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Temporal variation of soil sorptivity under conventional and no-till systems determined by a simple laboratory method

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ABSTRACT

Soil water sorptivity (S) is an important property that measures the soil capacity to take water rapidly under capillary forces. Usually S is not included in soil laboratory routine experiments because there is not a widely accepted methodology for its determination. The objectives of this work were: i) to propose a modification on the Leeds-Harrison et al. (1994) method (LH) to determine S in undisturbed soil samples; and ii) to determine the temporal variation of S and saturated hydraulic conductivity (K_0) in a soil under conventional tillage (CT) and no-tillage (NT) treatments. Additionally, the influence of soil pore size distribution (PoSD) on S was analyzed. Undisturbed soil samples (5 cm height, 5 cm diameter) were collected from the upper 10 depth cm of each plot, from each treatment at four different times during a maize growing season (before seeding (BS), 6 leaf stage (V6), physiological maturity (R5) and after harvest (AH)). PoSD was determined in a sand box apparatus. After that, S was determined in the same samples using a modified Leeds-Harrison approach. For the proposed modification the difference between initial and final water content was actually gravimetrically measured in each sample, rather than considering it equal to the total porosity (TP). The proposed improvement was validated comparing the obtained S values with those calculated using standard one-dimension horizontal infiltration in sieved soil (0.098 vs 0.079 $\mathrm{cm\,s^{-1/2}}$, respectively) and in calibrated sand (0.041 vs 0.040 $\mathrm{cm\,s^{-1/2}}$, respectively). These differences were not significant. Both S and K_0 were significantly affected by the sampling time in both treatments (mean values ranged between 0.022 and 0.077 $\mathrm{cm\,s^{-1/2}}$ and 1.57 and 3.75 $\mathrm{cm\,s^{-1}}$ respectively). We did not find a significant dependence of S with three pore size ranges analyzed. The proposed improvement of the Leeds-Harrison method allowed determining the temporal variation of S in representative undisturbed soil samples.

1. Introduction

Successful crop production in dryland agroecosystems depends heavily on capturing and storing adequate soil water to sustain the crop until the next precipitation event (Shaver et al., 2013). Thus, the aim of soil management practices in dryland agroecosystems is water conservation and in particular rapid water capture (Peterson et al., 2012). Sorptivity (S) [$LT^{-1/2}$] is an important hydraulic property that describes the soil's capacity to uptake water rapidly and it is a measure for the capacity of the soil to absorb water under capillarity forces (Koorevaar et al., 1983). This term was first introduced by Philip (1957) in his well-known two-term infiltration equation, and is one of the most important soil parameters governing the early portion of infiltration (Chong and Green, 1983). After that, several methods have been developed for obtaining S values, including simplified numerical solutions of infiltration (Philip, 1966, 1968), methodologies based on ponded infiltration using single and double-ring infiltrometers (Talsma, 1969, Scotter et al., 1982) and by infiltration at negative matric pressure (Clothier and White, 1981). In the last years, S was generally obtained from early stages field infiltration data, assuming that both gravity and

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lateral capillarity effects can be neglected (Vandervaere et al., 2000). So, cumulative infiltration I [L] is then approximated by Philip (1957) equation established for one-dimensional horizontal infiltration:

$$I = St^{1/2} \tag{1}$$

Where I is the cumulative infiltration, S is soil sorptivity and t is the time.

This method can lead to some errors; because the gravity and lateral capillary effects are always present and S can be overestimated (Smettem et al., 1995; Vandervaere et al., 2000). Moreover, other authors proposed different infiltration models and numerical solutions to estimate S. These methodologies require the knowledge of saturated hydraulic conductivity (K_0), soil water diffusivity or fitting parameters which are not easy to estimate (Zhang, 1997; Angulo-Jaramillo et al., 2000).

