***Research article***

**Soil organic carbon forms with different uses in the**

**Department of Magdalena (Colombia)**

**Formas de carbono orgánico en suelos con diferentes usos en el**

**Departamento del Magdalena (Colombia)**

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**Abstract**

Fractions of soil organic matter (SOM) labile and humified, can be affected by use and management practices, but the impact of these changes has not been evaluated in soils of tropical environments. The present study investigated the contents and some forms of soil organic carbon (SOC) in five warm tropical climate zones of the Department of Magdalena (Colombia), and the effect of the cropping practices on these forms of organic carbon in cultivated soils, associated with Coffee (*Coffea arabica*), Banana (*Musa* sp.), African palm (*Elaeis guineensis*), Aloe (*Aloe vera*) compared to natural forest soils. Significant differences (P < 0.05) were not found between zones neither between soil. The study areas had low average values of SOM and, the forest soils had higher contents of total carbon than cultivated soils. Forest soils had an total carbon accumulation average of 42.4 mg/ha at 20 cm, compared to 33.8 mg/ha in the cultivated soils, this equals to an average loss of 23% total C by the effect of crop management in these soils. Values of humified C (C extracted with sodium pyrophosphate), are very low in cultivated soils and almost zero in forest soils, but forest soils had a higher number of stable forms of C (Cnox). In the soil cultivated with bananas, Total Carbon corresponds to fully oxidized forms of C, however in the soil cultivated with African palm, C stable forms represented 83% of total carbon.

Key words: Agricultural soils, biogeochemical cycling, Carbon, Colombia, humus, Magdalena, plant nutrition.

**Resumen**

Las fracciones de materia orgánica del suelo (MOS) lábiles y humificadas pueden ser afectadas por las prácticas de uso y manejo; sin embargo el impacto de estos cambios no se ha evaluado en suelos y ambientes tropicales. El presente estudio tuvo como objetivo evaluar los contenidos y algunas formas de carbono orgánico del suelo (COS) en cinco zonas de clima cálido tropical (0 - 1110 m.s.n.m.) del departamento del Magdalena (Colombia) y el efecto que sobre ellas han tenido las prácticas asociadas a suelos cultivados con café (*Coffea arabica*), banano (*Musa* sp.), palma africana (*Elaeis guineensis*) y sábila (*Aloe vera*), comparados con suelos de bosques naturales. No se encontraron diferencias (P < 0.05) tanto entre zonas como entre usos del suelo, se presentaron valores medios a bajos de MOS en las zonas de estudio y contenidos de carbono total (Ct) mayores en suelos de bosques que en suelos cultivados, así los suelos de bosques presentan una acumulación media de Ct de 42.4 mg/ha a 20 cm, frente a 33.8 mg/ha en los suelos cultivados, esto equivale a una pérdida media de Ct del 23% por efecto del manejo de los cultivos. En relación con el carbono extraíble con pirofosfato sódico altamente relacionado con las fracciones humificadas de la MOS (Cp) se observaron valores muy bajos en los suelos cultivados y casi nulos en suelos de bosques; sin embargo estos últimos presentan mayor contenido de formas de carbono no-oxidables o estables (Cnox) determinado por diferencia entre Ct - carbono oxidable (Cox). En el suelo cultivado con banano, el Ct corresponde en su totalidad a formas de Cox; mientras que en el suelo cultivado con palma africana las formas estables Cnox representaron 83% del carbono total.

Palabras clave: Carbono, ciclo biogeoquímico, Colombia, humus, Magdalena, nutrición de plantas, suelos agrícolas.

**Introduction**

Stevenson (1994) divides the soil organic matter (OM) in two fractions ("pools") based on their reactivity: labile or active material and stable organic material. The active frac­tion includes the macroscopic organic matter even in the soil surface (litter). The light frac­tion is composed by the remains of living or­ganisms in different stages of decomposition, the microbial biomass and the non-humic organic compounds. Therefore, the stable fraction is the humus or complex colloidal fraction which has experienced different de­grees of stabilization. The soil organic carbon (SOC) is an important component of the global C cycle, occupying 69.8% of the organic C in the biosphere (FAO, 2001). Soil can act as a source or reservoir of C, depending on its use and management (Lal, 1999; Lal, 2005). It has been estimated that from the incorpora­tion of new land for agriculture to intensive farming systems, COS losses occur between 30 and 50% of the initial level (Reicosky, 2002). The Kyoto Protocol requests an under­standing of the stabilization of C in the soil because this represents the terrestrial reser­voir with the largest capacity (Schlesinger, 1995, quoted by Madinabeitia, 2007). Then, any actions on the soil can lead to it to act as a sink or as a source of C to the atmosphere. Regarding this statement, Lal (2001) states that until 1970 the consequences of agricul­tural and forestry techniques have led to a higher loss of C to the atmosphere than those produced in the same period by industrial activities and transport. Despite improve­ments with the sustainable agriculture and good agricultural practices, the agriculture still accounts for 25% of emissions.

