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SHORT COMMUNICATION

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# Soil carbon pools in different pasture systems

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## Abstract

The aim of this study was to assess the carbon pools of a tropical soil where the native forest was replaced with different pasture systems. We studied five pasture production systems, including four monoculture systems with forage grasses such as *Andropogon*, *Brachiaria*, *Panicum*, and *Cynodon*, and an agroforestry system as well as a native vegetation plot. Greater availability of fulvic acid was detected in the agroforestry system as compared with that in the other systems. Higher lability of C was detected in the *Andropogon* system during the dry and rainy seasons and during the dry season in *Cynodon*. During the dry season, all pastures systems showed deficits in the net removal of atmospheric $CO_2$. The structure and practices of the agroforestry system enables more carbon to be sequestered in the soil as compared with the monoculture pasture, suggesting that it is an important practice to mitigate climatic change and to improve soil quality.

**Additional key words:** humic substances; carbon management; agroforestry system

**Abbreviations used**: AE (alkaline extract); AFS (agroforestry system); AND (Andropogon); BRA (Brachiaria); C-FAF (C-fulvic acid fraction); C-HAF (C-humic acid fraction); C-HF (C-humin fraction); CMI (carbon management index); CPI (carbon pool index); CYN (Cynodon); HI (humification index); LC (labile organic carbon); L (lability); LI (lability index); NLC (non-labile organic carbon); NV (native vegetation); PAN (Panicum); SOM (soil organic matter); TOC (total organic carbon)

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## Introduction

The pasture ecosystem is characterized by interactions between plants, animals, soil, climate, and management practices implemented by the farmer. Meat and milk productions are important economic activities in Brazil, and the sustainable practices of these production systems contribute to efficient carbon cycling, thereby improving soil quality (Carvalho *et al*., 2014; Soussana & Lemaire, 2014). Soils are a carbon pool for terrestrial ecosystems; thus, they are relevant with regard to environmental problems associated with global warming and deforestation (Bao *et al.,* 2015).

Conversion from native forest to livestock grazing has decreased soil C storage (Carvalho *et al*., 2014) and has been the most common land use change in Brazil (Sousanna & Lemaire, 2014). It is estimated that Brazil releases more than 1.090 Mt $CO_2$/year into the atmosphere through deforestation, burning grasslands, and enteric fermentation by cattle (Bustamante *et al*., 2012).

Loss of organic carbon can be minimized by managing soil to reduce disturbances and maximize forage productivity using fertilizers and by integrating pastures and trees, which promotes benefits for the animals, increases productivity, litter inputs, nutrients cycling, and water infiltration (Murgeitio e*t al*., 2011). Therefore, the evaluation of the impact of agricultural systems on pasture, through the quantification of total organic carbon (TOC) stocks and humic fractions, as well as assessing carbon lability, is important to maintain soil quality (Yang *et al*., 2012).

Specifically in pastures, organic input from vegetation and animal activities can contribute to increase the organic C content and consequently cause an impact on C pools (Lopes *et al*., 2010). As it may vary according to different pasture system, we hypothetized that the management method applied for different pasture systems could influence the soil carbon pool. In this context, the objective of this study was to assess the C pools of a tropical soil where the native forest was replaced with different pasture systems.

## Material and methods

This study was conducted as a long-term experiment on pasturelands belonging to the Animal Science Department, Agriculture Science Center, Federal University of Piauí, Brazil (05°05′21″ S, 42°48′07″ W; 74 m asl). The climate is tropical with two seasons: rainy (January to May) and dry (June to December). The mean of precipitation is 1,300 mm/yr. The soil is a Haplic Acrisol. The experimental area presents plots with the following pasture system: a) *Andropogon gayanus* Kunth (AND) [plots without liming and chemical fertilization; production of 2.1 tons/ha (dry weight); 2.21% N and a C/N ratio of 21]; b) *Brachiaria brizantha* (BRA) [plots annually fertilized with 120, 180, and 100 kg/ha urea, triple superphosphate, and potassium chloride, respectively; production of 4.35 tons/ha (dry weight); 0.91% N and a C/N ratio of 37]; c) *Panicum maximum* (PAN) [plots annually fertilized with 70, 80, and 50 kg/ha urea, super triple phosphate, and potassium chloride, respectively; production of 3.0 tons/ha (dry weight); 1.22% N and a C/N ratio of 31]; d) *Cynodon dactilon* (CYN) [plots annually fertilized with 75, 30, and 30 kg/ha urea, super triple phosphate, and potassium chloride, respectively; production of 1.3 tons/ha (dry weight); 1.37% N and a C/N ratio of 36.9]; e) agroforestry system (AFS) [plots composed of grass (*A. gayanus* Kunth) and trees (*Mimosa* sp. and *Thiloa glaucocarpa* Benth); production of 7.4 tons of plant litter (dry weight)/ha]; and f) native vegetation (NV) (plots composed of native plant species, including *Cenostigma macrophyllum, Tabebuia serratifolia, Hymenaea courbaril, Orbignya phalerata, Combretum leprosum, Guarea kunthiana*, and *Lecythis pisonis*; production of 9.5 tons of plant litter (dry weight)/ha).

