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Integrated crop-livestock management system: C and N stocks in a Brazilian clayey Oxisol using NIRS

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ABSTRACT - Integrated crop-livestock management systems (ICLS) have been increasingly recommended in Brazil. However, knowledge on the indicators used to evaluate their impact on soil carbon (C) and nitrogen (N) concentrations and stocks is still limited. The study was undertaken to evaluate the effects of ICLS systems under two tillage and fertilization regimes on C and N stocks and concentrations at a 0-30 cm depth. The following soil management systems were studied: continuous pasture; continuous crop; crop/pasture rotation; and pasture/crop rotation. The native Cerrado was used as a control. The rotation systems were on a four year cycle. Under the rotation and continuous crop systems there were two levels of soil tillage (conventional and no-tillage) and fertility (maintenance and corrective fertility). The soil tillage and land use systems had a significant impact on the concentrations of C and N in the soil; however, no effect was observed for the fertilizer treatment. ICLS systems did not differ from continuous systems with regard to the C and N stocks; however, these elements tended to accumulate under ICLS systems associated with no-tillage. NIR spectroscopy proved to be a useful tool in quantifying the concentrations of C and N in the soil.

Introduction

Soil organic matter (SOM) is an important factor affecting soil quality and long-term agricultural sustainability. It plays a key role in optimizing crop production, in minimizing negative environmental impacts and in improving soil quality in tropical agroecosystems.

Recommended Management Practices (RMPs) are considered as alternatives in the sustainable management of tropical soils in order to minimize the impact of land use. Numerous studies have reported the benefits of adopting no-tillage in crop systems [1,2,3]. Their integration in rotation with pastures is a RMP currently used in many countries, which also has beneficial effects on soil physico-chemical and biological quality [4,5].

More research is needed to examine organic C and N storage under various land uses in intertropical regions. The C pool may be enhanced by adopting RMPs and restoring degraded soils. Integrated crop-livestock management systems (ICLS) have been increasingly recommended in Brazilian agroecosystems. The objectives of this study were estimate the land use effects on C and N stocks of ICLS systems in comparison with continuous crops or pasture and evaluate the impact of tillage (no-tillage versus conventional tillage) and fertilization regimes on SOM accumulation using NIRS.

Key-words: Cerrado, crop-rotation, NIR spectroscopy.

Material and methods

A. Study site

The experiment site is located at the Embrapa Cerrados Agricultural Research Center, 15º 35' S and 47º 42' W, altitude 1200 m, on a plateau in the center of the Cerrado region, at Planaltina, DF, Brazil. The soil is a Latossolo Vermelho Escuro according to the Brazilian classification [6].

B. Experimental design

Four different soil management systems, based on ICLS and continuous systems in a split plot desing were studied: (1) P – Continuous pasture; (2) C – Continuous crop; (3) CR – crop/pasture rotation; (4) PR – pasture/crop rotation. (5) Native Cerrado. In the field, the CR and PR rotations changed every four years beginning in 1991. Samples were taken at the end of a 4-year rotation cycle, in May 2004. At sampling, soybean (Glycine max (L.) Merr.) was cultivated (C and CR systems) and Panicum maximum was the forage

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specie in the PR rotation system. In the C, CR and PR systems, there were also two tillage (T^+ = Conventional and T^- = No-tillage system) and two fertilization (F1 = maintenance fertilization and F2 = corrective fertilization) regimes. The combination of management systems, tillage and fertilization regimes composed a total of 14 treatments. For crops, maintenance fertility corresponded to the fertilization calculated from the expected grain yield and nutrient export; corrective fertility was determined in order to gradually increase the level of phosphorus in the soil. For pastures, maintenance fertility meant no fertilizer was applied; corrective fertility corresponded to 10 kg ha^{-1} P + 40 kg ha^{-1} K + 60 kg ha^{-1} N per year, except for the year after the rotation from crop to pasture, when no fertilizer applications were made (residual fertilizer is used by the pasture). Lime was applied at the rate of 3.4 Mg ha^{-1} and 5.8 Mg ha^{-1} for the F1 and F2 treatments, respectively, at the beginning of the experiment. Rotacional put and take grazing system was used in the pasture plots (14 days grazing and 14 days resting). The stoking rate was determined according to the forage availability (8 to 10 kg DM 100 kg^{-1} LW^{-1} day^{-1}), adjusted every 28 days.