Soil management practices affect the soil pore system configuration (Lozano et al., 2013, Soracco et al., 2015) and related soil physical properties, especially on the uppermost surface soil layer, which is critical because it represents the initial soil-precipitation interface (Soracco, 2009). This implies a great impact on water infiltration, distribution and storage in agricultural soils (Hillel, 1998). S has been found to be positively related to total porosity (TP) (Ferrero et al., 2007; Lipiec et al., 2009; Raut et al., 2014). Several authors pointed out that a tillage system affects TP mainly by producing a modification on the macropore fraction (Kay and VandenBygaart, 2002; Lipiec et al., 2009; Soracco et al., 2012). No tillage (NT) management can create some macropores, increasing S (Shaver et al., 2013). However, the dependence of S on different pore size classes has been less studied and there is a lack of knowledge on this topic. Shaver et al. (2013) studied the effect of TP and effective porosity (TP minus volumetric water content at −10 kPa suction) on S. They found a weaker relationship between S and effective porosity than the one found with TP. This suggests that all pore size fractions are important for the water entry process. Hallett et al. (2004) studied S dependence on macroporosity. These authors found spatial variability of S at larger scales, attributed to macroporosity variation.

Many authors (Angulo-Jaramillo et al., 1997; Azevedo et al., 1998; Álvarez et al., 2006,2009) have studied the soil management effect on different soil hydraulic properties and its temporal variation during the crop cycle in different regions. Most of them found an increment on K_0 and on infiltration rate after tillage, and then a decrease during the growing season due to the settling of the soil structure created by tillage. In contrast, Álvarez et al. (2009) concluded that the effect of soil loosening before sowing on increasing water infiltration rate remained until last stages of crop growth. Nevertheless, there is few information about temporal variation of S during the crop cycle. Murphy et al. (1993) studied S variation during the growing season of different crops of an agricultural rotation under conventional tillage (CT) and NT. They found a temporal variation of S that led to an increment after harvest due to the macroporosity generated by roots under both managements. On the other hand, Starr (1990) reported temporal variation of S only under CT, and found constant values of S under NT. Angulo-Jaramillo et al. (1997) found a decrease of S values only in sandy soils under furrow irrigation during the growing season.

Moreover, usually S is not included in soil laboratory routine experiments. Leeds-Harrison et al. (1994) proposed a laboratory method (LH method) to estimate S in soil aggregates using a micro-infiltrometer, based on Wooding's equation (Wooding, 1968) that describes the infiltration process from a circular source of water at steady state:

$$\frac{Q}{\pi r^2} = K_0 + \frac{4b\Phi}{\pi r} \tag{2}$$

where Q is the steady-state rate of flow from the circular pond of radius r, K_0 is the hydraulic conductivity of saturated soil, Φ is the soil matric flux potential and b is a parameter that depends on the shape of the soil water diffusivity function.

White and Sully (1987) proposed the following expression for Φ:

$$\Phi = \frac{bS^2}{(\theta - \theta_0)} \tag{3}$$

Where S is the sorptivity, and θ and θ_0 are the final and the initial volumetric soil water content, respectively. The difference between θ and θ_0 is called f. Then Eq. (2) becomes:

$$\frac{Q}{\pi r^2} = K_0 + \frac{4bS^2}{\pi r f} \tag{4}$$

Leeds-Harrison et al. (1994) mentioned that the value of S is typically between 0.1 mm $s^{-1/2}$ for fine-textured soils having a value of K_0 of 0.0001 mm s^{-1}, and 4 mm $s^{-1/2}$ for coarse-textured soils having a K_0 of 0.1 mm s^{-1} (Youngs, 1968; Youngs and Price, 1981). Thus, with f typically around to 0.2, the ratio of the first and second terms on the right-hand side of Eq. (4) is less than 0.01 for a wetting radius r around 3 mm, so that the first term can be neglected. After rearrangement Eq. (4) becomes

