Soil physical quality changes under different management systems after 10 years in Argentinian Humid Pampa:

Soil physical quality changes after 10 years in Argentinian Humid Pampa

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Abstract

South American countries with the highest surface of land under no till (NT) are Brazil, Argentina and Chile. In Argentina, 78.5 % of the agricultural land is cropped under NT management. In several experiments have confirmed the improvements in soil aggregation and infiltration achieved by NT in dry land farming areas associated with increases of δ_b under NT. An increase to δ_b implies a reduction of the macro and meso porosity which is in contradiction with the increased infiltration which occurs at macro and meso-pores. We hypothesize that the increase in bulk density in NT mainly affects the mesopores. We evaluated the evolution of the soil physical parameters in three management systems in four farmers' fields. We found that: the reduction in total porosity under NT is mainly a product of a reduction in the percentage of mesopores in the soil. In this work, the results indicate a modification of some soil physical parameters (porosity, near-saturated hydraulic conductivity, soil structure) due to uninterrupted agricultural production but the management system did not affect the yields of crop.

Keywords: macro y mesoporosity, near-saturated hydraulic conductivity, crop sequence.

1. Introduction

Sustainable soil management in agriculture land is a need for a sustainable world. Efforts to achieve a sustainable management can be found in developed and non-developed countries (Perkins et al., 2013; Mekuria and Aynekulu, 2013). One of the most successful soil management in agriculture land is the no-tillage (NT), and is being applied worldwide (Barbera et al., 2012; Schneider et al., 2012; Thapa and Yila, 2012: Lieskovský and Kenderessy, 2014). No-tillage affects the pedological, hydrological and geomorphological processes (García-Orenes et al., 2009; Olang et al., 2014; Gao et al., 2014).

South American countries with the highest surface of land under NT are Brazil, Argentina and Chile (Lal et al., 2007). In Argentina, 78.5 % of the agricultural land is cropped under NT management (Aapresid, 2012). However, the southeast of the Humid Pampa, with 60 million hectares, 90% of which are agricultural lands, does not reflect this situation because most of the crops are managed with tillage practices. However, NT management is becoming more popular and little is known about the effects of this practice on soil properties.

Previous work demonstrated that under NT, the values of bulk density (δ_b) and the penetration resistance in the superficial layers of the soil are higher than those of the plowed soils due to soil compactation (Özcan et al., 2013). Intensive soil cultivation produces decreases in soil organic carbon (SOC) content (Studdert et al., 1997; Barbera et al., 2012: Lozano-García and Parras-Alcántara, 2014; Srinivasarao et al., 2014). The magnitude of such impact depends on the intensity of the management system, the tillage timeliness and the amount and quality of the residues: stubble, roots and exudates. Adopting NT and an adequate fertilization treatment may reduce the effects of intensive agriculture, through the maintenance and accumulation of SOC (Salinas-García et al., 1997) and the reduction in the soil and water losses (García Orenes et al., 2012).

Soil Organic Carbon has a very important role to play in other edaphic properties. Hati et al. (2006) emphasized its influence on the retention and movement of water in the soil, whereas Aparicio and Costa, (2007) reported a significant and positive correlation of SOC with hydraulic conductivity (r = 0.6) and a negative one with the δ_b of the soil (r = -0.6). There is a strong relationship between soil microbiological activity, organic matter and the structural stability of the soil (Garcia Orenes et al., 2010). Soil aggregate formation is influenced by biotic and abiotic factors and the SOC content plays an important role in the stabilization of aggregates and them on the reduction of the soil losses (Cerdà, 2000). Vegetation cover is the key factor on the control of soil erosion (Jordán et al., 2008), and on agriculture land the use of mulches under NT is a key factor of the recovery of the soil quality (Jordán et al., 2010). The mulches use to be organic (straw, chipped pruned branches) but they can be also mineral such as rock fragments (Martínez Zavala and Jordán, 2008).

In a review from Alvarez and Steinbach (2009), a number of experiments have confirmed the improvements in soil aggregation and infiltration achieved by NT in dry land farming areas associated with increases of δ_b under NT. An increase to δ_b implies a reduction of the macro and meso porosity which is in contradiction with the increased infiltration which occurs at macro and meso-pores. We hypothesize that the increase in bulk density in NT mainly affects the mesopores. On the other hand, averaging out soil SOC differences in various experiments under NT showed an increase of 2.1 Mg C ha^{-1} over MP and the steady state was reached after 25–30 years (Alvarez, 2005). When enough nutrients were applied, there was no difference in yields between tillage. With this scenario and the tendency to increase the surface under NT in the southeast of the Humid Pampa, we aimed to evaluate- i.-bulk density, the change in weighted average diameter, the hydraulic conductivity and organic carbon content on wheat / maize / sunflower crop sequence in three management systems; ii.- that pore size is affecting the differences in bulk density observed in three management systems and its relation to the hydraulic conductivity of the soil and iii.- yields the crop sequence over 10 years.

2. Materials and Methods

2.1 Experimental site

The Pampean region is a wide plain where Quaternary eolian sediments were partially reworked. The experiments area is located in the geological province named ¨Sierras Septentrionales¨ in the southeast of the Buenos Aires Province of Argentine. The loess deposits of the SE of Buenos Aires Province are from the Late Pleistocene and Holocene. The mineralogical composition of loess consists of a volcaniclastic assemblage derived mainly from reworked pyroclastic deposits (Zarate and Blasi, 1991). The soils are classified as Typic Argiudoll and Petrocalcic Argiudoll (Klingebiel and Montgomery, 1961) and are fine, illitic, thermal and mixed. The initial soil characteristics of the experiments are shown in Table 1.

