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Tillage and residue mulch on physico-hydric properties of an Alfisol cultivated for sugarcane in southern Brasil.

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ABSTRACT: The rapid growth in biofuel production can bring negative impacts to the environment because of intensive land use and inadequate soil management practices. This study was conducted to evaluate the effect of tillage and residue mulch on physico-hydric properties of an Alfisol cultivated for sugarcane in southern Brazil. The experiment was a randomized complete block design with split-plot arrangement where no-tillage (NT); no-tillage + compaction (NTC); conventional tillage (CT); chiseling (Chi) constituted the main block and residue cover (with and without) as sub-plots, in three replications. Soil samples were collected from soil layers, 0-10, 10-20, 20-40 and 40-60 cm to determine soil physical and hydraulic properties. Infiltration tests were performed using double ring infiltrometers. NTC had the highest bulk density (BD) and lowest total porosity (P_t), macroporosity (Ma), saturated hydraulic conductivity (Ksat) and microporosity (Mi). In the 0-20 cm layer, BD reduced while P_t, Ma and Ksat increased due to residue mulch. However, there was no significant ($P<0.05$) interaction between tillage and residue mulch and difference in the soil properties except Ksat that differed in 20-40 and 40-60 cm layers. Infiltration was higher in tilled treatments due to lower BD and higher Pt while it was lower in mulched plots. The improved soil surface structure is an indication of crop residue retention as a strategy for mitigating soil degradation.

KEYWORDS: Compaction, mulching, soil physical and hydraulic properties, infiltration.

INTRODUCTION

Biofuels are becoming established solution to the depleting fossil fuel reserve, global energy security strategies and environmental pollution. This has led to the large-scale mechanization of sugarcane and other energy crops worldwide (Dufey & Grieg-Gran, 2010). However, the large-scale mechanization of biofuel production has increased intensity of land use, so also agricultural machinery is on increase, heavier and more sophisticated (Berisso et al., 2012), resulting in soil compaction. Compaction promotes the rearrangement of the particles in the soil matrix, which can result not only in changes in form and continuity of soil pores, but also aggravate the degradation of structure (Reichert et al., 2007; Moraru & Rusu, 2009).

Attempts have been made to reduce soil compaction and ensure food security for the populace. In this context, conservation agriculture has become a strategy to conserve soil and water resources and increase crop productivity (Zhang et al., 2011). Thus, residue management in tillage systems plays an important role in soil ecosystem functioning. However, the effectiveness and degree of changes under conservation practices on soil physico-hydraulic processes vary across different soils and agro-ecological conditions (Aziz et al., 2011). Thus, the objective of this study is to characterize the soil physico-hydric properties of a sugarcane ratoon field under different tillage methods with and without residue mulch in southern Brazil.

MATERIALS AND METHODS

Study site and climate

The experiment was conducted in a sugarcane ratoon field at the experimental station of the Department of Soils, Federal University of Santa Maria, Santa Maria, Rio Grande do Sul State, Brazil, latitude 29° 42' S, longitude 53° 48' W, and altitude of 90 meters. The climate is classified as "Cfa" by Köppen. The mean temperature of the warmest month is above 22°C, and the temperature of the coldest month is between -3°C and 18°C. Precipitation is well distributed, with annual rainfall ranging from 1300 to 1800 mm yr^{-1}. The main soil series of the study area is sandy loam, Dystrophic Paleudalf (Soil Survey Staff, 2006).

Experimental design, treatments and soil sampling

The experiment was started in 2010 in a 4 x 3 randomized complete block design (RCBD) with tillage treatments, no-tillage (NT); no-tillage + compaction (NTC); conventional tillage (CT); chiseling (Chi) in three replications. In 2011, residue mulch was introduced and the layout became 4 x 2 x 3 factorial experiment in randomized complete block design (RCBD) with split-plot arrangement where tillage constituted the main block and residue cover (with and without) were the split-plots.

