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# Temporal Variation of Soil Physical Quality under Conventional and No-Till Systems

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**ABSTRACT:** Determination of soil physical quality (SPQ) is very important because it is related to many important soil processes. However, it is not clear which indicators should be considered in this evaluation, and information about temporal variation of SPQ under different soil tillage systems is scarce. The aim of this study was to determine the effects of no tillage (NT) and conventional tillage (CT) on temporal variation of capacity SPQ indicators [bulk density (BD), macroporosity (Pmac), air capacity (AC), plant available water capacity (PAWC), relative field capacity (RFC), Dexter's (S), and structural stability index (SSI)], and dynamic SPQ indicators [field saturated hydraulic conductivity ($K_0$), water-conducting macroporosity ($\varepsilon_{ma}$), and mesoporosity ($\varepsilon_{me}$); and pore continuity indexes based on water flux of total porosity ($C_W$TP), of macroporosity ($C_W$mac), and of mesoporosity ($C_w$mes)]. Additionally, the effect of the soil management system on corn yield was evaluated. Measurements and determinations were made at four different moments/cropping stages in the corn growing season (BS: before seeding; V6: six leaf stage; R5: physiological maturity; and AH: after harvest). Capacity SPQ indicators were derived from the soil water retention curve determined using sand box and pressure chambers, and dynamic SPQ indicators were derived from field infiltration data measured using a tension disc infiltrometer. Most capacity SPQ indicators were affected by the moment/cropping stage in which samples were taken, but followed similar trends and had similar values under both treatments, particularly in the AH stage. Dynamic SPQ indicators varied differently during the growing season depending on the management system. Under NT, most dynamic indicators increase from BS to V6 and decrease again at AH, whereas under CT, they follow a different trend, decreasing from BS to V6, remaining constant until R5, and increasing at AH. Corn yield was lower under CT (NT: 10,939 kg ha$^{-1}$; CT: 8,265 kg ha$^{-1}$). These results emphasize the need to include dynamic SPQ indicators, and their temporal variation when evaluating cropping systems with the aim of modeling crop yields. The capacity SPQ indicators were not able to distinguish between treatments.

**Keywords:** hydraulic conductivity, soil water retention curve, pore continuity index.

## INTRODUCTION

Assessing the soil physical quality (SPQ) of the A horizon of the soil is fundamental because soil quality determines many agronomical and environmental processes (Reynolds et al., 2002, 2009) related to crop yield.

Soil physical quality has usually been evaluated through information on organic carbon (OC), bulk density (BD), and soil water retention curve (SWRC) parameters (Reynolds et al., 2002; Dexter, 2004a; Reynolds et al., 2007, 2009). However, inclusion of dynamic indicators that account for water infiltration and movement has been proposed (Iovino et al., 2016; Mentges et al., 2016; Reichert et al., 2016). A capacity parameter gives information about composition of a given soil volume; however, does not describe its functionality (Horn and Kutilek, 2009). In this regard, Lozano et al. (2016) found that capacity indicators measured after crop harvest were not capable of distinguishing the effects of the decompaction of an Argiudoll from the Argentinean pampas region under no tillage in relation to soybean yield.

Singh et al. (2016) found that improvement in SPQ was related to an increase in crop yield. Poor SPQ is related to lower crop performance (Reynolds et al., 2002, 2009). In this regard, Keller et al. (2012) found that crop yield was correlated with hydraulic conductivity (K) in an agricultural field. Reichert et al. (2009) and Suzuki et al. (2013) found that soybean yield was related to the degree of compaction for Alfisols, Ultisols, and Oxisols. These authors emphasized that the optimal values obtained may vary for other crops, or depending on weather conditions. Stepniewski et al. (1994) found that low soil air conductivity may directly affect crop growth and yield, mainly due to lack of adequate aeration. Soil compaction was mentioned as responsible for lower crop yields under NT (Gregorich et al., 1993; Sasal et al., 2006). Other authors found that NT increased plant available water capacity (PAWC) compared to conventional tillage (CT), which resulted in higher corn yield under NT in a soil from the Argentinean pampas region. Alvarez and Steinbach (2009), studying soils from the Argentinean pampas region, concluded that soybean yield was not affected by the tillage system, whereas wheat and corn yields were higher under CT than under reduced tillage and NT without nitrogen fertilization.

