SOIL ORGANIC CARBON POOLS AS AFFECTED BY TILLAGE SYSTEMS AND ORGANIC NITROGEN SOURCES

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ABSTRACT: We assessed the impact of organic N sources on total organic carbon (TOC), particulate organic carbon (POC), and mineral-associated organic carbon (MAOC) pools in a Nitisol from Southern Brazil under contrasting soil tillage systems: conventional tillage (CT) and no-tillage (NT). The tested N sources were: 140 kg N ha^{-1} (total N input) either as mineral fertilizer (urea; MIN), pig slurry (PS), anaerobically digested pig slurry (ADS) and composted pig slurry (CS), besides a control without fertilization (CTR). The TOC stocks decreased by 1.0 and 5.1 Mg C ha^{-1} after two years of CT in both 0-5 and 0-30 cm soil layers, respectively. NT increased TOC stocks by 2.3 Mg C ha^{-1} at the soil surface and decreased by 1.7 Mg C ha^{-1} at the 0-30 cm soil layer. TOC, POC, and MAOC stocks were higher in NT than the CT soil. However, POC was a more sensitive pool than MAOC in response to soil management practices. Long-term assessment of SOC pools is needed to evaluate the impacts of organic N sources on C sequestration in NT soil.

Keywords: carbon sequestration, composting, no-tillage.

INTRODUCTION

Soil organic matter (1,550 Pg C up to 1 m depth) contains about twice as much C as the earth's atmosphere (780 Pg C) and up to three times more C than vegetation (500–650 Pg C) (Smith et al., 2008). Agricultural systems can affect C exchange among these pools and be an atmospheric CO_2 source or sink depending on soil management. Intensively tilled soils have lost up to 75% of soil organic C (SOC) (Lal, 2010). However, conservation agriculture (CA) as defined as minimal soil disturbance, permanent soil cover and crop rotations is a major global initiative to promote soil quality, provide food security and promote climate change adaptation and mitigation. No-tillage (NT) provides minimum soil disturbance and thus is considered a significant component of CA. Adoption of NT and increased C inputs can rebuild depleted SOC stocks in intensive tilled soils (Fabrizzi et al., 2009). Thus, CA soils have the potential to offset 5 to 15% of the global anthropogenic greenhouse gas emissions, or 0.4 to 1.2 Gt C yr^{-1} (Lal, 2004). Soil organic C accrual accounts for 89% of the greenhouse gases (GHG) mitigation options in agriculture and has the technical potential to significantly reduce atmospheric CO_2 (Lal, 2004; 2010; Smith et al., 2008).

Nonetheless, the association of organic fertilization and CA can promote faster recovery of SOC stocks. The application of pig slurry and cattle manure in NT soils was found to promote higher SOC accumulation rates in comparison with mineral fertilizers (Mafra et al., 2014; Nicoloso et al., 2016). However, SOC accumulation also depends on the quality of organic amendment (i.e. recalcitrance). However, the application of composted organic waste yielded larger SOC recovery in relation to the soil amended with cattle manure (Nicoloso et al., 2016). Thus, modifications of organic fertilizer quality by anaerobic digestion or composting can impact SOC accumulation in soils amended with these materials. For instance, labile C forms are promptly consumed during pig slurry treatment resulting in recalcitrant C-rich organic fertilizers (Vivan et al., 2010; Angnes et al., 2013). In order to assess the impact of organic fertilizers recalcitrance on SOC stocks we assessed SOC pools in a Nitisol from Southern Brazil amended with different organic N sources under contrasting soil tillage systems.

