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Multi-layer cross-scale analysis to determine the saturated hydraulic conductivity of a silty loam porous media

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Abstract

The main goal of this work is to determine and evaluate the saturated hydraulic conductivity for a silt loam soil at field and laboratory scale. The experimental area was located at the delta plain of Llobregat River (NE Spain). Hydraulic conductivity was measured in the field using the Guelph permeameter and field saturated hydraulic conductivity (Kfs) based on Elrick equation was calculated. The Guelph permeameter measures were carried out for two different moisture conditions and for soil profiles below two vegetation covers. To determine the saturated hydraulic conductivity at the laboratory (Ks) the constant head permeameter was used. The average Kfs values for the wet period was about 2 cm·h-1. During the dry period, both soil profiles presented higher values, about 7.5 cm·h-1. Under laboratory conditions, mean observed Ks values were between 19 and 15 cm·h-1. The relationship Kfs/Ks was of 0.1 cm·h-1 in wet conditions and about 0.6 cm·h-1 in dry conditions. The results indicated significant differences between both methods and between both seasons. Differences could be explained by the anisotropy of soils as a consequence of vegetation root system that promotes preferential flows paths.

Keywords: *preferential flow path, infiltration, Guelph and constant head permeameter, sorption*

1. Introduction

Three important physical properties govern the infiltration process: (i) the soil matric flux potential (ϕm) 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 under laboratory scale, and (ii) to compare both methods for determining hydraulic conductivity at variable saturated flow under natural conditions.

2. Materials and Methods

The experimental area was located in the Can Sole Road experimental area (NE, Spain) (Rubio et al., 2008). Four soil profiles grassland cover M-1 and M-2, and two under Cynara scolimus crop F-1 and F-2 were used (Figure 1). These profiles presented high textural homogeneity, and were classified according to USDA particle size class as silt loam textural class. Mean bulk density was 1.4 g·cm-3. Calcium carbonate content presented two well-defined groups (with 2% and 7% ,respectively). Mean organic matter content on the whole of soil profiles was 1.1% for grassland, and 2.1% for profiles under the crop.

Hydraulic conductivity was measured at field scale using the Guelph permeameter, and field saturated hydraulic conductivity (Kfs) was calculated with Elrick equation (Elrick et al., 1985). Nine measurements per plot at three depths (15, 25, and 50 cm) were carried out. These measures were performed in two conditions (i) winter dry season; and (ii) autumn wet season.

Laboratory scale saturated hydraulic conductivity (Ks) was determined using a constant head permeameter. 70 unaltered soil samples were collected from different depths on the whole of soil profiles (M-1, M-2, F-1, and

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F-2). Saturated hydraulic conductivity was determined using a constant water charge of 2 cm.

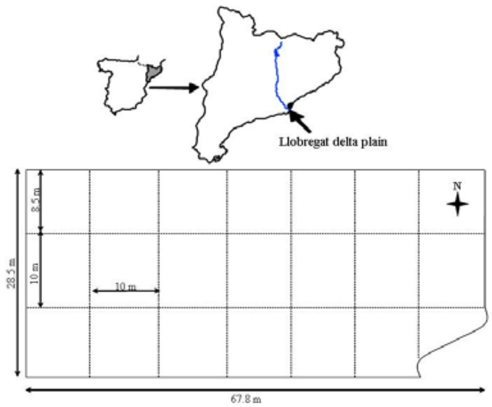

Fig. 1 Map of the Can Solé Road at Llobregat delta plain, showing location of the sampling plot.

2. Results and Discussion

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

The average Kfs 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), Rubio (2005), and Rubio et al. (2009) in soils profiles on similar soil as the Can Sole Road area. The Kfs values for all soil profiles in wet conditions decreased in depth, being this decrease more marked in the soil profiles under grass (Table 1).

For dry conditions, the soil profiles under crop 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 1).

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

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Table 1: Mean values of field saturated hydraulic conductivity (Kfs) measured with a Guelph permeameter under different soil moisture conditions. Std = standard deviation; CV = variation coefficient.

Soil depth (cm)	*n*	$\bar{K}_{fs}$ *(cm·h^{-1})*	*Std (cm·h^{-1})*	*CV (%)*
Dry conditions				
15	3	8.1	0.3	3.7
25	3	13.2	0.2	1.5
50	3	1.1	0.4	36.4
Grassland	9	7.5	0.3	4.0
15	3	16.4	0.6	3.7
25	3	3.1	0.2	6.5
50	3	3	0.4	13.3
Crop	9	7.5	0.4	5.3
Wet conditions				
15	3	5.1	0.2	3.9
25	3	1.5	0.2	13.3
50	3	0.3	0.1	33.3
Grassland	9	2.3	0.2	7.2
15	3	2.5	1	40.0
25	3	2	0.2	10.0
50	3	0.6	0.1	16.7
Crop	9	1.7	0.4	25.5

Table 2, shows that Ks measured at laboratory scale. The technique obtained mean values between 15 and 19 cm·h-1. These values, were higher than the measured Kfs, and the values ranged between 7.5 and 33.4 cm·h-1 depending on depth. On the whole of all profiles Ks decreased from surface to bottom. On the grassland profiles surface Ks (5-15 cm) was around 4 times higher than the deep levels (50 cm). This difference was larger in the crop soil profiles (Table 2).

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

Soil depth (cm)	*n*	*Ks (cm·h-1)*	*CV (%)*
Soil profile under grassland			
0-5	7	12.3	15.5
5-10	7	33.4	23.5

10-15	7	30.1	13.9
25-3	7	13.5	78.6
50-55	7	7.5	19.1
Average	35	19.4	30.1
Soil profile under crop			
0-5	7	20.6	15.2
5-10	7	14.8	8.1
10-15	7	22.1	8.3
25-30	7	8.6	5.6
50-55	7	7.9	9.3
Average	35	14.8	9.3

A comparison of the saturated hydraulic conductivity measured by both methods (Kfs and Ks) is presented in Table 3. In both cases, mean Kfs/Ks was 0.15 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 Ks values.

Table 3: Comparison between field saturated hydraulic conductivity (wet and dry conditions) (Kfs) and laboratory scale (Ks).

Soil depth	***Field***		***Lab***	***Wet***	***Dry***
(cm)	***Kfs-Wet***	***Kfs-Dry***	***Ks***	***Kfs/ Ks***	***Kfs/ Ks***
15	5.1	8.1	30.1	0.17	0.27
25	1.5	13.2	13.5	0.11	0.98
50	0.3	1.1	7.5	0.04	0.15
Grassland	2.3	7.5	17.0	0.14	0.44
15	2.5	16.4	22.1	0.11	0.74
25	2.0	3.1	8.6	0.23	0.36
50	0.6	3.0	7.9	0.08	0.38
Crop	1.7	7.5	12.9	0.13	0.58

These differences might be explained by some characteristics of the processes. Constant head permeameter measured Ks in a vertical direction, where preferential flows, due to the macro-porosity, bioturbation, and roots. These factors would affecting the variable saturated flow transfer. On the other hand, Guelph permeameter measured the Kfs as a wetting bulb, which included horizontal and vertical directions. In addition, the swelling-shrinking processes observed in these soils during the dry season, could entail the collapse of the macrospores, and as a consequence the reduction of the hydraulic conductivity. Eventually, textural homogeneity in the first 15 cm depth, determined a rapid steady-state conditions of the water flow, and fewer variations of the process.

4. Conclusions

To sum up, 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, where the Kfs 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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