SOIL CARBON STOCKS IN INTEGRATED CROP-LIVESTOCK AND CROP-LIVESTOCK-FOREST SYSTEMS IN THE BRAZILIAN CERRADO

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ABSTRACT
Pasture degradation is currently an important problem in livestock production in Brazil. Conventional agriculture, without crop rotation and constant soil preparation, it is a practice that causes loss in soil quality. Soil carbon is a fundamental component for chemical, physical and biological characteristics that assures soil quality. Crop-livestock (ICLS) and crop-livestock-forest (ICLFS) integration systems, combined with crop rotation practices and no-tillage system may be alternatives for recovering and maintaining C levels in the soil, providing adequate soil C stocks, through rates of accumulation that can improve in mitigating greenhouse gases emissions. This work aimed to evaluate different integrated systems, with reference to natural vegetation, as soil management alternatives that could minimize losses and increase soil carbon stocks after the recovery of degraded pastures in the Cerrado region of Brazil. After 8 years ICLS showed highest values of soil C contents, C stocks and rate of C accumulation as compared to ICLF22 and ICLF14, respectively. ICLS system (no trees) had less competition for light, water and nutrients, and provided greater source of organic matter for soil carbon, than grass/pasture combined with trees. ICLS has proved to be a promising system in helping to mitigate greenhouse gases in livestock production.
Key words: Agropastoral; *Brachiaria*; Mitigation

INTRODUCTION

Pasture degradation is currently an important problem in livestock production in Brazil. Conventional agriculture, without crop rotation and constant soil preparation, it is a practice that causes loss in soil quality. Soil carbon is a fundamental component for chemical, physical and biological characteristics that assures soil quality. Crop-livestock (ICLS) and crop-livestock-forest (ICLFS) integration systems, combined with crop rotation practices and no-tillage system may be alternatives for recovering and maintaining C levels in the soil, providing adequate soil C stocks, through rates of accumulation that can improve in mitigating greenhouse gases emissions. This work aimed to evaluate different ICLS and ICLFS systems, with reference to natural vegetation, as soil management alternatives that could minimize losses and increase soil carbon stocks after the recovery of degraded pastures in the Cerrado region of Brazil.

MATERIAL AND METHODS

The experiment was conducted at the National Center of Beef Cattle Research, of EMBRAPA, in Campo Grande, MS, Brazil, in the biome Cerrado, belonging according to the climatic classification of Köppen-Geiger, the transition band between Cfa and Aw tropical humid (KOTTEK et al., 2006), with average annual precipitation of 1,560 mm and characterized by hot and rainy summer and cold winter moderate and dry. The field experiment was carried out in an area of degraded pasture (20º26'S, 54º43'W, 530 m asl) since 2008/09. Local soil is classified as an Oxisol, clayed, acid and with low fertility (SOUSA; LOBATO, 2004). The agricultural practices adopted in the experimental area and the results of forage, agricultural and animal productivity are described in Oliveira et al. (2014), Pereira et al. (2014; 2021). Treatments included ICLS (integrated crop-livestock, no trees), ICLFS14 (integrated crop-livestock-forest with single line of trees, 14 m apart with 357 trees ha^{-1})

and ICLFS22 (lines of trees 22m apart, with 227 tress ha^{-1}) both composed of *Eucalyptus urograndis*, clone H13. Soybeans were cultivated conventionally in 2008/09 and no-tillage in 2012/13. Grazed pastures of *Brachiaria brizantha* cv. BRS Piatã were cultivated between eucalyptus trees, after soybeans. Two transects lines, composed by 10 single soil samples/transect, were taken yearly in May-June, to 20 cm depth, and analyzed for total C in an autoanalyzer (Sumika/Shimadzu). Soil density was measured in all paddocks up to 100 cm in 2014 and 2008 up to 20 cm. An equation to estimate soil density (SD) for all years was established in order to calculate soil carbon stocks and rates. Soil density data were validated using Pearson correlation, which reached over 80% of correspondence. Independent variables were soil pH $CaCl_2$, soil clay and soil carbon contents, as below:

$$SD= 1,2898-(0,0131*Clay) -(0,10868*Carbon) +(0,1240*pH_{CaCl_2})$$

Soil carbon stocks were calculated after soil mass, in 0-20 cm soil layer, be estimated by SD. Data of soil carbon stocks obtained through these calculations were corrected considering the excess of soil mass. It was assumed soil compaction due to tillage and treading by cattle in all imposed treatments. Untouchable soil mass content of the native vegetation (NV), in the same layer, was used for correction in accord with Sant-Anna et al. (2017) and Sisti et al. (2004).