C. Soil sampling and analysis

Undisturbed samples were collected in December 2004 at 0-2, 2-5, 5-10, 10-20, 20-30 cm depths. The first (0-2) and the second (2-5) layers were collected in triplicate and duplicate, respectively, and mixed to create a composite sample. In each treatment, the soil samples were collected in three replicates. From each undisturbed sample, a sub-sample of each layer was oven-dried at 105 °C and weighed to determine dry mass. Then, the bulk density was calculated. Another sub-sample was air-dried and sieved at 2 mm for NIR spectroscopy. The total set of samples (i.e. 390 samples) were scanned using a ring cup (5 cm diameter) in a spectrophotometer, FOSS 5000 model (Foss NIRSystems, Silver Spring, MD, USA). The spectral data obtained were analysed using WinISI III-version 1.50e software (Foss NIRSystems, Infrasoft International). From this sampling set, 92 samples were selected according to their spectral representativity [7] in order to constitute the calibration set. Thirty other samples were selected randomly for the validation set. These two sets of samples were analyzed by dry combustion after grinding and sieving at 0.2 mm, using a CHN 2400 Perkin-Elmer analyzer, to determine C and N contents in order to get the reference values. The modified partial least square (MPLS) regression [8] was used to correlate reference C and N data with the NIR spectra of the calibration set. After this process, the validation set was used to evaluate the regression equation. Finally, this model was developed for all samples to predict C and N contents of the total set.

Results

The results of Anova, presented in Table 1, showed the significant effect of the management system and soil tillage on Db, C and N. However, there was no significant effect of fertilization on C and N, which only affected Db. N and Db also varied significantly with soil depth ($p < 0.05$), although C did not present the same pattern ($p = 0.07$). C content ranged from 24.6 g kg^{-1} in the Cerrado area to 17.83 g kg^{-1} under PR T^+, in the 0-2 cm soil layer, without noticeable variation of content with depth (Table 2).

Carbon storage to the 30cm depth was equal to 60.87 Mg ha^{-1} under the native vegetation area (Cerr), and ranged from 47.74 Mg ha^{-1} in the 4- year-old pasture of Panicum maximum under ICLS rotation (PR T^+), to 62.96 Mg ha^{-1} in continuous crop under conventional tillage (C T^+). The comparison made between the management systems (Figure 2) showed a decrease, but not statistically significant, in the C stocks of the continuous pasture and the ICLS systems in relation with the native vegetation.

N stocks were significantly higher in the Cerrado area and ranged from 4.01 Mg ha^{-1} in continuous crop (C) to 3.6 Mg ha^{-1} in CR ICLS system, although this difference was not significant. Regarding the effect of soil tillage, the N stocks ranged from 3.62 Mg ha^{-1} in conventional tillage to 3.81 Mg ha^{-1} in no-tillage. Although the result of the Anova F test showed an effect of tillage type on C and N, the results of the means compared with Tukey's test did not show significant differences between soil tillage types.

Discussion

In most of the studies, the C and N stocks were calculated without correction for bulk density effect on the soil layers. Under these conditions, the magnitude of the C and N stocks up to 20 cm found in this study (ranging between 40-50 and 2.7-3.3 Mg ha^{-1}, respectively) was similar to those reported in others studies on Cerrado soils, except for those obtained by Corbeels et al. [9], which were slightly higher. Our results showed a positive effect of management system and soil tillage on C stock. However, some results were conflicting, for most of the published data also show C accumulation under pasture and crop under no-tillage in relation to the Cerrado native areas.