The southeast of the Province of Buenos Aires has a mean annual temperature of 13.3°C and the frost-free period extends from the beginning of October to mid-May. It has a sub-humid to humid hydric regime (Thornthwaite, 1948) and its rainfall regime comprises three seasons: a) *rainy* from October to March, b) *moderately rainy* in April, May and September, and c) *scarcely rainy* from June to August. Mean annual precipitation is about 900 mm in the region.

2.2 Experiment design

The experiment was installed in 1997, in soils managed with moldboard plow (MP). A randomized complete block design was used for the experiment, considering each locality as a block. Each plot was 50 m in width by 100 m in length and the treatments were: no till (NT), MP and chisel plow (CP). No-till consisted of chemical weed control during the fallow period using glyphosate [N-(phosphonomethyl) glycine] as herbicide, and seeding directly into the standing residues of the previous crop. Moldboard plow consisted of two tillage operations with a moldboard plow at a depth of 20 cm and two operations with disc harrow. Chisel low consisted of two chisel plow operations at a depth of 10 cm and two operations with disc harrow each year for seedbed preparation. The crop sequence analyzed was wheat - corn – sunflower; during the experimental period three crop sequences were performed and ended with wheat. The crops were fertilized according with your requirements of nitrogen as follows: at the V4-V6 stage in corn, at sowing in wheat, and at star stage in sunflower.

2.3 Physical and chemical determinations in soil

The soil physical parameters, except maximum δ_b, were determined after wheat harvests in two years (2004 and 2007) during the experimental period of 10 years (1997-2007). In the wheat harvest of the year 2004 the first determination of physical parameters was performed to begin after two complete cycles of the wheat-corn-sunflower sequence under three soil management systems. This decision was made because we consider necessary to allow a period of stabilization of the NT since it has been suggested that between 3 and 4 years is required for soils with tillage reduced succeed in developing a favorable porosity in the first centimeters deep (Voorhees and Lindstrom , 1984) at the end of the third cycle of the crop sequence determinations of the physical parameters were again carried out during the wheat harvests in the year 2007 to analyze trends between the two periods. The methodology used was as follows:

Bulk density (δ_b) was measured by the cylinder method (Blake and Hartge, 1986) with 12 sub-samples per plot, per year and per depth. The samples depths were: 3 to 8 cm and 13 to 18 cm.

Total porosity (ρ) was calculated as follows:

$$\rho = 1 - \frac{\delta_b}{\left[(1 - \frac{SOC}{100})\delta_r + (\frac{SOC}{100})\delta_{OC} \right]} \quad [1]$$

where δ_r the particle density (2.65 Mg m^{-3}), and δ_{OC} is the *SOC* density (1.3 Mg m^{-3}).

Maximum δ_b was estimated from the maximum compactability using the standard Proctor method (Felt, 1965), a soil sampled from 0-20cm depth was taken for each treatment and block in 2007. Bulk density was replaced by maximum δ_b in equation [1], the resulting value was considered the textural porosity (ρ_t) (Aparicio and Costa, 2007). The ρ_t values used to calculate the structural porosity (ρ_s) as following:

$$\rho_s = \rho - \rho_t \qquad [2]$$

total porosity, using eq. [2], was calculated using the average value of δ_b over time and depth for each treatment and block.

Change in mean weight diameter (CMWD) was measured by the De Leenheer and De Boodt (1959) method. The De Leenheer and De Boodt instability index was determined as the measured area between the two curves corresponding to the aggregate size distributions found before and after wet sieving water-moistened aggregates with diameters between 2 and 8 mm. The authors determined the index graphically, but it is numerically equivalent to CMWD between the dry aggregate distribution and the water stable aggregate size distribution. The larger the value of CMWD, the more unstable the aggregates (Diaz Zorita et al., 2002).

Four disturbed sub-samples from each plot were dry and wet sieved, obtaining the CMWD. The samples for CMWD were collected at a depth of 0 to 20 cm.

Unsaturated hydraulic conductivity (K_h) was measured using a tension infiltrometer (Soil Measurement System®, model SW-080B), which has a 20-cm diameter base-plate that was separate from the water tower. Infiltration runs were performed at matric potential (h) of -150, -70 and -20 mm, and readings were made for 40 minutes at each tension, beginning with 150 mm. The K_h was measurement using a disc infiltrometer, the K_h for each tension was taken once the equilibrium (steady-state flow) was achieved. The time required to reach steady-state in unconfined infiltration measurements depends on initial soil water content and on hydraulic properties of a given soil. In general, drier soil and lower hydraulic conductivity result in the need for a longer infiltration period in order to reach steady-state infiltration. Wooding (1968) proposed the following equations to describe the three-dimensional movement of water under a disk:

$$Q_{(k_h)} = \pi r^2 K_h \left(1 + \frac{4}{\pi r \alpha}\right) \quad [3]$$

$$K_h = K_s \exp(\alpha h) \quad [4]$$

where: $Q_{(Kh)}$ = infiltrated water volume expressed in $cm^3\ h^{-1}$, r = radius of the disk in cm, K_s = saturated hydraulic conductivity in cm h^{-1}, K_h = hydraulic conductivity at tension h in cm, and α is a constant. With equation [3] and the procedure proposed by Logsdon and Jaynes (1993), we obtained α to calculate K_s and K_h. Hydraulic conductivity was measured with four sub-samples in each plot on wheat stubble but during the wheat fallow period.

The maximum number of effective pores per unit area (N) was calculated using the procedure of Watson and Luxmoore (1986) and the effective porosity is given by:

$$\theta_\varepsilon = N\ \pi\ R^2 \quad [5]$$

where R is the minimum pore radius in each class.

Soil organic carbon (SOC) was determined by the Walkley-Black procedure (Nelson and Sommers, 1982), in composite soil samples collected at a depth of 0 to 20 cm from 10 different places in each plot per year. Samples were air-dried, ground and sieved through a 2-mm sieve. Results of SOC were expressed as concentration (%) and as stock ($g\ m^{-2}$) considering the soil δ_b and soil depth.