Soil sampling was carried out in March (rainy season) and September (dry season) 2014. Soil samples were obtained from three transects from each plot (three points per transect) at a depth of 0–20 cm. The soil samples were ground and passed through a 0.21-mm sieve to determine TOC by wet combustion using a mixture of potassium dichromate and sulfuric acid under heating (Yeomans & Bremmer, 1988). Labile organic carbon (LC) was quantified by wet oxidation with 0.33 M $KMnO_4$, as described by Blair *et al.* (1995). Non-labile carbon (NLC), that is equivalent to non-oxidized carbon by $KMnO_4$, was calculated as a difference (NLC = TOC – LC). Based on the difference between TOC-forest (reference) and TOC systems, a carbon pool index was created (CPI) and calculated as CPI = TOC-system/TOC-forest.

According to changes in the proportion of LC (*i.e.*, L = LC/NLC) in the soil, a lability index (LI) was calculated as LI = L system/L reference. These two indices were used to calculate the carbon management index (CMI) using the following expression: CMI = CPI × LI × 100 (Blair *et al*., 1995). C-$CO_2$ emission or sequestration rate was estimated for 0–20 cm depth, using native vegetation as a reference (TOC stocks native vegetation – TOC stocks management systems/number of years). A conversion factor of C to $CO_2$ of 3.67 (molar mass of $CO_2$/molar mass of C) was used.

Soil humic substances (humic acids, fulvic acids, and humin) were extracted and fractionated using the method recommended by the International Humic Substances Society, as described by Swift (1996). The carbon content of the fulvic acid (C-FAF), humic acid (C-HAF), and humin (C-HF) fractions was measured using the dichromate oxidation method (Yeomans & Bremmer, 1988). The ratios of C-HAF by C-FAF and the alkali soluble fractions (C-FAF + C-HAF = AE) by H (AE/C-HF) were calculated to characterize the humified fraction of soil organic matter (SOM). Additionally, the humification index (HI) was calculated using the following formula to estimate the proportion of humified organic matter in relation to TOC content: HI = (C-FAF + C-HAF + C-HF) / TOC × 100.

Data were analyzed using one-way analysis of variance, and means were compared using the least significant difference (LSD) values calculated at the 5% level of significance. All analyses were performed using STATISTICA 7.1 (StatSoft).

## Results and discussion

The C-HAF was lower than the C-FAF during the wet and dry seasons in all systems (Table 1). The lower C-HAF found in all systems may have occurred because this humic fraction can easily migrate in soil with high porosity (Martins *et al.,* 2009). Therefore, in the evaluated areas the soil porosity may facilitate the movement of C-HAF through the soil horizons. The C-HAF values in plots under *Brachiaria, Panicum* and *Cynodon* were similar to those in native vegetation during the dry season. Greater C-FAF availability was detected in the agroforestry system during the rainy and dry seasons because this plot showed higher TOC and $Ca^{+2}$ content, which is a favorable condition for the complexation of this C pool in the soil (Barros *et al.,*

**Table 1.** Carbon content from humic acid (HAF), fulvic acid (FAF), and humin (HF) fractions, HAF:FAF ratio (HAF/FAF), alkaline extract and HF ratio (HAF+FAF/HF), and humification index (HI) under different pastures and during two seasons (rainy and dry). AND - *Andropogon gayanus;* BRA - *Brachiaria brizantha;* PAN - *Panicum maximum;* CYN - *Cynodon dactilon;* AFS – Agroforestry system; NV - native vegetation.