With the procedure recommended by Sisti et al., [1], and used by Bayer et al. [3], which was also used in this study, the soil weight was corrected in order to use the same weight of soil in all systems, i.e. the weight of the 0-20 cm layer of the Cerrado soil. The soil management had a major effect on Db, leading to an increase of up to 33-53 % in the cultivated land (PR T^-) in comparison to the native one. Compaction after land use has been observed in various Oxisols of the Cerrado region, both under pastures and crop systems. Balbino et al. [10] interpreted the increase in Db in Oxisols as a decrease in microaggregate development when the native vegetation is cleared for pasture. The modification of the method of calculation had a considerable effect on the results, as shown in Figure 3 for C stocks. Without correction, there was an increase of the C stock for all the management systems (only significant for the continuous crop). With correction, there was a no significant decrease in the C stock in cultivated native Cerrado lands (Figure 2). Likewise, the C analysis method had an effect on stock results. In the literature data, we observed that the C stock values in the Cerrado soils measured by dry combustion presented higher values than those measured by wet oxidation (45.6 and 36.0 Mg ha^{-1} for dry and wet oxidation, respectively). Part of this difference may be related to the black-carbon, which is burnt during dry combustion, but is not oxidized by the wet oxidation.

The C and N contents were higher in the native vegetation than in pasture and crop systems (Figure 1). Neither the pastures nor the continuous crops under no-tillage promoted the accumulation of carbon in relation to the Cerrado area. These results conflict with most of the results observed in others soils of Cerrado region, which is partly due to the calculation method, as observed above.

The C and N contents in the profiles varied poorly according to the soil management systems. In Figure 2 it may be observed that stocks under the C T^-; C T^+; CR T^-; and PR T^- systems and the *Brachiaria decumbens* continuous pasture did not differ from the Cerrado area, indicating that for the 0-30 cm layer, under the continuous crop system (C), both for T^- and T^+, and under CR T^- system, the original soil carbon stocks did not change.

Pastures are thought to have a positive effect on C and N accumulation. Silva et al., [11], evaluating six types of pasture grasses, with or without legumes, observed an increase of the C stock of up to 28 % over that in the Cerrado, except for the single *Brachiaria decumbens* pasture without fertilization. The key factor was the amount of fertilizers which indirectly promoted C accumulation. Our results did not show such an increase in soil C under the continuous pasture system. In this study, simulating livestock farming conditions, the N input on pastures was remarkably low, which then limited pasture productivity.

The higher C and N stocks under T^- than under T^+ to a depth of 30 cm, though not significant, are of similar magnitude to those reported in other studies conducted in Brazil and North America. Corbeels et al. [9], studying the soil carbon storage potential of no-tillage in the Cerrados, reported an average increase in SOC stocks of 0.83 Mg C ha^{-1} yr^{-1} in the 0–20 cm topsoil, and a corresponding increase in total soil nitrogen of 79 kg N ha^{-1} yr^{-1}.

Under the conditions of our study, the ICLS systems did not promote C accumulation in the soil. However, as our data are the first published on these systems, they are insufficient, and further research is needed to confirm the carbon sequestration potential of ICLS systems. Nevertheless, a comparison between types of soil tillage revealed that, in spite of being higher, the C stock under no-tillage was significantly similar to conventional tillage. Zinn et al. [12], in a study of C stocks in different Brazilian ecoregions, observed that the existing data are insufficient and conflicting. Soil C stocks need to be further analyzed so that more data may be collected on organic C contents and bulk densities.

