

Changes in Soil Carbon Stocks under Integrated Crop-Livestock-Forest System in the Brazilian Amazon Region

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Abstract

Several studies indicate that the use of integrated production systems, such as integrated crop-livestock-forest systems (ICLF), improves the quality of the soil and consequently the sequestration of organic carbon in the soil. In this way, this work aims to evaluate the carbon stocks in soil under different management systems in the Cerrado/Amazonia transition zone, namely: ICLF, no-tillage, pasture and eucalyptus plantation. For this, two soil samplings were done in 2011 and 2014, in the 0 - 5, 5 - 10 and 10 - 30 cm layers. Soil carbon and nitrogen stocks were analyzed. ICLF system was the treatment that obtained the highest percentage of carbon gain (7.8%) after three years of establishment which represents to an increase of 5.5 Mg·ha⁻¹. Management systems, such as ICLF, with minimal soil disturbance combined with crop rotations that contribute to the quantity and quality of residues input, increase soil organic matter content. Carbon stock data show the potential of ICLF systems to increase soil carbon stocks.

Keywords

Agriculture, Soil Carbon, ICLF, Soil Management

1. Introduction

Until the end of the last century, agriculture development was based on the expansion of new areas for cultivation, leading to the deforestation of large areas of native forests and natural ecosystems [1], resulting in losses of environmental

services. According to [2], approximately 55 to 90 Pg of soil C have been lost from managed areas since the advent of agriculture, being one of the main causes of degradation and consequent decline of soil fertility.

As described by [3] and [4], while ensuring food security, there is an urgent need to reduce the impact of food production on the climate [5] and to improve the resilience of food production to future environmental changes [6], [7]. According to the projections of the Intergovernmental Panel on Climate Change (IPCC), the agricultural sector will be greatly affected by global climate change with impacts on its productivity, management and spatial distribution of crops. Thus, it is necessary to change the paradigm of agriculture with the use of management practices that favor the positive balance of physical and chemical attributes of the soil, such as increasing of C, N, water retention, reduction of soil loss by erosion and leaching.

During UNFCCC COP 15 (15th Conference of the Parties under United Nations Framework Convention on Climate Change) in Copenhagen, Brazil undertakes a voluntary national commitment to reduce GHG emissions. This commitment was to reduce by 36.1% and 38.9% the 2020 projected emissions. With this, Brazil will mitigate between 975 million and 1 billion tons of carbon dioxide by 2020. For The fulfillment of the commitment, the Brazilian government created several mitigation and adaptation plans for different sectors of the economy, among them are the Low Carbon Agriculture Plan.

The GHG emission reduction potential of this plan is approximately 150 million Mg CO₂e, and does not consider the potential for removal from the forest plan. This plan corresponds to seven programs, six of which are related to mitigation technologies, and a last program with actions to adapt to climate change: Recovery of Degraded Pastures; Integrated Crop-Livestock-Forest System (ICLF) and Agroforestry Systems (AFs); No-Tillage System (NT); Biological Nitrogen Fixation (BNF); Planted Forests; Animal Waste Treatment; and Climate Change Adaptation.

In addition to this, Brazil has made a new commitment for the NDC (Nationally Determined Contributions) under Paris Agreement (UNFCCC COP21) to implement more 15 million hectares for recovery of degraded pastures and 5 million hectares of ICLF systems by 2030, confirming the potential of these technologies to mitigate greenhouse gases emissions and develop a low carbon agriculture in Brazil.

In agricultural soils, the carbon stocks are affected by changes in land use systems or management practices. Thus, the adoption of more sustainable management systems, such as ICLF, emerges as an alternative to conventional farming systems, with great potential to promote improvements in soil quality, especially with regard to the increase carbon stocks in the short- and long-term [8] [9] [10] [11] [12]. Tee-based systems are expected to have better soil C sequestration potential than most row crop agricultural systems [13]. At the same time, appropriate pasture management may affect soil C balance under ICLF systems

and contribute to increase soil carbon stocks, because of higher biomass production associated with deep root systems while increasing physical protection of soil organic matter (SOM) against mineralization.

Soil organic matter (MOS) plays an important role in maintaining agricultural productivity. The accumulation of MOS promotes improvements in the physical, biological and chemical soil properties, allowing an increase in productivity and reduction of expenses with irrigation, fertilizers, soil conditioners and other agricultural inputs. Understanding how MOS behaves in different types of management is essential for the direction of public policies aimed at the dissemination of agricultural practices that increase the stocks of soil organic C and reduce GHG emissions.