RESULTS AND DISCUSSIONS

Soil chemical and physical characteristics

Results of soil chemical and physical characteristics in 2008 and 2016, after 8 years of soil, crop and animal management are presented in Table 1. It is observed that soil quality expressed by the soil fertility were significantly increased by the management of fertilization in the three systems studied in comparison with the native vegetation (NV). Soil base saturation (V%), as well as the levels of P extractable by Mehlich-1 increased considerably, going on average from 25-28, to 32-41%, while in the NV it remained around 2-4%. The levels of soil P after 8 years of agricultural and livestock exploitation reached 0.6, 1.81, 3.34 and 6.55 mg P dm^{-3} in VN, ICLS, ICLF22 and ICLF14, respectively. This gradient can be explained by forage and animal production presented in the inverse way, as demonstrated in Pereira et al. (2017). Light interception was greater in ICLF14 and demand for water and nutrients among pasture, crops and trees affected its productivity. This behavior reflected directly on remaining soil fertility.

Soil C contents

On the other hand, lower productivity by ICLF14 (PEREIRA et al., 2017) related to forage biomass, and consequently lower root system yield, decreased soil C content, as presented in Table 2. Treatments (systems) were significantly different ($p<0.0001$) as related to soil C contents and was greater in ICLS (no trees) as compared to both with trees (Table 2). Spacing lines of trees up to 22 m improve forage production and soil C content. It was observed also significant effects among years ($p<0.0001$) in soil C contents most probably due to precipitation, temperature and soil management related to crop and livestock operations.

Soil density

Soil density (SD) is presented in Table 2 and showed also significant differences among treatments and years of observation ($p<0.001$) there was no interaction between years and treatments ($p>0.48$). It was observed a gradient in SD among treatments in the field and this was close related to soil texture, being NV more clayed than, ICLS, ICLF22 and ICLF14, respectively.

Soil C stocks and accumulation

In table 2 are presented data of soil C stocks each 2 years from 2008 up to 2016. Treatments and years were highly significant ($p<0.0001$) as interaction between treatments and years ($p<0.004$). ICLS (no trees) reached, in 2016, the highest soil C stock with 43.0 Mg ha^{-1}, as compared to ICLF22 and ICLF14, with 37.8 and 30.3 Mg ha^{-1}, respectively. This latest one had practically no C accumulation along years, as the native vegetation. Higher stocks of C to the ICLS are attributed to longer permanence of forage in full sun, without the presence of trees, and the clayed texture of the soil of 42.6%, which was slightly greater than ICLF22, ICLF14, with 38.6 and 31.1%, respectively. Even with the corrected values of C stock, by soil mass related to natural vegetation, it was observed accumulation of C in the three systems studied. Between 2008 and 2016 accumulated values varied from 3 to 6 Mg ha^{-1}, with the exception of ICLF14 and the native vegetation. The up and down variations observed each two years, both in the production systems, as well as in the native vegetation, are attributed to variations in precipitation, temperature, crop, soil and animal management, and soil sampling as well. These were carefully taken in two assigned transects along each paddock, but it was not enough to avoid some variation. Another explanation for these variations could be the impact of climate and soil management on the portion of particulate carbon that make up the less stable fraction of the total soil carbon, which is more subject to variations caused by these variables. The absolute values of C stock observed in this study are close to those obtained by Braz et al. (2013) who measured C stocks in various soils under pastures, up to 30 cm deep, in different places of the Cerrado. Increased stocks values observed in this study are also similar to those obtained here. Following the same trending of carbon stocks, the rate of C accumulation between 2008 and 2016 in the different systems and native vegetation were greater in ICLS= 0.748 Mg/ha/year, as compared to ICLF22= 0.473 Mg/ha/year and ICLF14= -0.074 Mg/ha/year. These results are in accord with those cited by Urquiaga et al. (2010).