0.25% of global CO2 emissions are coming from Colombia. The 45% of greenhouse gases emissions is from agriculture and 9% of the total emission is produced by changes in land use and forestry (IDEAM –Ministry of Envi­ronment, Housing and Territorial Develop­ment, 2006). The county of Magdalena is no stranger to this reality, especially if it is con­sidered its excellent agricultural vocation, with large areas of productive land devoted to these activities. Magdalena is represented by 215.512 ha in agriculture, 79.734 ha in agroforestry, 1,219,769 ha in livestock, 233.815 ha of forest and 416,941 ha in con­servation (IGAC, 2002). In Colombia, espe­cially in the Caribbean region, the storage of C has been poorly evaluated with respect to changes in the landscape. The landscape is an element of great importance because this element depends on the specific conditions of each site and, it needs sampling methods that take into account the changes of each site and the landscape to identify patterns of dis­tribution. Moreover, agroecosystems can be managed to reduce C emissions and increase C pools, but choices should be based on knowledge of the soil storage capacity of a biome or agro-ecological region and their res­ponse to different uses (Carvajal et al., 2009).

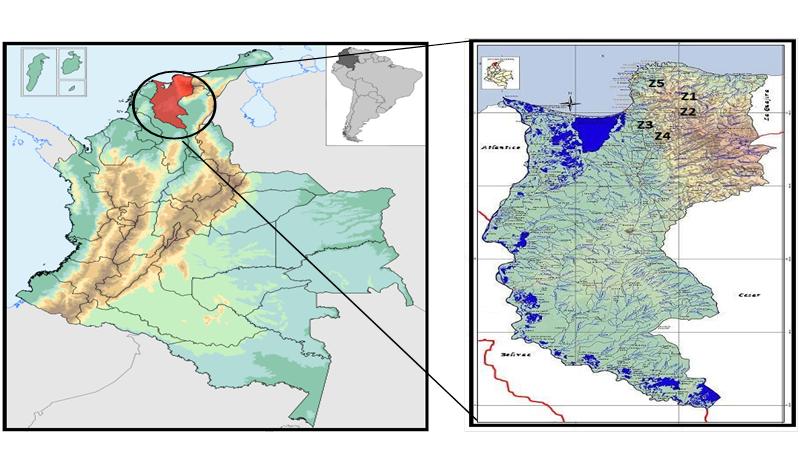
In Colombia, soils with low organic matter (OM) are in the middle and upper Guajira, largely Aridisols. Soils with higher content of MO are Andisols which are in the cold clima­tic zone (Jaramillo et al. 1994). According to IGAC (1988) cited by Jaramillo (2004), in the Caribbean the organic carbon content is bet­ween 0.5% and 1%. Environmental issues associated with the living areas in this region, give limited contributions of biomass affecting soil OM content. Low values predominate (45% of the soil), followed by medium (30% of the soil) and very low (20% of the soil), while soils with high organic carbon percentages include only 5% of the region. Despite the low OM contents (65% of the soil), humus evolves according to the alternating seasonal precipi­tation and high temperatures (aridic and ustic schemes cover 65%) (Malagón-Castro, 2003).

From the statement above, this study assesses the changes in C stocks in different forms and uses of soils located at different altitudes of the Department of Magdalena considering that the CO in this region is affected by changes in land use, without ne­glecting the losses of C in soils traditionally devoted to intensive agriculture.

**Materials and Methods**

The research was conducted in the north­western part of the Department of Magdalena in Santa Marta and the banana region, inclu­ding the northwest part of the Sierra Nevada de Santa Marta (11 º 36 '58 "- 8 º 56' 25" N, 73 ° 32 '50 "- 74 º 56 '45 "W), with a surface area of 23.188 km² (Figure 1).

