Soils and Plant Nutrition | Research Article

DOI: http://dx.doi.org/10.1590/1678-992X-2016-0219

Scientia Agricola

ISSN 1678-992X

Compressibility and water availability in Albaqualf soils under different deployment times in no-tillage

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Edited by: Axel Garcia y Garcia

Received June 04, 2016
Accepted July 13, 2017

ABSTRACT: The southern Brazilian lowlands have been historically used for flooded rice cultivation. Over time, heavy machinery and intensive tillage practices have resulted in soil structure disruption, soil compaction, higher production costs and lower agricultural profitability. This study aimed to evaluate the effect of different deployment times of no-tillage (NT). Soil properties including bulk density (BD), compression index (CI), preconsolidation pressure (σp), bulk density at preconsolidation pressure (BDσp), degree of compactness (DC), soil water retention curve (SWRC), plant available water (PAW) and total organic carbon (TOC) content were evaluated using a 30-yr non-cultivated field (NC), adjacent to the experimental plots as a control. The BD, σp, BDσp and DC decreased in response to NT adoption time while the soil water holding capacity increased, allowing for higher PAW. Results from this study demonstrated the positive effects of NT on the overall quality of soils.

Keywords: lowlands, preconsolidation pressure, degree of compactness, organic carbon

Introduction

In Brazil, the Pampa biome is located in the state of Rio Grande do Sul (RS), represented by 5.4 million hectares, the majority of which are Albaqualf soils. These areas are mainly cultivated with flooded rice (*Oryza sativa* L.); thus, most are levelled (Streck et al., 2008; Parfitt et al., 2014).

Although land levelling and flooding favor rice cultivation, such practices affect the soil structure, turning it into a plastic consistency when wet and hard or very hard when dry. Sequential ploughing and intense heavy machinery traffic due to conventional tillage (CT) have progressively reduced the total organic carbon content (TOC) of these soils (Tran Ba et al., 2016; Crittenden et al., 2015). Moreover, the total pore volume, the macropores and the larger aggregates are degraded, increasing bulk density (BD) and creating compacted layers that reduce water availability and agricultural productivity (Bajpai and Tripathi, 2000; Kechavarzi et al., 2010; Parfitt et al., 2014; Moraes et al., 2016; Singh et al., 2016).

Cropping practices that minimize soil disturbance, and favor the maintenance of cover crop succession and rotation are well known for their capacity to promote the quality of well-drained soils (Aziz et al., 2013; Crittenden et al., 2015). Despite the recent expansion of rainfed crops in the lowlands of the Pampa biome in southern Brazil, science-based information about the effects of no-tillage (NT) on soil physical properties is still limited. The hypothesis in this study was that increased deployment time of NT improves the physical quality of lowland soil, reduces soil compaction, and promotes the availability of soil water.

Thus, the objective of this study was to evaluate the effects of different NT deployment times on the compressibility and water properties of soil in different layers of an Albaqualf from southern Brazil.

Materials and Methods

This study was carried out in the city of Capão do Leão, in the state of Rio Grande do Sul (31°49′04,13″ S, 52°27′53,77″ W, 14 m above sea level), Brazil. The climate, classified as *Cfa*, according to Köppen's classification (Alvares et al., 2013), is characterized as hot mesothermal with the coldest average monthly temperatures ranging from 3 °C to 18 °C. The minimum average monthly rainfall is 60 mm. Thus, most of the time it is humid, and the average temperature of the hottest month is 22 °C. The soil was classified as an Albaqualf (NRCS, 2010) comprising 460 g kg^{-1} of sand, 370 g kg^{-1} of silt and 170 g kg^{-1} of clay in the top 0.2 m of the soil.

The surface soil layer in four experimental plots that were historically managed under CT was homogenized before NT deployment through chisel ploughing and corrected for pH with dolomitic limestone using disc harrows. Next, different cover crops (Table 1) were established, using 300 kg ha^{-1} of mineral fertilizer (N-P-K: 2-20-20) for summer crops, and 300 kg ha^{-1} of 5-20-20 (base fertilization) and 100 kg ha^{-1} of N-urea (cover fertilization) for summer and winter grasses. Furthermore, spontaneous plants were not fertilized.

