Geoderma 303 (2017) 60–69

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Ring diameter effects on determination of field-saturated hydraulic conductivity of different loam soils

Habib Khodaverdiloo[a,*], Hiva Khani Cheraghabdal[a], Vincenzo Bagarello[b], Massimo Iovino[b], Hossein Asgarzadeh[a], Shoja Ghorbani Dashtaki[c]

[a] Department of Soil Science, Urmia University, Urmia 57135-165, Iran
[b] Dipartimento Scienze Agrarie e Forestali, Università degli Studi, Viale delle Scienze, Palermo, Italy
[c] Department of Soil Science, Shahrekord University, Shahrekord, Iran

ARTICLE INFO

Keywords:
Saturated soil hydraulic conductivity
Ponding infiltration methods
Simplified falling head technique
Salt-affected soils

ABSTRACT

Establishing ring diameter effects on the field-saturated soil hydraulic conductivity, K_{fs}, determined with ponding infiltrometer methods can help to find a compromise between the need to sample a large area with an individual measurement and the impracticality of using large rings in the field. Five ring sizes (diameter, D = 5.5, 10.9, 16.0, 27.8 and 31.8 cm) were used to determine K_{fs} by the simplified falling head (SFH) technique in four loamy soils with different salinity (electrical conductivity of saturated extract, EC_e = 0.9–29.4 dS/m) and sodicity (exchangeable sodium percentage, ESP = 2.7–81.3%) levels. According to USDA classification, two soils were non-saline, non-sodic (NN1 and NN2), a soil was saline-sodic (SS) and another soil was non-saline and sodic (NS). Ring diameter did not have in general a statistically detectable influence on the mean K_{fs} of a given soil. The only exception was for the NS soil but also in this case the effect was negligible for many practical applications since K_{fs} increased by 2.3 times as D increased from 5.5 to 31.8 cm. However, smaller rings implied either higher or lower estimates of K_{fs} variability as compared with larger rings, depending on the soil. The former result probably occurred when only a part of total heterogeneity was sampled with a small ring. The latter result was probably obtained when insertion of small rings altered or even destroyed the fragile macroporosity and also when using small rings increased the probability to only sample relatively homogeneous soil volumes. As compared with the largest rings, those with a diameter in the range 10.9 to 27.8 cm yielded a similar information on the differences between the soil hydraulic conductivity of the four considered soils. More discrepancies were detected for the smallest rings (D = 5.5 cm). Even small rings appear usable to obtain a mean value of K_{fs} for the sampled soils, perhaps with the exception of the smallest ones. However, as large as possible rings should be used if K_{fs} variability has also to be determined.

1. Introduction

The saturated soil hydraulic conductivity is a key soil property for interpreting and simulating many hydrological processes having environmental importance, such as rainfall partition into infiltration and runoff or water and solute transport in the soil profile. It is used as a matching point to determine the unsaturated soil hydraulic conductivity function and also as a soil physical quality parameter (e.g., Alagna et al., 2016; Iovino et al., 2016; Lee et al., 1985; Reynolds et al., 2000, 2014).

Saturated hydraulic conductivity is a soil structure-dependent property. Therefore, field measurement techniques should be used to minimize disturbance of the sampled soil volume and also to maintain its functional connection with the surrounding soil (Bouma, 1982). Because of high spatial and temporal variability of hydraulic conductivity, many replicated measurements need to be carried out to characterize a given area (e.g., Logsdon and Jaynes, 1996; Prieksat et al., 1994). Therefore, the method to be applied should be chosen by considering several factors, including accuracy, speed, simplicity, portability, manpower, cost (Alagna et al., 2016; Lee et al., 1985). Different ponding infiltrometer techniques can be applied to determine the field-saturated soil hydraulic conductivity, K_{fs} (Angulo-Jaramillo et al., 2016), including the simplified falling head (SFH) technique (Bagarello et al., 2004). This technique makes use of a ring, or a cylinder, inserted into the soil to establish one-dimensional flow and offers the possibility to determine K_{fs} for a soil layer of a pre-established thickness.