**Soil sampling**. Five areas in the north­western department of Magdalena were se­lected for this study (Table 1), two areas on the west side of the Sierra Nevada de Santa Marta, one on the farm of the University of Magdalena and the last two areas in the ba­nana region. All selected areas had similar climate, topography and soil conditions. Given the inclusion of different land uses in each zone, the following sites were established at each place: cropland and forest land or fallow. Within each site a soil sample consisting of 10 subsamples were taken randomly in the field (Brady and Weil, 2002; ICA, 1992). In total 10 samples were taken to study the five zones.



**Figure 1.** Location of sampling sites.

Source: IGAC, 2009.

**Physical analysis.** Munsell table was used to determine the color of wet and dry soils. Bulk density (Bd) was determined by two methods, graduated cylinder (samples 1, 2, 3, 4, 7 and 8), and waxy lump (samples 5, 6, 9 and 10) (IGAC, 2006).

**Chemical analysis.** The pH in H2O and 0.1N of KCl were determined in a ratio of 1:2.5 respectively (IGAC, 2006). The exchan­geable cations Ca+2, Mg+2, K+, Na+ were ex­tracted with ammonium chloride and were determined by atomic absorption spectro­photometry. P was determined by the method of Olsen. C and total N were determined by a LECO analyzer (Model CHN-1000, LECO Corp., St. Joseph, MI). Oxidizable C (Cox) was determined by Walkley and Black technique (1934), cited by IGAC (2006). The SOM was calculated by multiplying Cox by the factor 1.724. The C bound to the soil humic fraction (C pyrophosphate, Cp) was determined accor­ding to the methodology described by Bas­comb (1968), cited by Velasco (2006). Lastly, the non-oxidizable C fraction (Cnox) was cal­culated by the difference between Ct and Cox.

**Analysis of results.** As for the forms of C (Ct, Cox, Cp, Cnox) and C/N variables, the Kruskal Wallis test for independent samples was performed with Statgraphics Centurion

XVI, 2011.

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| **Table 1.** Land use and weather classification of the studied zones. | | | | | |
| **Sampling Zones** | **Samples** | **Land Use** | **Weather and altitude** | **Classification and climate regime** | **Landscape and parent material** |
| 1 | 1 | Coffee crop | Warm Humid; Altitude 803 MASL; Precip. 1110 mm; 24°C | Haplic cambisol Typic Eutropepts Údic Isohyperthermic | Mountain landscape, hillside. Parent material schist |
| 2 | Pasture and secondary forest | Warm Humid; Altitude 808 MASL.; Precip. 1110 mm; Tem 24°C | Haplic cambisol Typic Eutropepts Údico Isohyperthermic | Mountain Landscape, hillside, PM: schist |
| 2 | 3 | Coffee crop | Warm Humid; Altitude 610 MASL; Precip. 905 mm; Temp. 25°C | Haplic Phaeozem Typic Hapludolls Údic Isohyperthermic | Mountain Landscape, hillside, PM: quartz monzonite |
| 4 | Secondary Forest | Warm Humid Altitude 616 MASL; Precip. 905 mm; Tem 25°C | Haplic Phaeozem Typic Hapludolls Údic Isohyperthermic | Mountain Landscape, hillside, PM:: quartz monzonite |
| 3 | 5 | African Palm Oil Crop | Warm Dry; Altitude 25 MASL.; Precip. 910 mm; Tem 27°C | Haplic Phaeozem Haplustolls Ústic Isohyperthermic | Plain Landscape. PM: colluvial-alluvial sediments |
| 6 | Secondary Forest | Warm Dry; Altitude 25 MASL; Precip. 910 mm; Tem 27°C | Haplic Phaeozem Haplustolls Ústic Isohyperthermic | Plain Landscape. PM: colluvial-alluvial sediments |
| 4 | 7 | Banana Crop | Warm Dry; Altitude 20 MASL Precip. 970mm; Tem 27 °C | Haplic Phaeozem Haplustolls Ústic Isohyperthermic | Plain Landscape. PM: colluvial-alluvial sediments |
| 8 | Secondary Forest | Warm Dry; Altitude 20 MASL; Precip. 970 mm; Tem 27 °C | Haplic Phaeozem Haplustolls Ústic Isohyperthermic | Plain Landscape. PM: colluvial-alluvial sediments |
| 5 | 9 | Aloe vera Crop | Warm Dry; Altitude 10 MASL; Precip. 600 mm; Tem 28.5 °C | Aric Regosol Typic Ustipsamments Ústic Isohyperthermic | Plain Landscape. PM: -alluvial sediments |
| 10 | Tropical dry Forest | Warm Dry; Altitude 10 MASL.; Precip. 600 mm; Tem 28.5 °C | Haplic Regosol Typic Ustipsamments ÚsticIsohyperthermic | Plain Landscape. PM: -alluvial sediments |