This study consisted of five treatments, four NT [one (NT1), three (NT3), five (NT5) and seven (NT7) years under no-till] and a control treatment comprising a 30-yr non-cultivated (NC) field located near the no-till treatments.

Soil samples were collected from the following depths: 0.00 to 0.03; 0.03 to 0.06; 0.06 to 0.10 and 0.10 to 0.20 m soil layers. The sampled layers were based on their susceptibility to physical and hydric changes that originated from the tillage and the root system activity of cultivated crops over time.

A total of 240 soil samples (three samples/layer × four layers × four replications × five treatments) of un-

Table 1 – Crop sequence cultivated in an Albaqualf soil under different deployment times of no-tillage (NT).

Deployment times of NT*	Agricultural year						
	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
NT1	...	...	...	...	...	Ma	Wh + Ma
NT3	...	...	...	Ma	Rg + Sp + Sb	Wh + Sb	Wh + Sb
NT5	...	Ma	Rg + Sp + Sb	Wh + Sg	Rg + Sp + Sb	Wh + Sb	Rg + Sp + Sb
NT7	Sb + Wh	Ma	Wh + Sf	Wh + Ma	Rg + Sp + Sg	Rg + Sp + Sb	Rg + Sp + Sb

*NT1 = one; NT3: three; NT5: five; and NT7 = seven years of no-tillage (NT) deployment, respectively; Ma = mayze (Zea mays L.); Wh = Wheat (Triticum aestivum L); Rg = ryegrass (Lolium multiflorum); Sp = plant of spontaneous development; Sb = soybean (Glycine max (L). Merr); Sg = sorghum (Sorghum bicolor (L.) Moench); Sf = sunflower (Helianthus annuus).

disturbed structure were collected with steel cylinders 0.05 m in internal diameter and 0.03 m in height. To determine compressive parameters, the samples were saturated with water by capillarity during 48 h and then equilibrated at a matric potential (Ψ_m) of 10 kPa using a Richard's pressure chamber (Klute, 1986). After equilibrium, each sample was weighed and subjected to a uniaxial compression test utilizing an automatic consolidometer, while successively applying static pressures of 25, 50, 100, 200, 400, 800 and 1,600 kPa (Krümmelbein et al., 2010).

The soil compression curves were obtained by relating the applied pressure (x-axis, $\log_{10}$) *versus* the BD (y-axis), which also allowed for obtaining the compression index (CI) and the preconsolidation pressure (σp) (Dias Junior and Pierce, 1995). In order to exclude the effect of initial soil compaction, data were normalized by dividing the BD after each applied load by the initial bulk density (Kondo and Dias Junior, 1999).

The soil degree of compactness (DC) was calculated using the bulk density at the preconsolidation pressure (BDσp) and 1.600 kPa, defining the DCσp and DC1.600 respectively (Reichert et al., 2009).

In the laboratory, samples presenting undisturbed structure were saturated by capillarity for 48 h (Ψm = 0 kPa) and weighed. Then tensions of 1 and 6 kPa were applied on a tension table, and 10, 100 and 300 kPa in a Richards pressure chamber (Klute, 1986). Additionally, disturbed samples were utilized to determine the water content at Ψ_m > 300 kPa, using a Dewpoint Potential Meter.

The adjustment of experimental data to obtain the soil water retention curves (SWRC) was performed through the combination of three methods: tension table, Richards pressure plate, and dew point method (Schelle et al., 2013) using the MathCad software support program. The experimental data of Ψm (kPa) versus volumetric water content (θ, m3 m^{-3}) were adjusted using the van Genuchten model (van Genuchten, 1980) to obtain SWRC fitted parameters, according to Equation 1 as follows:

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + \left(\alpha \left|\Psi_m\right|\right)^n\right]^m} \quad (1)$$

where θ (m^3 m^{-3}) is the volumetric water content at Ψ_m; θ_r (m^3 m^{-3}) the residual volumetric water content; θ_s (m^3 m^{-3}) the soil moisture at saturated condition; and α, n, and m are dimensionless and empirically fitting parameters, which depend on the SWRC shape and consider the dependence between the parameters m and n:$(m = 1-1/n)$ (Mualem, 1976). The initial van Genuchten parameters θ_r, θ_s, α, and n were obtained from Carsel and Parrish (1988), and consider the soil textural class.