MATERIAL AND METHODS

This study took place on a Rhodic Nitisol (FAO, 1998) located in Concordia-SC, Brazil (27º18'53"S; 51º59'25"O). The site was previously cultivated with maize and wheat crops. The clay, silt and sand contents of the 0-10 cm soil layer were 250, 460 and 290 g kg^{-1}, respectively, and the chemical characteristics as sampled in March/2012 were: pH-$H_2O_{(1:1)}$ 5.3, pH-SMP 5.8, Al^{3+} 0.3 cmol$_c$ dm^{-3}, organic matter 39.0 g kg^{-1}, $P_{Mehlich\text{-}I}$ 6.6 mg dm^{-3}, $K_{Mehlich\text{-}}$

l 249.6 mg dm^{-3}, Ca 7.5 $cmol_c$ dm^{-3}, Mg 3.3 $cmol_c$ dm^{-3}, CEC 11.9 $cmol_c$ dm^{-3} and base saturation of 68%. The local climate is humid subtropical (Cfa) based on the Köppen classification system (Embrapa, 2004). Lime was applied at the soil surface (2 Mg ha^{-1}) in order to increase pH at the 0-10 cm soil layer to 5.5 (CQFS-RS/SC, 2004).

The experiment was initiated in October/2012 and was arranged in a split-plot randomized blocks with four replications in plots with maize (*Zea mays* L.) during spring/summer and black oats (*Avena strigosa* Scherb) during autumn/winter. The tillage systems were the main plots (25 m x 10 m; W x L) and the N sources were the sub-plots (5 m x 10 m). The tillage systems were conventional tillage (CT) and no-tillage (NT). The CT consisted of disk plowing followed by offset disking in the spring and offset disking in the autumn, while NT consisted of planting directly through the crop residues with minimal soil disturbance. The disk plow and offset disking operations were performed to an average depth of 25 and 10 cm, respectively. The N sources were applied just before maize planting: 140 kg N ha^{-1} (total N input) either as mineral fertilizer (urea; MIN), pig slurry (PS), anaerobically digested pig slurry (ADS) and composted pig slurry (CS), besides a control without fertilization (CTR). The PS was collected from deep storage tanks, while the ADS was collected from an anaerobic lagoon composed of effluent from a covered lagoon biodigester (Vivan et al., 2010). The CS consisted of a mixture of pig slurry with sawdust and wood shavings composted for 150 days (Angnes et al., 2013). Mineral P and K were applied as requested in order to supply 115 kg P_2O_5 ha^{-1} and 77 kg K_2O ha^{-1} for an expected maize grain yield of 8.7 Mg ha^{-1} (CQFS-RS/SC, 2004).

Carbon inputs were determined by sampling and analyzing organic fertilizers and crop residues (aboveground and root biomass) for total organic carbon (TOC) contents by dry combustion with a C/N elemental analyzer (Flash EA 2000 Series, ThermoScientific, Waltham, MA). Maize and black oats aboveground biomass were dried at 65ºC and weighed. The maize roots biomass in the 0-5, 5-10, 10-20 and 20-30 cm soil layers was assessed in the 2013/2014 growing season and the results were extrapolated for other years. The black oats roots biomass in the 0-30 cm soil layer was estimated as 10% of aboveground biomass, considering 40% of C content. Composite soil samples were collected in the 0-5, 5-10, 10-20, and 20-30 cm soil layers using a 5 cm diameter soil probe in October of 2012 and 2014. About 2-3 subsamples were taken for one composite soil sample from each sub-plot. The undisturbed soil cores were measured and the soil layers were separated in the field to prevent contamination among soil layers. Samples were air-dried, sieved (<2 mm) and roots removed for further analysis. The particulate organic carbon (POC) and mineral-associated organic carbon (MAOC) pools were isolated as described by Cambardella and Elliott (1992). Sub-samples of the bulk soil and isolated fractions were finely grounded and analyzed for total organic carbon (TOC) content by dry combustion. The comparison of TOC, POC and MAOC pools were performed in equivalent soil masses (ESM) as described by Wendt and Hauser (2013). However, the SOC stocks in ESM are referred in the text to the 0-5 and 0-30 cm soil layers for better clarity.

Two-way analysis of variance (ANOVA) was performed to assess differences on C inputs and SOC pools considering the effects of soil tillage systems as the main plots and N sources as the subplots. We used the Fisher´s LSD test to assess the differences between soil tillage systems and N sources. Regression analysis was performed to assess the correlations between C inputs and SOC pools within soil layers. All analyses were performed by soil depth using SigmaPlot v12.5 (Systat Software, San Jose, CA). All results were considered statistically significant at $p<0.05$.