2.4. Crop Yield

Crop yield was for sunflower and corn determined by manual harvest of three sub-samples of each treatment and crop, representing 10 m^2 of harvest area (Noellemeyer et al., 2013). Crop yield for wheat was done by mechanical harvest, using an experimental harvester similar to one use by Velazco et al., (2012), representing 20 m2 of harvest area..

2.5. Statistical Analyses

The Shapiro-Wilk (1965) test was used to providing evidence of normality. Under no evidence of normality log transformation of the data were made.

Analyses of variance were performed using mixed linear models (SAS Institute, Inc. 2002). The data at different years were analyzed as repeated measurement. The random effect was block and the fixed effects were N rates and soil management. The different levels of a fixed factor, such as the treatments were tested using the post-hoc test pairwise comparison of the least square mean.

3. Results and Discussion

3.1. Bulk density (δ_b)

Time ($F=7.0$, $p<0.009$), depth ($F=7.98$, $p<0.005$) and treatment ($F=11.75$, $p<0.0001$) had a statistically significant effect on δ_b and there were no time-per-depth (F=,0.84 $p<0.36$), depth-per-treatment ($F=1.37$, $p<0.25$), time-per-treatment ($F=1.84$, $p<0.16$) and time-per-depth-per-treatment ($F=1.15$, $p<0.32$) interactions. Bulk density decreased over the time and was low at 3-8 cm (Table 2). There is a hypothesis that in the first years under NT soil δ_b increases and later decreases. Voorhees and Lindstrom (1984) suggested that three to four years are required for the soils with reduced tillage to be able to develop a more favorable porosity in the first 15 cm, which would be closely related to the biological activity and proportion of plant residues. In contrast, in another long-term experiment conducted in Argentina, no statistically significant differences in δ_b due to time were reported (Domínguez et al., 2009).

When changing the management system from conventional tillage to NT, the initial physical condition of the soil is a critical factor that can affect the soil productivity of the region under this new management system (Elissondo et al., 2001). The δ_b values decrease over time in the three management systems studied under wheat, corn and sunflower rotation (Table 2). In addition, δ_b was statistically different between treatments. No-till had δ_b higher values than those of other management system in several experiments carried out in Argentina (Aparicio and Costa, 2007; Fabrizzi et al., 2005; Ferreras et al., 2000).

Finally, we found significant differences in δ_b in relation to the sampling depth of the sample. The average values were 1.19 and 1.21 Mg m^{-3} for the depths of 3 to 8 cm and 13 to 18 cm, respectively. Bermejo and Suero (1981) reported δ_b values that fluctuated between 1.22 Mg m^{-3} and 1.26 Mg m^{-3} under continuous cropping on Typical Argiudolls in a similar region, whereas δ_b measurements taken in a three-year pasture were a little higher (1.35 Mg m^{-3}). In degraded soils, within the EEA Balcarce, Ferreras et al. (2000) reported δ_b values higher than 1.4 Mg m^{-3}.

Soil δ_b was significantly higher under NT, but no differences were detected between MP and CP. Although with proper rotation δ_b can be reduced in all treatments, high traffic intensity under NT (tractors used for seeding, crop protection and treatments and harvest operations) has a significant effect on increasing the δ_b. It is known that NT helps to retain a large percentage of the crop residue over the soil surface. These residues, in addition to protecting the soil, reduce soil evaporation, thereby increasing soil moisture in the upper 10 cm. Soils under conservation tillage are wetter than those under conventional tillage (Alvarez and Steinbach, 2009). When tillage operations are performed with moist soil, the chances of soil compaction increase (Botta et al., 2004). Consolidation in the surface horizon induced by no-tillage may also contribute to increase δ_b (West et al., 1990). Under MP or CP, tillage generates artificial macropores which in turn reduce δ_b.

Structural porosity is an estimator of the percentage of pores involved in water flow; a soil is considered moderately porous when total macroporosity ranges from 10% to 25% (Pagliai, 1988). Although textural porosity measured in the year 2007 was moderate, NT structural porosity was significantly lower than the other treatments (Table 3).

3.2. Change to Mean Weight Diameter (CMWD)

The time had statistically significant effect on CMWD ($F=70.18$, $p<0.0001$), while treatment ($F=2.95$, $p<0.1280$) had not effects on CMWD and the interaction treatment-per-time was significative ($F=3.12$, $p<0.049$) (Fig. 1). The CMWD in 2007 increased significantly compared to 2004 in all the management systems evaluated, indicating a decrease in the structural stability of the soil due to the agricultural activities. However, the time-per-treatment interaction indicates that the MP system suffered a higher difference in the values of CMWD that the NT recorded the lowest value, and MP and NT was no different from CP. The CMWD increased between 2004 and 2007 as the management system became more intensive (MP > CP > NT) (Fig. 1). In agreement with our results, Castro Filho et al. (2002) reported higher rates of aggregate stability under NT compared with CT. These authors suggest that the NT had the best aggregation indices for the 0 - 20 cm layer due to the increase in the organic carbon content.

Working in similar soils of the present work, Aparicio and Costa (2007) reported that CMWD accounted for 36% of the variability in the number of years under continuous agriculture, thus becoming the only physical parameter related to the years of agriculture. The CMWD was significantly higher in MP than in NT in 2007 but was not significantly different in 2004. The CMWD was found to be higher in MP than in NT (Aparicio and Costa, 2007; Gómez et al., 2001), whereas no differences were found beween MP and NT in degraded soils (Ferreras et al., 2000) or between CP and NT in non-degraded soils (Elissondo et al., 2001). The latter authors pointed out that adopting CP in a soil with a good initial physical condition does not lead to important changes in the soil structure.