2. Material and Methods

The sampling areas were located on experimental field at the Embrapa Agrosilvopastoral Research Center (11° 51' S, 55° 35' W; 384 m asl) in Sinop, State of Mato Grosso, Brazil. The mean annual temperature is 25°C and mean annual rainfall is 2.550 mm [14]. The soil of the experimental site is classified as a Red Yellow Latosol (Oxisol) [15], a Udox [16]. The soil is a well-drained clay (32% sand, 56% clay), with non-hydromorphic characteristics. The top 0-20 cm layer has the following properties: pH (H₂O) = 5.6; CEC = 7.5 cmol_c·kg⁻¹; Ca²⁺ = 2.5 cmol_c·kg⁻¹; Mg²⁺ = 0.81 cmol_c·kg⁻¹; K⁺ = 0.19 cmol_c·kg⁻¹; P = 14.3 mg·kg⁻¹.

The experimental area was cleared of its native vegetation in 1984 for cultivation of cassava (*Manihot esculenta* Crantz) [17]. Any additional deforestation was stopped during the 2000s. [18] reported that rice (*Oryza sativa* L.) was cultivated on this land during the early 1990s, followed by soybean [*Glycine max* (L.) Merrill]. Between 2002 and 2007, soybeans and maize (*Zea mays* L.) were incorporated into the conventional system.

During the 2007/2008 and 2008/2009 crop seasons, subsequently, the soybean and cotton (*Gossypium hirsutum* L.) successions were followed. During the 2009/2010 and 2010/2011 crop seasons the area was left fallow. In November 2011, subsoiling (chisel plowing to 40 cm depth) was done to alleviate compaction.

The experiment was then established in 2011 and comprised the following treatments: 1) Eucalyptus plantation (*Eucalyptus urograndis*, clone H13); 2) No-tillage system with soybean “BRSGO 8560RR” followed by corn (*Z. mays*) intercropped with *Urochloa brizanta*; 3) Pasture of *U. brizanta* “Marandu”; and 4) ICLF-integrated crop-livestock-forest system, comprising of three rows of eucalyptus (*E. urograndis*), soybean followed by corn (*Z. mays*) intercropped with *U. brizanta* cultivated between tree rows. An area under Native Forest was used as a reference.

Soil samples were taken from 0 - 5, 5 - 10, 10 - 30 cm layers were obtained in 2011 and 2014 for determination of total C and N content. Each replicate was obtained of four subsamples bulked together. Samples were air dried, sieved

through a 2-mm sieve, then further ground by a mill to pass through a 0.106 mm sieve and analyzed for total N and C concentrations by dry combustion (Vario Macro, Elementar Analysensysteme, Hanau, Alemanha) [19].

Soil cores (100 cm³) were also collected from 0 - 5, 5 - 10 and 10 - 20 cm layers to evaluate soil bulk density (*BD*). The C and N stocks for each depth, were determined according to [20]:

$$Y_{\text{stock}} (\text{Mg} \cdot \text{ha}^{-1}) = X \times BD \times th \times (1 - S) \times 10^{-1} \quad (1)$$

where *X* is the C or N concentrations (g kg⁻¹); *BD* is the bulk density (Mg·m⁻³), *th* is the thickness of the soil layer (cm), and *S* is the stone content.

The amounts of carbon and nitrogen stocks were corrected by the equivalent mass method [21]:

$$C_s/N_s = \sum_{i=1}^{n-1} C/N_{T_i} + \left[M_{T_n} - \left(\sum_{i=1}^n M_{T_i} - \sum_{i=1}^n M_{S_i} \right) \right] C/N_{T_n} \quad (2)$$

where *C_s/N_s* correspond to the stock of carbon or nitrogen (Mg·ha⁻¹) in the soil to a depth equivalent to the reference. $\sum_{i=1}^{n-1} C/N_{T_i}$ the sum of the total content of carbon present in the first layer to the penultimate layer (*n* - 1) evaluated treatment. *M_{T_n}* the corresponding soil mass last layer of the estimated treatment. $\sum_{i=1}^n M_{T_i}$ the sum soil mass of the first to the last layer of the evaluated treatment. $\sum_{i=1}^n M_{S_i}$ the sum of the soil mass first to the last layer of the reference area and *C/N_{T_n}* the C or N concentrations (Mg·Mg⁻¹) in the last layer of the evaluated treatment.