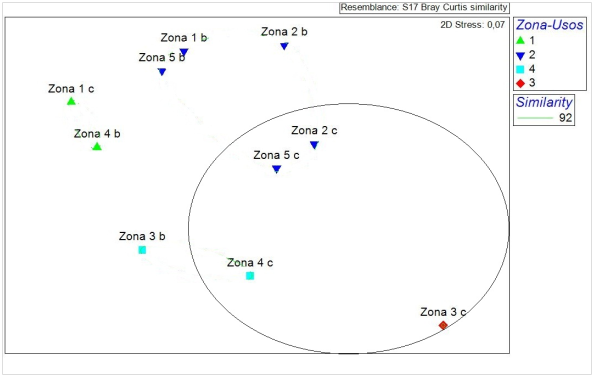
Based on similarity ranges and with the purpose of complying with the "map" or set of samples over the content of Ct (in a specific number of dimensions), a non-metric multi­dimensional scaling analysis (MDS) was per­formed following the procedure adopted by the first program routine V. 6.1.6 (Clarke and Warwick, 2001). Other physicochemical va­riables were analyzed taking into account the descriptive statistics. The stress estimated for this analysis was 0.07, which if not an exce­llent representation of P <0.05, provides a good data management without adding the information from the group structure when examined with three or more dimensions.

**Results and discussion**

Physical and chemical results of soils in this study are displayed in table 2. A range of colors between 10YR 4/2 and 10 YR 5/4 re­present dark yellowish red as the typical sur­face horizons influenced by the presence of small quantities of OM. The pH values are in the range of slightly acid to moderately alka­line. Zones 1 and 2 showed the lowest values of pH, marked by the difference in altitude, rainfall and topography, which agrees with Rubiano et al. (1995) cited by IGAC (1995) and the General Soil and Land Zoning Survey of Magdalena County (IGAC, 2009) for soils in warm weather mountains located at the foot­hills of the Sierra Nevada de Santa Marta. Zone 5 showed a moderate alkalinity condi­tion that clearly indicates an important eva­potranspiration which exceeds the average annual rainfall (Vasquez and Baena, 2009). Zones 3 and 4 have low organic C in the first horizon and high natural fertility. These zones correspond to soils developed from alluvial deposits formed by the rivers that descend from the Sierra Nevada and have higher con­tent of Ca. According IGAC (2009), the physi­cal soil properties of these areas show com­paction processes with BD values reaching 1.7 g/cm3, which is not reflected in the soils of this study.