In the Argentinean Humid Pampa, the increase in structural stability that took place due to the adoption of NT was agriculturally significant. The soils under NT are less susceptible to water erosion and soil crusting and as a consequence can store a higher amount of water for crops. After 11 years implementing the NT system in Mollisols with silty clay loam in the north of the Humid Pampa, Micucci and Taboada (2006) observed a recovery of the CMWD, which reached values similar to those obtained in a pasture. Gramineous crops (wheat and corn) leave a large amount of stubble on the soil surface after the harvest. The absence of tillage and the accumulation of plant residue in the soils under NT have contributed to reducing the loss of structural stability as a consequence of continuous cropping. Similar results have been reported with corn-wheat-soybean and wheat-soybean crop sequences (Gómez et al., 2001).

3.3. Near-saturated Hydraulic Conductivity ($K_{(h)}$)

We did not find significant differences in time and treatments in $K_{(0)}$ and $K_{(-20)}$ but we did find significant differences in time and treatments in $K_{(-70)}$ and $K_{(-150)}$ (Fig. 2 a). No interactions were detected between time and treatments in all water h tested.

Differences of $K_{(h)}$ between treatments were not the same over the range of applied h; at near to saturation conditions (h = -20 mm), there were no significant differences. However, with more negative h, differences between treatments occurred. At h=-70 mm, the measured $K_{(h)}$ values were greater for CT and MP and significantly smaller for NT. At h=-150 mm, the measured $K_{(h)}$ values were greater for CT and significantly smaller for NT and MP. This finding agrees with Hu et al. (2009) in an Entisol from Shenmu County, China, and Schwen et al. (2011) on a silt loam soil from Austria.

Other authors have reported lower K under NT than under MP (Ferreras et al., 2000). In a review of Alvarez and Steinbach, (2009), the authors conclude from several experiments that the infiltration rate was significantly higher under NT than in MP.

Differences of $K_{(h)}$ between years had a similar behavior than differences between treatments (Fig. 2 b), and close to saturation (h=0 and h=-20) differences among time were not significant. However, at h=-70 and h=-150, the $K_{(h)}$ reduced with time when water flow was dominated by mesopores. In a study carried out in the southeast of the Humid Pampa, a significant decrease in $K_{(-40)}$ was observed as the number of years of continuous agriculture increased (R^2 = 0.70), when the determinations were carried out under NT in a fallow period after a wheat crop (Aparicio and Costa, 2007).

The hydraulic conductivity values are heavily affected by temporal variability. After plowing, the soil infiltration for MP or CP is very high compared to NT, but over time the tilled soil is consolidated due to natural compaction and its hydraulic conductivity decreases. This temporal dynamic should be considered when modeling soil water flow (Strudley et al., 2008). To avoid that, in this study, the determinations were always carried out on wheat fallow, as far apart from the last tillage as possible, in order to evaluate only the cumulative effect of the different treatments in the soil properties.

The decrease in NT K_{-70} and K_{-150} is consistent with the low value of structural porosity and the high value of δ_b (Table 3). The main impact of different techniques on soil hydraulic properties is expected to occur in the structural pores, macro- and mesopores. The pore classification of Luxmoore (1981) was used, where macropores have a pressure head range h>-30 mm and mesopores -30 mm <h>-0.003 mm, corresponding to a pore radii of R > 0.5 mm for macropores and 0.5 mm > R > 0.005 mm for mesopores. The lower values of K_h for NT were found when water flow was dominated by mesopores (h>-30).

Moldboard plow created macro- and mesoporosity in the top soil layer, while macroporosity showed a considerable reduction after harvest. As time elapses after the last plowing, through reconsolidation processes, the macropores decrease but the mesopores are kept intact. In NT, the cumulative effect of the passage of machinery exerts a direct physical action upon the soil which affects both macropores and mesopores. However, macroporosity increases. This increase could be due to the fact that biological activity (the decaying roots from the predecessor crop, wheat, and the earthworms) plays a very important role in macropore origin (Shirmohammadi and Skaggs, 1984). This biological activity effect overlay the effect of structure reconsolidation. Bodner et al., (2014) demonstrated that plant roots conditioned soil pore properties via pore stabilization, macropore formation upon coarse root penetration and pore space heterogenization by dense fine root growth. Although macroporosity is a very small fraction of total porosity, it is responsible for the largest fraction of the water fluxes (Table 4 and Fig 3). The increase of δ_b of the soil under NT implies a decrease in the ρ_t (Table 3). This decrease in ρ_t should be reflected in a decrease in infiltration. However, some authors report an increase in infiltration associated with an increase in δ_b (Álvarez and Steinbach, 2009) (this would appear to be a contradiction from a physical point of view). The data provided in this study show that when water flow is produced through macropores, there is no difference between soil under NT and tilled soils; significant differences between treatments are only found when water flow is produced via mespores (Figure 2a). As the water flow via mesopores accounts for a small percentage of total water flow (Figure 4) we can attribute to this the fact that in some studies no significant differences were found in infiltration between soil under NT and tilled soils even though ρ_t is less. We can, therefore, conclude that the reduction in ρ_t under NT is mainly a product of a reduction in the percentage of mesopores in the soil.

3.4. Soil Organic Carbon (SOC)

Time had no statistically significant effect on the SOC content when expressed either as a concentration or as SOC stock. The SOC content, did not show a statistically significant effect among management systems while, when the results were expressed as a stock; NT presented the higher stock of SOC than the other treatments (Fig. 4). Álvarez (2005) suggest that, at the same sampling depth, in soils under NT, a larger amount of soil mass is sampled compared to other management systems, because in NT the δ_b is generally higher than in other tillage systems. Thus, the SOC stock could be overestimated. In the current study, MP and CP presented the lowest values of δ_b, and the SOC stock was significantly lower from NT, which showed the highest values of δ_b.

