases, the average soil thickness does not exceed 25 cm. In these soils, it is necessary to establish conservation measures and above all to avoid overgrazing specifically in the case of the F-7 profile under Savoy grass or guinea-grass (*Panicum máximum*) of 20 years.

In the case of soils of the lower parts Fluvisols (profiles F-1 and F-9), the continued cultivation in them has an average of 30 cm of the A horizon, which should be preserved above all with the current practices of organic agriculture Begin to enter the region.

Changes in reserves of organic soil carbon

This is a property that is currently being paid attention; on the one hand, a good content of soil organic matter and therefore in their reserves of organic carbon, implies that the soil has good structure, good nutrient content and values of density, porosity and water storage, very suitable for crops (4); and on the other hand, has a topical importance in the problems of carbon sequestration and sequestration in relation to the global warming of the atmosphere (5, 16). It has been estimated that the soil organic carbon stocks account for two-thirds of terrestrial carbon stocks (17).

Therefore, today it is a matter of capturing carbon from the soil, either with adequate agricultural practices or with the addition of organic materials (18-20), thus seeking suitable soil management technologies that maintain a high content of Carbon in the same (21, 22).

The results obtained in this study are presented in Table III.

These results show that the best contents in organic carbon reserves are found in soils under forests (primary and secondary), with accumulations greater than 200 Mg ha^{-1} for the 0-100 cm layer; which coincides with criteria that suggest that tropical soils are the ones that can accumulate the most carbon (23). They are followed by the cacao groves of many years, of a few years and the lowest contents in those of pastures with overgrazing and under crops. This shows how in the region, cocoa cultivation over time achieves stabilization of the organic matter and organic carbon content of the soil by the contribution of litter.

Table III. Changes in the contents of organic carbon reserves in soils

Land use	Nu. Profile	Reserves of C in Mg ha^{-1} 0 -20 0-50 0-100 (cm)
Primary forest Secondary primary	F-5 F-8	56 128 247 68 134 231
Cocoa for many years	F-2 (100 years) F-3 (30 years)	56 108 nd 60 122 197
Cocoa for few years	F-10 (3 años) F-6 (1 año)	55 117 nd 41 92 nd
Pastures with overgrazing	F-4 F-7	37 nd nd 49 103 nd
Maize 14 months Maize 12 months	F-1 F-9	43 90 113 42 nd nd

nd: No determined

These results are within the limits of carbon losses in the natural ecosystems posed by different researchers (24), who assert that agricultural soils have lost between 30 and 75 % of the organic carbon reserves or 30 to 40 mg c ha $^{-1}$.

This shows us that forests represent the type of cover that best stores organic carbon in the soil, and for this region the sowing of cacao groves is adequate in that sense. However, farmers have to stock up on food and must farm; for this reason, the sustainable management of the soils is important. It should not be lost sight of in the future to look for a type of organic amendment that allows improving the organic carbon content of the soil, improving at the same time its physical and chemical properties, with results that also lead to environmental improvement.

Changes in Soil Volume Density

Volume density is a property that changes rapidly either through cultivation, erosion or overgrazing and it is closely related to organic matter and soil moisture content. Therefore, in soils with a mollic horizon, with a nuciform granular structure and good moisture content, these values are usually between 0,9 and 1,05 mg m^{-3}, indicating that the soil has a friable consistency. However, in soils with high values of volume density, it is compact with values greater than 1,3 mg m^{-3} and it may be the case that values such as these limit the development of the roots, preventing the penetration of aggregates. In this case the so-called “critical density for crops” is reached. Table IV shows the results obtained for this characteristic in the A horizon, for each soil profile.

Average of several samples in the volume density

From the above results it is observed that as the soil is improperly used, the values of the volume density increase. It is observed that the forest soils have the lowest values, followed in that order by the soils under cocoa of many years, of a few years and are the highest values in degraded soils and under maize cultivation.