Water content at field capacity (θ_{FC}) and at the permanent wilting point (θ_{PWP}) were considered as the adjusted volumetric water content at Ψm of 10 and 1.500 kPa, respectively. The plant available water (PAW) was calculated as the difference between the θ_{FC} and θ_{PWP} (Reynolds et al., 2007).

Disturbed soil samples were collected from each plot within each NT and within the NC, totaling 80 samples (four layers × four replicates × five treatments). In the laboratory, these samples were manually fragmented into their weakness planes and were air-dried to determine the total soil organic carbon content (TOC) by dry combustion, using a Perkin Elmer elemental analyzer.

The normal distribution of data sets was verified by applying the Shapiro-Wilk test (W) ($n \leq 200$) (Razalli and Wah, 2011). Outliers beyond the lower and upper range limits (LL and UL) were identified and excluded, while considering the first quartile (Q1), the third quartile (Q3) and 1.5 interquartile range.

The percentage of variation (Δref, %), calculated for the evaluated variables in the plots of each treatment, indicating the increase (+) or reduction (-) in relation to NC, was utilized. Each soil property was submitted to analysis of variance (ANOVA) and NC was considered in this analysis just as a reference area. When the mean values of NT were significant, they were compared by Duncan test (p < 0.05). Moreover, by using regressive models and Pearson's coefficient of correlation (r) (p < 0.05), the relationships between the soil properties were verified utilizing, respectively, the PROC ANOVA, PROC NLIN and PROC CORR in SAS (Statistical Analyses System Institute, version 9.2).

Results and Discussion

The soil compression curves (Figure 1) showed high BD values for NT1, followed by NT3 in 0.00 to

0.03; 0.03 to 0.06 and 0.06 to 0.10 m soil layers, differing in the 0.10 to 0.20 m soil layer, where NT3 presented the highest BD.

These results were caused by the loss of structure due to consecutive soil disturbances, land levelling and flooding which occurred in the plots before NT establishment. Moreover, the lowlands showed adverse drainage conditions, therefore, tillage under high soil moisture conditions, favored clay orientation and increased BD and soil compaction (Lima et al., 2009).

Associated with tillage operations during wet conditions, intensive soil disturbance also promotes the aggregate destruction and exposure of organic matter (OM) to oxidation, which, similar to wetting-drying cycles, increases the BD (Lima et al., 2009; Pedrotti et al., 2005; Zhang et al., 2013; Pires et al., 2008).

Considering soils with approximately 20 % of clay content (the studied soil is close to this condition), 1.84 Mg m^{-3} was chosen as the BD threshold for non-restrictive plant growth (Reichert et al., 2009). Therefore, only in the 0.00 to 0.03 m soil layer did the NT present unrestrictive conditions, while the NT1 and NT3 showed values critical to plant growth (Figure 2), configuring soil compaction, reduced porosity and vertical restriction of soil water movement.

The reduction of BD values as a function of the increase in deployment time of NT fit well to a quadratic model in the surface soil layer (0.00-0.03 m) while the following layers showed a linear pattern (Figure 2). The reduction of BD in the 0.00-0.03 m soil layer was limited during the first three years (NT1 to NT3). On the other hand, the reduction of BD from NT3 to NT7 was intense, showing the positive effect of NT on topsoil compaction after 3 years of NT adoption.

The reduction of BD could be related to the superficial addition of OM (Duval et al., 2013), and also to the intense root activity and the control of machinery traffic. Crop successions under NT promote root diversity across soil layers, creating a continuous process of OM allocation in deeper soil layers.

The CI in NT7 (Table 2) was ~10 % lower than in the NC in the 0.00 to 0.03 m soil layer, whereas CI in NT5, NT3, and NT1 was ~26 %, ~26 %, and ~18 % lower, respectively. In the 0.03 to 0.06 m soil layer, the susceptibility to degradation between NT7 and NC was similar, representing an improvement due to higher deployment time of NT, while NT5, NT3 and NT1 was ~16 %, ~12 % and ~6 % lower than that from NC. Similar results were found at 0.06 to 0.10 and 0.10 to 0.20 m (Table 2).