The stock and the concentration of SOC followed the same trend as the concentration. When the content of SOC is expressed in stock, the experimental error is reduced, compared to expressing it as a concentration. Using SOC as stock made it possible to detect statistically significant differences between NT and the other treatments.

In the southeast of the Humid Pampa, Domínguez et al. (2009) have reported that the SOC content expressed both as concentration and as stock, was not affected by the tillage systems. Moreover, after 11 years of cropping under MP, Studdert and Echeverría, (2000) found a decrease in the soil SOC content. The high SOC content that characterizes the soils of the southeast of the Humid Pampa may be preserved by means of both a careful choice of the crops to be included in the rotation and pastures (Studdert et al., 1997). Also the use of conservation tillage systems reduces the SOC loss (Havlin et al., 1990; Eghaball et al., 1994).

In the Sub-humid Pampa, Díaz Zorita and Grove, (1999b) observed an accumulation of SOC in NT four years after the implementation of this tillage system. When the proportion of corn in the crop sequence was higher, the accumulation of SOC content tended to increase. In an analysis of mega-environments, involving test data distributed in several sites across the Argentinian Pampas, Alvarez, (2005) observed an increase in the SOC content in NT and till. Fabrizzi et al. (2003) have reported increases in the SOC content in NT when the soil was degraded after eight years of continuous agriculture, but not in non-degraded soils with five years of continuous agriculture.

The contribution of crop residues and the soil management practices influences the balance of SOC in the soil. In the present work, the contributions of wheat (2.18 Mg ha^{-1}), corn (1.26 Mg ha^{-1}) and sunflower (0.96 Mg ha^{-1}) residues were similar among the management systems and did not explain the difference of stock found between NT and the other treatments (Alvarez, 2005). This result is also supported by the absence of significant differences in crop yield among the different management systems (Fig. 5). Our results showed that most of the SOC stock in NT, as compared to that in MP and CP, may cause this effect of reduction in the losses of SOC, whereas in MP and CP similar contributions were lost rapidly by effect of the tillage.

Whereas a significant difference was detected in the SOC stock after the 10-year experiment, we could assume that, as suggested by Steinbach and Alvarez (2005), this difference is due to an overestimation by considering higher soil mass in NT.

3.5. Crop Yield

By analyzing the crop yield of the first ten years of this work, we found that the management system did not significantly affect crop yield (Fig. 5). The crop yield in the wheat-corn-sunflower rotation does not behave differently depending on the management system in which they are developed.

The absence of effect of the management system on crop yield has been previously reported for the Humid Pampa (Domínguez et al., 2009; Fabrizzi et al., 2005; Elissondo et al., 2001) as well as for other regions of Argentina (Díaz Zorita et al., 2002). However, in the Sub-humid and Semi-arid Pampas, the crop yields of soybean, wheat and sorghum have been found to be higher with conservation tillage systems (NT and CP). Corn and sunflower have not evidenced the same result (Buschiazzo et al., 1999). Díaz Zorita et al. (2002) in the sub-humid area, found that the yields were favorable to NT only after a five-year sequence. The Semi-arid and Sub-humid Pampas predominant soils are Hapludol and Haplustol and the precipitations do not meet the requirements of water needed by the crops and thus normally limit the yield in MP. The higher moisture content in NT in the first 10 cm of soil in semi-arid areas makes a significant difference in yields (Quiroga et al., 2005). Changes in crop production were also found in other regions due to land management (Ahmad et al., 2013; Nabahungu and Visser, 2013).

4. Conclusions

The continuously agricultural activity for the last 10 years in the humid Pampa is changing the soil properties. Those changes were due to different land managements:

(i) the δ_b values showed a tendency to decrease over time in the three management systems studied under wheat-corn-sunflower rotation. In addition, soil δ_b was significantly higher under NT, but no changes were detected between MP and CP. The δ_b values showed differences in relation to the sampling depth of the sample;

(ii) the CMWD values showed a decrease in the structural stability of the soil due to the agricultural activities. The CMWD increased more between 2004 and 2007 as the management system became intensive (MP > CP > NT);

(iii) we did not find significant differences in time and treatments in $K_{(0)}$ and $K_{(-20)}$ but we did find significant differences in time and treatments in $K_{(-70)}$ and $K_{(-150)}$. The decrease in NT K_{-70} and K_{-150} was consistent with the low value of structural porosity and the high value of δ_b. We can conclude that the reduction in ρ_t under NT is mainly a product of a reduction in the percentage of mesopores in the soil;

(iv) no statistically significant effect on the SOC content when expressed either as a concentration or as SOC stock. The SOC content, expressed as a concentration (%), did not show a statistically significant effect among management systems while, when the results were expressed as a stock, NT presented the higher stock of SOC than the other treatments;

(v) the management system did not affect the yields of the wheat-corn-sunflower crop rotation.

5. Author contribution

JL Costa designed the experiments, performed the statistical analysis and try to keep the financing for 10 years; VC Aparicio followed up the experiments, performed the determinations of field and much of the laboratory measurements and prepared the manuscript with contributions from all co-authors; A. Cerda reviewed the manuscript introduced original contributions in the introduction and he corrected the language.

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Figures

Figure 1. Effect of time on change in the mean weight diameter (CMWD, mm). Bars indicate significant differences (LSMEANS, $p<0.05$).

Figure 2. Near-saturated hydraulic conductivity $K_{(h)}$ as a function of the matric potential (h). a) of the treatments: moldboard plow (MP), chisel plow (CP) and no till (NT) and b) of the time (years 2004, 2007). Different letters indicate significant differences among treatments ($p < 0.05$).