Undisturbed soil samples were collected using soil cores, 57 mm in diameter and 30 mm high, from soil depths, 0-10, 10-20, 20-40 and 40-60 cm for the determination of saturated hydraulic conductivity (Ksat), bulk density (BD), total porosity (P_t), macroporosity (Ma), microporosity (Mi) and volumetric moisture content before the infiltration tests. A total of 96 samples were collected in three replicates from the four tillage treatments with or without residue cover after harvest in 2012. For organic matter, granulometric analysis and textural classification (Table 1), another set of disturbed samples were collected. The soil samples were stored in sealed plastic cans, transported to the laboratory and analyzed using Embrapa (1997) procedures.

Infiltration test

Infiltration tests were conducted using double ring infiltrometers (Bouwer, 1986), 20 and 40 cm diameter for the inner and outer rings, respectively. The initial and steady-state sorptivity of Philip equation, were obtained using the equations derived by Amer (2012). Cumulative infiltration, initial and steady-state infiltration rates were determined at the beginning and end of the tests, respectively.

Statistical analysis

Data was subject to analysis of variance (ANOVA) test for comparison of means. Means were separated using Tukey test at 5% probability level with the aid of statistical package (SAS, 1999).

Results and Discussion

Results

Bulk density

Tillage and residue mulch did not significantly ($P<0.05$) affect BD. The BD ranged from 1.51 to 1.76 g cm^{-3} and there was an increase in BD in the soil profile down to the 40 cm depth, indicating compacted layers after the 10 cm depth (Table 2). The highest values were obtained in NTC plots and in the 20-40 cm layer. However, the BD values in the 0-20 cm layer were slightly lower in the mulched plots compared to the no-mulch treatments.

Table 1. Some soil physical properties and texture of the sugarcane ratoon field.

Soil Depth, cm	OM g kg^{-1}	Sand	Silt	Clay	Texture
		------------ g kg^{-1}	-------------		
0-10	14	666	235	98	SL
10-20	13	653	244	102	SL
20-40	12	625	271	104	SL
40-60	10	621	273	106	SL

OM: organic matter; P: phosphorus; K: potassium; Ca: calcium SL: sandy loam.

Porosity

The effect of tillage and residue mulch on total porosity, macroporosity and microporosity was not significant. P_t was highest (0.37 cm^3 cm^{-3}) in Chi in the surface layer while it was lowest (0.29 cm^3 cm^{-3}) in NTC in the compacted layers (Table 2). Similarly, Pt was slightly higher in mulched plots in the 0-20 cm layer compared to no-mulch treatments. The Ma ranged from 0.04 to 0.12 cm^3 cm^{-3}, the highest in Chi plots. Mulched treatments gave slightly higher Ma in the 0-10 and 10-20 cm layers, while it was slightly higher in no-mulch plots in sub-soil layers (Table 2).

The highest Mi, 0.26 cm^3 cm^{-3}, was recorded in NT treatments and while the lowest value, 0.22 cm^3 cm^{-3}, was obtained from Chi plots. Mi was slightly lower in mulched plots also in the surface soil layers (Table 2).

Saturated hydraulic conductivity

Saturated hydraulic conductivity was not significantly affected by tillage treatments in the 0-10 and 10-20 cm soil layers but was significant in the 20-40 and 40-60 cm soil layers. Ksat ranged between 0.48 and 17.99 cm hr^{-1}, the tilled plots having higher values in the surface layer and was least in 20-40 cm where the BD was highest. Residue mulch had no significant ($P<0.05$) effect on Ksat, however, it was higher in mulched plots up to the 40 cm layers while it was higher in no-mulched treatments in the 40-60 cm layers (Table 2).

Infiltration

At the beginning of infiltration (unsaturated condition), the initial sorptivity, S_i, ranged from 0.15 to 0.59 cm/min$^{0.5}$ in the different tillage treatments, the highest value from no-mulch CT plots (Table 3). After a relatively long time of infiltration, the steady state, S_s, ranged between 0.018 and 0.061 cm/min$^{0.5}$, representing about 90 % reduction. At the end of infiltration, the accumulated infiltration was highest (9.59 cm) in mulched NT treatments and lowest (1.54 cm) in no-mulch NT plots. At the onset of infiltration, the initial infiltration rate ranged between 16.23 and 32.49 cm/hr, the highest from NT+M (no-tilled with residue mulch) while the least was for the NTC+M. The final infiltration rate was between 0.18 and 3.56 cm/hr, the greatest value from Chi plots and the least for the NT treatments.