Volume density in soils is closely related to the organic matter content, forming part of the micro and macro-structure of the soil. As the soil loses content in organic matter by continued cultivation, either by mineralization or erosion or both at the same time, the initial soil structure is lost and the soil bulk density increases. This mechanism is explained for Red Ferralitic soils from Cuba (5) (Ferric alcoholic rubric nitisols, according to the WRB classification). In addition, the transformation of soil structure and increase in volume density by continuous cultivation has been reported by several authors (5, 25-28). It is also necessary to consider the agrosystems under pastures that are subject to overpowering, in which the trampling of the animals leads to the compaction of the soil, as in the soil represented by the profiles F-4 and F-7, which coincides with results obtained in Brazil (26).

The doses of irrigation

The Regional Office of FAO is promoting the use of irrigation in this Parish, for this, although in an estimated form, the calculation of the irrigation dose of the soils studied is carried out. As can be seen, in the results presented in Table V,

Table IV. Changes in Soil Volume Density

Crop	Group of soils	N u . Profile	Mean of Dv(1) in the horizont A (Mg m^{-3})
Primary forest Secondary forest	Feozems	F-5 F-8	0,98
Cocoa for many years (30 – 50 years)	Feozems	F-2 F-3	1,13
Cocoa of a few years (less than 10 years)	Feozem Cambisol	F-10 F-6	1,16
Pastures with overgrazing	Cambisol Feozem	F-4 F-7	1,21
Maize	Fluvisoles	F-1 F-9	1,23

Table V. Theoretical rules of irrigation for the studied soil profiles

Land use	Soil	N u . Profile	Theoretical norms of irrigation(m^3 ha^{-1}) 0-20 0-50 0-100 (cm)
Primary forest Secondary fore	Feozem Feozem	F-5 F-8	169 463 1067 161 483 1042
Cocoa for many years	Feozem Feozem	F-2 (100) F-3 (30)	225 607 nd 232 555 1186
Cocoa of a few years	Feozem Cambisol	F-10 (3) F-6 (1)	229 610 nd 215 491 nd
Pastures with overgrazing	Cambisol Feozem	F-4 F-7	218 nd nd 233 524 1094
Maize 14 meses Maize 12 meses	Fluvisol Fluvisol	F-1 F-9	219 635 1233 nd nd nd

the lowest amount of water to be applied would be for forest soils, which are conserved and do not need irrigation, both for depths of 0-20, 0-50 and 0-100 cm and the highest in soils that have been under cultivation, which present a certain level of degradation. In the future, hydrophysical tests should be done to clarify the values obtained in this work.

With the degradation of the soil by erosion, whether caused by overgrazing or by continued cultivation, the water storage capacity in the soil is reduced, which results in the application of more water (m^3 ha^{-1}) to maintain soil moisture at the limits of productive moisture in those soils with the above-mentioned problems. Table IV presents the results obtained in this section.

In Cuba (5), they report that for 30 % of the soil's capacity to retain moisture, for intensive Ferralitic soils (Erythrocyanic ferricic nitisols) due to intensive cultivation for many years. This is related to the degradation of the soil by the crop with losses of the organic matter reserves, degradation of the structure, increase of the volume density and decrease of the total porosity and aeration of the soil.

CONCLUSIONS

- Practices such as cultivation in sloping areas and overgrazing lead to the degradation of some soil properties in relation to land use.
- Soils, in terms of the conservation of their properties, can be classified as follows: Soils under forests> soils under many years 'cocoa> soils under a few years' cocoa> soils under cultivation> degraded fallow soils.
- Cocoa cultivation, which is maintained for many years (50-100 years), is beneficial to soil properties, achieves a high content of organic matter and therefore of carbon stocks and also improves the physical properties of the soil.
- It is verified that in the areas of cultivation a policy of application of organic products and irrigation is being carried out that is necessary to improve the quality of the floors and therefore the quality of life of the farmers.

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Received: September 9th, 2015
Accepted: June 1st, 2016

Revista Cultivos Tropicales
Instituto Nacional de Ciencias Agrícolas