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Physical Condition of Central Argentina Haplustolls Under Different No Tillage Variants

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Abstract: Our objective was to characterize the physical condition of Central Argentina Tipic Haplustolls and to evaluate different no tillage variants. Eleven sites were selected; two under low disturbed conditions (NAT) and nine agricultural sites. These nine sites were clustered through surveys into: NT: no tillage, NTPnt1: NT except peanut crop (tillage with disk harrow and roller), NTPnt2: similar to NTPnt1 with paratill or disk harrow tillage every two years, and MT: disk harrow and chisel tillage. Soil physical properties measured in Ap and Bw horizons were: organic carbon (OC), bulk density (BD), basic infiltration rate (BIR), soil cover percentage (%COV), proctor test determined maximum compaction (BDmax) and critical water content (CWC). In NT, OC was concentrated in Ap horizon, while in other treatments it was found more equally distributed along the two upper horizons. NAT had the lower BD while the rest of the treatments did not differ between themselves. Treatments and horizons with higher OC were found to have the lower BDmax and higher CWC. The OC vs. BDmax relationship was only significant at 1% or higher OC values. The BIR was significantly higher in NAT than in NTPnt2 and NT, and MT with NTPnt1 presented the minimum value. NT was found to have a good physical Ap horizon condition but a poor Bw horizon condition. This is associated to a high and low OC value respectively. In contrast, NTPnt2 was found to have a relative good physical condition along both horizons.
Key words: soil physics, compaction, Haplustolls, Proctor test.

INTRODUCTION

Soil management has a direct incidence on the soil's physical, chemical and biological properties. Thus, it would be expected that a change in soil management would have an effect on them.

In Argentina, over the last decade, no tillage emerged as the main soil management system, and ever since 1996-1997, soybean (*Glycine max* L. Merr) became the main crop within crop rotations mainly due to the release of glyphosate (N-(phosphonomethyl glycine) resistant cultivars (SAGyPA, 2008). The south-central region of Cordoba was influenced by these changes, with a particular impact on the peanut-growing areas that had a century long agricultural history (De Prada et al. 1994). These areas underwent a transition from minimum tillage (MT) and conventional tillage soil management systems along with a high peanut percentage in rotations, towards no tillage (NT) and soybean prevalence. Currently, the latter is the dominant crop in rotations (approximately 60% soybean, 30% corn, 7% peanut and 5% wheat-soybean double-crop), with NT as the main soil tillage system though presenting a great diversity of variants (Parra et al. 2008). A number of studies have been carried out prior to the major NT breakthrough or the transition towards it (Bonadeo y Cholaky, 1993; Moreno, 1996; Bonadeo, 1997; Cisneros et al. 1997, Uberto et al., 2002, Cholaky, 2003; among others). However, no studies have been carried out after the widespread adoption of these new soil management systems. The object of the present study was to evaluate and characterize the soil physical condition in different representative agricultural systems from the area of General Deheza, in south-eastern Cordoba, Argentina.

MATERIALS and METHODS

Site characteristics

Research was conducted between August and September 2006 in a 15.000 ha watershed located to the west of National Road 158, draining from the west into the city of Gral. Cabrera (32°47′60″S 63°52′00″W), Cordoba in Argentina.

The climate is template sub-humid, with a marked dry winter season. The area is 330-300 m above sea level with an average yearly temperature and rainfall of 16, 09 ºC and 695 mm, respectively. The latter is concentrated mainly in the spring-summer seasons. The soil from the area of study is a coarse loamy thermic lythic Tipic Haplustoll (Blarasin et al., 1996) characterized by an Ap-Bw1-Bw2-BC-C horizon sequence.

A total of nine representative agricultural sites were selected based on surveys carried out with the farm managers from the area of study. The sites were clustered according to the management systems described below. **No Tillage (NT):** Mainly soybean and wheat-soybean double crop (70% of rotation in equal proportions) and corn (30%); without soil remotion. **No Tillage except Peanut Crop (NTPnt1):** No tillage crops except with peanut crop where disk harrow and roller are used (55% soybeans, 30% corn, and 15 % peanut approx.). **No Tillage Except With Peanut 2 (NTPnt2):** No Tillage crops with paratill or disk harrow tillage every two years approximately (50% soybeans, 35% corn, and 15 % peanut). Peanut is planted before the disk harrow and roller or paratill and roller are used. **Minimum Tillage Without Peanut (MT):** Soybean prevalence (70% soybean and 30% corn) and disk harrow use in seed bed preparation.