| | Rainy season | | | | | | Dry season | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **AND** | **BRA** | **PAN** | **CYN** | **AFS** | **NV** | **AND** | **BRA** | **PAN** | **CYN** | **AFS** | **NV** |
| HAF (g/kg) | 1.1 b | 0.7 c | 0.7 c | 0.5 c | 1.3 a | 1.2 ab | 1.30 b | 0.70 c | 0.60 c | 0.70 c | 1.50 a | 0.80 c |
| FAF (g/kg) | 2.2 b | 2.1 c | 2.0 c | 2.0 c | 3.0 a | 2.7 b | 2.80 a | 1.90 b | 2.00 b | 1.80 b | 3.20 a | 2.10 b |
| HF (g/kg) | 5.3 b | 4.9 c | 4.8 c | 5.0 c | 7.2 a | 4.3 d | 6.00 c | 6.10 b | 6.20 bc | 6.30 bc | 5.90 c | 7.00 a |
| HAF/FAF | 0.50 a | 0.33a | 0.35 a | 0.25 a | 0.43 a | 0.44 a | 0.46 a | 0.36 a | 0.30 a | 0.38 a | 0.46 a | 0.38 a |
| (HAF+FAF)/HF | 0.62 b | 0.57 b | 0.56 b | 0.50 b | 0.59 b | 0.90 a | 0.68 b | 0.42 c | 0.41 c | 0.39 c | 0.79 a | 0.41 c |
| HI (%) | 94.5 a | 95.0 a | 94.9 a | 94.8 a | 96.6 a | 95.3 a | 95.9a | 88.7b | 95.7a | 95.6a | 96.3a | 94.2a |
| TOC (g/kg) | 9.1 b | 8.1 b | 7.9 b | 7.9 b | 11.9 a | 8.6 b | 10.5 b | 9.8 c | 9.1 c | 11.0 a | 10.5 b | 9.1c |

Means followed by the same letter in each row and season do not differ statistically from each other at $p < 0.05$ (LSD test).

2012). The high carbon content from FAF in this system may have stimulated microbial diversity because that fraction is more easily used as an energy source by soil microorganisms, generating more negative charges and improving nutrient cycling and ecosystem productivity (Moraes *et al*., 2011).

The C-HF was higher than the C-HAF and C-FAF in all evaluated plots during both seasons, suggesting a greater stability of humin to mineralization than of humic and fulvic acids (Barros *et al*., 2012). The C-HF was higher in the native vegetation (dry season) and agroforestry system (rainy season), indicating the presence of more stable humus, low degradation, and strong stimulus to soil microbial activity (Barros *et al*., 2012). The presence of lignin derived from plant residues increased also the humin in soil (Carvalho *et al*., 2014). This increase in humin in soil is resulting from the loss of oxidative C and, at the same time, an increase in the C stable (Moraes *et al*., 2011). Therefore, the permanent inputs of organic C from herbaceous plants and trees in the agroforestry system may indicate a high potential for nutrient cycling and increased fertility.

No significant difference in the HA:FA ratio was observed between areas. The ratio (HAF + FAF)/HF in the native vegetation (rainy season) and agroforestry system (dry season) was higher than in the pasture systems, indicating that these systems contain more chemically stable organic C, for which the turnover time is approximately 2,000 years (Chan *et al*., 2001). The humification index did not differ between systems, which was likely because of the low proportion of labile C found in all plots. These results are indicative of soils with low organic matter input; however, with potential to stimulate the microbial growth in these ecosystems because of the complexity of their organic molecules (Bausenwein *et al*., 2008).

Higher lability of C was detected in the soil with *Andropogon* during the dry and rainy seasons, whereas soil with *Cynodon* showed higher lability of C during the dry season (Table 2). All plots showed a

**Table 2.** Labile carbon (LC), labile carbon: total organic carbon ratio (LC/TOC), non-labile carbon (CNL), lability (L), lability index (LI), carbon pool index (CPI), carbon management index (CMI), and carbon stock (C stock) under different pastures and during two seasons (rainy and dry). AND - *Andropogon gayanus;* BRA - *Brachiaria brizantha;* PAN - *Panicum maximum;* CYN - *Cynodon dactilon;* AFS – Agroforestry system; NV - native vegetation.

