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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 cm $s^{-1/2}$, respectively) and in calibrated sand (0.041 vs 0.040 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 cm $s^{-1/2}$ and 1.57 and 3.75 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 over-estimated (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 macro-porosity. 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.