$$S = \sqrt{\frac{Qf}{4br}} \tag{5}$$

This is a simple and non-consuming way to estimate S, and allows to run many replications in a very short time. The LH method takes the water content difference, f, equal to TP, because the wetting bulb is at saturation. However, complete soil saturation is rarely reached in real experiments, and there is no way to be sure if saturation was achieved (e.g. entrapped air, preferential flow pathways) (Kutilek and Nielsen, 1994). Furthermore, this method was developed for soil aggregates. Measuring S on undisturbed soil samples would be useful when whole soil pore system evaluation, including inter-aggregate porosity, is the aim of the study. Moreover, in the LH method, water infiltration rate is estimated visually from the advance of water menisci, which is a tedious methodology. After that, different authors proposed to measure the cumulative infiltration from the difference in weight of the reservoir of liquid, with a balance connected to a datalogger, obtaining several data in a simple way (Vogelmann et al., 2010). However, the most important imprecision in the LH method is that f is assumed equal to TP, leading to errors in S estimates. This problem could be solved by measuring the actual initial and final soil water content gravimetrically; which is relevant information in S determinations.

The determination of S and K_0 at different moments under CT and NT will allow us to better understand the temporal variation of soil water dynamics. Additionally, the comparison between the K_0 and S values, will allow us to verify the suitability of S as a good indicator in order to determine soil structure changes.

We hypothesized that i) it is possible to determine S with a simple laboratory method on undisturbed soil samples; and that ii) S and K_0 presents temporal variation during the crop cycle under CT and NT treatments, following a similar trend.

The objectives of this work were: i) to propose a modification on Leeds-Harrison et al. (1994) method to determine S in undisturbed soil samples; and ii) to determine the temporal variation of S and K_0 in a soil under CT and NT treatments. Additionally, the influence of soil PoSD on S was analyzed.

2. Materials and methods

2.1. Site and treatments

The experiment was carried out near the town of Chascomús, Argentina (located at 35°44′37,61″ South and 58°03′10,22″ West). The soil was classified as a fine, illitic, thermic abruptic Argiudoll (Soil Survey Staff, 2006), Luvic Phaeozem (IUSS Working Group WRB, 2007). The climate in the region is temperate (the temperature seldom goes below 0 °C) and the approximate annual rainfall reaches 1000 mm.

The plots were under the same treatments and with a crop rotation including maize and soybean for the last 15 years. The experimental design was completely randomized with two treatments: a) no tillage (NT), in which only a narrow (5 cm) strip of the soil was drilled to deposit crop seeds, b) conventional tillage (CT) in which the soil was ploughed (disc plough + tooth harrow) at 20 cm depth, and later smoothed using the tooth harrow every year in October, just before maize or soybean seeding.

Soil sampling and infiltration runs were carried out at four different times of maize growing season: in October 2014, one week before seeding (BS), in December 2014 (V6, 6 leaf stage), in March 2015 (R5, physiological maturity) and one week after harvest (AH) in June 2015.

Undisturbed soil samples (5 cm height, 5 cm diameter) were collected from the upper 10 cm depth of each of two plots, avoiding rows and visible wheel tracks. Eight replicates from each treatment and moment were collected (the total number of samples was 64). The samples were covered with plastic caps to protect the soil from mechanical disturbance and evaporation.

Additional disturbed soil was sampled in order to determine organic carbon (OC) content (Walkley and Black, 1934) and particle size distribution using the pipette method (Gee and Bauder, 1986).

2.2. Pore size distribution and sorptivity determinations

The samples were brought to different potentials (−50 cm and −100 cm water head) at which pores with equivalent diameters larger than 60 μm and 30 μm, respectively, drain in a sand box apparatus. Pore fractions corresponding to macropores (diameter > 60 μm), mesopores (30 μm < diameter < 60 μm), and micropores (diameter < 30 μm) were calculated as the ratio between the amount of water retained in those pores (1 g = 1 cm^3) and the sample volume (Lozano et al., 2013).