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| **Table 2.** Soil properties of the studied zones. | | | | | | | | | | | | | | | | | | | | | | |
| **Properties** | **Cultivated Soils** | | | | | | | | |  | | **Forest Soils** | | | | | | | | | |  |
| **Zone 1** | **Zone 2** | | **Zone 3** | | **Zone 4** | | **Zone 5** | | | **Zone 1** | | **Zone 2** | | **Zone 3** | | **Zone 4** | | **Zone 5** | |
| **1** | | **3** | | **5** | | **7** | | **9** | | | **2** | | **4** | | **6** | | **8** | | **10** | | |
| Color S1 | 10YR 4/2 | | 10YR 5/4 | | 10YR 5/4 | | 10YR 5/4 | | 10YR 5/2 | | | 10YR 5/3 | | 10YR 5/2 | | 10YR 5/2 | | 10YR 4/2 | | 10YR 5/3 | | |
| Color H1 | 10YR 2/3 | | 10YR 3/3 | | 10YR 3/3 | | 10YR 3/2 | | 10YR 2/3 | | | 10YR 3/3 | | 10YR 3/2 | | 10YR 3/2 | | 10YR 2/3 | | 10YR 3/3 | | |
| BD (gr/cm-3) | 1.20 | | 1.3 | | 1.4 | | 1.3 | | 1.5 | | | 1.1 | | 1.2 | | 1.3 | | 1.2 | | 1.3 | | |
| pH H2O | 6.10 | | 5.9 | | 7.2 | | 6.7 | | 8.3 | | | 5.9 | | 5.8 | | 6.2 | | 6.9 | | 8.2 | | |
| pH KCl | 5.40 | | 4.8 | | 5.7 | | 5.3 | | 7.4 | | | 4.9 | | 4.7 | | 5.2 | | 6.0 | | 7.4 | | |
| Ca+2 (cmol(+)/kg) | 14.0 | | 7.1 | | 7.4 | | 10.7 | | 20.2 | | | 8.0 | | 8.5 | | 8.4 | | 11.9 | | 23.9 | | |
| Mg+2 (cmol(+)/kg) | 1.60 | | 1.2 | | 3.0 | | 3.9 | | 4.0 | | | 1.7 | | 1.2 | | 2.3 | | 4.0 | | 6.8 | | |
| Na+ (cmol(+)/kg) | 0.10 | | 0.1 | | 0.1 | | 0.1 | | 0.3 | | | 0.1 | | 0.1 | | 0.2 | | 0.2 | | 0.3 | | |
| K+ (cmol(+)/kg) | 0.20 | | 0.2 | | 0.2 | | 0.3 | | 1.2 | | | 0.2 | | 0.2 | | 0.4 | | 0.3 | | 1.7 | | |
| CICE (cmol(+)/kg) | 15.90 | | 8.6 | | 10.8 | | 15.0 | | 25.8 | | | 10.0 | | 10.0 | | 11.3 | | 16.4 | | 32.7 | | |
| % Ca Sat. | 88.30 | | 83.0 | | 68.8 | | 71.2 | | 78.4 | | | 80.0 | | 85.4 | | 74.5 | | 72.8 | | 73.2 | | |
| % Mg Sat. | 10.20 | | 14.0 | | 28.0 | | 25.9 | | 15.5 | | | 17.3 | | 11.6 | | 20.4 | | 24.3 | | 20.8 | | |
| % K Sat. | 1.00 | | 1.8 | | 1.9 | | 1.9 | | 4.8 | | | 1.9 | | 1.9 | | 3.1 | | 1.7 | | 5.1 | | |
| % Na Sat. | 0.50 | | 1.2 | | 1.3 | | 0.9 | | 1.3 | | | 0.8 | | 1.1 | | 2.0 | | 1.2 | | 0.9 | | |
| P (Olsen) ppm | 14.00 | | 4 | | 12 | | 20 | | 34 | | | 4 | | 6 | | 21 | | 8 | | 15 | | |
| % Total N. | 0.100 | | 0.2 | | 0.1 | | 0.1 | | 0.1 | | | 0.2 | | 0.2 | | 0.1 | | 0.1 | | 0.2 | | |
| 1 S= Dry; H= wet | | | | | | | | | | | | | | | | | | | | | | |

According to the criteria of the Colombian Agricultural Institute (ICA, 1992), in general, all areas have a high content of Ca2+, due to its dominant position in the exchange com­plex. Mg2+ content is low in zone 2, followed by zone 1 with medium and high levels in other areas. Except for high values in zone 5, moderate level of K+ is in all areas of study.



**Figure 2.** Ordering of non-metric multidimensional scaling (MDS) of the zones and land uses (zones 1, 2, 3, 4 and 5 - uses: crop = c, b = forest), based on the similarity of Bray Curtis (stress = 0.07) (Clarke y Warwick, 2001).

**Figure 3.** Distribution of carbon extractable by pyrophosphate and humified organic carbon of soil organic matter.



**ZONE 1 ZONE 2 ZONE 3 ZONE 4 ZONE 5**

**Carbon forms**

C = Crop

B= Forest

Extractable carbon with pyrophosphate

Non-humified organic carbon

Na+ levels are low and the CEC (10-20 Cmol(+)/kg) is moderate for all areas. P con­tent is low in forest areas and moderate in cropping areas, probably due to the high fixa­tion of this element that occurs in many of the soils in dry warm climate of the department of Magdalena. Total N content shows moderated values for crop and forest areas despite the high doses of nitrogen fertilizers applied in the region to coffee, banana and palm crops, and its low efficiency.

No significant difference (P < 0.05) was found nor between zones neither betweenland uses. However, evaluating the distance based on sample similarity (92%), it is im­portant to highlight how even though, there are no differences in Ct contents between land use, there is a clear trend to get clusters of crop soils in the similarity graph (Figure 2) which noticeable, has lower Ct than forest soils, with only one exception on the crop soil of zone 1. This is caused by the climatic con­ditions that benefit CO accumulation in soils including higher altitude over the level of the sea, higher precipitation and lower tempera­tures.