Information on temporal variation of SPQ indicators is scarce in the literature (Alletto et al., 2015). Several authors emphasized that soil physical properties show temporal variation (Angulo-Jaramillo et al., 1997; Strudley et al., 2008; Alletto and Coquet, 2009; Hu et al., 2009; Afzalinia and Zabihi, 2014) during the crop season (Angulo-Jaramillo et al., 1997; Bodner et al., 2013) and during the crop rotation sequence (Lozano et al., 2014). Total porosity (TP) and K increase with tillage and decrease during the crop season under CT (Angulo-Jaramillo et al., 1997; Bormann and Klaassen, 2008). Under NT, stabilization of soil properties after some years was reported (Wander and Bollero, 1999; Álvarez et al., 2009a). However, other authors found that soil physical properties vary temporally under NT. Lozano et al. (2014) found that after a long period under NT, the porous system configuration and K of a Argiudoll from the pampas region did not reach steady values, regardless of the specific time in the crop sequence. Moreira et al. (2016) concluded that soil physical properties under NT vary during the crop growing season. Afzalinia and Zabihi (2014) concluded that measuring BD and cone index during the crop growing season gave more accurate data than measuring these parameters at the end of growth season.

Reynolds et al. (2002) concluded that further work is required to determine if field-crop yield will be consistently improved by the proposed indicator parameters within their respective optimal ranges. The study of variation in different SPQ indicators during the crop cycle, taking into account weather conditions and critical crop stages, could help us better understand the usefulness of different indicators in relation to crop yield.

We hypothesized that the temporal variability of SPQ indicators during the crop growing season exhibits different behavior under CT than under NT, and that capacity and dynamic SPQ indicators follow different temporal trends during the growing season and depend on the tillage system. Thus, this study aimed to assess the effect of NT and CT systems on the temporal variation of soil physical quality indicators. Additionally, the effect of the soil management system on corn yield was evaluated.

## MATERIALS AND METHODS

### Soil description and experimental design

The plots studied were located at the agricultural experimental station of INTA (National Institute of Agricultural Technology) in Chascomús, Argentina, at 35° 44' 37.61" South and 58° 3' 10.22" West. The climate is temperate, with average annual rainfall of 946 mm. The soil is an abruptic Argiudoll. The A horizon texture is loam (25 % clay, 41.5 % silt, and 33.5 % sand). The OC content of the A horizon was similar among plots, with a value of 2.85 %.

Before the treatments were applied, the plots were under CT and had grown the same crops (corn, sunflower, and winter cover grass) for more than 20 years. In the year 2000, an experimental design with two treatments (NT and CT) was applied. A detailed description of the soil, experimental design, and treatments was provided by Villarreal et al. (2017). From the year 2000 the crops were corn, sunflower, and winter cover grass. The crop for the last 4 years was corn. In October 2014, a glyphosate-resistant hybrid of corn was sown at a row space of 0.75 m. Fertilizers were applied at sowing (80 kg $ha^{-1}$ monoammonium phosphate + 90 kg $ha^{-1}$ urea). Weeds were chemically controlled in both treatments using 3 L $ha^{-1}$ atrazine + 2 L $ha^{-1}$ acetochlor at pre-emergence (two days after sowing, October 2014) and 1.5 kg $ha^{-1}$ glyphosate (79 %) at post emergence (V10, January 2015). Two adjacent plots corresponding to NT and CT were studied.

Four moments/cropping stages of the corn growing season were evaluated: October 2014, just after tillage was applied in the CT treatment; before seeding (BS), in December 2014 (V6, 6 leaf stage); in March 2015 (R5, physiological maturity); and after harvest (AH) in June 2015. Manual harvest (four 6-m length rows of each treatment) was used to determine corn yield. Corn yield was normalized to 12 weight % grain moisture content.