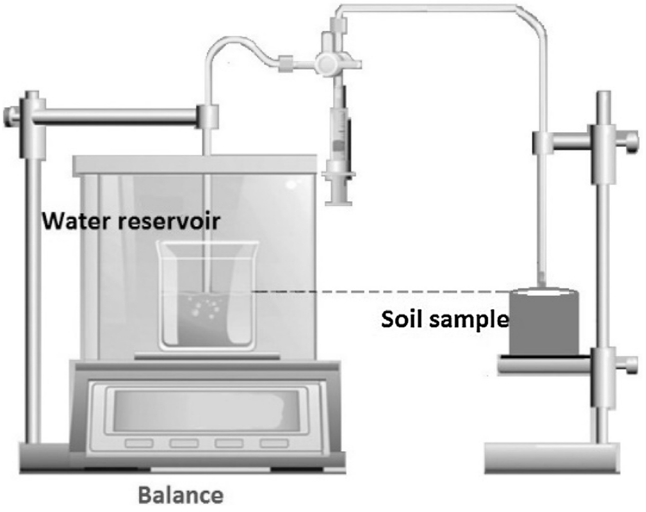

Fig. 1. Apparatus used for sorptivity measurement (adapted from Vogelmann et al., 2013).

After that, samples were air dried. Then, S was determined in the same samples. The methodology used in this work is an improvement to the LH method, modified by Vogelmann et al. (2010).

The device used was a micro-infiltrometer, consisting of a tube connected to a tank with a small sponge in the other extreme (Sponge radius: 4 mm), to provide good hydraulic contact with the sample (Fig. 1). The water reservoir was put on an analytical balance (±0.001 g), connected to a computer. Air bubbles in the micro-infiltrometer were eliminated prior to test.

Each soil sample was placed on a scissor jack, and then brought into contact with the porous sponge by rising the jack. Every determination took approximately four minutes and the mass of water which infiltrated the soil by capillarity was recorded as the mass variation in the analytical balance at every second.

S was determined for each sample using Eq. (5). Q was calculated as the slope of the water infiltrated volume (estimated from the mass loss in the water reservoir) versus time, once steady state flow was achieved. The factor b was taken as 0.55 (White and Sully, 1987), r was 4 mm. The improvement proposed in this paper consisted in measuring the soil water content difference (f). It was done by removing very carefully the wet soil at the end of each determination (the removed depth was approximate 2 cm) to determine the gravimetric water content, later transformed in volumetric water content through the bulk density (BD). The initial water content for all the samples was around 3%. The mean final water content was around 30%.

2.3. Soil field saturated hydraulic conductivity

In order to test the suitability and potential use of the proposed method and S as indicator, saturated hydraulic conductivity (K_0), one of the most studied soil physical properties, was measured in the field at the same time in both treatments. A tension disc infiltrometer (Perroux and White, 1988) was used in order to determine steady-state infiltration rate in the field. Five replicates were carried out for each treatment and moment. The infiltrometer disc had a base radius of 6.25 cm. Infiltration measurements were conducted in five randomly selected sites of each plot, avoiding rows and visible wheel tracks. To consider only the effects of tillage on soil water infiltration, the crop residues were removed from the soil surface. To ensure good hydraulic contact between the device and the soil, the surface was flattened with a spatula and a thin dry sand layer was spread on it. Infiltration runs were performed at three values of soil water pressure head, h (namely, −6, −3 and 0 cm, applied in this order and at the same place). This sequence of supply water pressure heads was adopted, because a descending order may cause hysteresis, with progressive drainage occurring close to the disk while wetting continues at the infiltration front (Jarvis and Messing, 1995). Flow was monitored until steady-state flow from the disc was attained. The cumulative infiltration was recorded every minute until 10 min, every five minutes until 30 min and every ten minutes until the end of the test. When the amount of water entered into the soil did not change with time for four consecutive measurements taken at ten minute intervals, steady-state flow was assumed and steady-state infiltration rate was calculated based on the last four measurements. The time necessary to reach the steady state was around 1.5 h for each tension.

The soil saturated hydraulic conductivity (K_0) was thus calculated from the cumulative water infiltration using the multiple-head method (Ankeny et al., 1991).