Table1. Chemical and physical soil characteristics in the 0-20 cm layer in different integrated crop, livestock, forest systems and native vegetation, in 2008 and 2016. Campo Grande, MS, Brazil.

System	**Year**	**pH**	**Ca^{+2}**	**Mg^{+2}**	**K^{+}**	**Al^{+3}**	**H+AL**	**CTC**	**V**	**m**	**PM1**	**Sand**	**Silt**	**Clay**
		$CaCl_2$	------------------ cmolc/ dm^3 ----------------------						------ % -----		mg/dm^3	--------- % ---------		
Nat Veg	**2008**	4.18	0.09	0.11	0.12	1.37	7.24	7.56	4.3	81.0	0.09	50.5	9.2	40.3
	2016	4.32	0.02	0.11	0.08	1.07	8.03	8.21	2.1	86.3	0.65			
ICLS	**2008**	4.68	1.21	0.73	0.08	0.22	5.13	7.16	28.3	9.9	0.42	44.0	13.4	42.6
	2016	5.20	1.94	1.32	0.16	0.06	4.78	8.20	41.6	2.0	1.81			
ICLFS22	**2008**	4.62	0.85	0.67	0.11	0.38	4.83	6.46	25.3	18.9	0.31	49.8	11.7	38.6
	2016	4.94	1.44	0.89	0.19	0.19	5.23	7.76	32.4	7.8	3.34			
ICLFS14	**2008**	4.60	0.99	0.69	0.09	0.42	4.29	6.06	29.1	19.6	0.37	57.7	11.2	31.1
	2016	5.16	1.84	1.00	0.17	0.20	4.88	7.88	38.4	7.2	6.55			

Table 2. Soil C content (C, %), soil density (SD, g/cm^3) and soil C stocks (Mg/ha) in the 0-20 cm layer in different integrated crop, livestock, forest systems and native vegetation, measured yearly in the period of 2008 and 2016. Campo Grande, MS, Brazil.

System	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
					C, %					
CLS	1.79	1.91	1.95	2.01	2.19	2.10	2.20	2.20	2.03	2.04 A
CLFS22	1.64	1.92	1.80	1.78	2.05	1.88	1.90	1.90	1.79	1.85 B
CLFS14	1.49	1.69	1.53	1.62	1.65	1.70	1.64	1.64	1.43	1.60 C
Mean	1.64 d	1.84 bc	1.76 cd	1.80 bc	1.96 a	1.89 ab	1.91 ab	1.91 ab	1.75 cd	1.83
Nat Veg	2.23	1.99	2.04	2.08	2.19	2.19	2.20	1.98	2.19	2.12
					SD, g/cm^3					
ICLS	1.11	1.13	1.16	1.20	1.16	1.15	1.13	1.13	1.15	1.15 A
ICLFS22	1.18	1.20	1.23	1.25	1.21	1.20	1.18	1.17	1.20	1.20 B
ICLFS14	1.29	1.34	1.35	1.41	1.37	1.34	1.33	1.32	1.36	1.35 C
Mean	1.19 f	1.22 cde	1.25 b	1.28 a	1.25 bc	1.23 bcd	1.21 def	1.20 ef	1.24 bc	1.23
Nat Veg	1.04	1.07	1.08	1.08	1.06	1.04	1.04	1.07	1.06	1.06

	2008	2010	2012	2014	2016	Mean
			C, Mg/ha			
ICLS	37.1	42.2	46.3	45.8	43.0	42.8 A
ICLFS22	34.0	39.0	43.4	39.7	37.8	38.7 B
ICLFS14	30.9	33.2	35.0	34.2	30.3	32.7 C
Mean	34.0 d	38.1 bc	41.6 a	39.9 ab	37.0 c	38.1
Nat Veg	46.2	44.2	46.4	45.8	46.2	45.7

Note: There is no significant difference between values with same letters in line or column, as estimated by Tukey (p=0.05).