To sum up, Ct contents are higher in forest soils than in crop soils for all zones (Figure 3). These results confirm Moreno and Lara (2003) studies who worked in Inceptisols and Enti­sols from Antioquia in Colombia. They found that the CO in the primary forest soils was higher than in soils of secondary forests and disturbed areas. On the other hand, Carvajal et al. (2009) showed a different trend for many profiles (0 – 30 cm) with a gain in soil C storage at the Colombian Andean landscapes. The C accumulation was principally from natural vegetation cover (forest relicts) that became crops, mainly coffee and bananas. The opposite occurs when crops became pastures with significant reductions of C.

**Figure 4.** Distribution of the organic carbon forms from the extracted organic matter of each zone

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| **Table 3.** Percentage of carbon and C/N ratio of the studied soils. | | | | | | | | |
| **Zone** | **Soils** | **Use** | **C. Total** | **C. Oxi** | **C. Piro** | **O.M.** | **C. nox** | **C/N** |
| 1 | 1 | Coffee | 1.75 | 1.49 | 0.12 | 2.6 | 0.26 | 12.6 |
| 2 | Forest | 1.92 | 1.67 | 0.12 | 2.9 | 0.26 | 11.3 |
| 2 | 3 | Coffee | 1.70 | 0.77 | 0.06 | 1.3 | 0.93 | 10.6 |
| 4 | Forest | 2.03 | 1.49 | 0.37 | 2.6 | 0.54 | 10.5 |
| 3 | 5 | Palm, | 0.67 | 0.11 | 0.00 | 0.2 | 0.55 | 10.1 |
| 6 | Forest | 1.01 | 0.91 | 0.00 | 1.6 | 0.10 | 11.8 |
| 4 | 7 | Banana | 0.94 | 0.93 | 0.00 | 1.6 | 0.01 | 10.7 |
| 8 | Forest | 1.68 | 0.94 | 0.12 | 1.6 | 0.74 | 12.4 |
| 5 | 9 | Aloe vera | 1.42 | 0.92 | 0.12 | 1.6 | 0.50 | 10.8 |
| 10 | Forest | 2.01 | 1.37 | 0.00 | 2.4 | 0.64 | 11.7 |



**ZONE 1 ZONE 2 ZONE 3 ZONE 4 ZONE 5**

**Carbon forms**

C = Crop

B= Forest

Extractable carbon with pyrophosphate

Non-humified organic carbon

Cox values ​were low in all zones, except for the zone 1 (Table 3). Zone 4 presented most of the Ct content as Cox form in the cultivated soil. The above statement was possibly due to the composition of the waste, the great return of crop residues to the soil by agricultural management associated with banana crop, and also due to the climatic conditions of the area. Cp values ​​were very low or almost zero (Figure 4). The lowest values ​​of Cp were found in forest soils, however their Cnox values are high, and present stable forms due to the in­herent stabilization process of C in these soils. The C/N ratio was between 10.1 and 12.6 which favors mineralization processes (Table 3).

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| **Table 4**. Relationship between the different carbón forms content in the studied soils. | | | | | | |
| **Zone** | **Soil** | **Use** | **Cox/Ct** | **Cnox/Ct** | **Cp/Ct** | **Cp/Cox** |
| 1 | 1 | Coffee | 0.85 | 0.15 | 0.07 | 0.08 |
| 2 | Forest | 0.87 | 0.13 | 0.06 | 0.07 |
| 2 | 3 | Crop | 0.45 | 0.55 | 0.04 | 0.08 |
| 4 | Forest | 0.73 | 0.27 | 0.18 | 0.25 |
| 3 | 5 | Palm | 0.17 | 0.83 | 0.00 | 0.00 |
| 6 | Forest | 0.90 | 0.10 | 0.00 | 0.00 |
| 4 | 7 | Banana | 0.99 | 0.01 | 0.00 | 0.00 |
| 8 | Forest | 0.56 | 0.44 | 0.07 | 0.13 |
| 5 | 9 | Aloe vera | 0.65 | 0.35 | 0.08 | 0.13 |
| 10 | Forest | 0.68 | 0.32 | 0.00 | 0.00 |