Two other minimal disturbance sites were used as reference (NAT). These are characterized by presenting natural or near natural conditions due to only eventual grassland cuts along the past 100 years. These sites are characterized by herbaceous vegetation with predominating genres such as *Stipa, Paspalum, Esporobolus, Poa, Eragrostis, Chloris, Setaria, Bromus, Cynodon, Sorghum, Echinichloa, Bidens, Ammi, Sisymbrium,* among others.

Table 1. No tillage implementation year and predecessor crop for each site.

Site	Treatment.	Impl. NT	Predecessor Crop
1	NAT	0	-
2	NAT	0	-
3	MT	0	Soybean
4	MT	0	Soybean
5	NT	1997	Corn
6	NT	1990	Wheat/Soybean
7	NTPnt1	2002	Corn
8	NTPnt1	2002	Soybean
9	NTPnt2	1999	Soybean
10	NTPnt2	2004	Corn
11	NTPnt2	1998	Soybean

Each management system was represented by two sampling sites except for NTPn2 which was represented by three. In each site, three samples were taken before the 2006/2007 summer crop planting. These samples were taken from Ap and Bw horizons and the following properties were determined:

- Organic Carbon (OC) (%) using the modified Walkey-Black method (Jackson, 1970).
- pH determined by a potentiometric method (water: soil 2.5:1).
- Bulk Density (BD) (g cm^{-3}) determined by the core method (Blake y Hartgue, 1986).
- Maximum Bulk Density (BDmax) and Critical Water Content (CWC) (% gg^{-1}) determined by the proctor test (ASTM D 698.91).
- Relative Compaction (RC) determined by Campbell equation (1994).

$$RC= (BD - BDmin)/ (BDmax - BDmin) \qquad (1)$$

Where RC = Relative Compaction, BD = Bulk Density in a horizon from a treatment, BDmin = Bulk Density from a minimal disturbance situation (NAT) for an equivalent horizon, and BDmax = Maximum Bulk Density.

- Basic Infiltration Rate (BIR) determined by the double ring method (ASTM D 3385-88) (cm $hour^{-1}$).
- Soil Cover Percentage (%COV) through visual estimation using 0.25 m^2 frames thrown randomly 10 times per site.

Statistical procedures: Statistical analysis were performed using INFOSTAT (UNC, 2008). Using an ANOVA test, each variable was separately analyzed for each horizon using the following model:

$$Y_{ijk} = \mu_{ijk} + M_i + H_j + (M \times H)_{ij} + ee_{ijk}$$

where μ is the population mean, *M* the effect of each management treatment (NAT included), *H* the horizon effect (Ap o Bw), *MxH* the interaction between these two factors and *ee* the experimental error. The means were separated by LSD-test at alfa level 0.05.

RESEARCH RESULTS

As regards organic carbon (OC), when ANOVA was performed, a significant interaction was observed between horizon and management system factors (Figure 1). This could be mainly due to the great OC difference between the two NT horizons, which is in turn a result of the organic matter concentration in the upper layers (Musso et al. 2004, Parra et al. 2007, Hermle et al. 2008), making this treatment approximate to the values from the near natural sites (NAT). NTPnt2 did not show significant differences from NAT since the differences between Ap and Bw horizons were smaller than those found in NT due to the OC from Bw was significantly greater than the OC from Bw in NT.

The minimal disturbance site (NAT) obtained the highest media value for horizons A and Bw, although it only significantly differed from all treatments for the latter horizon.

In figure one it can be observed that NT (without any soil remotion), shows the largest OC content difference between horizons. Furthermore, this difference was smaller in NTPnt1 and NTPnt2 and even smaller in MT (with annual remotion).

A direct relationship was observed between %COV and OC (Figure 2) where high %COV sites tended to have a greater organic carbon content in their Ap horizons.

Bulk density (BD) did not show a significant interaction between horizon and management system factors. Therefore, these two factors were analyzed separately (Table 2). BD was significantly lower in NAT as well as in A/Ap horizon. No significant differences were observed between agricultural treatments.