Figure 3. Comparison of pores contribution to flow (% of the total flow) among tillage treatment: moldboard plow (MP), chisel plow (CP), and no till (NT).

Figure 4. Soil organic carbon (SOC, %) in the principal axes and soil organic carbon stock (SOC, g m^{-2}) in the secondary axes of the treatments: moldboard plow (MP), chisel plow (CP) and no till (NT). Different letters indicate significant differences among treatments ($p < 0.05$).

Figure 5. Ten years of average grain yield for Sunflower, Corn and Wheat under moldboard plow (MP), chisel plow (CP) and no till (NT). Bars indicate significant differences (LSMEANS, $p<0.05$).

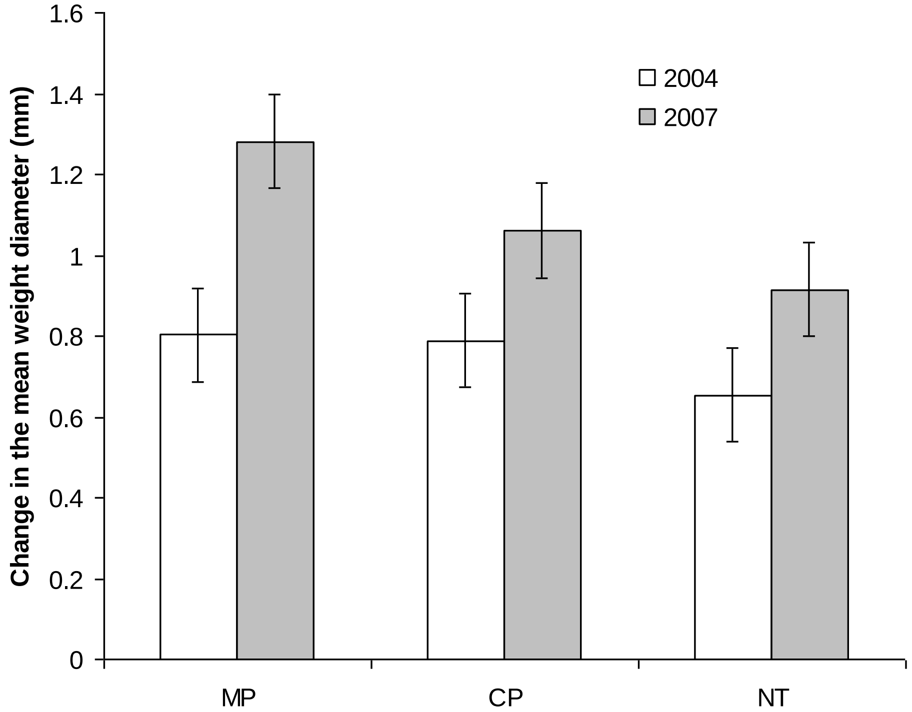
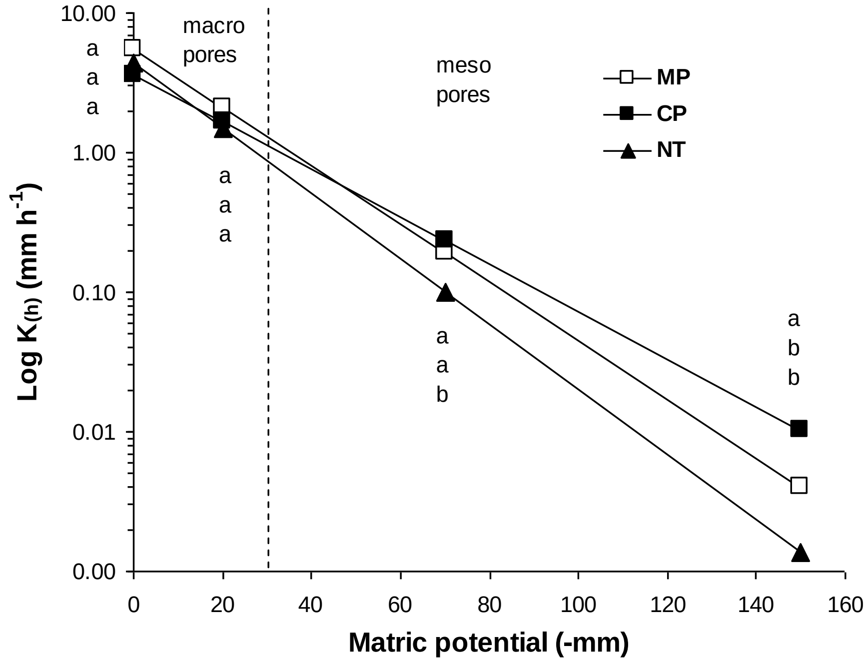
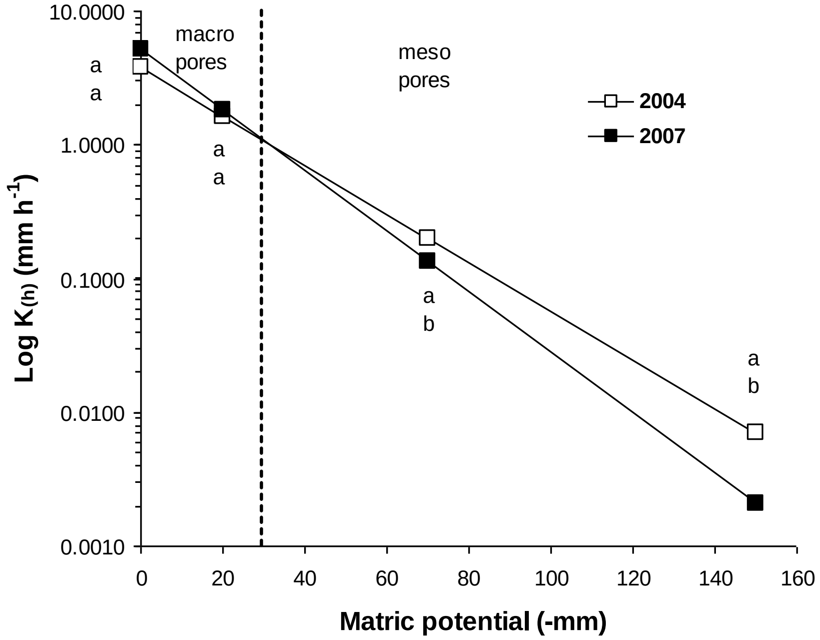