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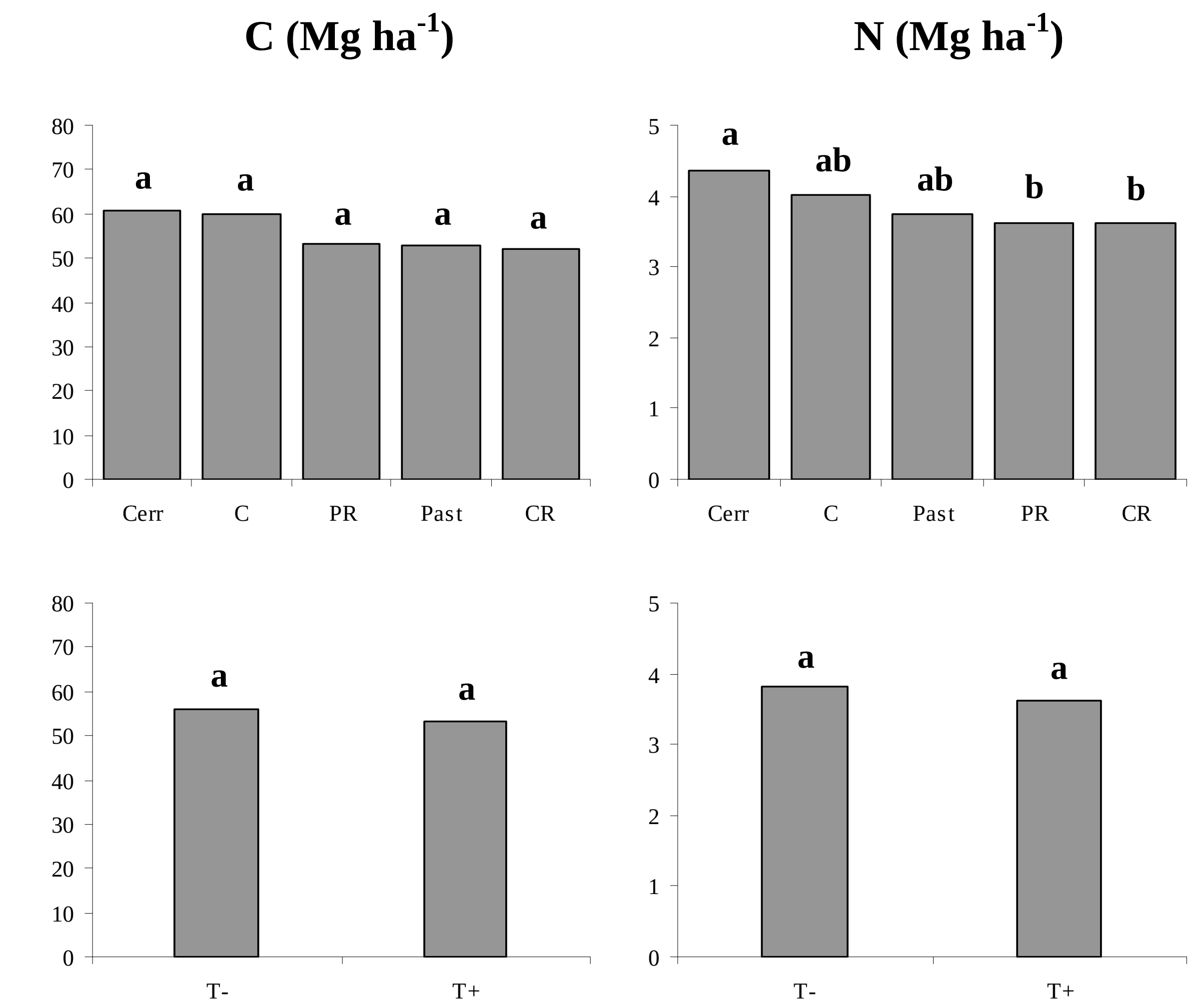
Table 1. Results of Anova for principal effects of management systems, soil tillage types, fertilization regimes and soil depth on bulk density (D_b), total soil organic carbon (C) and total nitrogen (N).