RESULTS AND DISCUSSION

No significant differences on cumulative C inputs (2 years) from maize and black oat were noticed regardless soil tillage system and fertilization treatments (Table 1). However, total C input in CS treatment was higher in relation to ADS, MIN, and CTR treatments and similar to the PS treatment. Although all fertilization treatments had the same N input (280 kg N ha^{-1}), CS had a substantially higher C content while PS promoted higher maize biomass production in relation to other treatments. Thus, total C inputs in CS, PS and ADS treatments under organic fertilization were 3.6, 2.2, and 1.5 Mg C ha^{-1} higher than the treatment under mineral fertilization (MIN) and 5.1, 3.7 and 3.0 Mg C ha^{-1} higher than the control treatment without fertilization (CTR), respectively.

The baseline TOC stocks (2012) in CT plots were 15.6 and 67.6 Mg C ha^{-1} at the 0-5 and 0-30 cm soil layers, respectively (Table 2). The baseline TOC stocks were very similar in NT plots averaging 15.8 and 70.2 Mg C ha^{-1} at the same soil layers, respectively. However, at the following assessment (2014), TOC stocks in NT were significantly higher than CT regardless of sampling layer, although no significant differences were noticed among fertilization treatments. The TOC stocks on the average of CT treatments (14.6 and 62.5 Mg C ha^{-1} for the 0-5 and 0-30cm soil layer, respectively) decreased by 1.0 and 5.1 Mg C ha^{-1} at the same soil layers between the two assessments. For the NT treatments, average TOC stocks in 2014 (18.1 and 68.5 Mg C ha^{-1} for the 0-5 and 0-30cm soil layer, respectively) increased by 2.3 Mg C ha^{-1} at the soil surface and had a slight decrease of 1.7 Mg C ha^{-1} when considering the 0-30 cm soil layer. Sá et al. (2001) also observed SOC loss at the 5-10 cm soil layer of a Ferralsol in the first years after the adoption of NT. However, long-term NT was found to promote the recovery of SOC stocks even when considering a deeper sampling layer (0-40 cm).

The POC is a labile SOC pool containing partially decomposed organic residues, while the MAOC consists of more stable and humified organic matter (Cambardella and Elliott, 1992). Both POC and MAOC stocks were higher in the NT than CT at soil surface (0-5 cm) although no differences were noticed among tillage systems at the 0-30 cm soil layer, as assessed in 2014. POC and MAOC stocks were not affected by fertilization treatment regardless of sampling layer. Although MAOC was a larger pool for SOC in this Nitisol (62-68% of TOC), the POC pool was more sensitive to changes in soil tillage system ($\Delta C = 2.6$ and 0.9 Mg C ha^{-1} for POC and MAOC, respectively, between the average of NT and CT at the 0-5 cm soil layer). We observed positive relationships between C inputs and SOC pools in the 0-5 cm soil layer of NT soil (data not shown). The slope of the adjusted linear equations which indicates the recovery of the added C as TOC, POC or MAOC was ranked as following: TOC (0.61) > POC (0.36) > MAOC (0.25). This result corroborates the larger recovery of the added C in the POC pool. When considering the 0-30 cm soil layer, no relationships were observed between C inputs and TOC and POC pools regardless of soil tillage system. MAOC had negative correlation with C inputs in NT soil (slope = -0.56), although no significant changes were observed in MAOC stocks between 2012 and 2014 (-1.1 Mg C ha^{-1}). This result indicates that the decomposition of MAOC in the subsurface soil layers (5-30 cm) was not compensated by C inputs to the same soil layer during this short evaluation period as most of C inputs to NT soil remain at the soil surface due to the lack of soil disturbance. Long-term NT is needed to stablish a flow between C inputs and SOC pools (and from POC to MAOC) to compensate the mineralization and recover SOC stocks at deeper soil layers (Sá et al., 2001).

CONCLUSION

The adoption of NT increased TOC, POC, and MAOC stocks at the soil surface (0-5 cm) in relation to the CT soil. Increased C inputs by PS and CS was positively correlated with higher recovery of TOC, POC, and MAOC in the NT soil. The POC pool was more sensitive to soil management practices than MAOC. Further assessments are necessary to assess the contribution of organic fertilizers for soil C sequestration in long-term NT soil.