### Capacity SPQ indicators

Ten intact soil cores (0.05 m height, 0.05 m diameter, $98 \times 10^{-4}$ $m^3$) from each treatment and cropping stage were taken from the 0.00-0.10 m topsoil layer for determination of the soil water retention curve (SWRC). Soil bulk density (BD) and derived total porosity (TP) were determined in the samples (Blake and Hartge, 1986). Values of water retention data at pressure head, h (L), of 0, 0.1, 0.3, 0.5, 0.7, -1.0, -3.0, and -150.0 m were determined using a sand box apparatus for h values between 0 and -1, and a pressure chamber for h values ≤ -3 m. The retention curve (RETC) code (van Genuchten et al., 1991) was used to fit the van Genuchten (1980) model to the water retention data obtained for each soil sample (Figure 1). The $R^2$ values for observed versus fitted values was >0.95 in all cases. The capacity indicators of SPQ (macroporosity, Pmac; air capacity, AC; plant available water capacity, PAWC; and relative field capacity, RFC) were calculated from fitted SWRC data following Reynolds et al. (2009). Dexter's S was determined from SWRC parameters (Dexter, 2004a). The methodology proposed by Pieri (1992) was used to calculate an index that evaluates structural stability (SSI). Finally, the values obtained from each indicator were evaluated in comparison to ranges proposed by different authors (Table 1).

### Dynamic SPQ indicators

Dynamic SPQ indicators were derived from infiltrometry data. Steady-state infiltration rates at three tensions, h (-6, -3, and 0 cm), were obtained using disc infiltrometers