Table 3. Initial moisture content and infiltration characteristics of the sugarcane ratoon field.

Trt	θ_i %	S_i	S_s --cm $min^{-0.5}$--	I cm	i_0	i_f ---cm hr^{-1}----
NTCM	25.90	0.37	0.039	3.86	16.23	1.11
NTC	23.40	0.37	0.037	4.22	21.01	1.08
ChiM	23.90	0.37	0.029	7.84	23.01	2.53
Chi	21.40	0.51	0.051	9.44	25.75	3.56
CTM	25.00	0.34	0.032	4.86	18.95	1.44
CT	21.00	0.59	0.061	8.89	23.01	2.89
NTM	25.60	0.47	0.044	9.59	32.49	2.98
NT	23.90	0.15	0.018	1.54	18.28	0.18

NTCM, NTC: no tillage + compaction with and without residue cover, respectively; ChiM, Chi: chisel tillage with and without residue cover, respectively; CTM, CT: conventional tillage with and without residue cover, respectively; NTM, NT: no tillage with and without residue cover, respectively; θ_i: initial moisture content; S_i: initial sorptivity ($S_i = m^{0.5}/ \alpha$); S_s: steady state sorptivity (S_s = I(1- α)/$t^{-0.5}$) Amer (2012); t: time to reach steady state infiltration; I: cumulative infiltration; i_0: initial infiltration rate; i_f: final infiltration rate, m & α are parameters of Kostiakov equation.

Discussion

Tillage and crop residue mulching can significant affect soil structural conditions and influence soil physico-hydraulic processes. Higher BD in NTC and lower values in CT, were also reported by Fontanela (2012) in the same experiment. The high BD obtained in the subsurface layers showed the effect of continuous compaction on this soil. Although the average BD values in almost all the tillage treatments were less than the 1.75 g cm^{-3} considered critical to root growth (Reinert et al., 2008), the increase in BD in the subsurface layers shows the disappearance of mobilization effect of tillage and soil reconsolidation due to alternate drying and wetting cycles, machine traffic during planting and harvest and raindrop impact. The reduced BD in the surface layers may be attributed to added organic matter, which may have increased aggregation and enhanced biological activity by the residue mulch.

Total porosity and Ma were at par or slightly increased in the surface layer while they were reduced in the compacted layers in all the treatments during the second year of evaluation, compared with the results of Fontanela (2012). Ma was near or slightly above the 0.10 cm^3 cm^{-3} considered minimum for root development (Drewry et al., 2008) in the surface layer, however, it was generally below the limit in the compacted layers. The increased porosity (P_t and Ma) in the surface layer was a result of the reduced BD as an inverse relationship exists between BD and P_t and Ma while the reduced P_t and Ma in the subsurface layers is attributed to increased BD by compaction. The Mi values were generally reduced compared to those obtained by Fontanela (2012), indicating the soil may store less water.

The Ksat increased in the second year of evaluation. The higher Ksat obtained in the tilled plots and in the surface layer is attributed to reduced BD and higher porosity. Also the higher values from the mulched plots may be as a result of increased soil aggregation by residue mulch. According to Reichert et al (2007), Ksat is dynamic property governed by the degree of compaction, quantity and continuity of pores, any measure that increase the BD leads to reduced Pt and volume of macropores responsible for conducting water and air.

The higher infiltration characteristics obtained in tilled plots may be attributed to lower BD and higher total porosity and hydraulic conductivity, especially in the surface layers. This is in line with the results reported by Netto and Fernandes (2005) who obtained higher infiltration characteristics in CT than NT and attributed it to soil loosening, reduced BD and higher macropore volume. The infiltration characteristics were higher in plots without residue cover. This may be due to the higher sorptive forces and lower initial soil moisture condition before the infiltration tests since drier soils suck more water. The higher moisture content in mulched plots shows the importance of residue mulch in soil and water conservation. This corroborates the results of Amer (2012).