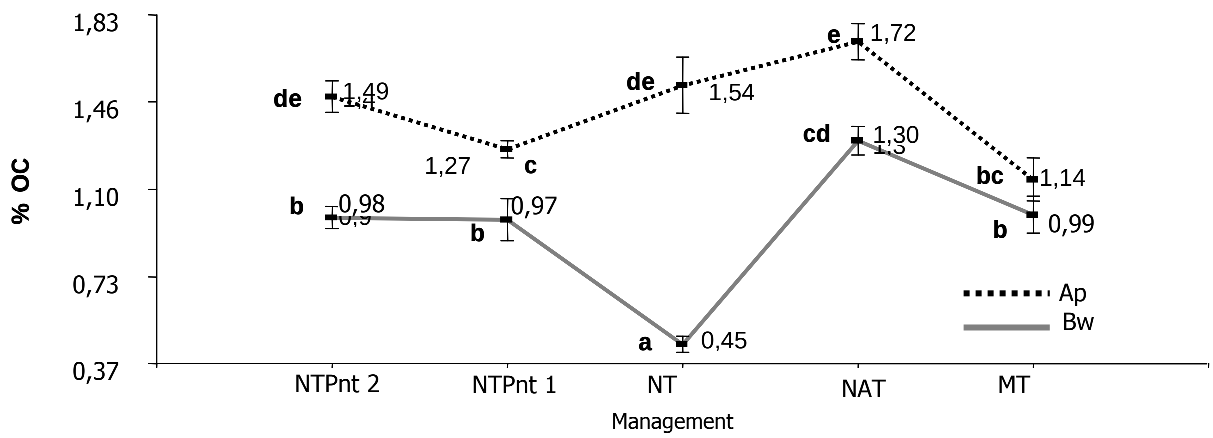

Figure 1. Organic carbon percentage (OC) from Ap and Bw horizons in management system. Values followed by the same letter are not significantly different at p <0.05 according to LSD test.

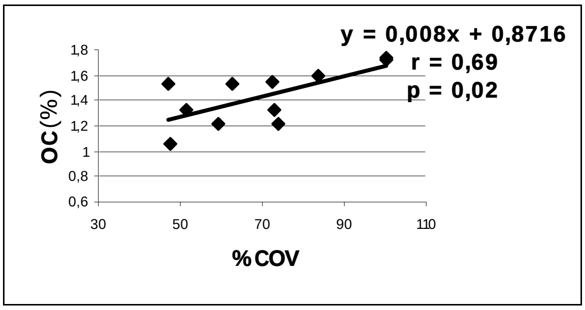

Figure 2. %COV and OC relationship in Ap horizon.

The difference observed between NAT and agricultural treatments would indicate the resulting soil compaction due to its anthropic use (Figure 2).

At Bw horizon a negative correlation was observed between OC and BD (Figure 3). However, no significant correlation was observed for Ap horizons.

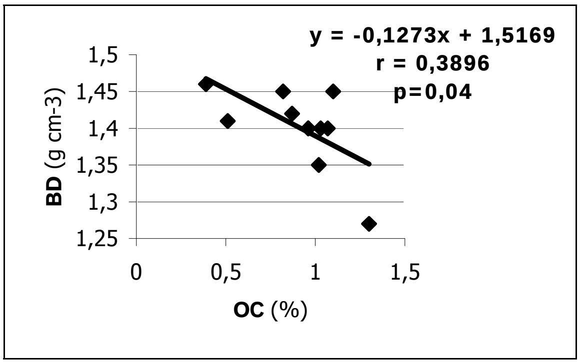

Figure 3. OC and BD relationship in Bw horizons.

Table 3 shows the comparison of BDmax values for the interaction between the managements and horizons ($p<0.05$). When compared within each horizon, NAT significantly differed for Ap and Bw horizons in relation to the rest of the horizons from the other treatments. Furthermore, when considering the different treatments a significant difference could be observed between horizons Ap and Bw. These can be observed in Table 3 under different letters. Significant interaction is mainly due to NT as it presents the lowest value for horizon Ap and one of the highest for Bw.

The inverse relation between BDmax and OC can be observed in Figure 4.

Table 2. Bulk density (BD).
Values followed by same letter are not significantly different at p <0.05 according to LSD test.

Management	BD (g cm^{-3})	
NAT	1.21	a
MT	1.33	b
NTPnt1	1.33	b
NTPnt 2	1.35	b
NT	1.35	b
Horizon		
Ap	1.24	a
Bw	1.39	b

Figure 5 shows BDmax in relation to OC in all repetitions for each horizon of all analyzed treatments. Locally weighed scatterplot smoothing or LOWESS was used (LOWESS, INFOSTAT), clearly showing that the OC effect on BDmax appears to be limited to values approximately higher than 1% of OC.

