Soil carbon sequestration affected by no-tillage and integrated crop-livestock systems in Midwestern Brazil

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Abstract
Conservation management systems can improve soil organic matter stocks and contribute to atmospheric C mitigation. This study was carried out in a 15-year long-term field experiment established on a tropical Oxisol in Dourados/MS, Brazil, to assess the potential of tillage systems [conventional tillage (CT), no-tillage (NT) and no-tillage integrated crop-livestock (ICL)] for mitigating atmospheric C. For that, the soil organic carbon (SOC) accumulation in the 0-100 cm depth and the C equivalent (CE) costs of the different management systems were taken into account for comparison with the CT. More SOC accumulation was observed in NT and in ICL systems because of the lesser oxidative environment compared to CT. SOC accumulation rate in NT was 0.21 Mg ha^{-1} yr^{-1} higher in the 0-30 cm layer, and lower rates were observed below 30-cm depth. ICL system accumulated three times more SOC in the 0-30 cm layer than NT. Probably, this greater SOC accumulation in ICL system is due to greater amounts of forage root mass compared to crops like soybean, wheat, oat, which were cultivated in NT systems. SOC accumulation rates increased by 30% when SOC was assessed up to deep layers (i.e. 100 cm depth) as the result of carbon addition in deep layers by tropical forage. These results indicated that ICL system can be a better strategy to provide C mitigation in Midwestern Brazil compared to no-tillage alone.

Key Words
Global warming, C mitigation, C addition, C equivalent costs

Introduction
Soil is an important terrestrial C reservoir which plays a significant role in the global C cycle. However, use and management it may function either as a C source or sink. The increase of the soil organic matter stock can be a strategy for mitigating the potential greenhouse effect (Lal 2004). The adoption of no-tillage management systems (NT) in subtropical Brazilian soils has lead to soil organic carbon accumulation indicating that NT soils can function as an atmospheric C sink (Bayer *et al*., 2006). Nowadays, integrated crop-livestock system (ICL) has been a good alternative to practice NT in tropical soils, mainly because it can provide high C addition and permanent soil cover. However, soil carbon sequestration should consider the carbon equivalent costs relative to each management system like consumption of diesel and fertilizers (Lal 2004). The objective of this study was to evaluate C sequestration rates in NT and ICL systems in a long-term field experiment that has been carried out for 15 years in a tropical Brazilian Oxisol.

Methods
Experimental area
The study was carried out in a 15-year long-term field experiment located at Embrapa Western Region Agriculture in Dourados, MS, Brazil (24º 19’S e 54º 49’W and altitude of 430 m). Annual average temperature is about 23 ^{o}C and precipitation about 1635 mm concentrated in summer season. Soil is an Oxisol with 630 g kg^{-1} of clay, 210 g kg^{-1} of silt and 160 g kg^{-1} of sand in 0-20 cm layer. Original vegetation was Savannas constituted by grass and bush distributed randomly in the landscape. The experimental area had been previously cultivated using CT system for 20 years with annual grain production. The following management systems were tested: conventional tillage (CT) applied with heavy disk, no- till (NT) with a three-year crop rotation (rape/maize/oat/soybean/wheat/soybean) and integrated crop-livestock (ICL) with two years of cropping (oat/soybean) followed for two years of pasture (*Brachiaria decumbens*) both using NT.

Soil sampling
Four samples per plot were taken for determination of organic carbon and bulk density at 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90 and 90-100 cm depth. We used a spatula for taken samples of organic carbon and volumetric rings for bulk density. Thereafter, soil samples were air dried, ground to pass a 0.05-mm mesh and analyzed by wet combustion for measuring organic carbon concentration while soil

bulk density was determined using core method with the soil inside the core being dried to 105°C for 24 hours.

Carbon sequestration

To estimate the annual atmospheric C sequestration rate of NT and ICL systems we considered the SOC accumulation in the different soil management systems as well as the hidden C equivalent (CE) costs due to tillage operations, fertilization and pesticide use for the whole period of 15 years. CT system was taken as reference for calculation of SOC accumulation and sequestration rates. To calculate CE costs due to tillage operations we considered that each liter of consumed diesel did release 0.8 kg of C-CO_2 and each kilogram of applied N, P_2O_5 and K_2O did release 1.3, 0.2 and 0.15 kg of C-CO_2 (Lal, 2004). Pesticide use did contribute with 6.3 kg of C-CO_2 kg^{-1} of a.i. These costs were individually calculated for each management systems and taken into account to obtain the carbon sequestration rate. In this study, the carbon costs relative to fossil fuel consumed during tillage operations (26 kg CE ha^{-1} y^{-1}) were added to C sequestration rate of NT and ICL systems because it considered the amount of CO_2 that not was released to atmosphere by replacing CT to NT or ICL systems.