| | Rainy season | | | | | | Dry season | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **AND** | **BRA** | **PAN** | **CYN** | **AFS** | **NV** | **AND** | **BRA** | **PAN** | **CYN** | **AFS** | **NV** |
| LC (g/kg) | 0.96 a | 0.86 b | 0.74 c | 0.69 d | 0.83 b | 0.60 d | 0.87 a | 0.78 b | 0.73 c | 0.89 a | 0.76 b | 0.67 d |
| LC/TOC (%) | 10.50 a | 10.60 a | 9.30 b | 8.70 b | 6.90 c | 6.90 c | 8.20 b | 7.90 c | 8.02 b | 9.60 a | 6.90 d | 6.30 d |
| CNL (g/kg) | 8.14 b | 7.24 b | 7.16 b | 7.21 b | 11.07 a | 8.00 b | 9.63 cd | 9.02 c | 8.37 d | 8.31 cd | 10.24 a | 9.83 b |
| L | 0.11 a | 0.10 b | 0.10 c | 0.09 c | 0.07 d | 0.07 d | 0.09 a | 0.08 b | 0.08 b | 0.10 a | 0.07 c | 0.06 c |
| LI | 1.57 a | 1.57 b | 1.42 c | 1.28 c | 1.00 d | – | 1.50 a | 1.33 b | 1.33 b | 1.66 a | 1.10 c | – |
| CPI | 1.05 b | 0.94 b | 0.91 b | 0.91 b | 1.38 a | – | 1.00 a | 0.93 b | 0.86 b | 0.87 b | 1.04 a | – |
| CMI | 164.8a | 147.5 b | 129.2 d | 117.3 e | 138.8 c | – | 150.0 a | 123.6 b | 111.3 b | 143.1 a | 114.4 b | – |
| TOC (g/kg) | 9.1 b | 8.1 b | 7.9 b | 7.9 b | 11.9 a | 8.6 b | 10.5 b | 9.8 c | 9.1 c | 9.2 c | 11.0 a | 10.5 b |
| C stock (Mg C/ha) | 25.9 b | 20.7 c | 21.9 c | 24.3 b | 32.8 a | 25.4 b | 27.3 b | 23.5 d | 23.6 d | 25.7 c | 30.5 a | 29.4 b |

Means followed by the same letter in each row and season do not differ statistically from each other at $p < 0.05$ (LSD test).

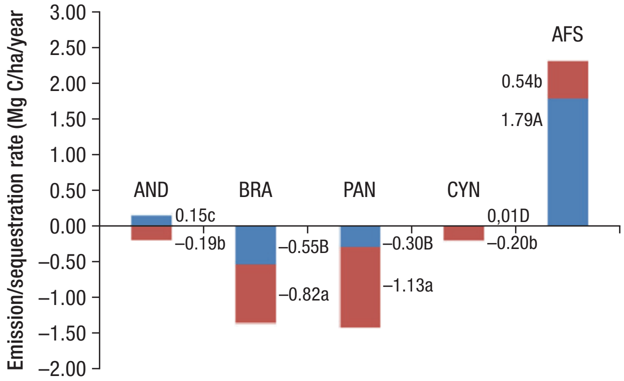


**Figure 1.** Emission and sequestration rate of C-$CO_2$. Means with similar small letters in the dry season (red bars) and capital letters in the rainy season (blue bars), do not differ significantly according to LSD test ($p$<0.05). Plots: AND, *Andropogon gayanus*; BRA, *Brachiaria brizantha*; PAN, *Panicum maximum*; CYN, *Cynodon dactilon*; AFS, Agroforestry system. Positive values indicate C sequestration and negative values indicate C loss.

CMI < 100 (Table 2), indicating high plant input and minimal soil disturbance (Leite *et al*., 2014). According to Blair *et al*. (1995), a CMI < 100 indicates a strong negative impact of management practices on a soil ecosystem. Specifically, the agroforestry system showed a higher CMI than in the *Brachiaria, Panicum*, and *Cynodon*. The absence of trees and different pasture management practices reduce the C management index over time, reflecting a decrease in the potential to restore pre-existing carbon stocks (Leite *et al*., 2014).

The agroforestry system showed highest carbon stock values and high C sequestration rate for the rainy and dry seasons, whereas *Brachiaria, Panicum,* and *Cynodon* showed the lowest C stock and a high C loss (Fig. 1). It means that in multicropping systems, such as agroforestry system, the presence of pioneer tree species and the lesser removal of plant residues contribute significantly to mitigate the loss of C and decrease greenhouse gas emissions. Also, agroforestry systems have higher potential to build up and sequester C in soils because of the increased rates of organic matter addition and retention (Lenka *et al.,* 2012).

In conclusion, conversion of native vegetation to pasture system causes changes in C pools, increasing $CO_2$ emissions into the atmosphere. The agroforestry system has the potential to sequester more carbon in the soil than the pasture system, and it may be an alternative to produce forage for animal production.