The high CI in the 0.00 to 0.03 and 0.03 to 0.06 soil layers for NT7 revealed that higher deployment time of NT resulted in a CI level that was closer to those observed in the NC plot, when compared to other NT deployment times. Likewise, the lower σp showed that the higher deployment time of NT also mitigated the loss of soil structure promoted by CT in the past, thus increasing the CI of these areas.

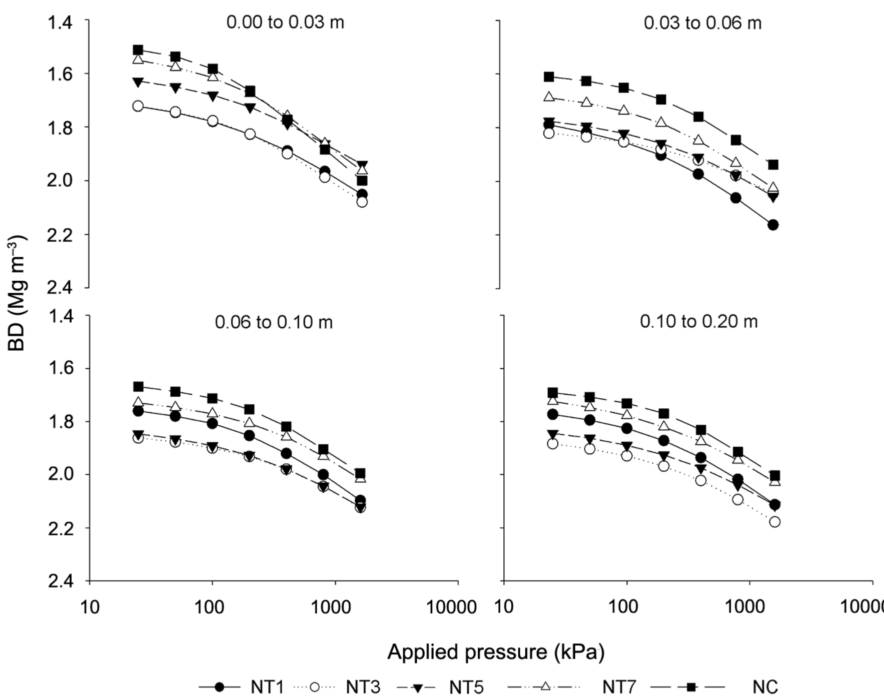

Figure 1 – Normalized soil compression curves, (Bulk density as a function of applied pressure) of an Albaqualf soil under different deployment times of no-tillage (NT) and non-cultivated field (NC) in different soil layers; NT1 = one; NT3 = three; NT5 = five; and NT7 = seven years of no-tillage deployment, respectively.

Table 2 – Mean compression index (CI, dimensionless), pre-consolidation pressure (σp), bulk density at pre-consolidation pressure (BDσp), degree of compactness at pre-consolidation pressure (DCσp) and at 1.600 (DC1.600), and standard errors of an Albaqualf soil under different deployment times in no-tillage (NT) compared with a non-cultivated field (Δref) at different soil layers.