Due to heterogeneity of soil, ponding infiltrometers may give ring

---

* Corresponding author.
E-mail address: h.khodaverdiloo@urmia.ac.ir (H. Khodaverdiloo).

http://dx.doi.org/10.1016/j.geoderma.2017.04.031
Received 21 January 2017; Received in revised form 22 April 2017; Accepted 28 April 2017

size-dependent results because K_{fs} may change considerably even within short distances (Lai and Ren, 2007). The dependence of the measured soil hydrodynamic properties on the sampled soil volume or surface area has been documented and physically discussed in the literature (e.g., Anderson and Bouma, 1973; Bagarello and Provenzano, 1996; Bagarello et al., 2012; Haws et al., 2004; Lauren et al., 1988; Mallants et al., 1997; Shouse et al., 1994; Wuest, 2005; Youngs, 1987; Zobeck et al., 1985). According to Lai and Ren (2007), scale effects are not expected for homogeneous soils. Instead, the measured K_{fs} of heterogeneous media should increase with the ring size, becoming constant above a certain threshold. Sisson and Wierenga (1981) and Clothier and White (1981) showed that the mean infiltration rate increased and the variance decreased as the measurement scale increased. Ring size effects could also be due to ring insertion into the soil, that can determine disturbance of the soil volume to be sampled and also creation of gaps close to the ring walls (Reynolds, 2008; Zhang et al., 2016). The magnitude of the errors in K_{fs} determination is expected to decrease with larger rings because, in these cases, the ratio of the ring edge length (where compaction or preferential flow can occur) to the area (likely undisturbed or less disturbed zone) decreases and therefore only a minor portion of the confined soil volume is expected to be disturbed.

Ring size effects on the K_{fs} data obtained specifically with the SFH technique were tested only in a few investigations. Bagarello et al. (2009), sampling a sandy-loam and a silt-loam soil, obtained means of K_{fs} that did not vary appreciably with the ring diameter (15 to 30 cm). However, using smaller rings implied more noticeable preferential flow phenomena and non-representative sampling of soil macroporosity and, consequently, overestimation of K_{fs} variability. More recently, Bagarello et al. (2012, 2013a) suggested that, with the SFH technique, measurement scale effects should be more noticeable in low conductivity soils than in highly conductive porous media. In the former situation, macropores or other small zones with a locally high conductivity are rare. Therefore, higher K_{fs} values are expected with larger rings because the wider sampled surface implies a higher probability to intercept these zones. In the latter situation, macropores or other high conductivity zones are more evenly distributed and even a small ring may yield a representative result, i.e. similar to the one obtained by a larger ring.

The explanations by Bagarello et al. (2009, 2012, 2013a) are not method dependent, in the sense that they could also be suggested with reference to other infiltrometer methods. Therefore, the SFH technique can be considered a good candidate method for improving our general knowledge about ring diameter effects on the measured conductivity by ponding infiltration procedures. The need to go ahead on this topic is demonstrated by the fact that, although some guidelines can be found in the literature (Reynolds and Elrick, 2005; Youngs, 1987), rather small rings are generally used due to constraints of practical nature. In particular, the most commonly used diameters are of the order of 10 cm (Mertens et al., 2002; Reynolds et al., 2000; Vauclin et al., 1994) or 15 cm (Alagna et al., 2016; Bagarello and Sgroi, 2004; Bagarello et al., 2006b, 2013a), whereas larger rings, e.g. close to 30 cm, have been used only in a few cases (Verbist et al., 2009, 2010, 2013).