	df	D_b (g cm^{-3})		C (g kg^{-1})		N (g kg^{-1})	
		F	*p*	F	*p*	F	*p*
Management system	2	51.03	0.0001	13.34	0.0001	5.13	0.0064
Soil tillage	1	7.21	0.0076	11.63	0.0007	7.45	0.0067
Fertilization	1	15.53	0.0001	0.33	0.5683	1.64	0.2015
Soil depth	4	4.99	0.0007	2.18	0.0716	2.77	0.0274

Table 2. Soil bulk density (D_b), total organic carbon (C) and nitrogen (N) in treatments for the different soil depths. Each value in the table represents the mean and the standard deviation in brackets.

Depth (cm)		Cerr	Past	PR T$^+$	PR T$^-$	CR T$^+$	CR T$^-$	C T$^+$	C T$^-$
0 – 2	D_b (g cm^{-3})	0.81	1.11	1.12	1.24	1.06	0.96	1.03	0.96
		(0.04)	(0.06)	(0.09)	(0.21)	(0.04)	(0.11)	(0.06)	(0.07)
	C (g kg^{-1})	24.60	18.50	17.83	19.98	18.17	22.00	22.38	20.78
		(3.34)	(4.78)	(3.56)	(2.82)	(3.25)	(5.89)	(4.96)	(3.37)
	N (g kg^{-1})	1.74	1.41	1.20	1.29	1.22	1.54	1.47	1.37
		(0.22)	(0.40)	(0.23)	(0.19)	(0.16)	(0.47)	(0.32)	(0.21)
2 – 5	D_b (g cm^{-3})	0.92	1.15	1.18	1.26	1.09	1.05	1.07	1.14
		(0.06)	(0.08)	(0.05)	(0.04)	(0.08)	(0.09)	(0.07)	(0.08)
	C (g kg^{-1})	25.01	20.37	19.03	21.86	17.75	20.53	23.89	22.29
		(2.25)	(5.34)	(2.90)	(2.75)	(2.95)	(3.05)	(5.31)	(5.83)
	N (g kg^{-1})	1.77	1.47	1.30	1.48	1.26	1.35	1.57	1.55
		(0.24)	(0.40)	(0.18)	(0.38)	(0.18)	(0.24)	(0.32)	(0.56)
5 – 10	D_b (g cm^{-3})	0.83	1.07	1.11	1.15	1.07	1.09	1.05	1.10
		(0.06)	(0.06)	(0.05)	(0.04)	(0.07)	(0.09)	(0.06)	(0.03)
	C (g kg^{-1})	21.70	19.52	19.72	22.96	21.61	20.91	23.46	23.50
		(2.54)	(5.38)	(3.42)	(4.70)	(5.71)	(2.58)	(5.57)	(6.44)
	N (g kg^{-1})	1.53	1.36	1.35	1.61	1.54	1.47	1.50	1.66
		(0.15)	(0.44)	(0.35)	(0.52)	(0.48)	(0.32)	(0.32)	(0.61)
10 – 20	D_b (g cm^{-3})	0.90	1.09	1.11	1.20	1.09	1.07	1.09	1.13
		(0.05)	(0.04)	(0.02)	(0.06)	(0.05)	(0.03)	(0.04)	(0.05)
	C (g kg^{-1})	21.89	21.49	17.38	22.18	19.52	20.67	24.67	20.58
		(3.57)	(5.13)	(3.50)	(3.42)	(4.20)	(3.69)	(3.87)	(4.16)
	N (g kg^{-1})	1.56	1.55	1.19	1.49	1.38	1.41	1.62	1.41
		(0.30)	(0.45)	(0.31)	(0.30)	(0.42)	(0.30)	(0.42)	(0.30)
20 – 30	D_b (g cm^{-3})	0.89	1.06	1.08	1.22	1.10	1.03	1.07	1.12
		(0.04)	(0.03)	(0.08)	(0.10)	(0.04)	(0.13)	(0.05)	(0.05)
	C (g kg^{-1})	23.99	17.32	17.05	21.37	17.84	21.04	22.67	21.45
		(6.19)	(4.11)	(3.66)	(3.55)	(2.50)	(3.99)	(1.32)	(3.85)
	N (g kg^{-1})	1.76	1.14	1.18	1.41	1.22	1.41	1.55	1.39
		(0.51)	(0.33)	(0.28)	(0.35)	(0.28)	(0.29)	(0.16)	(0.27)