Deployment times of NT*	CI	Δref	σ_p	Δref	BDσp	Δref	DCσp	Δref	DC1600	Δref
		%	kPa	%	Mg m^{-3}	%				
				0.00 to 0.03 m						
NT1	0.31 ± 0.01 ab	-18.4	221.7 ± 14.77 a	72.8	1.80 ± 0.03 a	16.9	90.44 ± 1.41 a	-0.6	78.42 ± 1.44 a	6.7
NT3	0.28 ± 0.01 b	-26.3	215.7 ± 11.54 a	68.1	1.82 ± 0.05 a	18.2	90.50 ± 1.30 a	-0.6	79.10 ± 2.38 a	7.6
NT5	0.28 ± 0.02 b	-26.3	195.3 ± 11.78 ab	52.2	1.68 ± 0.04 b	9.1	92.32 ± 0.98 a	1.4	81.42 ± 1.09 a	10.7
NT7	0.34 ± 0.03 a	-10.5	171.0 ± 11.62 b	33.3	1.61 ± 0.03 b	4.5	89.98 ± 1.25 a	-1.1	76.37 ± 1.47 a	3.9
NC	0.38 ± 0.02		128.3 ± 14.81		1.54 ± 0.03		91.01 ± 0.96		73.52 ± 1.51	
				0.03 to 0.06 m						
NT1	0.29 ± 0.01 ab	-6.5	237.0 ± 10.78 ab	32.3	1.85 ± 0.07 a	11.4	86.42 ± 2.64 b	-4.8	75.30 ± 2.90 b	-2.8
NT3	0.27 ± 0.01 bc	-12.9	251.3 ± 12.84 a	40.2	1.90 ± 0.04 a	14.5	91.94 ± 1.05 a	1.3	82.30 ± 1.13 a	6.2
NT5	0.26 ± 0.01 c	-16.1	198.5 ± 19.64 bc	10.8	1.82 ± 0.05 a	9.6	90.95 ± 0.98 ab	0.2	78.75 ± 1.22 ab	1.7
NT7	0.31 ± 0.01 a	0.0	182.2 ± 12.40 c	1.7	1.74 ± 0.04 a	4.8	88.74 ± 1.63 ab	-2.2	74.44 ± 2.47 b	-3.9
NC	0.31 ± 0.01		179.2 ± 7.85		1.66 ± 0.02		90.74 ± 1.48		77.47 ± 1.65	
				0.06 to 0.10 m						
NT1	0.31 ± 0.01 a	3.3	247.6 ± 16.81 a	62.3	1.85 ± 0.05 ab	7.6	88.38 ± 1.29 a	-5.4	76.84 ± 1.56 b	-0.7
NT3	0.26 ± 0.01 b	-13.3	255.0 ± 12.96 a	67.1	1.91 ± 0.03 a	11.0	88.62 ± 2.46 a	-5.1	81.33 ± 2.16 ab	5.1
NT5	0.26 ± 0.01 b	-13.3	224.8 ± 7.10 a	47.3	1.91 ± 0.04 a	11.0	91.48 ± 0.75 a	-2.1	82.47 ± 0.93 a	6.6
NT7	0.28 ± 0.01 ab	-6.7	225.8 ± 14.08 a	48.0	1.79 ± 0.02 b	4.1	91.22 ± 1.16 a	-2.4	80.53 ± 1.34 ab	4.1
NC	0.30 ± 0.02		152.6 ± 9.14		1.72 ± 0.04		93.43 ± 1.51		77.39 ± 1.65	
				0.10 to 0.20 m						
NT1	0.30 ± 0.01 a	0.0	261.8 ± 14.62 a	47.0	1.81 ± 0.02 bc	3.4	90.09 ± 1.44 a	-0.1	77.40 ± 1.58 b	-1.9
NT3	0.28 ± 0.01 ab	-6.7	252.5 ± 15.64 ab	41.8	1.94 ± 0.04 a	10.9	90.92 ± 0.81 a	0.9	81.63 ± 1.00 a	3.4
NT5	0.25 ± 0.01 b	-16.7	221.2 ± 8.24 bbc	24.2	1.90 ± 0.04 ab	8.6	90.45 ± 1.16 a	0.3	81.85 ± 1.32 a	3.7
NT7	0.28 ± 0.01 ab	-6.7	207.4 ± 7.63 c	16.5	1.78 ± 0.04 c	1.7	91.01 ± 1.18 a	1.0	79.68 ± 1.54 ab	1.0
NC	0.30 ± 0.01		178.1 ± 12.94		1.75 ± 0.03		90.14 ± 1.27		78.91 ± 1.09	

*NT1 = one; NT3 = three; NT5 = five; and NT7 = seven years of no-tillage (NT) deployment, respectively; NC = non-cultivated field; Means with standard errors followed by the same letter within the same column are not significantly different, according to the Duncan test at 5 %.