2.4. Method validation and comparison

The validation was carried out by measuring S with the proposed methodology and comparing these values with those obtained from standard one-dimensional horizontal infiltration and single test method (Vandervaere et al., 2000). Additionally, these values were also compared with those obtained using the original LH method, assuming f equals to TP. The comparisons were made in two different porous materials: a- soil (previously 2 mm sieved); and b- calibrated sand (75–100 μm). The soil was obtained from the A-horizon of the investigated site. Both porous materials were packed into steel cylinders (5 cm height, 5 cm diameter). Ten cylinders were packed for each material. The soil was packed to a BD value of 1.1 Mg m^{-3}, similar to mean BD in the field, and the sand was packed to a BD value of 1.4 Mg m^{-3}. S was measured in each sample using the proposed methodology. In order to determine S by the single test method, the infiltrated volume data from these runs, were transformed into cumulative infiltration using the infiltration area. Then, S was calculated as the slope of I versus t$^{1/2}$ plot for the initial 10 s (Vandervaere et al., 2000). For horizontal standard infiltration, the soil and the calibrated sand were packed in horizontal PVC columns, with 10 cm length and 3 cm inside diameter. The water entry was recorded as the mass variation in the analytical balance at every second, connected to the column using the system described previously for the proposed method. The volume infiltrated was transformed into infiltration using the column transversal area. S was calculated as the slope of I versus t$^{1/2}$ plot, following Philip's equation (Eq. (1)). Ten replicates of horizontal infiltration were carried out for each porous material. The results of S for different soil porous materials and methodologies are shown in Table 1. S values were normally distributed. There were no significant differences between S values obtained by the proposed methodology and horizontal infiltration for both porous materials. These results show that the proposed improvement on the LH method allows obtaining reliable S values. S values obtained by the single test method were significantly higher than the other two methods, and showed higher variation between repetitions. This behaviour can be attributed to the fact that S values in three dimensional infiltration runs may be overestimated because the gravity effect cannot be neglected (Smettem et al., 1995; Zhang, 1997; Vandervaere et al., 2000), and the chosen time interval has strong influence on the calculated S value (Bonell and Williams, 1986). The LH method is based on the steady state data, which is much more precisely defined. The S values obtained using the original LH method, assuming f equals to TP, were significantly higher than those obtained using the proposed method, supporting the improvement introduced in this work. Fig. 2, shows the imprecision in the LH method based on the fact that f is assumed equal to TP, leading to errors in S values.

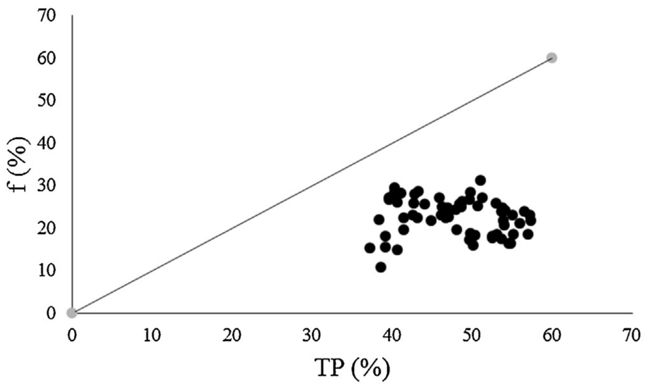

Fig. 2. Soil water content difference between θ and θ_0 during the sorptivity measurements (f) versus total porosity (TP) for all treatments and sampling times. The straight line represents the 1:1 relationship.

Table 1
Sorptivity values calculated by the proposed methodology, standard horizontal infiltration, single test method and Leeds-Harrison method for the two porous materials (2 mm sieved soil; calibrated sand (75–100 μm)). n: number of tests; CV: variation coefficient; SE: standard error.

	Methodology	Sorptivity (cm s$^{-1/2}$)			
		n	Mean	CV	SE
Sieved soil	Proposed method	10	0.09872a	15.28	0.02
	Horizontal infiltration	10	0.07937a	13.16	0.01
	Single test method	10	0.41493c	37.7	0.16
	Leeds-Harrison method	10	0.14787b	14.1	0.02
Calibrated sand	Proposed method	10	0.04135a	4.81	0.002
	Horizontal infiltration	10	0.04006a	22.45	0.1
	Single test method	10	0.21308c	30.81	0.7
	Leeds-Harrison method	10	0.08765b	4.21	0.003

Different letters in the same column mean significant differences between methodologies (P = 0.05).