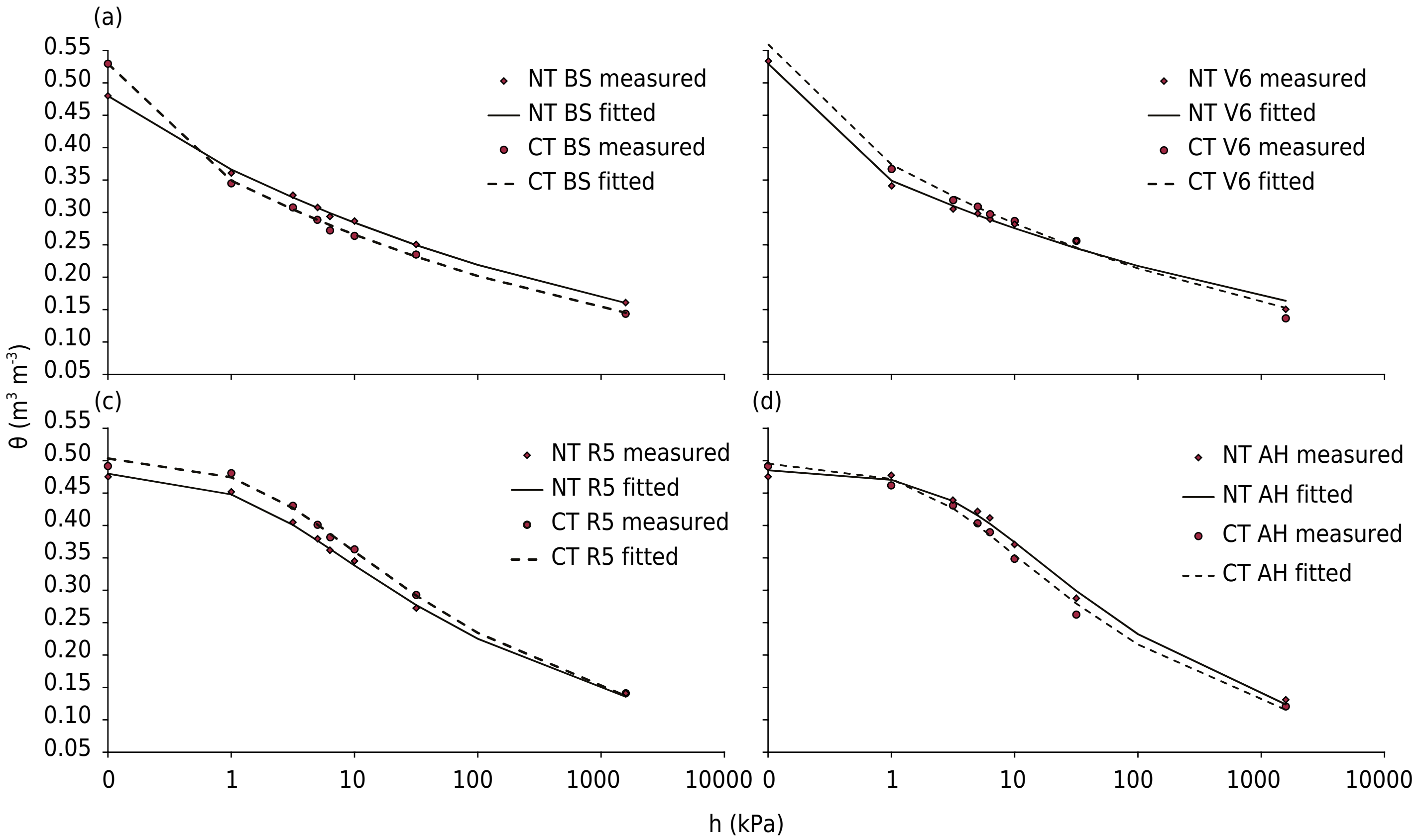


**Figure 1.** Water retention curves for each treatment and cropping stage of sampling. One representative sample for each treatment and cropping stage of sampling is shown. Lines represent van Genuchten fits ($R^2$ >0.95), and dots represent measured data.

(Perroux and White, 1988). Five replicates for each treatment and cropping stage were carried out. The full procedure is described in Lozano et al. (2016). Hydraulic conductivity, at the different tensions, h (i.e., $K_6$, $K_3$, and $K_0$), was calculated using the multiple-tension method (Ankeny et al., 1991).

Water-conducting macroporosity ($\varepsilon_{ma}$, equivalent r >0.5 mm) and water-conducting mesoporosity ($\varepsilon_{me}$, 0.5> equivalent r >0.25 mm) were determined from K data (Watson and Luxmoore, 1986).

The continuity of each pore size family (TP; macropores, d >1 mm; and mesopores, 1< diameter <0.5 mm) was calculated according to Lozano et al. (2013). This index ($C_w$) is the quotient between K and the volumetric fraction of each pore size family, and it provides valuable information regarding the effects of soil management on soil pore configuration and pore functionality (Soracco et al., 2015; Lozano et al., 2016).

### Statistical analysis

For SPQ indicators, analyses of variance (Anova) were used with two factors: the treatment and the cropping stage of sampling. For crop yield, Anova with treatment as factor was used. Means were compared using the LSD test. The distribution of $K_0$ was log-normal, and then, analyses were carried out on log-transformed values.

## RESULTS AND DISCUSSION

### Capacity soil physical quality indicators

The values of capacity SPQ indicators for both treatments and different cropping stages of sampling are shown in table 2. From two-way Anova, non-significant interactions between the factors were found, except for BD. This means that these capacity SPQ indicators