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Table 1. C and N inputs in a Nitisol according to soil tillage and fertilization practices (2012-2014).

Source	Tillage	Fertilization					Mean
		CTR	MIN	PS	ADS	CS	
		---------- C input (Mg ha^{-1}) ----------					
Fertilizer	CT/NT	0.00	0.00	1.45	0.82	4.15	N/C
Maize	CT	13.08	14.05	14.91	14.07	13.03	13.82 **ns**
	NT	11.93	13.78	14.21	14.37	13.34	13.53
Black oat	CT	4.61	4.66	4.69	5.42	4.67	4.81 **ns**
	NT	4.92	5.19	5.39	5.07	5.47	5.21
Total	CT	17.69	18.71	21.05	20.31	21.85	19.92 **ns**
	NT	16.86	18.98	21.04	20.26	22.96	20.02
	Mean	17.27 **c**^{1}	18.84 **c**	21.05 **ab**	20.29 **bc**	22.41 **a**	19.97
		---------- N input (kg ha^{-1}) ----------					
Fertilizer	CT/NT	0	280	280	280	280	N/C

CTR: control without fertilization; MIN: mineral fertilization; PS: pig slurry; ADS: anaerobically digested pig slurry; CS: composted pig slurry; CT: conventional tillage; NT: no-tillage; ns: differences were not significant according to the F test ($p>0.05$); ^{1}Means followed by the same letter are not different according to the Fisher's LSD test ($p<0.05$).

Table 2. TOC, POC and MAOC pools in a Nitisol according to soil tillage and fertilization practices.

Soil Depth^{1}	Tillage	Baseline	Fertilization					Mean
			CTR	MIN	PS	ADS	CS	
cm			---------- TOC (Mg ha^{-1}) ----------					
0-5	CT	15.6	15.1	14.5	13.8	14.2	15.5	14.6 **B**^{1}
	NT	15.8	16.0	17.8	18.9	18.0	19.8	18.1 **A**
	Mean	15.7	15.5 **ns**	16.1	16.4	16.1	17.7	16.3
0-30	CT	67.6	58.2	63.6	68.9	58.5	63.3	62.5 **B**
	NT	70.2	68.6	69.9	67.7	68.9	67.1	68.5 **A**
	Mean	68.9	63.5 **ns**	66.8	68.3	63.7	65.2	65.5
			---------- POC (Mg ha^{-1}) ----------					
0-5	CT	4.7	4.9	4.9	4.4	4.7	5.6	4.9 **B**
	NT	5.1	6.3	7.1	8.1	7.5	8.4	7.5 **A**
	Mean	4.9	5.6 **ns**	6.0	6.3	6.1	7.0	6.2
0-30	CT	21.1	17.6	18.8	21.8	18.2	20.5	19.4 **ns**
	NT	19.7	20.5	23.3	22.2	23.2	22.3	22.3
	Mean	20.4	19.0 **ns**	21.0	22.0	20.7	21.4	20.8
			---------- MAOC (Mg ha^{-1}) ----------					
0-5	CT	9.2	10.1	9.6	9.3	9.5	9.9	9.7 **B**
	NT	9.9	9.7	10.7	10.8	10.4	11.4	10.6 **A**
	Mean	9.5	9.9 **ns**	10.1	10.1	10.0	10.6	10.1
0-30	CT	42.4	40.7	44.8	47.1	40.3	42.7	43.1 **ns**
	NT	47.2	48.1	46.6	45.5	45.7	44.7	46.1
	Mean	44.80	44.4 **ns**	45.7	46.3	43.0	43.7	44.6

CTR: control without fertilization; MIN: mineral fertilization; PS: pig slurry; ADS: anaerobically digested pig slurry; CS: composted pig slurry; CT: conventional tillage; NT: no-tillage; ns: differences were not significant according to the F test ($p>0.05$); ^{1}Means followed by the same letter are not different according to the Fisher's LSD test ($p<0.05$).