# Soil physical properties affected by soil management and crop rotation in a long term experiment in Southern Brazil

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## Introduction

Soil organic matter (SOM) plays a key role in the formation and stabilization of soil aggregates (Oades 1984); and continual addition of crop residue increases labile SOM near the soil surface, which increases soil aggregation and has a large impact on soil structure (Lu et al., 1998). No-tillage (NT) systems have higher SOM stock and also greater and more diverse biological activity in the upper soil layers, enhancing the soil macroporosity and decreasing soil bulk density compared to conventional tillage (CT). In NT including 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), in 21 years of work on a clay distrophic red latosol in north Paraná, Brazil, found the best aggregation indices in the 0-20 cm layer in the NT system, mainly due to the increase in the organic carbon content. The main objective of this work is to evaluate such soil physical properties affected by cover crop rotations and soil management after 19 years of applying NT and CT systems with different winter species on a clayey Oxisol in South Brazil.

## Material and 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 temperature of the hottest month lower than 22 °C. Annual rainfall ranges from 1200 to 1500 millimeters. The soil at the experimental site is an acidic Oxisol acid with a high clay content (72 percent clay, 14 percent silt, and 14 percent sand), formed from basaltic materials and thus containing kaolinite and iron oxides minerals (Costa 1996). The experimental site was previously cropped for 10 years in a conventionally tilled system mainly with maize and beans. Experimental treatments combined six winter species, and two tillage systems, i.e. CT and NT, in order to obtain a large variety of situations in term of biomass inputs and soil management. Treatments were laid out in a split-plot design in three blocks, with the winter species as the main plots (240 $m^2$) and the tillage treatments as subplots (120 $m^2$). The winter crop treatments were blue lupin (*Lupinus angustifolius* L.), hairy vetch (*Vicia villosa* Roth), black oats (*Avena strigosa* Schreb), oilseed radish (*Raphanus sativus* L.), winter wheat (*Triticum aestivum* L.), and fallow. The CT consisted of one disc ploughing and two disc harrowings, both twice a year before summer and winter crop planting. All cover crops, except wheat, were terminated at the flowering stage by cutting with a knife roller (lupin, hairy vetch, black oats and oilseed radish) or killed by herbicide (fallow). In some years the knife-roller was complemented with herbicide in the cover crop plots. Except wheat, all crop residues were left on the soil surface as mulch (NT) or incorporated before planting the summer crop (CT). From winter 1986 until October 2005, the biomass production (winter species) was evaluated at the flowering stage (before termination of growth) and as well as the amount of summer crop residues left on the soil surface after harvesting. The maize and soybean were planted during each year (summer). A total of 9.5 Mg/ha dolomitic lime was applied over 5 applications (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 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: 1300 kg/ha $P_2O_5$, 745 kg/ha $K_2O$, and, in corn 425 kg/ha N for corn only. Generally P and K fertilizer was applied at planting and N was split, 1/3 at planting and 2/3 at 45 days after planting of corn. 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 using 5 cm undisturbed cores (Blake and Hartage, 1986), and soil texture using the pipette method. Soil moisture was determined gravimetrically with samples oven dried at 105 ºC (until constant soil mass weight) to determine water content. For comparison, soil samples were also taken in a forest on the border of the experiment. The experiment statistical analysis considered the soil layers as sub-sub-plots. Results were subjected to analyses of variance and means compared by Least Significant Differences (LSD) when the analysis of variance was significant.

**Results and discussion**

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 in the no-tillage treatment than in the conventional tillage plots. 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. The winter crop treatment was the major factor contributing to differences in the amount of biomass produced.
Soil bulk density in the forest soil was lower than 1.01 kg/dm$^3$ in the all soil layers sampled (Table 1). In the trial, the bulk density of the arable layer (0-30 cm) increased to, on average, 1.2 kg/dm$^3$whereas in the deeper soil layers, bulk density remained close to the natural (forest) 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 was very similar between CT and NT treatments, except in 10-20 cm layer where it was slightly higher under CT. No significant difference was observed in soil bulk density between winter crop treatments. In the NT system the proportion of large aggregates (> 2 mm) was higher than in CT in both surface layers (0-10, 10-20 cm), while the reverse was true below 20cm (Table 2).The winter fallow treatment, with lowest organic residues added during the 19 years (Calegari *et al*. 2008) had a lower proportion of large aggregates (>2 mm) and a higher proportion of small aggregates (<0.25 mm) than the other treatments. No significant differences were found in aggregate distribution between winter crops. Presumably the lack of soil disturbance and the effects of winter species root 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. The crop residues added improved soil aggregation, and no soil compaction occurred at NT, and the winter fallow showed lowest values for soil aggregate (> 2 mm) than other winter treatments. In the two soil depths (0-10 and 10-20 cm), the aggregation parameters (MWD, GMD and AS) enhanced under the NT system, and the values for MWD and GMD were higher in the upper layer (0-10 cm) than the beneath soil layer (10-20 cm) whereas, the MWD increased with depth in CT system. Values of MWD, GMD and AS were lower in fallow than winter crops but no differences among winter crop species.The NT compared with CT was superior of 78% for MWD, and 238% for GMD. At beneath soil layer (10-20 cm) presented the same trend in upper layer, with 51%, for MWD, and 83%, for GMD, favorable to no-tillage. For the AS %, independent of soil depth, was 7% higher under NT than under CT.

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## Tables

**Table 1**. The effects of soil management and cropping system on soil bulk density in an Oxisol. Pato Branco, Brazil. 2005.

| 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 |

**Table 2.** The effects of soil management and cropping system on aggregate size distribution in an Oxisol. Pato Branco, Brazil. 2005.

| 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.