Ring size effects should also be checked in soils with specific features, like the salt-affected soils, since they are widely diffused in arid and semiarid regions and have specific physical, chemical, and biological characteristics because of high salt concentration and/or high sodium content (Amini et al., 2015; Qadir and Schubert, 2002). Salt-affected soils are generally classified on the basis of electrical conductivity of the saturated extract (EC_e), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP), and pH (e.g., Rengasamy, 2010). Elevated exchangeable Na^+ levels cause structural deterioration resulting in reduced pore volume and poor air and water circulation in soil (Rengasamy and Olsson, 1991; Srivastava et al., 2014). Aggregate breakdown due to sodicity involves slaking, clay swelling, and dispersion mechanisms that negatively affect soil hydraulic properties such as water retention and hydraulic conductivity (Bagarello et al., 2006b; Crescimanno et al., 1995; Frenkel et al., 1978; Rengasamy and Sumner, 1998). Soil flocculation is favoured by high electrolyte concentration of the soil solution. Therefore, higher levels of salinity can improve aggregate stability and maintain adequate air and water permeability. Conversely, low salinity and high sodicity induce swelling and dispersion of clay particles that result in occlusion of conducting pores and reduction of infiltration rate (Amini et al., 2015; Ghafoor et al., 2008; Murtaza et al., 2009). Salt-affected soils are mainly located in areas with difficult access and limited water sources. Therefore, rapid and simple field techniques, such as the SFH technique, have to be used to assess the negative effects of salinity/sodicity on soil hydrodynamic properties for these kind of soils. To our knowledge, however, the SFH technique was never applied in salt-affected soils.

The general objective of this investigation was to improve our knowledge of potential and limits of the simplified falling head technique. The specific objective was to establish the ring diameter effects on the K_{fs} estimates obtained with the SFH technique in four texturally similar soils with different levels of salinity and sodicity.

2. Materials and methods

2.1. Site description

The studied area, located in the western edge of the hypersaline Lake Urmia, NW Iran, has the geographical coordinates of 45° 05′ E to 45° 08′ E and 37° 32′ N to 37° 38′ N, and an elevation of 1290 to 1350 m a.s.l. Annual rainfall is around 300 mm and mean temperature is 11.8 °C, with xeric soil moisture and mesic soil temperature regimes (Banaei, 1998).

Four sites with similar soil texture and different salinity/sodicity levels and land uses were investigated in the area (Table 1). According to the USDA classification (U.S. Soil Salinity Staff, 1954), soils belong to three different salinity-sodicity classes. Two soils are "normal" non-saline and non-sodic (NN1 and NN2), a soil is saline-sodic (SS) and another soil is non-saline and sodic (NS).

Soils NN1 and NN2 were under pasture land use. The soil NN2 had relatively higher EC_e and ESP values than soil NN1. Both soils were covered with grass and the vegetation density was high (Fig. 1a,b). For both soils, ring insertion did not cause observable changes in soil surface conditions, probably because the relatively dense plant root networks supported particle arrangement. At the time of sampling, few uniformly distributed fine cracks were discernible especially in the NN2 soil. No biopores other than the uniformly distributed plant root

Table 1
Selected physical and chemical properties of the studied soils (NN1and NN2 non-saline non-sodic soils; SS: saline-sodic soil; NS: sodic soil).

Properties[a]	NN1	NN2	SS	NS
EC_e (dS/m)	0.9	1.8	29.4	1.4
pH	8.3	8.5	7.5	8.4
ESP (%)	2.7	10.8	81.3	23.6
SAR $(meq/l)^{0.5}$	0.8	4.4	13.45	13.5
CEC ($cmol_c$/kg)	30.89	21.16	19.61	14.96
OM (%)	4.58	4.88	4.79	1.57
CCE (%)	33.5	17.25	22.75	19.7
BD (Mg/m^3)	1.1	0.8	1.1	1.4
Sand (%)	37.5	30.0	27.5	37.5
Silt (%)	45.0	45.0	48.7	37.5
Clay (%)	17.5	25.0	23.7	25.0
Gravel (%)	0.3	1.4	0.6	0.6
Salinity/sodicity class	Normal	Normal	Saline-sodic	Sodic
Textural class	Loam	Loam	Loam	Loam
Land use	Pasture	Pasture	Salt marsh	Salt marsh

[a] EC_e: electrical conductivity of the saturated extract, ESP: exchangeable sodium percentage, SAR: sodium adsorption ratio, CEC: cation exchange capacity, OM: organic matter, CCE: calcium carbonate equivalent, BD: bulk density.