Comparison of means was done by using standard errors values and the differences were attributed to the management systems, since evaluated treatments and Native Forest area presented similar soil type and topography.

3. Results and Discussion

Total carbon concentrations varied from 17.2 to 38.4 g·kg⁻¹ (Figure 1). From 2011 to the end of 2014, changes in the contents of C and N were observed only in the uppermost soil layer (0 - 5 cm). However, the observed carbon values did not differ from 2011 and 2014 among the evaluated treatments.

After three years of cultivation, ICLF presented the highest increase of carbon concentration (15%) in the 0 - 5 cm layer, followed by Eucalyptus (13%), Pasture (9%) and No-tillage (8%). Except for Eucalyptus, management systems also contribute to increase total nitrogen, in the 0 - 5 cm layer. However, the increase in total nitrogen in all investigated soil layers was only observed for ICLF. The increase in total carbon concentration is probably related to the higher inputs of vegetal residues in the surface layer. Especially in the ICLF system, higher residues input were probably due to the combination of tree, pasture and crop in the same area. This higher availability of total carbon and nutrients, mainly in the

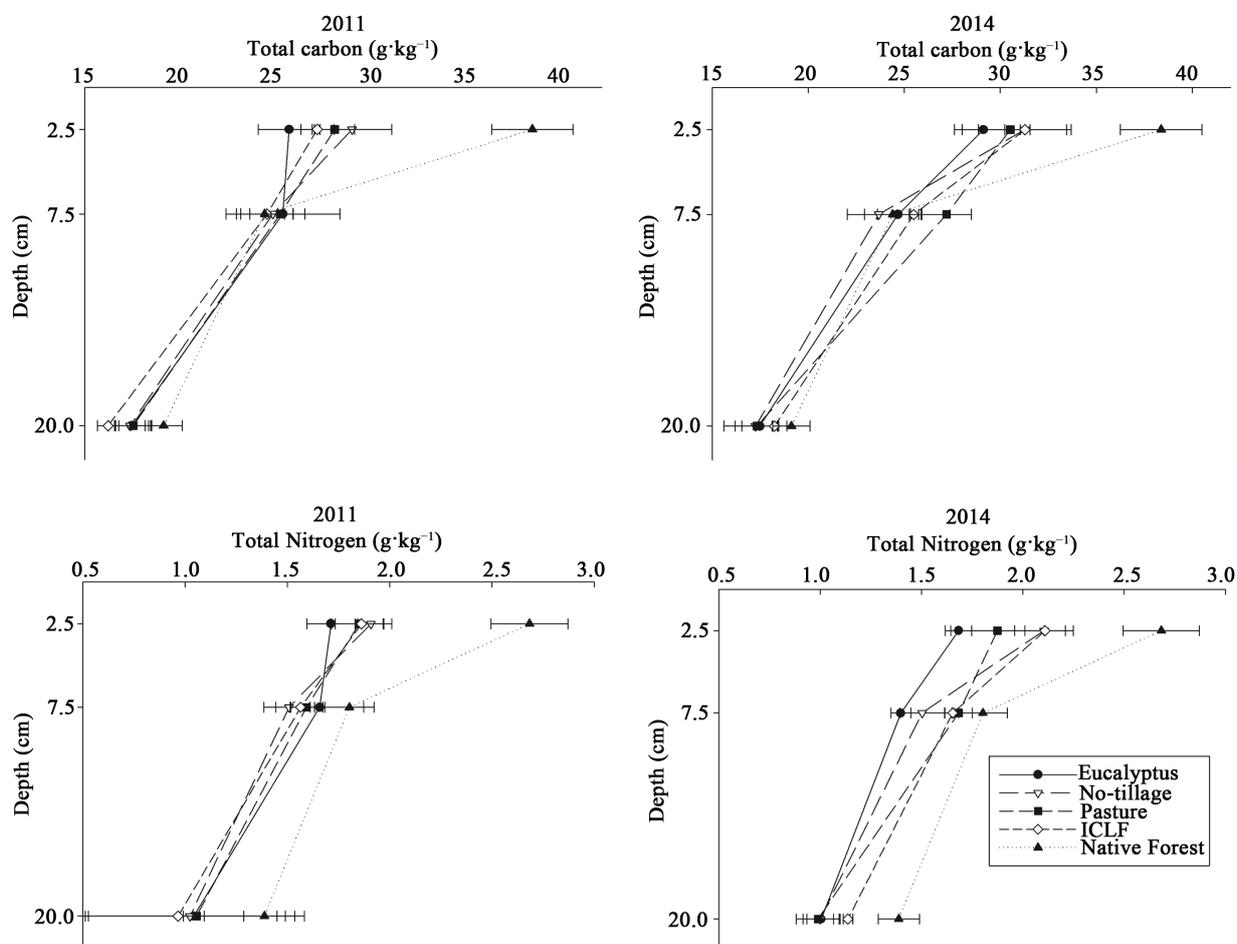