2.5. Statistical analysis

In order to determine the temporal variation of PoSD, S and K_0 both tillage treatments were analyzed separately (ANOVA with sampling time as factor) (Sokal and Rohlf, 1995). When a significant sampling time effect was found, the Fisher's least significant difference (LSD) test was used to compare the means. Simple regression analyses were carried out to determine the dependence of S on different pore size families (Sokal and Rohlf, 1995). All data from the different sampling times for each treatment were used for regression analyses. For all analyses significance was determined at P = 0.05.

3. Results and discussion

3.1. General soil characteristics

The mean particle size distribution of the A horizon did not differ significantly between treatments and gave 25% clay, 41.5% silt, 33.5% sand (loam). There were no significant differences in the

Table 2
Soil pore size distribution (TP: total porosity, θ_{ma}: macroporosity (diameter > 60 μm), θ_{me}: mesoporosity (30 μm < diameter < 60 μm), and θ_{mi}: microporosity (diameter < 30 μm)); Sorptivity (S) and Saturated Hydraulic Conductivity (K_0) for No tillage (NT) and Conventional tillage (CT) treatments, depending on the sampling moment (BS: Before seeding; V6: 6 leaf stage; R5: physiological maturity; AH: After Harvest).

	Moment	TP %	θ_{ma} %	θ_{me} %	θ_{mi} %	S cm s$^{-1/2}$	K_0 cm s^{-1}
NT	BS	39.5a	9.7a	2.1b	27.7a	0.032b	1.57a
	V6	40.5a	11.6b	1.6a	27.3a	0.039b	3.23b
	R5	50.8b	12.4b	2.9c	35.5b	0.031b	3.23b
	AH	52.8b	11.8b	1.9b	39.0c	0.022a	1.67a
CT	BS	45.1a	15.2b	2.3a	27.5a	0.077c	3.75b
	V6	45.1a	15.0b	2.1a	28.1a	0.042b	1.83a
	R5	54.4b	15.0b	3.8c	35.6b	0.037b	1.73a
	AH	52.3b	12.6a	2.5b	37.1c	0.030a	2.40a

[a] Different letters in the same column mean significant differences between times for each property and treatment (P = 0.05).

OM content of the A horizon between treatments and sampling times, with a mean value of 4.9%.

3.2. Temporal variation of S, PoSD and K_0

The values of S, different pore size fractions and K_0 are shown in Table 2. PoSD, S and K_0 were significantly affected by sampling time in both treatments ($P = 0.05$). Overall, S values were in the same order of magnitude of the values mentioned by Leeds-Harrison et al. (1994) as typical for fine-textured soils.

Under CT, S and K_0 followed similar temporal trends. Both properties were higher BS, just after tillage practices were applied, decreasing AH. These results show that tillage practice effects on these hydraulic properties have low persistence. The results are in agreement with previous reports for K_0 from the Pampas region (Álvarez et al., 2006) and from other regions (Angulo-Jaramillo et al., 1997; Azevedo et al., 1998; Bormann and Klaassen, 2008). These authors emphasized that K_0 often increases with tillage and then decreases during the growing season due to the settling of the soil structure created by tillage. However, the results are in disagreement with Álvarez et al. (2009) who found that the effect of soil loosening previous to sowing on increasing water infiltration rate remained until the last stages of crop growth. The results are partially in agreement with Murphy et al. (1993), who mentioned that S values, under CT, are higher just after sowing practice, decreasing due to the sealing of seedbed caused by rainfall and increasing again towards harvest due to the effect of crop roots. Starr (1990) mentioned a similar trend of S under CT, also attributed to the settling produced by rainfall.