1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Change in the mean weight diameter (mm)
2004
2007
MP
CP
NT

Figure 1

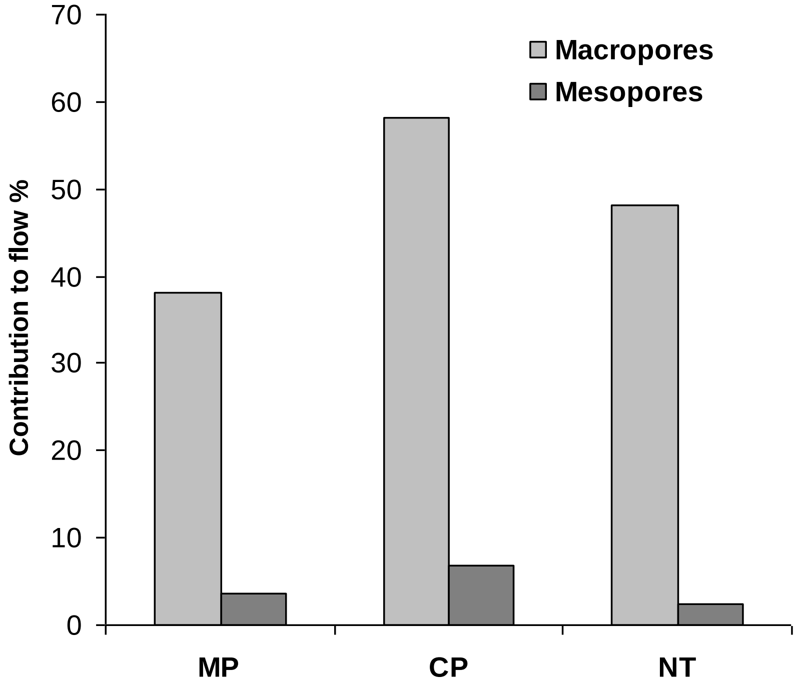

10.00
1.00
0.10
0.01
0.00
Log K(h) (mm h-1)
macro
pores
meso
pores
MP
CP
NT
a
a
a
a
a
a
a
a
b
a
b
b
0
20
40
60
80
100
120
140
160
Matric potential (-mm)

a)


10.0000
1.0000
0.1000
0.0100
0.0010
Log K(h) (mm h-1)
macro
pores
meso
pores
2004
2007
a
a
a
a
a
b
a
b
0
20
40
60
80
100
120
140
160
Matric potential (-mm)

b)

Figure 2.


Macropores
Mesopores
Contribution to flow %
70
60
50
40
30
20
10
0
MP
CP
NT

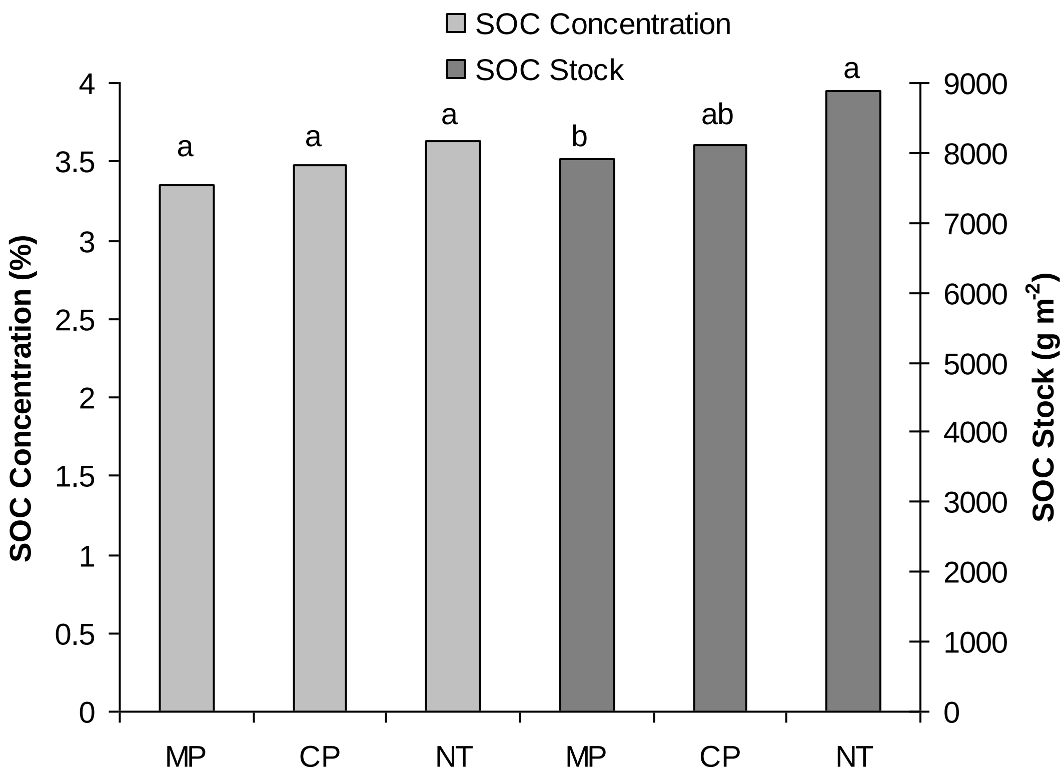

SOC Concentration
SOC Stock
SOC Concentration (%)
SOC Stock (g m-2)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
a
a
a
b
ab
a
MP
CP
NT
MP
CP
NT

Figure 4.

