Evaluation of two methods for measuring saturated hydraulic conductivity of soils under two vegetation covers

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ABSTRACT

The main goal of this work is to determine and to evaluate the saturated hydraulic conductivity for a silt loam soil in field and laboratory conditions. The experimental area was located in the Vallcebre research catchments, in headwaters of the Llobregat River (NE Spain). Hydraulic conductivity was measured in the field using the Guelph permeameter and field saturated hydraulic conductivity (K_{fs}) based on Elrick equation was calculated. The Guelph permeameter measures were made in two conditions (dry and wet) and in profiles below two vegetation covers (meadows and forest). To determine the saturated hydraulic conductivity at the laboratory (K_s) the constant head permeameter was used. The average K_{fs} values for the wet period was about 2 $cm \cdot h^{-1}$. During the dry period, both soil profiles presented higher values, about 7.5 $cm \cdot h^{-1}$. Under laboratory conditions, mean observed K_s values were between 12 and 25 $cm \cdot h^{-1}$. The relationship K_{fs}/K_s was of 0.1 $cm \cdot h^{-1}$ in wet conditions and about 0.4 $cm \cdot h^{-1}$ in dry conditions. The results indicated significant differences between both methods and between both seasons. Differences can be explained by the anisotropy of soils as a consequence of vegetation root system that promotes preferential flows paths.

Keywords: Preferential flows, Soil water content, Constant head permeameter, Guelph permeameter

INTRODUCTION

Three important physical properties govern the infiltration process: (i) the soil matric flux potential (ϕ_m) defining the soil water retention capacity (Gardner, 1958); (ii) the hydraulic conductivity (K) defining the flow transfer in the porous media (Hillel, 1980); and (iii) the sorptivity (S) defining the soil capacity to absorb water when the water flow is influenced by a pressure gradient (Philip, 1957).
According to the studied scale, the hydraulic conductivity can be measured by different instruments. Some of these are the constant head permeameter used to obtain measurements at the laboratory (Kessler and Oosterbaan, 1980), and the Guelph permeameter to measure the hydraulic conductivity *in situ* (Reynolds and Elrick, 1985, 1986).

The main goal of this work is to determine and to evaluate the hydraulic conductivity for a silt loam soil in field and laboratory conditions. This objective was split in two tasks (i) to determine soil saturated hydraulic conductivity under different vegetated covers in situ and in the laboratory , and (ii) to compare both methods for determining hydraulic conductivity at saturation regime.

MATERIALS AND METHODOLOGY

The experimental area was located in the Can Vila research catchment (NE, Spain) (Gallart et al., 2005). Four soil profiles (two under mesophylous grassland cover M-1 and M-2, and two under Scott pines cover F-1 and F-2) were used. These profiles presented high textural homogeneity, and were classified according to USDA particle size class as silt loam (profiles M-1, M-2 and F-2), and silty-clay loam (profile F-1). Mean bulk density was 1.3 g·cm^{-3}. Calcium carbonate content presented three well-defined groups (with 5%, 30%, and about 50% respectively). Mean organic matter content on the whole of soil profiles was 4.1% (Rubio, 2005).

Hydraulic conductivity was measured in the field using the Guelph permeameter, and field saturated hydraulic conductivity (K_{fs}) was calculated with Elrick equation (Elrick et al., 1985). In plots M-1 and F-1 Nine measurements per plot at three depths (15, 25, and 50 cm) were done. These measures were made in two conditions (i) dry season; and (ii) wet season.

At the laboratory, saturated hydraulic conductivity (Ks) was determined using a constant head permeameter. 71 unaltered soil samples were collected from different depths in all soil profiles (M-1, M-2, F-1, and F-2). Saturated hydraulic conductivity was determined using a constant water charge.

RESULTS AND DISCUSSION

Table 1, presents the results of the measurements performed with the Guelph permeameter.. The values of field saturated hydraulic conductivity (K_{fs}) were multiplied by a factor of 2 (Reynolds and Elrick, 1985) to obtain a reasonable estimation of saturated hydraulic conductivity (K_s).

The average K_{fs} values for wetting season were about 2.0 cm·h^{-1}. During the dry season, both soil profiles presented values more than 3 times higher (about 7.5 cm·h^{-1}). Similar values were determined by Haro et al. (1992) in soils profiles in close proximity to the Can Vila catchment. The K_{fs} values for all soil profiles in wet conditions decreased in depth, being this decrease more marked in the grassed profiles (Table 1).

For dry conditions, the soil profiles under forest decreased clearly in depth as a consequence of high quantity of roots at surface, which increase the porosity and the water flow into the porous media. The soil profiles under grassland presented profiles with two differentiated Ks values, the superficial values being 10 time greater than the deepest ones (Table 2).

Table 1. Mean values of Field saturated hydraulic conductivity (K_{fs}) measured with a Guelph permeameter under different soil moisture conditions. Std = standard deviation; CV = variation coefficient.