The non-significant effect of tillage and residue mulch may be due to the relative short period of evaluation after the imposition of the various treatments, indicating more time is required if there would be.

CONCLUSIONS

Bulk density decreased in the surface layer in the second year but increased in the subsurface layers and was highest in compacted no-till treatments, indicating increased compaction.

Total porosity and macroporosity increased in the surface layers in all the tillage treatments but decreased in the compacted layers whereas microporosity decreased in all the tillage plots and soil layers.

Saturated hydraulic conductivity was higher in tilled plots especially in the surface layers.

Infiltration was higher in tilled treatments and lower in mulched plots.

The improved soil surface physical quality attributes is an indication of crop residue retention as a strategy for mitigating soil degradation.

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Table 2. Soil physical and hydraulic properties in the sugarcane ratoon field.

Trt	Soil layer, cm 0-10	10-20	20-40	40-60
	Bulk density, g cm^{-3}			
NTC	1.64a[1]	1.72a	1.76a	1.66a
NT	1.59a	1.67a	1.68a	1.60a
CT	1.54a	1.64a	1.73a	1.67a
Chi	1.51a	1.67a	1.65a	1.62a
M	1.50a	1.67a	1.71a	1.65a
NM	1.59a	1.68a	1.70a	1.63a
T x M	ns	ns	ns	ns
LSD_T	0.1863	0.3223	0.1074	0.1340
	Total porosity, cm^3 cm^{-3}			
NTC	0.33a	0.29a	0.29a	0.31a
NT	0.35a	0.29a	0.30a	0.33a
CT	0.36a	0.33a	0.29a	0.31a
Chi	0.37a	0.29a	0.30a	0.32a
M	0.35a	0.31a	0.29a	0.32a
NM	0.35a	0.30a	0.29a	0.32a
T x M	ns	ns	ns	ns
LSD_T	0.056	0.138	0.049	0.031
	Macroporosity, cm^3 cm^{-3}			
NTC	0.09a	0.05a	0.04a	0.09a
NT	0.09a	0.05a	0.06a	0.11a
CT	0.11a	0.06a	0.05a	0.08a
Chi	0.12a	0.07a	0.06a	0.10a
M	0.11a	0.07a	0.05a	0.09a
NM	0.09a	0.04a	0.06a	0.11a
T xM	ns	ns	ns	ns
LSD_T	0.107	0.072	0.047	0.035
	Microporosity, cm^3 cm^{-3}			
NTC	0.24a	0.24a	0.24a	0.22a
NT	0.26a	0.24a	0.24a	0.22a
CT	0.25a	0.27a	0.24a	0.23a
Chi	0.26a	0.22a	0.24a	0.22a
M	0.25a	0.24a	0.24a	0.23a
NM	0.26a	0.26a	0.24a	0.21a
T x M	ns	ns	ns	ns
LSD_T	0.057	0.078	0.015	0.020
	Saturated hydraulic conductivity, cm hr^{-1}			
NTC	4.03a	9.06a	0.84ab	0.74b
NT	11.48a	16.06a	0.87ab	3.22a
CT	17.99a	2.48a	0.48b	1.39ab
Chi	17.27a	8.78a	3.01a	1.89ab
M	13.95a	9.79a	1.95a	1.17a
NM	11.43a	8.40a	0.65a	2.45a
T x M	ns	ns	ns	Ns
LSD_T 5%	1.107	1.552	0.410	0.552

Trt: treatments; NTC: no tillage + compaction; NT: no tillage; CT: conventional tillage; Chi: chisel tillage; T: tillage; M: residue mulch; NM: no-mulch; LSD_T: least significant difference of the tillage treatments at 5% probability level. [1]Treatment means followed by the same letter in the column differ by Tukey test at the 5% significance level.