**Table 1.** Reference ranges and critical limits of capacity soil physical quality indicators

| Indicator[(1)] | Critical limits | Reference |
|---|---|---|
| BD | 0.9≥ BD ≥1.2 Mg m$^{-3}$, optimal BD range for maximum field crop production in fine- to medium-textured soils.<br>1.2≤ BD <1.25 Mg m$^{-3}$, good BD<br>BD ≥1.25, poor values of BD potentially reduces crop yield due to inadequate soil aeration<br>BD <0.9 Mg m$^{-3}$, poor values of BD potentially reduces crop yield due to inadequate plant anchoring, reduced PAWC, and unsaturated flow of water and solutes. | Reynolds et al. (2008), Reynolds et al. (2009) |
| Pmac | Pmac ≥0.07 m$^3$ m$^{-3}$, optimal values of macroporosity, which indirectly indicate the soil's ability to quickly drain excess water and facilitate root proliferation.<br>0.04≤ Pmac <0.07 m$^3$ m$^{-3}$, good value<br>Pmac <0.04 m$^3$ m$^{-3}$, poor value, soil degraded by compaction. | Reynolds et al. (2008), Reynolds et al. (2009) |
| AC | AC >0.14 m$^3$ m$^{-3}$, optimal/ideal value for minimum susceptibility to crop-damaging or yield-reducing aeration deficits in the root zone<br>0.10≤ AC <0.14 m$^3$ m$^{-3}$, good value<br>AC <0.10 m$^3$ m$^{-3}$, poor value | Reynolds et al. (2009), White (2006) |
| PAWC | PAWC >0.20 m$^3$ m$^{-3}$, "ideal" for maximal root growth and function<br>0.15≤ PAWC <0.20 m$^3$ m$^{-3}$, good for root growth and function<br>0.10≤ PAWC <0.15 m$^3$ m$^{-3}$, limited for root growth and function<br>PAWC <0.10 m$^3$ m$^{-3}$, poor for root growth and function | Reynolds et al. (2009) |
| RFC | 0.6≤ RFC ≤0.7, ideal values, indicate optimal balance between root-zone soil water capacity and soil air capacity<br>RFC <0.6, poor value, indicate water limited soil<br>RFC >0.7, poor value, indicate aeration limited soil | Reynolds et al. (2008), Reynolds et al. (2009) |
| S index | S ≥0.050, optimal/ideal soil physical or structural quality<br>0.035≤ S ≤0.050, good physical quality<br>0.020≤ S ≤0.035, poor physical quality<br>S ≤0.020, very poor or degraded physical quality | Dexter (2004b), Dexter and Czyż (2007) |
| SSI | SSI >9 %, optimal value, indicates stable structure<br>7≤ SSI ≤9 %, very good values, indicate low risk of structural degradation<br>5≤ SSI ≤ 7%, good values, although indicate high risk of degradation<br>SSI ≤5 %, poor values, indicate structurally degraded soil | Pieri (1992) |

[(1)] BD was determined by Blake and Hartge (1986) method; Pmac, AC, PAWC, and RFC were calculated from fitted SWRC data following Reynolds et al. (2009); S index was determined following Dexter (2004a); SSI index was determined by Pieri (1992).

followed similar temporal trends in both treatments. Capacity SPQ indicators were affected by the cropping stage of sampling and the treatment. This is in disagreement with some previous reports that stated that, under NT, a stabilization without significant changes in soil physical properties is reached after five years (Álvarez et al., 2009a), but in agreement with Moreira et al. (2016), who concluded that soil physical properties under NT show significant temporal variation. These indicators followed similar trends and showed similar values under both treatments, particularly in the AH stage. This indicates that the effects of tillage do not remain until the AH stage, which had been reported for similar soils (Álvarez et al., 2006; Sasal et al., 2006; Álvarez et al., 2009a,b; Soracco et al., 2010, 2012; Lozano et al., 2016). Similar values of Pmac and AC between treatments in the AH stage may be attributed to the effect of harvest traffic on macropores created by tillage. Differences between NT and CT were not evident among these capacity SPQ indicators at the last stage of cropping. The BD was similar between treatments in the BS stage, and followed different trends through the growing season. Under NT, the BD values decreased significantly from BS to V6, and were not statistically different between V6, R5, and AH, whereas under CT, the BD values were not statistically different between BS, V6, and R5, but decreased significantly in the AH stage. Under CT, the soil had optimal values of Pmac (>0.07 m$^3$ m$^{-3}$) and AC (>0.14 m$^3$ m$^{-3}$) from BS to V6, due to the effect of tillage, and then decreased until R5. These SPQ indicators showed the same behavior under NT.