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| **Table 5.** C accumulation in the first 20cm of soil depth (mg/ha). | | | | | | |
| **Zone** | **Soil** | **Use** | **Ct** | **Cox** | **Cp** | **Cnox** |
| 1 | 1 | Coffee | 41.2 | 35.1 | 2.8 | 6.1 |
| 2 | Forest | 43.1 | 37.3 | 2.7 | 5.8 |
| 2 | 3 | Coffee | 43.6 | 19.8 | 1.5 | 23.8 |
| 4 | Forest | 49.6 | 36.3 | 9.0 | 13.2 |
| 3 | 5 | Palm | 18.8 | 3.2 | 0.0 | 15.6 |
| 6 | Forest | 25.7 | 23.2 | 0.0 | 2.5 |
| 4 | 7 | Banana | 24.0 | 23.8 | 0.0 | 0.2 |
| 8 | Forest | 40.7 | 22.8 | 2.9 | 17.9 |
| 5 | 9 | Aloe vera | 41.2 | 26.8 | 3.5 | 14.4 |
| 10 | Forest | 53.0 | 36.2 | 0.0 | 16.9 |

The relation between different types of C, regarding the total C content (Ct), shows how the highest percentage of Ct is composed of liable forms, except for crop areas in zones 2 and 3 (Table 4). These areas show mainly re­calcitrant and stable C forms, which repre­sent 83% of Ct on the soil with African palm cultivation. A further evaluation should be made ​​with more repetitions in the same area and cultivar in order to rule out the influence of a particular management in that site. Cp is related with different intensity in each of the studied C fractions (Table 4). In general, the ratio Cox/Ct is higher in forest soils than in cultivated, being the highest ratio in zone 3 (73%), and lowest in zone 5 (3%). The Cox/Ct ratio was higher in the soils cultivated with Zone 4 cultivated with banana, with a diffe­rence of 43% between the forest soil and the cultivated soil.

Table 5 shows the accumulation of diffe­rent shapes C to 20 cm deep from the top of the soil. This accumulation is estimated from the concentration of C and bulk density (Bd) of the soil (Malagón, 2001). The average accumulation of the studied C forms was higher in the forest soil than in cultivated soils, except for the Cnox form. In the same table, forest sites in zone 5 (10 MASL, 29°C) shows that Cox values ​​are similar to those of zones 1 and 2 (600 and 800 MASL, 24°C and 25°C, respectively). it is possibly due to the condition of secondary forest in zones 1 and 2 vs. the primary forest in zone 5, plus the effects of erosion due to topographic condi­tions in zones 1 and 2. Cultivated soils showed low or zero values ​​of Cp showing little evolution of OM to humified forms, possibly due to the effect of agronomic practices and perhaps by the low microbial activity on the Cnox forms.

The analysis within each area allows ob­serving the percentage of Ct losses in rela­tion to land use, assuming that the original condition of Ct is determined by the forest soils. Moreover, the major losses of Ct (41%) occur in cultivated soils where banana crop was planted in zone 4, here, the entire Ct is the Cox form described above. The percentaje of Ct losses in other areas were 4, 11, 26 and 23 for zones 1, 2, 3, and 5, respectively. Calvo de Anta (1992), cited by Macías et al. (2004) found that soil C losses are between 26% to 49% in cultivated soils compared to forest soils at the province of La Coruna (Spain). Bayer (2002) found that labile and humified CO forms are more stable in light planting systems in Hapludox soils in the southern Brazil and, as a consequence, those soils are less vulnerable to mineralization.

**Conclusions**

• The use and management of cultivated soils compared to forest soils in each of the studied areas from the hot thermic floors in the Magdalena region, influence the content of the different forms of C.

• The total C content showed no statistically significant differences due to the height above sea level for the areas studied. In this case the values ​​ranged between 0.7% to 2%, being lower in cultivated land and higher in forests soils.

• The fraction of Cox represents more than 50% of the total C in all the studied areas, while forms of Cnox do not differ between cultivated and forest soils.

• The humified fraction (extractable with py­rophosphate) is not representative for the organic C in the studied areas. Their va­lues ​ were not above 13% of the oxidizable C in cultivated soils while 25% was for fo­rest soils.

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**References**

**Bayer, C. 2002. Carbono stocks in organic matter fracctions as affected by land use and soil mana­gement, with emphasis on no-tillage effect. Santa María, Ciencia Rural 32(3):401 - 406.**

**Brady, N. C.; y Weil, R. R. 2002. The nature and properties of soils. 13th Ed. New Jersey: Prentice-Hall. p. 720 - 725.**

**Carvajal, A. F.; Feijoo, A.; Quintero, H.; and Rondón, M. A. 2009.** Carbono orgánico del suelo en diferen­tes usos del terreno de paisajes andinos colombia­nos.Rev. Ci. Suelo Nutr*.* **9(3):222 - 235.**