Under NT, S remained constant between BS and R5, and decreased AH. K_0 increased significantly from BS to V6, remaining high until R5, and then decreasing AH. The decrease in S and K_0 AH may be attributed to a change in soil pore configuration (connectivity and orientation), due to high traffic intensity associated to harvest. Soracco et al. (2015) found that different traffic intensities produced a change on dynamic indicators such as

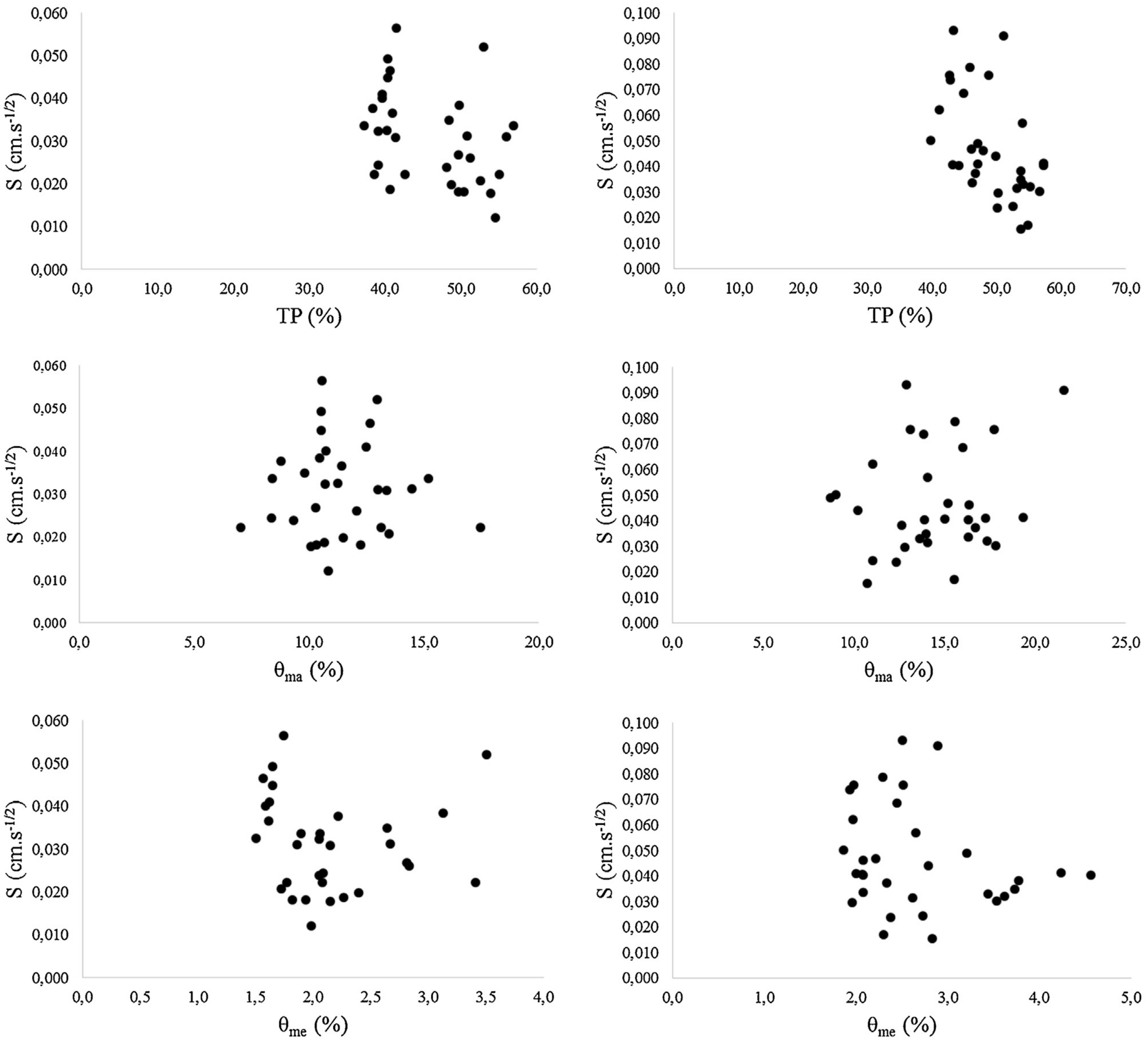

Fig. 3. Dependence of S on different pore sizes fractions: TP (Total porosity), macroporosity, θ_{ma} (diameter > 60 μm) and mesopores, θ_{me} (30 μm < diameter < 60 μm), for both treatments: NT (No Tillage, left) and CT (Conventional Tillage, right).

