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Testing infiltration run effects on the estimated water transmission properties of a sandy-loam soil

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ABSTRACT

Testing factors influencing determination of soil water transmission properties by an infiltrometer method helps better interpretation of the collected data and allows the development of appropriate sampling strategies for the intended use of the data. These factors include the soil water content at the start of the experiment, the height from which water is poured onto the soil surface, and the duration of the infiltration run. A sandy-loam soil was sampled with the BEST (Beerkan Estimation of Soil Transfer parameters) procedure of soil hydraulic characterization and two heights of pouring of water (0.03 and 1.5 m) under three different initial soil water content, θ_i ($0.12 \le \theta_i \le 0.20$ m^3 m^{-3}), conditions. According to the BEST guidelines, relatively short infiltration runs (average run duration ≤1.5 h, depending on both the date and the height from which water was poured) were carried out. However, three long infiltration runs (10 h) were also carried out when θ_i was of 0.075 m^3 m^{-3}. The saturated soil hydraulic conductivity, K_s, and the soil water sorptivity, S, were estimated for each infiltration run with the BEST-steady algorithm. The mean values of K_s varied with the height of pouring of water and θ_i from 13 to 496 mm h^{-1}, and a low height from which water was poured yielded 13 to 27 times higher K_s means than a high height, depending on θ_i. An inverse relationship between K_s and θ_i was clearer with the low height of pouring of water than the high one. The mean saturated hydraulic conductivity obtained with the long runs (15 mm h^{-1}) was close to the means of K_s obtained with the high and shorter runs (13–19 mm h^{-1}, depending on θ_i). The means of S varied from 35 to 126 mm h$^{-0.5}$, with the low runs yielding 2.3 to 2.8 times higher means than the high runs. The high sorptivity obtained with the long runs (160 mm h$^{-0.5}$) was in line with the low initial soil water content. In conclusion, the water application procedure and the duration of the infiltration run can have a noticeable effect on the estimated soil water transmission properties. Long duration runs or runs carried out with a high height of pouring of water appear more appropriate than short duration runs with a low height of pouring of water to obtain data usable to explain surface runoff generation phenomena during intense rainfall events, especially when the soil is relatively dry at the time of sampling. In the future, the effects of both the height from which water is poured and the run duration on the water transmission properties measured with BEST should be tested for different initial soil water conditions in other soils. The usability of the height from which water is poured onto the soil surface as a parameter to mimic high intensity rain should also be investigated specifically.

1. Introduction

Measuring soil hydraulic properties is necessary for interpreting and simulating many hydrological processes having environmental and economic importance, such as rainfall partition into infiltration and runoff. Especially for the soil water transmission properties that depend strongly on soil structure, field measurement techniques should be used to minimize disturbance of the sampled soil volume and to maintain its functional connection with the surrounding soil (Bouma, 1982). Many replicated measurements of these properties have to be carried out to characterize an area of interest since they are known to vary widely both in space and time (e.g., Prieksat et al., 1994; Logsdon and Jaynes, 1996). Therefore, the technique to be applied at the near point scale should be simple and rapid.

Reasons for using ponding infiltrometer techniques to determine soil water transmission properties in the field include robust theory, simple devices, relatively small volumes of water, generally rapid experiment, extensive testing, and possibility to determine different water transmission properties, such as saturated soil hydraulic conductivity, K_s, and sorptivity, S (Reynolds, 2008a,b). Infiltrometer runs can also be used to obtain a complete soil hydraulic characterization, i.e. not limited to soil water transmission parameters. In particular, in the BEST (Beerkan Estimation of Soil Transfer parameters) procedure of soil

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hydraulic characterization (Lassabatère et al., 2006; Yilmaz et al., 2010; Bagarello et al., 2014a), the shape parameters of certain analytic formulae for the hydraulic characteristic curves are estimated from particle-size analysis whereas the structure dependent scale parameters are obtained by a three-dimensional field infiltration experiment at theoretically zero pressure head, using the infiltration model by Haverkamp et al. (1994).

Generally, the analysis of the infiltration data is based on an idealized representation of the sampled soil that is assumed to be rigid, homogeneous, isotropic and uniformly unsaturated before the run (e.g., Reynolds and Elrick, 1990; Lassabatère et al., 2006). However, structure dependent soil properties have a dynamic nature and they can vary appreciably upon wetting due to different phenomena, such as aggregate breakdown promoted by raindrop impact or weakening of interparticle bonds (Collis-George and Laryea, 1971; Assouline and Mualem, 2002, 2006; Chen et al., 2013). Therefore, there is the need to explore the link between hydraulic characterization of initially unsaturated real soils and experimentally controllable factors of the infiltration run. This is still an open issue although some investigations developing this topic can be found in the literature. For example, K_s under rainfall conditions appears to be better represented by the tension infiltrometer than ponded head infiltrometers in stony soils (Verbist et al., 2013) but the opposite was suggested for other soils (Alagna et al., 2015; Bagarello et al., 2012, 2014b).