**Clarke, K. R.; and Warwick, R. M. 2001. A further biodiversity index applicable to species lists: varia­tion in taxonomic distinctness. Mar. Ecol .Prog. Ser. 216:265 - 278.**

**FAO. 2001. El ciclo global del Carbono. Memorias divulgativas. 52 p.**

**IDEAM (**Ministerio de Ambiente, Vivienda y Desa­rrollo Territorial)**. 2006. Inventario nacional de fuentes y sumideros de gases de efecto invernadero. Colombia. 29 p.**

**ICA (Instituto Colombiano Agropecuario). 1992. Ma­nual del laboratorio de suelos. 218 p.**

IGAC (Instituto Geográfico Agustín Codazzi)**. 1995. Estudio general de suelos de la zona quebrada de la sierra nevada de Santa Marta. Colombia. 385 p.**

IGAC-Corpoica. (Instituto Geográfico Agustín Codazzi-Corporación Colombiana de Investigación Agrope­cuaria )**. Zonificación de los conflictos de uso de las tierras en Colombia. Bogotá. Colombia. 87 p.**

IGAC (Instituto Geográfico Agustín Codazzi). 2006. Métodos analíticos del laboratorio de suelos. 2006. p. 720 - 725.

IGAC (Instituto Geográfico Agustín Codazzi). 2009. Estudio general de suelos y zonificación de tierras del Departamento del Magdalena. 496p.

Jaramillo, D. F. 2004. El recurso suelo y la competiti­vidad del sector agrario colombiano. Universidad Nacional de Colombia. Medellín. 26 p.

Jaramillo, D. F.; Parra, L. N. **and** González, L. H. 1994. El recurso suelo en Colombia: distribución y evaluación. Universidad Nacional de Colombia. Me­dellín. 88 p.

**Lal, R. 1999. Soil management and restoration for C sequestration to mitigate the accelated greenhouse effect. Prog. Environ. Sci. 1:307 - 326.**

Lal, R. (ed.). 2001. Soil C sequestration and the greenhouse effect. SSSA Special Pub. #57, Madison, WI. 236 p.

Lal, R. 2005. Los suelos y el cambio climático. En: Protección del suelo y el desarrollo sostenible: Se­minario Europeo Soria, 15-17 de mayo de 2002. Callaba, A.; Iribarren, I.; y Fdez.-Canteli, P. (Eds.). Madrid. Instituto Geológico y Minero de España. **Serie: Medio Ambiente No. 6. p. 163-177.**

Macías, F.; Calvo de Anta, R.; Rodriguez-Lado, L.; Verde, R.; Pena-Pérez, X.; **and** Camps-Arbestain, M. 2004. El sumidero de carbono de los suelos de Ga­licia (España). Edafología 11 (3):341 - 376.

**Madinabeitia, Z. 2007. Oxidabilidad de la materia orgánica del suelo con permanganato potásico. Aplicación al fraccionamiento de las formas de car­bono orgánico. Trabajo de Investigación Tutelado. USC. 115p.**

**Malagón-Castro, D. 2003. Ensayo sobre tipología de suelos colombianos -Énfasis en génesis y aspectos ambientales-.** Rev. Acad. Colomb. Ci. 27(104):319 - 341**.**

**Malagón, D. 2001. Los Suelos de Colombia.** Instituto Geográfico Agustín Codazzi (**IGAC).** Bogotá D.C., Colombia. **21 p.**

**Moreno, F. H.; and Lara, W. 2003. Variación de car­bono orgánico del suelo e bosques primarios inter­venidos y secundarios. En: Medición de la captura de carbono en ecosistemas forestales tropicales de Colombia. S.A. 50 p.**

**Reicosky, D. C. 2002. Tillage and gas exchange. En: R. Lal (ed.). Encyclopedia of soil science. Boca Ra­ton, Fla.: Taylor & Francis. p. 1333-1335.**

**Statgraphics Centurión XVI, 2011. Data analysis and Statistical Software.**

**Stevenson, F. J. 1994. Humus chemistry. John Wiley & Sons. Nueva York. 2nd ed. 496 p.**

**Vásquez, J. R.; and Baena, D. 2009. Caracterización de la variabilidad espacial de propiedades físicas y químicas en suelos de la granja experimental de la Universidad del Magdalena. 103 p.**

**Velasco, M. 2006. Formas de carbono en suelos de ambientes subtropicales de Brasil y Argentina. Tra­bajo de Investigación Tutelado. USC. 120 p.**