K_0, while static indicators as TP and θ_{ma} were not significantly affected. These authors mentioned that the lower K_0 value found in the treatment with more tractor passes was associated with a change in the orientation of the porosity.

Some authors found the same trend on K_0 and infiltration rate values (Soracco et al., 2012, 2015). Starr (1990) found no significant temporal variation of S under conservation tillage management, with a slight increase toward harvest. They attributed this behavior to the organic mulch generated by this management.

TP and pore fractions derived from water retention curves varied significantly between sampling moments under both treatments. In both treatments, TP remained constant between BS and V6, and increased from V6 to R5. θ_{ma} values remained constant between BS and R5 and decreased AH for CT. These results are in agreement with several reports from the Pampas region, that show that tillage effects on soil pores configuration do not persist until harvest (Ferreras et al., 2000; Álvarez et al., 2006; Sasal et al., 2006; Soracco et al., 2010). Under NT, θ_{ma} values increased between BS and V6 and did not change significantly between V6 and AH. These results are in disagreement with other authors who mentioned that a stabilization of soil physical properties (Wander and Bollero, 1999; Rhoton, 2000; Álvarez et al., 2009), and in particular of PoSD (VandenBygaart et al., 1999), is reached under long-term NT management system. The increase of θ_{ma} toward AH could be attributed to the crop. The maize roots are strong and create continuous macropores (Fahad et al., 1982; Bathke and Blake, 1984; Lozano et al., 2014). Then, the increase on θ_{ma} from BS to V6 can be attributed to the decay of the roots of the previous crop (maize) during the studied season.

Overall, the fact that K_0, obtained from the field infiltration data, followed a similar trend as compared with S (Table 2), supports the idea that S, a very easy measure, is a good indicator for evaluating soil structure and soil water temporal dynamics.

3.3. Dependence of S on PoSD

We did not find a significant dependence of S on any pore size class (Fig. 3). This result is in disagreement with previous reports by Lipiec et al. (2009) and Shaver et al. (2013), who found that S depended on TP. However, Lipiec et al. (2009) arrived at those results measuring S with the original LH method (Eq. (5)) and assuming f (difference between final and initial soil water content) equal to TP. Since S is calculated with f as input data, and assumed equal to TP, S will depend on TP. With the proposed improvement that implies a real measurement of f, we found that it is not correct to consider f equal to TP. Our experiments resulted in values of TP higher than f in an order of two. From Eq. (5), f is the difference in soil water content, and never equals TP, which implies an imprecision in the method. Fig. 2 supports the idea that it is not correct to consider f equal to TP. Another possible reason for the difference between f and TP could be attributed to temporal shifts on hydrophobicity, supporting the idea that f should not be considered equals to TP. Further studies regarding the effects of hydrophobicity on f would be useful to gain knowledge on this possible influence. Moreover, Shaver et al. (2013) concluded that S, estimated from field infiltration data using a model proposed by Smith (1999), depends on TP. S values obtained from field infiltration data are usually overestimated due to the fact that gravitational effects cannot be neglected (Smettem et al., 1995; Zhang, 1997; Vandervaere et al., 2000). Furthermore, these authors assumed that TP equals the saturated water content.

Soracco et al. (2011) found that K_0 depended on water-conducting macroporosity. Soracco et al. (2015) emphasized that static determinations such as TP and θ_{ma} are not good predictors of water dynamics since they cannot account for the connectivity of the different pore size classes, which is crucial for water entry and movement into the soil (Lozano et al., 2013).

The proposed improvement in the methodology to determine S allows a higher precision, because f is not estimated but measured. In addition, the new methodology allows determining the temporal variation of soil hydraulic properties during the crop cycle.

4. Conclusions

The proposed improvement of the LH method allows determining the temporal variation of soil S for representative undisturbed soil samples with high precision in a simple and rapid way.

Soil sorptivity presents temporal variation during the crop cycle under CT and NT treatments, following a similar trend as compared with K_0, showing the suitability of S in order to determine soil structure and water dynamics.

Soil S obtained by the proposed improved LH method did not show dependence with the studied soil pore size fractions.

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