**Table 2.** Capacity SPQ indicators (mean values ± standard deviations) for the different treatments (NT and CT) and cropping stages of the corn growing season (BS, V6, R5, and AH)

| Treatment | Cropping stage | BD[1] | Pmac | AC | PAWC | RFC | S | SSI |
|---|---|---|---|---|---|---|---|---|
| | | Mg m$^{-3}$ | m$^3$ m$^{-3}$ | m$^3$ m$^{-3}$ | m$^3$ m$^{-3}$ | | | % |
| NT | BS | 1.24±0.04 a+[2] | 0.06±0.01 b+ | 0.15±0.01 b++ | 0.10±0.01 c- | 0.68±0.02 c+ | 0.034±0.004 d- | 7.2 c+ |
| | V6 | 1.12±0.03 b++ | 0.07±0.004 a++ | 0.15±0.01 b++ | 0.09±0.01 c- | 0.67±0.01 c+ | 0.033±0.003 d- | 8.6 a+ |
| | R5 | 1.10±0.02 b++ | 0.01±0.002 c- | 0.07±0.01 c- | 0.19±0.01 b+ | 0.84±0.02 b- | 0.056±0.004 b++ | 8.7 a+ |
| | AH | 1.09±0.01 b++ | 0.01±0.003 c- | 0.06±0.02 d- | 0.21±0.01 a++ | 0.88±0.04 a- | 0.063±0.008 a++ | 7.6 b+ |
| CT | BS | 1.21±0.04 a+ | 0.07±0.008 a++ | 0.17±0.01 a++ | 0.12±0.01 c- | 0.65±0.01 c- | 0.043±0.002 c+ | 7.2 c+ |
| | V6 | 1.24±0.05 a+ | 0.08±0.007 a++ | 0.18±0.01 a++ | 0.11±0.01 c- | 0.64±0.02 c- | 0.040±0.003 c+ | 7.6 b+ |
| | R5 | 1.24±0.05 a+ | 0.01±0.002 c- | 0.08±0.01 c- | 0.20±0.01 b++ | 0.84±0.02 b- | 0.059±0.005 b++ | 7.8 b+ |
| | AH | 1.08±0.03 ab+ | 0.01±0.003 c- | 0.07±0.02 c- | 0.22±0.02 a++ | 0.85±0.03 b- | 0.065±0.006 a++ | 7.5 b+ |

[1] BD was determined by Blake and Hartge (1986) method; Pmac, AC, PAWC, and RFC were calculated from fitted SWRC data following Reynolds et al. (2009); S index was determined following Dexter (2004a); SSI index was determined by Pieri (1992). [2] For each indicator, values followed by the same letter are not statistically different (LSD test, p=0.05). Optimal values are followed by (++), good values by (+), and poor values by (-), based on table 1.

The PAWC was poor (PAWC <0.15 m$^3$ m$^{-3}$) from BS to V6, but had ideal values (PAWC >0.20 m$^3$ m$^{-3}$) from R5 to AH, in both treatments. This can be attributed to a change in pore size distribution. In the CT treatment, this can be attributed to rearrangement of tillage-generated clods. The value of RFC was greater than the optimal values (0.6≤ RFC ≤0.7) from R5 to AH in both treatments, which is considered to be a limited aeration soil (Reynolds et al., 2009). The SPQ indicator S also increased from V6 to R5 in both treatments, arriving in the range of optimal values (S ≥0.050) at R5. In contrast, the values of SSI were always within the range of very good values (7≤ SSI ≤9 %) in both treatments.

Capacity SPQ indicators and their optimal ranges and critical values were not capable of distinguishing between treatments. Similar results were obtained by Lozano et al. (2016).

### Dynamic soil physical quality indicators and pore continuity indexes based on water flux

The values of $K_0$, dynamic SPQ indicators, and $C_w$ for both NT and CT in accordance with the cropping stage of sampling are shown in table 3. From two-way Anova, a significant interaction between treatment factors and cropping stage of sampling was found for all dynamic SPQ indicators. This means that these indicators followed different temporal trends depending on the tillage system.