Figure 1. Total C and N concentrations in the 0 - 5, 5 - 10 and 10 - 30 cm layers in soils under Eucalyptus plantation; No-tillage; Pasture; ICLF–integrated crop-livestock-forest system and Native Forest. Horizontal bars represent the standard error ($n = 4$).

soil surface layer (0 - 5 cm) could contribute to higher amounts of microbial biomass and activity promoted by ICLF system.

ICLF and Pasture showed the highest total C stock in the 0 - 30 cm layer. Nitrogen stocks followed the same trend of carbon, however only ICLF presented the highest nitrogen stock (**Figure 2**). Soil carbon stocks values observed in 2014 for Pasture ($71 \text{ Mg}\cdot\text{ha}^{-1}$) and ICLF ($70 \text{ Mg}\cdot\text{ha}^{-1}$) were similar to that found in the Native Forest ($75 \text{ Mg}\cdot\text{ha}^{-1}$).

Three years of ICLF promoted changes in soil C and N stocks (**Table 1**). Despite the similar values of carbon stocks in soil under Pasture and ICLF treatments, after three years, ICLF contribute to increase total carbon stock by $5.5 \text{ Mg}\cdot\text{ha}^{-1}$ in the 0 - 30 cm layer. This result indicates that ICLF could be promising to improve soil carbon sequestration and nutrient cycling.

According to [22], significant increase in soil C stocks is only possible under a management system that reduces degradation of soil organic matter as well as contributes to increase N in the soil-plant system. In the ICLF system, pasture contributes to great amounts of high C/N ratio residues, providing an increase in