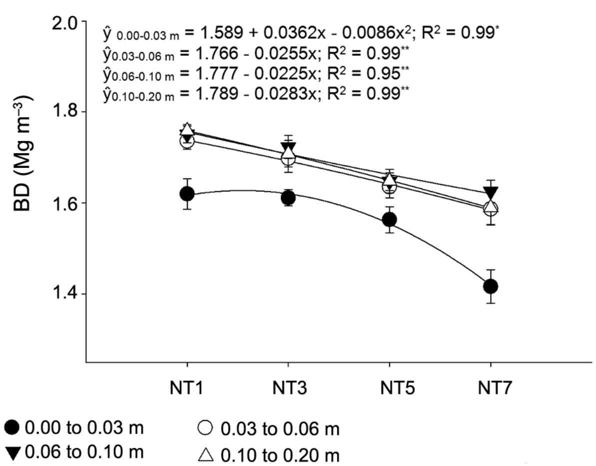

Figure 2 – Bulk density (BD) of an Albaqualf soil under different deployment times of no-tillage (NT) in different soil layers. Vertical bars represent mean standard deviation; ns: non-significant difference; *,** significantly different at 5 % and at 1 %, respectively. NT1 = one; NT3 = three; NT5 = five; and NT7 = seven years of no-tillage (NT) deployment, respectively.

Our findings (Table 2) are in agreement with those reported by Vogelmann et al. (2012) who found that NT with additional traffic (traffic intensity of 24,67 Mg km ha^{-1}) increased the BD and σp in the top 0.10 m soil layer, while NT caused the lowest load support capacity and greater susceptibility to compaction.

However, lower CI suggests higher σp, especially due to a history of pressures on the soil, reducing susceptibility to compaction. On the other hand, higher susceptibility to compaction reduces the soil load support capacity and, therefore, it will limit machinery traffic in humid soil conditions.

The σp values decreased when NT is consolidated (Table 2), but increased with soil depth. The σp observed in NT1 was ~72 % greater than those verified in NC, whereas the observed value in NT7 was only ~33 % greater, suggesting a historical of higher pressures on NT1. Furthermore, the reduction in σp demonstrates that compaction can be mitigated with conservation tillage systems, especially when sufficient amount of OM is added to the soil.

Evaluating the effect of deployment times of NT in a subtropical Hapludox, Reichert et al. (2016) considered

NT with 5 years as in transition, and with 14 years as in a stabilized phase. According to these authors, soon after NT adoption, physical conditions were poorer than in consolidated NT, which were evidenced by the reduction of σp and DC, confirming the results obtained in this study. Nevertheless, a study conducted by Reichert et al. (2016) suggested that CI decreased with NT deployment time was mainly due to processes related with soil aggregation after 14 years of NT implementation.

The BDσp in NT1 were ~16 % (0.00 to 0.03 m), ~11 % (0.03 to 0.06 m), ~7 % (0.06 to 0.10 m), and ~3 % (0.10 to 0.20 m) greater than in NC, suggesting degradation of soil structure prior to NT (Table 2). Furthermore, DCσp in the top 0.03 m soil layer was higher in NT5 (+1.4) than in NC (Table 2), a result similar to the 0.03 to 0.06 m soil layer (+0.2), while in the 0.10 to 0.20 m layer of the NT7 DCσp was 1 % higher than NC, thus suggesting improvements in soil physical conditions.

Lower BDσp in the top 0.03 m soil layer (1.61 Mg m^{-3} for NT7) suggested that external pressures should be avoided to prevent irreversible soil compaction. The results for BDσp varied from 1.61 to 1.94 Mg m^{-3} (Table 2), and support those obtained by Reichert et al. (2009). The mean BDσp (1.82 Mg m^{-3}) also corroborates these authors as a limit to adequate plant growth and development, evidencing the ability of NT to mitigate soil compaction.

The mean DCσp were different between NT treatments only in the 0.03-0.06 m soil layer. No trends with the NT deployment time were obvious. In addition, DC1.600 showed significant differences in the 0.03 to 0.06, 0.06 to 0.10 and 0.10 to 0.20 m soil layers (Table 2) and were generally higher than NC.

Differences in DC1.600 in the 0.06 to 0.20 m soil layer indicate an effect of applied loads on the soil that cannot be observed when considering DCσp. However, BDσp, representing the critical limit of BD where the soil is consolidated, was sufficient to warrant disregarding the differences observed in DC1.600. Under this condition, the soil would have to be highly compacted to support plant growth.