Results

Management systems affected the total SOC stocks between 0 to 30 cm and 0 to 100 cm layers (Table 1). The greatest SOC stocks were observed for the NT and ICL systems and the lowest ones for the CT system in both layers. Compared to the CT system, NT and ICL systems did show an SOC stocks increment of 3.2 and 10.1 Mg ha^{-1} in the 0 – 30 cm layer, respectively. In the 0-100 cm layer, these increments decreased to 2.0 Mg ha^{-1} in the NT and increased to 13.7 Mg ha^{-1} in the ICL system. These results have shown the important contribution of conservation management systems to increase SOC stocks in tropical soils as well as in temperate and subtropical soil as reported by studies of Six *et al.* (2002) and Diekow *et al.* (2005). The less oxidative environment and the physical protection mechanism imparted by the stable aggregates support SOC accumulation in soils under NT and ICL, while the mobilization of soil in CT system has lead to its exposure to microbial activity and climate effects (Conceição *et al*., 2007). The addition of forage residue and their roots in ICL system provided enough input for the accumulation of organic C in deep layers. These results are in agreement with those reported by Noble *et al*. (2008).

Table 1. Stocks and accumulation rates of carbon, equivalent costs and carbon sequestration rates in management systems in the 0-30 and 0-100 cm soil layers.

Management systems	Stocks C	C accumulation rate	C equivalent costs	C sequestration rate
	Mg ha^{-1}	---------------- Mg ha^{-1} ano^{-1} --------------		
---------------------- 0 - 30 cm -------------------------				
CT	52.1 (±11.6)	-	0.074	-
NT	55.3 (±1.0)	0.21	0.126	0.11
ICL	62.2 (±8.5)	0.67	0.033	0.66
----------------------- 0 - 100 cm ---------------------				
CT	102.1 (±15.5)	-	0.074	-
NT	104.1 (±5.9)	0.13	0.126	0.03
ICL	115.8 (±11.6)	0.92	0.033	0.91

CT = conventional tillage; NT = no- till; ICL = integrated crop-livestock.

CE costs were higher in NT systems than in the others management systems (Table 1 and 2). The reason for this was because two crops were cultivated in the NT system needed nitrogen fertilizer (maize and wheat), which had a high carbon cost that reached in a 15-year period about 806 kg C ha^{-1} y^{-1}. ICL showed the lowest CE cost due to the no need of fertilization in the pasture cycle and reduced use of pesticides and fossil fuel. In the total experimental period, the use of herbicide was reduced in the ICL system because cover straw controlled weeds. Total CE were about 126.3, 74.9 and 33.6 kg CE ha^{-1} y^{-1} for NT, CT and ICL, respectively. The great carbon costs reduced significantly C sequestration rate in NT system, which showed values lower than 0.11 Mg ha^{-1} y^{-1} (Table 1). However, ICL system reached C sequestration rates of about 0.66 and 0.91 Mg ha^{-1} y^{-1} in the 0 - 30 cm and 0 - 100 cm layers, respectively showing that this system can be a good strategy to mitigate green house effects by agriculture. The ICL system in this region contributed to mitigate about 50 Mg CO_2 ha^{-1} in 15 years.

Table 2. Carbon equivalent (CE) costs relative to consumed diesel, fertilizers and pesticides for each management system.

Input	C equivalent cost[2]	Total carbon equivalent cost		
		CT	NT	ICL
	kg CE unit^{-1}	---------- kg CE ha^{-1} y^{-1} ----------		
Fossil fuel (L)[1]	0.80			
- power harrowing		14.2	0	0
- harrow leveling		11.8	0	0
- sowing		2.6	3.0	2.3
- pesticide application		3.6	3.6	1.8
- harvest		16.0	16.0	8.0
Sub-total		***31.9***	***22.6***	***12.1***
Fertilizers				
- N (kg of N)	1.30	0	53.7	0
- P_2O_5 (kg of P_2O_5)	0.20	12.2	17.2	6.2
- K_2O (kg of K_2O)	0.15	9.2	11.2	4.7
Sub-total		***21.4***	***82.1***	***10.9***
Pesticides (kg of a.i)	6.30	21.6	21.6	10.6
TOTAL		**74.9**	**126.3**	**33.6**

[1]Based in the consumetion of diesel estimated by Portela *et al.* (1980). [2]Based in Lal (2004). CT = conventional tillage; NT = no- till; ICL = integrated crop- livestock.

Conclusion

Integrated crop-livestock systems promotes atmospheric C mitigation by reducing C costs due to tillage operations and fertilization and because it increases soil organic C accumulation in comparison to soils which are conventionally tilled. In crop- livestock systems the soil organic C accumulation occurs also in deep soil layers, affected probably by the use of tropical pasture. The balance of soil C in NT system does not necessarily result in atmospheric C mitigation because the benefits of increasing soil organic C stocks may be counterbalanced or surpassed by the C equivalent costs related to the applied N-based fertilizers.

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