The $K_0$ followed a trend similar to $\varepsilon_{ma}$ in both treatments. Several authors (Capowiez et al., 2009; Soracco et al., 2011; Lozano et al., 2016) reported that both variables are highly correlated. Under CT, $K_0$, $\varepsilon_{ma}$, and $C_w$TP exhibited higher values at the BS stage, just after tillage practices were applied, decreasing in V6, and increasing again in AH, whereas $C_w$mac showed a different behavior, with a higher value in AH. These results show that in this soil, tillage practices have low persistence, and that the improvements in pore connectivity and in hydraulic properties induced by the machinery did not remain through the crop growing season. The increase in $C_w$mac in AH may be attributed to the decrease in the volume of macropores and the slight increase in $K_0$. This implies that the remaining macropores have better connectivity. These results are in agreement with some previous reports from the Pampas region (Álvarez et al., 2006) and from other regions (Angulo-Jaramillo et al., 1997; Bormann and Klaassen, 2008). These studies concluded that $K_0$ increases with tillage and then decreases during the growing season due to the settling of the soil structure.

**Table 3.** Dynamic SPQ indicators (mean values and standard deviations) for the different treatments (NT, CT) and cropping stages of the corn growing season (BS, V6, R5, and AH)

| Treatment | Cropping stage | $K_0$[(1)] | $\varepsilon_{ma}$ | $\varepsilon_{me}$ | $C_wTP$ | $C_wmac$ | $C_wmes$ |
|---|---|---|---|---|---|---|---|
| | | cm $h^{-1}$ | % | % | cm $h^{-1}$ | cm $h^{-1}$ | cm $h^{-1}$ |
| NT | BS | 1.57±0.6 c[**] | 0.0008±0.0002 c | 0.0014±0.0002 bc | 3.17±0.16 c | 64.61±3.91 c | 17.50±0.72 c |
| | V6 | 3.23±1.1 ab | 0.0013±0.0003 b | 0.0018±0.0003 a | 6.01±0.16 a | 92.04±2.39 c | 20.55±1.37 b |
| | R5 | 3.23±0.9 ab | 0.0012±0.0002 b | 0.0024±0.0006 a | 5.87±0.17 a | 254.81±9.51 a | 26.60±2.34 a |
| | AH | 1.67±0.4 c | 0.0009±0.0001 c | 0.0011±0.0003 bc | 2.98±0.10 c | 150.29±4.56 b | 23.24±3.45 a |
| CT | BS | 3.75±1.2 a | 0.0022±0.0004 a | 0.0021±0.0005 a | 7.13±0.30 a | 70.59±4.05 c | 26.92±0.86 a |
| | V6 | 1.83±0.4 c | 0.0015±0.0003 b | 0.0008±0.0002 c | 3.25±0.18 c | 28.45±1.34 d | 19.15±1.16 b |
| | R5 | 1.73±0.6 c | 0.0014±0.0002 b | 0.0009±0.0003 c | 3.08±0.09 c | 72.89±3.46 c | 22.96±4.54 b |
| | AH | 2.40±0.8 bc | 0.0019±0.0001 a | 0.0006±0.0001 c | 4.47±0.08 b | 234.75±8.45 a | 13.87±1.25 c |

[(1)] Saturated hydraulic conductivity ($K_0$), water-conducting macro- and mesoporosity ($\varepsilon_{ma}$, and $\varepsilon_{me}$, respectively), and pore continuity indexes based on water flux for total porosity, macroporosity, and mesoporosity (CwTP, Cwmac, and Cwmes, respectively). [**] For each indicator, values followed by the same letter are not statistically different (LSD test, p=0.05).

Under NT, the dynamic SPQ indicators and Cw values followed a different trend than under CT. The values of $K_0$, $\varepsilon_{ma}$, $\varepsilon_{me}$, and $C_wTP$ increased significantly from BS to V6, remaining high until R5, and then decreasing in AH until reaching values similar to the initial ones. In contrast, $C_wmac$ and $C_wmes$ increased until R5, and then decreased in AH to values higher than the initial values in the BS stage. The increase in $\varepsilon_{ma}$ and $\varepsilon_{me}$ from BS to V6 can be attributed to decay of the roots of the previous crop (corn) during the season studied. Corn roots have been reported to create vertical macropores (Lozano et al., 2014). The decrease in $K_0$ and in pore size fractions and connectivity in AH can be attributed to the high traffic intensity associated with harvest (Soracco, 2009; Soracco et al., 2012). Furthermore, root growth of the current crop may have blocked some pores.