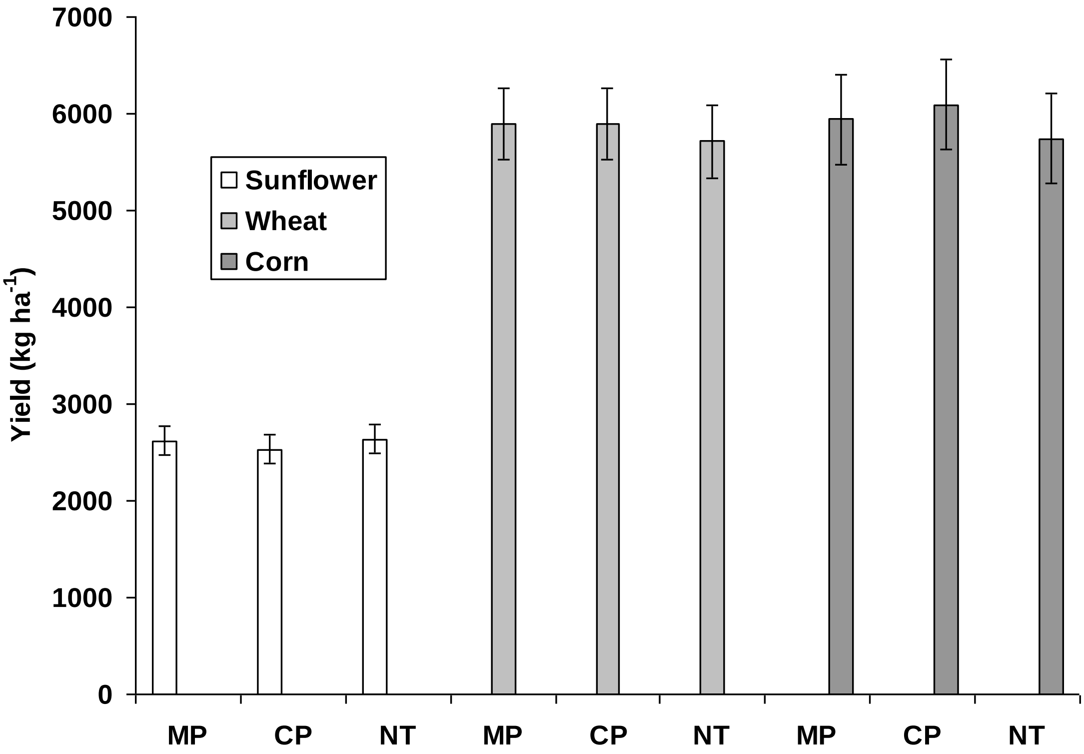

7000
6000
5000
4000
3000
2000
1000
0
Yield (kg ha-1)
Sunflower
Wheat
Corn
MP
CP
NT
MP
CP
NT
MP
CP
NT

Figure 5.

Tables

Table 1. Initial soil characteristics of the experiments: pH, phosphorous content, soil OC stock, cation exchange capacity (CEC), sand, silt and clay content.

Sites	Deph	pH	Phosphorous	SOC stock	CEC	Sand	Silt	Clay
			mg kg^{-1}	g m^{-2}	cmol$_{(+)}$ kg^{-1}		kg kg^{-1}	
Napaleofú	0-20	5.9	11.5	86255	26.5	0.244	0.487	0.270
Balcarce	0-20	5.8	12.2	82272	22.2	0.368	0.445	0.187
Tandil	0-20	5.8	12.2	81226	24.0	0.259	0.462	0.279
Miramar	0-20	5.8	12.9	84125	25.2	0.290	0.507	0.203

Table 2. Effect of time: years 2004 and 2007, depth: from 3 to 8 cm and from 13 to 18 cm and treatments: mouldboard plow (MP), chisel plow (CP) and no till (NT) on soil bulk density.

Effect		Bulk density	
		Mg m^3	
Time	2004	1.20	a*
	2007	1.18	b
Soil depth	3-8 cm	1.21	a
	13-18 cm	1.18	b
Tillage system	NT	1.22	a
	MP	1.19	b
	CP	1.17	b

*Different letters indicate significant differences (LSMEANS, $p<0.05$).

Table 3. Maximum soil density (δ_{bmax}), total porosity (ρ) textural porosity (ρ_t) and structural porosity (ρ_s) by no till (NT), moldboard plow (MP) and chisel plow (CP).

Treatment	δ_{bmax}	ρ	ρ_t	ρ_s
	Mg m^{-3}		m^3 m^{-3}	m^3 m^{-3}
NT	1.50 a (0.01)	0.52 b (0.01)	0.42 a (0.01)	0.11 b (0.02)
MP	1.60 a (0.05)	0.54 a (0.05)	0.38 a (0.02)	0.16 a (0.02)
CP	1.56 a (0.08)	0.54 a (0.08)	0.39 a (0.03)	0.15 a (0.03)

Different letters in the columns meaning significantly different ($p<0.05$).

The numbers in parentheses are standard deviation

Table 4. Effective porosity calculated for each pore class and tillage treatment: moldboard plow (MP), chisel plow (CP), and no till (NT).

Treatment	R† >0.7	0.7>R>0.2	0.2>R>0.1
		$m^3\ m^{-3}$	
NT	0.00013	0.0007	0.024
MP	0.00015	0.0010	0.045
CP	0.00009	0.0008	0.055

† R is the pore radius (mm).