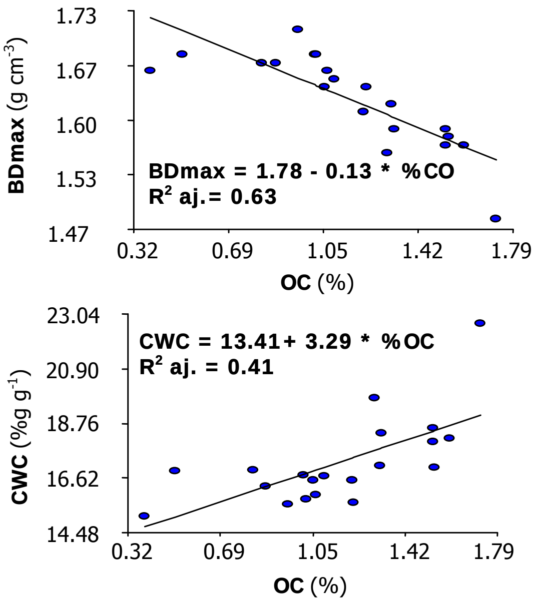

Figure 4. Relationship between organic carbon (OC) and maximum bulk density (above) and relationship between organic carbon and critical water content (below).

Table 3. Maximum bulk density (BDmax). Values followed by same letter are not significantly different at $p < 0.05$ according to LSD test.

Management	**Horizon**	**BDmax** (g cm^{-3})	
NAT	**Ap**	1.48	a
NAT	**Bw**	1.56	b
MT	**Ap**	1.58	b
NTPnt 2	**Ap**	1.58	b
NTPnt 1	**Ap**	1.62	c
MT	**Ap**	1.64	c
NTPnt 1	**Bw**	1.66	d
NTPnt 2	**Bw**	1.67	d
NT	**Bw**	1.67	d
MT	**Bw**	1.69	e

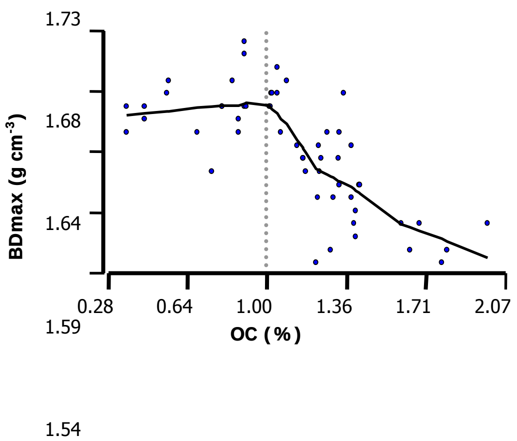

Figure 5. Maximum bulk density (BDmax) and organic carbon percentage (OC%) dispersion diagram with local regression smoothing line (LOWESS).

Table 4 shows that NAT significantly differs from all other sites in CWC as well as in horizons Ap and Bw, having the greatest value. NTPn2 presents a higher CWC differing from NTPn1 and NT. NTPn2 is the treatment with the highest CWC differing from NTPn1 and MT.

Table 4. Critical water content (CWC). Values followed by same letter are not significantly different at $p < 0.05$ according to LSD test.

Management	**CWC (%g g^{-1})**	
MT	15.88	a
NTPnt1	16.46	ab
NT	16.90	bc
NTPnt2	17.49	c
NAT	21.21	d
Horizon	**CWC (%g g^{-1})**	
Bw	16.86	a
Ap	18.31	b

RC was determined using NAT BD as BDmin (Equation 1) for horizons A or Bw accordingly. Results are presented in Table 5. Nat results are not shown since through this formula the RC obtained is zero due to its reference situation. No differences were observed between treatments due to the lack of existing differences with BD. (Table 2). However, differences between horizons were observed with Bw presenting the highest RC due to its higher BD in proportion to its BDmax.

Table 5. Relative compaction. Values followed by same letter are not significantly different at $p < 0.05$ according to LSD test.

Management	**CR**	
MT	25.73	a
NTPnt 1	29.11	a
NTPnt 2	34.80	a
NT	35.24	a
Horizon	**CR**	
Ap	26.02	a
Bw	36.42	b

Table 6 shows the values obtained for Basic Infiltration Rate (BIR) from each treatment. It can be observed that NAT presented the higher BIR value differentiating itself from NT and NTPnt2 and these from NTPnt1 and MT.

Table 6. Basic infiltration rate (BIR) (cm hour^{-1}). Values followed by same letter are not significantly different at $p < 0.05$ according to LSD test.