CONCLUSIONS

After 8 years under ICLS this system showed highest values of soil C contents, C stocks and rate of C accumulation as compared to ICLF22 and ICLF14, respectively. ICLS system (no trees) had less competition for light, water, and nutrients, and provided greater source of organic matter for soil carbon, than grass/pasture combined with trees. Grass biomass and animal production were greater in ICLS as compared to systems with trees as reported in cited papers. ICLS has proved to be a promising system in helping to mitigate greenhouse gases in livestock production.

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REFERENCES

BRAZ, S. P.; URQUIAGA, S.; ALVES, B. J. R.; JANTALIA, C. P.; GUIMARÃES, A. P.; DOS SANTOS, C. A.; DOS SANTOS, S. C.; MACHADO PINHEIRO, E. F.; BODDEY, R. M. Soil carbon stocks under productive and degraded Brachiaria pastures in the Brazilian Cerrados. **Soil Science Society of America.** v.77, p.914–928, 2013. DOI: 10.2136/sssaj2012.0269

OLIVEIRA, C. C.; VILLELA, S. D. J.; ALMEIDA, R. G.; ALVES, F. V.; BEHLING NETO, A.; MARTINS, P. G. M. A. Performance of Nellore heifers, forage mass, and structural and nutritional characteristics of *Brachiaria brizantha* grass in integrate production systems. **Tropical Animal Health and Production**, v.46, p. 167-172, 2014.

PEREIRA, M. A.; ALMEIDA, R. G.; LAURA, V. A.; COSTA, F. P.; ALVES, F. V. Carbon Neutral Brazilian Beef: an analysis of its economic viability for livestock sustainable intensification. In: XXII INTERNATIONAL FARM MANAGEMENT CONGRESS, 2019. **Proceedings...** Launceston, Australia: IFMA. p.1-13.

PEREIRA, M.; BUNGENSTAB, D. J.; ALMEIDA, R. G.; SCHWARTZ, H. J. An agro-silvo-pastoral production system in Brazil. In: CONFERENCE ON TROPICAL AND SUBTROPICAL AGRICULTURAL AND NATURAL RESOURCE MANAGEMENT - TROPENTAG, 2014. Prague, Czech Republic. **Proceedings...** Prague, Czech Republic: Czech University of Life Sciences Prague. p.1-4.

PEREIRA, M.; MORAIS, M. G.; FERNANDES, P. B.; SANTOS, V. A. C.; GLATZLE, S.; ALMEIDA, R. G. Beef cattle production on Piatã grass pastures in silvopastoral systems. **Tropical Grasslands**, v.9, n.1, p.1-12, 2021.

SANT'ANNA S.A.C. DE; JANTALIA, C. P.; SA´, J.M.; VILELA L.; MARCHÃO R. L.; ALVES. B. J. R.; URQUIAGA, S.; BODDEY, R. M. Changes, in soil organic carbon during 22 years of pastures, cropping or integrated crop/livestock systems in the Brazilian Cerrado. **Nutrient Cycling in Agroecosystems**, v.108, n.1, p.101-120, 2017.

SISTI, C.P.J.; SANTOS, H.P.; KOHHANN, R.; ALVES, B.J.R.; URQUIAGA, D.; BODDEY, R.M. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. **Soil & Tillage Research**, v.76, p.39–58, 2004.

SOUSA, D.M. G.; LOBATO, E. **Cerrado:** correção do solo e adubação. 2ª Ed. Brasília, DF: Embrapa Informação Tecnológica, 2004. 416p.

URQUIAGA, S.; ALVES, B. J. R.; JANTALIA, C. P.; BODDEY, R. M. Variações nos estoques de carbono e emissões de gases de efeito estufa em solos das regiões tropicais e subtropicais do Brasil, uma análise crítica. Instituto da Potassa. Piracicaba, SP. **Informações Agronômicas**, n.130, p.12-21, 2010.