Effect of soil management and crop rotation on physical properties in a long term experiment in Southern Brazil

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Abstract
No-tillage system associated with crop rotation increases the amount of crop residues left as mulch on the topsoil, and can be an important and sustainable alternative for soil management in tropical and subtropical conditions. The objective of this work was to evaluate the soil physical properties affected by cover crop, rotation and soil management in a long-term experiment in South Brazil. The experimental site was cultivated for 10 years in a conventional system. Subsequently, the field experiment was established in 1986, and treatments combined six winter cover crop species, and two tillage systems (conventional tillage - CT and no-tillage - NT). The treatments were laid out using a split-plot design in three blocks. The soil samples were collected in October 2005 from trenches at six depths. The bulk density, aggregate size fractions and porosity were determined. The NT system contributed to increase the formation of coarse aggregates and improved the soil aggregation parameters. In the first upper layers, the soil disturbance due to ploughing every season, enhanced the macroporosity and diminished the microporosity on conventional system comparatively to NT. Independently of the type of soil management all winter species increased the higher aggregate size class.

Key Words
Conservation tillage, subtropical soil, sustainability, soil organic matter, cover crop.

Introduction
Soil organic matter (SOM) plays a key role in the formation and stabilization of soil aggregates (Oades 1984). Nevertheless, it was observed changes in aggregate stability following land use changes without changes in total SOM content (Puget *et al.*1999). Normally the macroaggregates are more susceptible to physical disruption because of the labile nature of binding agents (Hussain *et al*. 1999). Persistent binding agents are important in microaggregation (< 250 µm) of soil (Tisdall and Oades 1982). In the no-tillage system (NT) introducing winter crops into the rotation can enhance the soil aggregate size and stability when compared to winter fallow treatment (Calegari and Pavan 1995). Castro Filho *et al.* (2002), working during 21 years in a clay distrophic red latosol in north Paraná Brazil, found the best aggregation indices for the 0-20 cm layer in the NT system, mainly due to the increase in the organic carbon content. Biological activity, enhanced by NT (Holland 2004) plays a crucial role in aggregate stabilization. The root exudates can produce cementing agents which can strongly adsorbed to inorganic materials, thereby helping to stabilize soil aggregates (Tisdall and Oades 1982). Further, both accumulated carbon and root exudates increase soil microorganisms activity with subsequent production of microbial binding agents. Also the roots physically can influence aggregation by exerting lateral pressures inducing compaction, and by continually removing water during plant transpiration, leading to localized drying of the soil and cohesion of soil particles around the roots (Six *et al*. 1999). These effects in the soil are more important than the shoot residues left on soil surface in the formation of aggregates and stabilization of aggregate-associated SOM (Puget *et al.* 1995; Gale *et al*. 2000).

The main objective of this work is to evaluate such soil physical properties affected by cover crop rotations and soil managements NT and CT systems, after 19 years cultivating in a clayey Oxisol in South Brazil with different winter cover crop species.

Methods
The field experiment was established in 1986 in the IAPAR (Agronomic Institute) Experimental Station at Pato Branco, southwestern Paraná State, Brazil (26°7'S, 52°41'W, and 700 m altitude). Climatologically the area belongs to the sub humid tropical zone (Köeppen's Cfb) with a climate without dry season, fresh

summer and an average of hottest month lower than 22 °C. Annual rainfall average ranges from 1200 to 1500 millimeters per year. The soil of the experimental site is a clayed Oxisol acid with a high clay content (72 percent clay, 14 percent silt, and 14 percent sand), inherited from basaltic materials and thus containing kaolinite and iron oxides minerals (Costa 1996).

The experimental site was before cultivated for 10 years in a conventional system mainly with maize and bean. Experimental treatments combined six winter species, and two tillage systems, i.e. conventional tillage and no-tillage, in order to obtain a large variety of situations in term of biomass inputs and soil management. The conventional tillage consists in one disc plough and two discs harrowing two times a year before summer and winter crop planting. The winter specie treatments were blue lupin (*Lupinus angustifolius* L.), hairy vetch (*Vicia villosa* Roth), black oat (*Avena strigosa* Schreb), oilseed radish (*Raphanus sativus* L.), winter wheat (*Triticum aestivum* L.), and fallow. Except wheat the other cover crops were controlled at the flowering stage cutting with a knife roller (lupin, hairy vetch, black oats and oilseed radish) or by the application of glyphosate (fallow) some years after the knife-roller it was complemented with herbicide. After the wheat grain was harvested a mat of dead material was left on the surface of the soil as mulch or incorporated before planting the summer crop. From the winter 1986 until October 2005, the biomass production (winter species) was evaluated at the flowering stage (management time) and also the amount of summer crop residues left on the soil surface after harvesting. Summer crops of maize and soybean were planted during each year following the winter species.