Treatment	**BIR (cm hour^{-1})**	
NAT	12	a
NTPnt2	5.0	b
NT	4.5	b
NTPnt1	3.0	c
MT	3.0	c

Table 7 shows the relationships between BIR and other analyzed variables.

Table 7. Relationship between basic infiltration rate (BIR) and other soil properties.

	R	p
%COV	0.71	0.01
OC Ap	0.64	0.03
BDmax Ap	-0.89	0.00025
BDmax Bw	-0.91	0.00012
CWC Ap	0.95	0.000001
CWC Bw	0.79	0.0041

%COV: soil cover percentage, OC Ap: Ap horizon organic carbon percentage, BDmax Ap: Ap horizon maximum bulk density, BDmax Bw: Bw horizon maximum bulk density, CWC Ap: Ap horizon critical water content, CWC Bw: Bw horizon critical water content.

DISCUSSIONS and CONCLUSIONS

With regards to OC distribution, NT presented, in most cases, a tendency towards organic matter concentration in the higher layers due to the lack of incorporation de residues. On the other hand, no difference was observed between Ap and Bw under MT. This could be due to a greater mineralization in the first horizon as a result of the previously mentioned remotions rather than to the mixture of materials from Ap and Bw horizons, since tillage is carried out with 12-15 cm disk harrows, a depth that coincides with the base of the Ap horizon.

OC and %COV relationship should be monitored over a longer period of time in order to describe more effectively the relationship between these variables since %COV would be quite dependant on the preceding crop in a short term basis. When analyzed over a long period of time, this variable (%COV) would contribute to the better interpretation of management related aspects, since it synthesizes management related properties and is easily measured.

BD was sensitive to the effect of the soil's anthropic use since as table 2 shows NAT was the only treatment that differed with the lowest value.

The greater compaction found in Bw in relation to Ap (Table 2) would be the result of two probable causes. On the one hand, the soils' natural tendency to increase their density with depth (USDA, 2008), and on the other the long history of conventional tillage that contributed to the dense layer formation at a similar depth as the one in this study (Cisneros et al. 1997).

The inverse relationship that exists between BDmax and OC (Figure 4) can be used in order to explain the BDmax differences between treatments. Therefore, it would be logical to expect the treatment with the highest OC surface concentration such as NT to have a lower BDmax in Ap and a higher in Bw. This inverse relationship between OC and BDmax has been observed in several previous studies (Howard et al. 1981; Zhang et al. 1997; Aragón et al. 2000; Díaz Zorita y Grosso 2000; Aparicio y Costa 2006; Diaz-Zorita y Alvarez 2006; Micucci et al. 2006; Nhantumbo y Cambule 2006; Ferreras et al. 2007; Parra et al. 2007; Zhao et al 2008 among others). These authors explained BDmax variations in relation to the OC or texture changes.

The OC effect on the BDmax decrease would be the result of the soil's structural stability increase on the one hand, and the greater water retention that would be having a buffer effect on the mineral particles during compaction (Husein et al. 1999) on the other.

Zhang and Hartge (1995) explain this phenomenon as due to the organic matter capacity for water retention. According to these authors, as water is retained, the mineral particle friction increases resulting in a lower BDmax and higher water content.

The OC threshold values observed affecting BDmax (Figure 5) might be interesting for the use of OC as a physical soil quality indicator. A direct relationship can be observed between CWC and OC. The OC and CWC relationship can be explained by the OC and BDmax relationship mentioned above, inasmuch as a soil sample with a higher OC will retain a greater amount of water and, thus, reach a lower compaction level as well as higher water content. Rawls et al. (2003) and Aggelides and Londra (2000) found that as the OC content increases so does the water retention capacity for the same matrix potential.

The BIR differences between treatments could be explained by the analysis of the relationship between BIR and the rest of the variables. Furthermore, the direction of these relationships (direct or indirect) could be explained by taking into consideration the structural or porous space quality as a central variable. In this way, those variables that favor this condition such as OC and %COV are positively related with BIR, while those that are the consequence of a poor structural quality such as a high BDmax (since a higher BDmax would indicate a weak, more easily alterable structural condition) are negatively related.

OC was related to all the other variables with a higher OC condition being always more favorable, although an OC fractioning would be convenient as it is possible the effect of the different fractions will differ.

Those managements that affect the OC distribution in the profile will affect most of the physical soil quality properties.

No significant differences were found between treatments in many variables. This would be minimized in a controlled experimental study where most, if not all factors are controlled. The importance of the results obtained in this study lie in the fact that they were obtained from real agricultural sites.

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