The shape of the SWRC that reflects soil structure changes belongs to the wetter part, whereas soil texture and clay mineralogy characteristics affect the drier part. While no-tillage creates biopores and increases pore volume at near-saturation in the saturated region of SWRC, CT destroys soil structure, reversing the no-till benefit. Considering the water content in a saturated condition, NT1 showed lower mean values more than NC in all soil layers, with an exception in the 0.03 to 0.06 m soil layer (Figure 3). In contrast, higher deployment time of NT (7 years) resulted in an SWRC shape closer to NC than other NT treatments, reflecting greater volumetric water content at Ψ_m = 10 for all soil layers, suggesting that NT enables changes in soil water availability in the wetter part of SWRC (Figure 3).

The greater water content at Ψ_m = 10 in the 0.10 to 0.20 m soil layer in NT7 can be attributed to improvement in the physical quality of the soil over the deployment time of NT as a result of better soil aggregation. Reis et al. (2016), evaluating NT presented in Albaqualf soils in the Pampa Biome, observed that the deployment time of NT generated mean weight diameter, carbon stocks, and physical quality of the soil overall, corroborating the results observed in this study.

The water content at field capacity (θ_{FC}) as well as PAW increased with higher NT deployment time. The increase in θ_{FC} can be related to NT influence on soil structure, mainly in the volume of pores responsible for water retention at near field capacity potentials (Figure 4).

CI presented negative correlation with DCσp, DC1.600, and BD (Table 3). As observed by Reis et al. (2016), the mechanical action of plant roots, proportioned

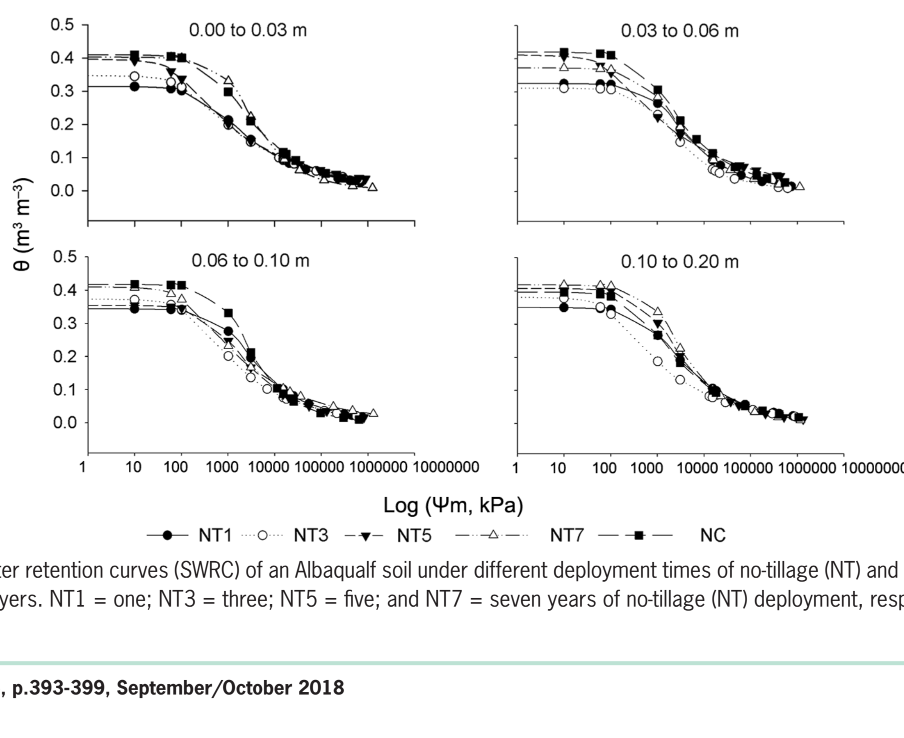

Figure 3 – Soil water retention curves (SWRC) of an Albaqualf soil under different deployment times of no-tillage (NT) and non-cultivated field (NC) in different soil layers. NT1 = one; NT3 = three; NT5 = five; and NT7 = seven years of no-tillage (NT) deployment, respectively.

Table 3 – Correlation analysis between attributes of an Albaqualf soil under different deployment times of no-tillage (NT).