Lime prepared with dolomite was applied 5 times on a total of 9.5 Mg/ha (1.0, 2.0, 3.0, 1.5 and 2.0 Mg/ha of lime in all plots, in 1989, 1992, 1995, 1999 and 2001, respectively). On the NT system the lime was broadcast on the soil surface and in the CT was incorporated by ploughing. The summer crops received chemical fertilizer every year, and the total amount of chemical fertilizer applied during 19 years were, in kg/ha: 1300 of P_2O_5, 745 of K_2O, and 425 of N for corn only. Generally the fertilizer was applied at planting time (P and K), and for N 1/3 at planting time and 2/3 at 45 days after planting of corn.

The soil samples were collected in October 2005 from trenches at six depths: 0-5, 5-10, 10-20, 20-30, 30-40, and 40-60 cm. Bulk density measurements were made on steel cylinders (5 cm diameter). Soil texture was measured by the pipette method. The soil sample was dried in the oven at 105 ºC to determine water content. The mean weight diameter (MWD), geometric mean diameter (GMD), aggregate stability index (AS%) of soil aggregate, microporosity (MIP, pores < ~50 μm), soil density, and particle density were measured. The total porosity (TP) and macroporosity (MAP) was estimated.

The treatments were laid out using a split-plot design in three blocks. The winter species were the main plots (240 m^2) and the tillage treatments were subplots (120 m^2). Also soil samples were taken in a forest on the border of the experiment just for comparing. The experiment statistical analysis considered the winter crops as a main plot, the soil management (NT and CT) are the subplot, and the soil layers the subsubplot (trifactorial) (2 soil management x 6 cropping sequence x 5 or 2 soil layers). The mean values were compared by the Test of Least Significant Differences (LSD) when the analysis of variance was significant.

Results

Plant Residues

The total amount of organic residues (winter crop, maize and soybean residues) added to the soil during the 19 years of this experimental study has been reported in Calegari *et al*. (2008). The total amount of winter crop residues was higher for no-tillage treatment compared to that of conventional tillage. Because the fallow treatment is not cultivated during the winter season, it produced fewer residues than other winter treatments in both NT and CT systems. Thus, the winter crop is the main factor that contributed to differentiate the amount of biomass introduced to the soils.

Soil bulk density

The soil bulk density values for forest were lower than 1.01 kg/dm^3 in the all soil layer sampled (Table 1). The bulk density at arable layer (0-30 cm) increased to, in average, 1.2 kg/dm^3. In the deeper soil layers assessed, the bulk density remained very close to the natural condition, even if the soil has been disturbed intensively (38 times by plough and 76 times by disc harrowing) during 19 years of cultivation. Bulk density of the soil layers is very similar between CT and NT treatments, except in 10-20 cm layer where bulk density is a little higher under conventional tillage. No significant difference can be observed between winter crop treatments.

Soil particle aggregate size distribution
In the NT system the proportion of big aggregates (> 2 mm) is higher than in CT, for both topsoil layers (0-10, 10-20 cm), and the reverse for other fractions (Table 2). Thus, the NT system is characterized with the formation of coarse aggregates and the CT with finer aggregates. There is a gradient between 0-10 and 10-20 cm in most of the aggregate size under no till, while this difference was not observed in CT. Winter crop treatments show a lower proportion of big aggregates (>2 mm) and a higher proportion of small aggregates (<0.25 mm) in fallow compared to other treatments. Thus, the winter fallow treatment, which had the lowest amount of organic residues added during the all 19 years (Calegari *et al*. 2008), is characterized by finer aggregates. No significant differences were found between winter crops.

Probably in our site, the effects of winter crop root systems, and the lack of soil disturbance during 19 years in NT contributed to promote higher soil aggregation classes (> 2.00 mm) than fallow and CT. From 13 to 24% of the soil organic carbon was considered to be physically protected against biodegradation due to its location in clay or silt sized microaggregates.

Table 1. Bulk density in clayed Oxisol of Brazil affected by soil management and crops system.