Cerr – native Cerrado; Past – continuous pasture of *Brachiaria decumbens*; PR T$^+$ - pasture/crop rotation under conventional tillage; PR T$^-$ - pasture/crop rotation under no-tillage; CR T$^+$ - crop/pasture rotation under conventional tillage; CR T$^-$ - crop/pasture rotation under no-tillage; C T$^+$ - continuous crop under conventional tillage; C T$^-$ - continuous crop under no-tillage.



Figu a depth calculated corrected by relative soil mass of Cerrado. Cerr – native Cerrado; Past – continuous pasture of *Brachiaria decumbens*; PR - pasture/crop rotation; CR - crop/pasture rotation; T^+ - conventional tillage; T^- - no-tillage. Columns with the same letter did not differ at p = 0.05 probability level.

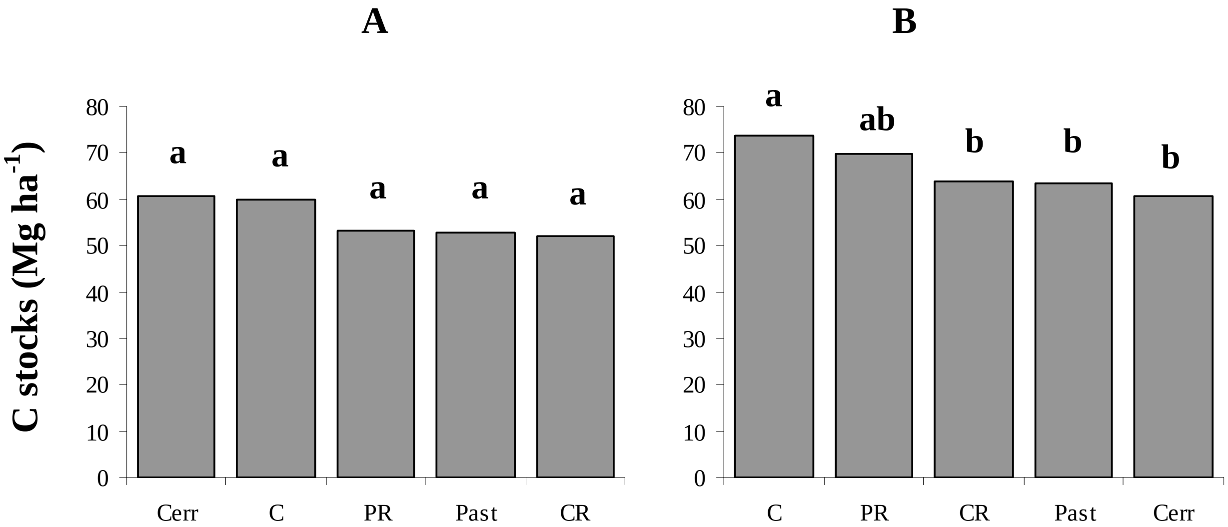


Figure 2. Carbon stocks comparison under continuous and crop-livestock rotation systems in 0-30 cm soil depth calculated corrected by relative soil mass of Cerrado (A) and only with bulk density (B). Cerr – native Cerrado; Past – continuous pasture of Brachiaria decumbens; PR - pasture/crop rotation; CR - crop/pasture rotation; T^+ - conventional tillage; T^- - no-tillage. Columns with the same letter did not differ at p=0.05 probability level.