The results show that under both treatments, the properties studied have strong differences depending on the cropping stage at which sampling occurs. Even when under NT, there was crop induced improvement in K and in porosity, but these changes did not persist in AH, which is probably related to the initially poor physical condition of the soil before NT was adopted (Ferreras et al., 2000; Fabrizzi et al., 2005).

Overall, the dynamic SPQ indicators were able to detect changes in the soil due to tillage practices, and different temporal dynamics of the soil. The Cw proved to be particularly useful as an SPQ indicator since it integrates dynamic and capacity information in a single value.

## Crop yields

Mean crop yields were as follow: NT = 10,939 kg $ha^{-1}$ and CT = 8,265 kg $ha^{-1}$; the latter was significantly lower. Similar results were reported in studies from the Pampas region (Kleine and Puricelli, 2001) and from other regions (Javeed et al., 2013). However, some studies reported the opposite (Blevins et al., 1983; Munkholm et al., 2013; Afzalinia and Zabihi, 2014), and other studies found similar corn yields between NT and CT (Echeverría and Sainz Rojas, 2001; Elissondo et al., 2001). The lack of agreement between different studies may be due to the effects of different weather conditions. In a ten-year study, Bailey et al. (1996) found that the corn yield was higher, lower, or similar between NT and CT depending on the weather conditions.

Total rainfall and average monthly temperatures between sowing (October) and harvest (April) are shown in table 4. Plant emergence was favored by high values of air temperature and rainfall (October). Mean air temperatures were higher than the 40-year-average

**Table 4.** Monthly weather values during the period studied

| Period[(1)] | Rainfall | | Temperature | |
|---|---|---|---|---|
| | 2014-2015 | 1961-2011 | 2014-2015 | 1961-2011 |
| | mm | | °C | |
| October | 141.0 | 96.8 | 17.4 | 14.9 |
| November | 131.6 | 84.8 | 18.8 | 17.3 |
| December | 97.3 | 69.2 | 21.8 | 20.6 |
| January | 156.5 | 83.7 | 22.1 | 21.7 |
| February | 46.2 | 92.4 | 22.1 | 21 |
| March | 7.6 | 94.7 | 20.8 | 18.8 |
| April | 55.6 | 78.3 | 18.1 | 15.5 |
| Total | 1,110.5 | 823.8 | 20.2 | 18.5 |

(1) In Chascomús, Buenos Aires (National Institute of Agricultural Technology).

temperatures throughout the crop growing period. The 40-year-average rainfall (1961-2011) in the period studied was 823.8 mm, whereas in 2014-2015, average rainfall was 1,110.5 mm. However, the distribution was inadequate, with very high rainfall amounts from October to January, and very low rainfall amounts from February to April. The rainfall was particularly low in March (7.6 mm versus a historic average of 94.7 mm), and the temperature was two degrees higher than the historic average. This led to a higher water deficit in this period. In March, the crop was in the last reproductive stages, which mainly determine grain weight and thus crop yield.

The difference in crop yield between NT and CT may be attributed to several factors, including weather conditions, weed population, and competition, soil quality, and others. Predicting crop yield is very complex, and models including all these factors are the best tool.

Our results indicate that including temporal variability of SPQ indicators, particularly dynamic SPQ indicators, is useful for better predicting crop yield through modelling. The capacity SPQ indicators were not able to distinguish between treatments.

## CONCLUSIONS

The tillage system affects the temporal dynamics of soil physical quality during the growing season. Both capacity and dynamic SPQ indicators vary temporally under NT and CT.

Dynamic indicators are the most affected, and they vary differently during the growing season depending on the management system.

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