Attributes	CI	σp	BDσp	DCσp	DC1.600	BD (Mg m^{-3})
TOC (g kg^{-1})	0.08 ns	-0.47**	-0.38**	0.09 ns	-0.03 ns	-0.60**
CI (dimensionless)		-0.05 ns	-0.11 ns	-0.14*	-0.22**	-0.23*
σp (kPa)			0.46**	-0.12 ns	0.13 ns	0.37**
BDσp (Mg m^{-3})				-0.13 ns	0.13 ns	0.46**
DCσp (%)					0.73**	-0.02 ns
DC1.600 (%)						0.11 ns

Number of observations (*n*) = 192; TOC = total organic carbon; CI = compression index; σp = preconsolidation pressure; BDσp = Bulk density at the preconsolidation pressure; DCσp = degree of compactness at the preconsolidation pressure; DC1.600 = degree of compactness at 1.600 kPa; and BD = Bulk density; ns = non-significant difference; *,**significance level of 5 % and 1 %, respectively.

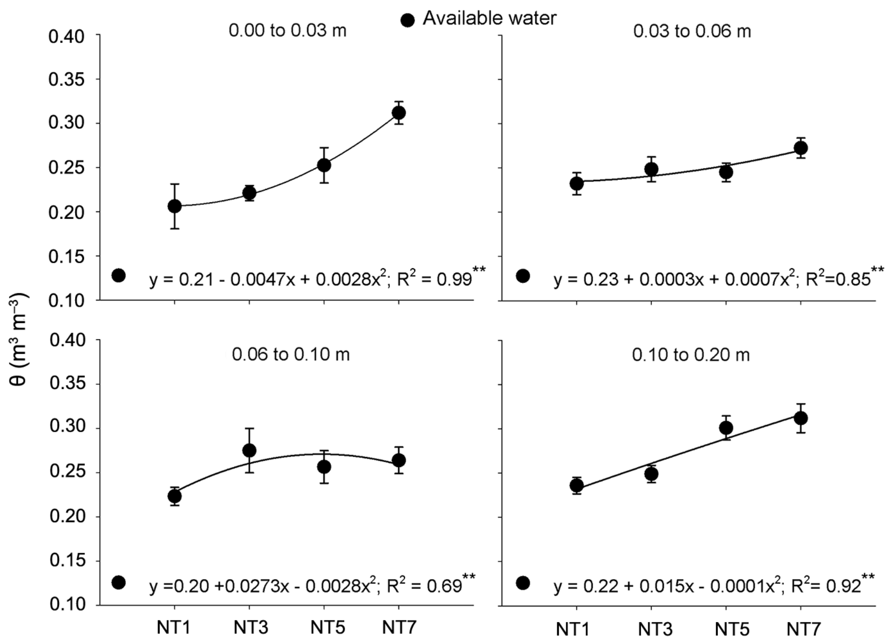

Figure 4 – Plant available water (PAW) of an Albaqualf soil under different deployment times in no-tillage (NT) in different soil layers. ns: non-significant difference; **significantly different at 1 %. NT1 = one; NT3 = three; NT5 = five; and NT7 = seven years of no-tillage (NT) deployment, respectively. Vertical bars represent mean standard deviation.

and maintained by NT, reduces BD and promotes macropores, which make the soil susceptible to compression due to higher pore space available for soil rearrangement under NT. Furthermore, TOC showed negative correlation with σ_p, BDσp, and BD, indicating that higher porosity reduces the σ*p*. This happens because, in denser soils, there is less pore space for particle movement and friction forces between particles are higher (An et al., 2015).

Our findings for NT7 are in agreement with those of Aziz et al. (2013), specifically for the relationship between TOC and other soil physical properties (Table 3). The higher deployment time of NT can effectively reduce BD as well as increase the CI and all these changes are a result of the continuous addition of OM associated with the adoption of NT.

For no-tillage in lowlands we found the higher the deployment time the lower the BD, the σp, the BDσp, and the CI. Furthermore, we demonstrated in this study that the dynamic alteration of physical attributes in lowlands which have adopted no-till is beneficial and similar to the benefits of this practice in well-drained soils.

Acknowledgments

To Brazilian National Council for Scientific and Technological Development (CNPq) for a scholarship granted to the first author; to the Federal University of Pelotas and Embrapa Temperate Agriculture for the opportunity, financial and laboratory support and infrastructure; to the anonymous reviewers for the improvements in this paper.

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