## References

Bao X, Li Q, Hua J, Zhao T, Liang W, 2015. The interactive effects of elevated ozone and wheat cultivars on soil microbial community composition and metabolic diversity. Appl Soil Ecol 87: 11-18. http://dx.doi.org/10.1016/j.apsoil.2014.11.003

Barros KRM, Lima HV, Canellas LP, Kern DC, 2012. Fracionamento químico da matéria orgânica e caracterização física de Terra Preta de Índio. Rev Cienc Agrar 55: 44-51. http://dx.doi.org/10.4322/rca.2012.037

Bausenwein U, Gattinger A, Langer U, Embacher A, Hartmann HP, Sommer M, Munch JC, Schloter M, 2008. Exploring soil microbial communities and water extractable organic matter: availability and interactions in an integratedly managed arable soil. J Appl Soil Ecol 140: 67-77. http://dx.doi.org/10.1016/j.apsoil.2008.03.006

Blair GJ, Lefroy RDB, Lisle L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust J Agr Res 46: 1459-1466. http://dx.doi.org/10.1071/AR9951459

Bustamante MMC, Nobre CA, Smeraldi R, 2012. Estimating greenhouse gas emissions from cattle raising in Brazil. Clim Ch 115: 559-577. http://dx.doi.org/10.1007/s10584-012-0443-3

Carvalho JLN, Raucci GS, Frazao LA, Cerri CEP, Bernoux M, Cerri CC, 2014. Crop pasture rotation: A strategy to reduce soil greenhouse gas emissions in the Brazilian Cerrado. Agr Ecosyst Environ 183:167-175. http://dx.doi.org/10.1016/j.agee.2013.11.014

Chan KY, Bowman A, Oates A, 2001. Oxidizible organic carbon fractions and soil quality changes in a paleustalf under different pasture leys. Soil Sci 166: 61-67. http://dx.doi.org/10.1097/00010694-200101000-00009

Leite LFC, Iwata BF, Araujo ASF, 2014. Soil organic matter pools in a tropical savanna under agroforestry system in northeastern Brazil. Rev Árvore 38: 1-8. http://dx.doi.org/10.1590/S0100-67622014000400014

Lenka NK, Choudhury PR, Sudhishri S, Dass A, Patnaik US, 2012. Soil aggregation, carbono build up and root zone soil moisture in degraded sloping lands under selected agroforestry based rehabilitation systems in eastern India. Agr Ecosyst Environ 150: 54-62. http://dx.doi.org/10.1016/j.agee.2012.01.003

Lopes MM, Salviano, AAC, Araujo ASF, Nunes LAPL, Oliveira ME, 2010. Changes in soil microbial biomass and activity in different Brazilian pastures. Span J Agric Res 8: 1253-1259. http://dx.doi.org/10.5424/sjar/2010084-1411

Martins EL, Coringa JES, Weber OLS, 2009. Carbono orgânico nas frações granulométricas e substâncias húmicas de um Latossolo Vermelho. Amarelo distrófico-LVAd sob diferentes agrossistemas. Acta Amaz 39: 655-660. http://dx.doi.org/10.1590/S0044-59672009000300021

Moraes GM, Xavier FA, Mendonca E, Filho JA, Oliveira JN, 2011. Chemical and structural characterization of soil humic substances under agroforestry and conventional systems. Rev Bras Ci Solo 35: 1597-1608. http://dx.doi.org/10.1590/S0100-06832011000500014

Murgeitio E, Calle Z, Uribe F, Calle A, Solorio B, 2011. Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. Forest Ecology and Management 261: 1654-1663. http://dx.doi.org/10.1016/j.foreco.2010.09.027

Soussana JF, Lemaire G, 2014. Coupling carbon and nitrogen cycles for environmentally sustainableintensification of grasslands and crop-livestock systems. Agr Ecosyst Environ 190: 9-17. http://dx.doi.org/10.1016/j.agee.2013.10.012

Swift RS, 1996. Organic matter characterization. In: Methods of soil analysis; Sparks DL *et al*. (eds). pp. 1011-1020. Soil Sci Soc Am, Madison, WI, USA.

Yang X, Ren W, Sun B, Zhang S, 2012. Effects of contrasting soil management regimes on total and labile soil organic carbon fractions in a loess soil in China. Geoderma 177: 49-56. http://dx.doi.org/10.1016/j.geoderma.2012.01.033

Yeomans C, Bremmer JM, 1988. A rapid and precise method for routine determination of organic carbono in soil. Comm. Soil Sci Plant Anal 19: 1467-1476. http://dx.doi.org/10.1080/00103628809368027