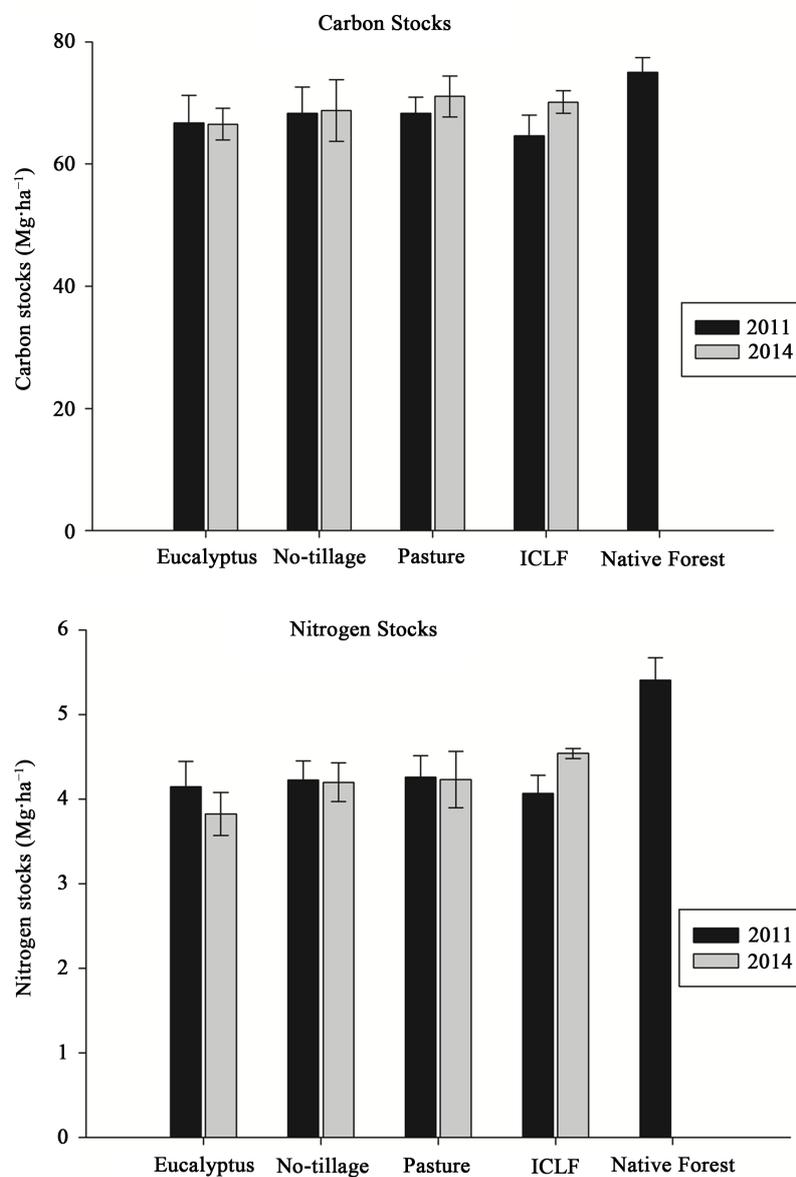


Figure 2. Total C and N stocks in the top 0 - 30 cm layers in soils under Eucalyptus plantation; No-tillage; Pasture; ICLF-integrated crop-livestock-forest system and Native Forest. Vertical bars represent the standard error (n = 4).

Table 1. Gains and losses in soil C and N stocks of different management systems after three years establishment.

Soil layer (cm)	Gains and losses in soil carbon (%)			
	Eucalyptus	No-tillage	Pasture	ICLF
0 - 30	-0.3	+0.6	+3.9	+7.8
	Gains and losses in soil nitrogen (%)			
	Eucalyptus	No-tillage	Pasture	ICLF
0 - 30	-8.3	-0.7	-0.6	+10.4

(-) Losses; (+) Gains.

the persistence of soil cover. However, high C/N ratio residues could reduce N availability for crops [11], [23], [24].

On the other hand, leguminous crops in the rotation system, such as soybeans, can provide a significant source of N for the subsequent crops [25]. [10] attributed the increase of total carbon in soil under crop-livestock integration systems to the combination of maize with brachiaria. According to the authors, higher deposition of plant residues combined with slower degradation rate of the residues could contribute to increase soil organic matter. On this context, brachiaria call attention, because of the well-developed root system, distributed along the soil profile.

Additionally, the tree component (eucalyptus) in the ICLF system is also an important carbon sink, because of its high potential to accumulate large amounts of carbon in the woody biomass and to provide more recalcitrant residues [26]. [27] observed that ICLF promoted higher carbon stocks when compared to an integrated crop-livestock system, no-tillage and native vegetation, not only in the surface layer, but also in deep soil layers (1 m). The higher carbon stocks observed for ICLF was attributed to the deposition of the crop residues on the soil surface, but also the greater amounts of residues provided by pasture and trees in deeper soil layers.

According to [28], the highest concentration of C in the soils under ICLF systems is likely due to the combination of pasture and forest on the same area, since both ICLF components have high capacity to accumulate carbon in deeper soil layers through accretion and deposition of organic material resistant to degradation.

Combined with minimal soil disturbances that favor carbon protection [8], [29], all these mentioned benefits provide by ICLF systems could contribute to the increase of soil carbon stocks. [30] and [31] suggested that the use of legumes, combined with a greater diversity of species in succession or crop rotation, such as the ICLF, significantly increase C and N retention in the soil, with important implications for the balance of both elements on a regional and global scale and for sustainable production and environmental quality.

In addition, ICLF systems are the target of public policies to promote a more sustainable and resilient agriculture to climate change in Brazil. The data of this work show that ICLF promotes improvements in the chemical, physical and biological soil conditions, besides promoting increases of the CO₂ removal from the atmosphere, through tree growth and soil carbon accumulation.

4. Conclusion

After three years establishment, the integrated crop-livestock-forest system showed the highest potential of soil carbon sequestration with values similar of those found under Native Forest. Thus, we consider that ICLF could be an important tool to help Brazil meet its voluntary greenhouse gas emission targets in COP15, especially in agriculture sector.

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