Soil depth	n	$\bar{K}_{fs}$ (cm·h^{-1})	Std (cm·h^{-1})	CV (%)	n	$\bar{K}_{fs}$ (cm·h^{-1})	Std (cm·h^{-1})	CV (%)
	Dry conditions				Wet conditions			
15 cm	3	8.3	0.4	123.4	3	4.6	0.1	26.5
25 cm	3	13.1	0.1	11.9	2	1.2	0.2	154.1
50 cm	3	1.0	0.3	85.9	2	0.1	0.6	402.1
Meadows	9	7.5	6.1	81.5	7	2.0	2.3	114.8
15 cm	3	18.2	0.4	88.4	3	2.2	1.1	834.5
25 cm	3	2.5	0.1	25.2	2	1.9	0.1	28.9
50 cm	3	2.3	0.2	38.1	1	0.5	—	—
Forest	9	7.7	9.1	119.1	6	1.5	1.4	82.7

This difference could be related with a highest gravel and sand content above 50 cm. Sorptivity ($S(\psi)$) values of the soil profiles were very similar, decreasing its in depth during the wet season for the grassed plots, and increasing for the forested ones.

Table 2 shows that K_s measured at the laboratory had mean values around 18 cm·h^{-1}. These values, higher than the measured K_{fs}, ranged between 0.2 and 38.6 cm·h^{-1} depending on depth. For all profiles Ks decreased from surface to bottom. At the grassed profiles surface Ks (5-15 cm) was about 6 times greater than at depth (50 cm). This difference was probably large in the forested profiles, but the lack of information at depth prevents to clearly affirm this tendency (Table 2).

Table 2. Mean values of K_s according to constant head permeameter CV = variation coefficient.

Soil depth	n	K_s (cm·h^{-1})	CV (%)	n	K_s (cm·h^{-1})	CV (%)
			Soil profile under meadows			
0-5 cm	3	13.7	15.5	3	35.7	10.3
5-10 cm	3	36.5	24.1	3	26.7	9.6
10-15 cm	3	32.2	14.3	3	18.7	31.4
25-30 cm	2	11.1	105.6	2	38.6	15.2
50-55 cm	2	5.4	21.3	2	4.2	10.7
Average	14	16.9	71.4	13	24.8	36.4
			Soil profile under forests			
0-5 cm	3	21.5	20.7	3	21.7	6.9
5-10 cm	3	15.0	7.6	3	28.7	5.6
10-15 cm	3	27.6	9.6	3	17.6	34.4
25-30 cm	1	8.7	—	2	1.1	450.3
50-55 cm	—	—	—	1	0.2	—
Average	10	18.2	44.9	14	11.9	98.3

A comparison of the saturated hydraulic conductivity measured by both methods (Kfs and Ks) is shown in Table 3. In both cases, Mean K_{fs}/K_s was 0.10 in wet conditions, and 4 times greater in dry conditions (Table 3). These values were much lower than those found by Bouwer (1966), which established a range for this relation between 1.67 and 2.50. An ANOVA test indicated statistically significant differences between both methods. These differences could be explained considering the possible alterations suffered by the samples during the extraction. In fact, the extraction of samples to perform laboratory analyses could involve the formation of preferential flow paths, and therefore increase K_s values.

Table 3. Comparison between field saturated hydraulic conductivity (wet and dry conditions) (K_{fs}) and laboratory scale (K_s).

		Field				**Laboratory**	**Wet Cond.**	**Dry Cond.**
Soil depth	**n**	$K_{fs\text{-}Wet}$	**n**	$K_{fs\text{-}Dry}$	**n**	K_s	K_{fs}/K_s	K_{fs}/K_s
15 cm	3	4.6	3	8.3	3	32.2	0.14	0.26
25 cm	2	1.3	3	13.1	—	—	—	—
50 cm	2	0.3	3	1.0	2	11.1	0.03	0.09
Meadows	7	2.1	9	7.5	5	21.6	0.10	0.35
15 cm	3	2.2	3	18.2	3	27.6	0.08	0.66
25 cm	2	2.1	3	2.5	1	8.7	0.24	0.29
50 cm	1	0.1	3	2.3	—	—	—	—

Forest	6	1.7	9	7.7	4	18.2	0.09	0.42

Differences may perhaps be explained by some characteristics of the processes. Constant head permeameter measured K_s in a vertical direction, where preferential flows, due to the macro-porosity or the conducts produced by bioturbation and roots plants could be important. On the contrary, Guelph permeameter measured the K_{fs} of a wetting bulb, which included horizontal and vertical directions. In addition, the swelling-shrinking processes observed in these soils, could entail collapses of the macrospores, and as a consequence a reduction of the hydraulic conductivity. Finally, textural homogeneity in the first 15 cm depth, determined a rapid steady-state conditions of the water flow, and fewer variations of the process.

CONCLUSIONS

The highest field saturated hydraulic conductivity of the studied soil profiles during the dry period, may probably be explained by swelling-shrinking processes, which allowed the development of macropores. The opposite process occurred during the wet period and K_{fs} values decreased considerably. The comparison between field and laboratory methods shown significant differences, with field saturated conductivity values always lower than laboratory ones.

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