Soil management	Soil layer (cm)				
	0-10	10-20	20-30	30-40	40-60
	(kg/dm^3)				
NT	1.25aA	1.19bB	1.11bC	1.06aD	1.00aE
CT	1.24aB	1.28aA	1.17aC	1.08aD	1.02aE
* Forest	0.80	0.90	1.00	1.00	1.00

Means followed by the same lower case letters in the same column comparing soil management for each depth into the same aggregate size class , and also winter treatment into each aggregate size class, do not differ at the 5% level of probability by the *F*-test in the analysis of variance. Means followed by the same upper case letters in the same line comparing depth into each soil management into the same aggregate size class do not differ at the 5% level of probability by the *F*-test in the analysis of variance.
* Forest soil is not included in statistical analysis

Table 2. Aggregate size class distributions in clayed Oxisol in Brazil affected by soil management and crops system.

Soil layer (cm)	Soil management	Aggregate size (mm)				
		> 2.00	2.00-1.00	1.00-0.50	0.50-0.25	< 0.25
		(g/100g)				
0-10	No-tillage	39.97 aA	6.65 bB	5.28 bB	3.45 bB	4.92 bB
	Conventional	22.39 bA	12.30 aA	11.38 aA	7.23 aA	9.29 aA
	* Forest	28.37	8.78	8.93	5.24	5.81
10-20	No-tillage	36.08 aB	8.40 bA	7.37 bA	4.34 bA	4.85 bB
	Conventional	23.76 bA	11.73 aA	11.57 aA	6.59 aB	8.63 aA
	* Forest	31.05	9.05	7.77	5.47	6.07
Winter treatment						
	Fallow	27.31 b	10.18ns	9.36ns	5.82ns	8.91 a
	Vetch	31.83 a	9.88	9.03	5.38	6.08 b
	Lupin	31.31 a	9.58	8.59	5.18	6.47 b
	Radish	31.26 a	9.21	8.76	5.27	6.92 b
	Oat	31.14 a	9.98	8.74	5.23	6.41 b
	Wheat	30.45 a	9.80	8.93	5.53	6.74 b

Means followed by the same lower case letters in the same column comparing soil management for each depth into the same aggregate size class , and also winter treatment into each aggregate size class, do not differ at the 5% level of probability by the *F*-test in the analysis of variance. Means followed by the same upper case letters in the same column comparing soil layer into each soil management into the same aggregate size class do not differ at the 5% level of probability by the *F*-test in the analysis of variance.
* Forest soil is not included in statistical analysis

Soil aggregation parameters
In the two soil depths studied (0-10 and 10-20 cm), the three soil aggregation parameters (MWD, GMD and AS) enhanced under the NT system. In this system the values found for MWD and GMD were superior in the upper layer (0-10 cm) when is compared with the beneath soil layer (10-20 cm) whereas, the MWD

increased with depth in CT system where the soil and organic residues are incorporated into the soil. Values of MWD, GMD and AS were found lower in fallow compared to winter crops but no significant differences were found between winter crop species. The relative enhance promoted by NT compared with CT was of 78% for MWD, and 238% for GMD. The comparison at beneath soil layer (10-20 cm) also presented the same trend observed previously in upper layer, with 51%, for MWD, and 83%, for GMD, favorable to no-tillage. For the AS %, independent of soil depth, presented 7% higher under NT than under conventional.

Soil porosity

In the first upper layers (0-10 and 10-20 cm), the soil disturbance by plough every season, enhanced the macroporosity on conventional system compared to no-till. But at beneath layers from 20 cm to 60 cm soil depth, where there are no more effects of plough, NT presented higher macroporosity compared to CT. These differences are significant at 0-10, 20-30 and 40-60 cm soil depth. The higher values for microporosity were found on NT at the upper layers (0-10 and 10-20 cm), but below this no difference were found among the two soil management systems. The comparison among the different winter crop treatments showed no significant differences of macroporosity (despite a lower value in the fallow treatment) and a significantly higher microporosity on the oat and the fallow treatments. As a result, total porosity in NT system was lower at 0-10 cm soil depth, higher at 10-30 cm and similar at 30-60 cm, compared to CT system. Total porosity is often reduced under NT compared with CT in comparison of < 10 years; but conversely in our experiment with 19 years NT presented higher total porosity.

Conclusions

The high amount of crop residues added to the soil during the years improved the soil aggregations parameters, and NT not promoted soil compaction, and the fallow treatment presented the lowest values for MWD, GMD and also for AS%. Furthermore, under conventional system, the soil disturbance by plough every season, enhanced the macroporosity and diminished the microporosity on conventional system comparatively to no-tillage, and promoted the formation of smaller diameter classes.

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1 – 6 August 2010, Brisbane, Australia. Published on DVD.