Although BEST appears attractive for a simple, rapid and complete soil hydraulic characterization, little is known about the dependence of the calculated soil water transmission properties on the applied experimental procedure in the field. Bagarello et al. (2014c) suggested that the K_s values determined by applying water at a relatively large distance from the soil surface could be more appropriate than those obtained with a low height of pouring of water to explain surface runoff generation phenomena during intense rainfall events. However, it should be established, for a given soil, to what extent the height from which water is poured influences the calculated soil water transmission properties under different initial soil water conditions since changes in soil structure due to wetting depend on the antecedent wetness conditions (e.g., Le Bissonnais, 1996; Cerdà, 1998). Another factor needing consideration is the duration of the infiltration run, that is often chosen quite subjectively. BEST calculations need measurement of steady-state infiltration rate but relatively short runs are generally carried out in the field. Although the measured infiltration rates generally suggest rapid attainment of quasi steady-state conditions (Reynolds et al., 2000; Lassabatère et al., 2006), a long run could be expected to yield more robust estimates of steady-state infiltration rates than a short run (e.g. Elrick et al., 1990). However, a long run may also imply more time and opportunities for altering the sampled soil volume due, for example, to swelling and weakening of particle bonds (Hillel and Mottes, 1966; Talsma and Lelij, 1976). Therefore, long runs may not be a valid alternative to short runs in any case. Even in this case, it is necessary to establish what happens in the field with runs of different duration to make an appropriate use of the calculated soil parameters. In addition, repeatedly pouring water on the surface of an initially dry soil, according to the BEST original procedure, implies a possible effect of deterioration of the exposed soil surface and air entrapment in the sampled soil volume on the measured infiltration rates. These factors have to be considered because alteration of soil surface during the run and even small changes in the entrapped air content may have a noticeable effect on the experimentally determined K_s values (Arya et al., 1998; Faybishenko, 1995; Reynolds, 2008a,b; Sakaguchi et al., 2005).

The relationship between the applied experimental approach and the measured parameter is not totally clear for sandy-loam soils. For example, similar estimates of K_s were obtained with two infiltrometer techniques differing by several factors, including flow field (one- or three-dimensional), stage of the infiltration process used for K_s calculation (transient, steady-state), and expected soil disturbance effects during the run (more noticeable with the steady-state technique than the transient one; Bagarello and Sgroi, 2007), but this similarity was only partially confirmed in a subsequent investigation (Bagarello et al., 2014b). Moreover, a noticeable dependence of K_s on the height from which water was poured was detected for BEST but not for the Simplified Falling Head technique (Bagarello et al., 2004, 2014c). The high percentage of coarse particles in these soils could suggest a certain rigidity of the porous medium, and hence a reduced sensitivity to disturbance due to wetting. However, the limited content in clay particles could also imply weak soil aggregation and hence the possibility that water application determines particle detachment and clogging of the largest pores. Moreover, soil swelling during the infiltration run cannot be completely excluded due to the clay that is present in the soil. The importance to establish factors specifically influencing measurement of K_s of sandy-loam soils was also acknowledged by other authors (Somaratne and Smettem, 1993; Lado et al., 2004).

The investigation reported in this paper was carried out on a sandy-loam soil to test how the height from which water was poured for the BEST infiltration experiment affected estimation of saturated soil hydraulic conductivity and sorptivity for different initial soil water contents. The dependence of the K_s and S estimates on the duration of the infiltration run was also tested.

2. Materials and methods

The study was performed at the Department of Agriculture and Forestry Sciences of the Palermo's (Italy) University, in a citrus orchard with trees spaced 4 m × 4 m apart. The soil (Typic Rhodoxeralf), having a relatively high gravel content and an organic matter content in the 0–0.1 depth range of 3.9% (Bagarello et al., 2014c), was classified as sandy-loam (Table 1). The soil surface was gently leveled and smoothed before sampling. The superficial herbaceous vegetation was cut with a knife while the roots remained in situ.

2.1. Height of pouring of water

An area of approximately 150 m^2, already used for an earlier investigation (Bagarello et al., 2014c), was sampled on May 2014 and January 2015.

On a sampling date, a total of 20 undisturbed soil cores (0.05 m in height by 0.05 m in diameter) were collected at the 0 to 0.05 m and 0.05 to 0.10 m depths in randomly chosen sampling points. These cores were used to determine the dry soil bulk density, ρ_b, and the soil water content at the time of the experiment, θ_i. The soil porosity, f, was calculated from the ρ_b data, assuming a soil particle density of 2.65 Mg m^{-3}. According to other investigations, the field saturated soil water content, θ_s, was assumed to coincide with f (Mubarak et al., 2009; Bagarello et al., 2011, 2014c).

Small diameter (i.e., 0.08 m) rings inserted to a depth of 0.01 m were used for the beerkan infiltration runs (Lassabatère et al., 2006). Ring insertion was conducted by gently using a rubber hammer and ensuring that the upper rim of the ring remained horizontal during insertion. The rings were particularly small to more clearly detect possible effects of soil disturbance due to water application. A total of 20 runs were

Table 1
Coordinates, land use, management practices, clay (%), silt (%) and sand (%) content (USDA classification system) in the 0–0.1 m depth range and soil textural classification. Standard deviations are indicated in parentheses.

Variable	Site characteristic
Coordinates	33S 355511E–4218990N
Land use	Citrus orchard
Management practices	Conventional tillage
clay	17.6 (1.9)
silt	29.8 (2.8)
sand	52.6 (4.7)
Textural classification	Sandy-loam