Combining rain simulation and single ring infiltration to determine the hydraulic resistance of a surface crust.

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1. Abstract

According to the analysis of Hillel and Gardner (1969) for steady infiltration in a crusted soil, the hydraulic resistance of the crust can be inferred from the infiltrationrate and the relationship between the soil water conductivity and soil water pressure. The steady infiltration rate was measured during rain simulation experiments conducted in Central Tunisia. The soil hydraulic properties were determined from pedotransfer function and analysis of single ring infiltration tests conducted in the immediate vicinity of rain simulation plots after removing the crust from the soil surface. The crust resistance was inferred from the steady infiltration flux measured during the rain simulation experiment and from the hydraulic conductivity curve. The determined soil properties and crust resistance were used to solve the flow equation in a crusted soil. Comparison of computed results to those observed under simulated rain showed that this method is reliable. Experiments on other types of soil are needed in order to confirm its reliability.

2. Introduction

The presence of a crust at the soil surface greatly reduces infiltration and favours runoff. This results in a loss of available water for agricultural and/or domestic needs, which consequences can be dramatic in semi arid regions. Due to its small thickness, the hydraulic properties of a surface crust, i.e. water retention and/or hydraulic conductivity curve, are very difficult to determine. Hillel & Gardner (1969) showed that the infiltration rate in a crusted soil is given by the ratio of the pressure head that develops at the interface between the crust and the soil to the infiltration rate; the crust resistance being defined as the ratio of its thickness to its hydraulic conductivity. When infiltration is steady its rate is equal to the hydraulic conductivity corresponding to the pressure head at the soil surface. In this special case, the crust resistance can be estimated from the measurement of the infiltration rate and the knowledge of the hydraulic conductivity relation of the soil. This paper presents a method to estimate the hydraulic resistance of a surface crust by combining information obtained from rain simulation and ring infiltration experiments.

3. The site study

The experimental site is located in the small catchment of El Gouazine (18 km²) in central Tunisia. The mean annual rainfall is 370 to 380 mm. Most of the precipitations occur from November to February. The potential evaporation is very high (about 1800 mm/year), especially in summer, because of the temperature which can reach 45 °C. The site (35° 53' N, 9° 41' E) is located 50 km to the north-west of the town Kairouan in central Tunisia. The soil is homogeneous and left fallow for several years, so that the soil surface is covered by a thin crust. The soil is sandy with practically no organic matter. Vegetation is rather stunted and sparse.

4. Materials and methods

In order to estimate the crust resistance it is necessary to measure the steady infiltration rate and determine the soil conductivity of the soil as a function of its pressure head. The steady infiltration rate is measured at the end of a rain simulation experiment; while the dependency of the soil hydraulic conductivity and water content on the pressuure head are determined from single ring infiltration test as described below.

The rain simulation plot, 1 m² plot is delimited by a metallic frame driven a few centimeters in the soil. Runoff is collected in a reservoir, and measured continuously with an automatic level recorder. Rain was applied at three intensities 35, 60 and 90 mm/h for 45, 15 and 10 minutes respectively, separated by two periods without rain for 15 minutes between each two intensities. Runoff measurements at the end of the experiment showed that infiltration is practically steady. Steady infiltration rate was determined as the difference between rain and runoff intensities.

The soil properties, i.e., the water retention and conductivity curves which describe the relationships water content-water pressure head and water content-hydraulic conductivity respectively; were determined from the grain size ditribution and the analysis of single ring infiltration test as described by Braud et al, (2005).

Three single ring infiltration tests were made in the immediate vicinity of the plot after the rain simulation, so that the soil in the rain simulation plot and the ring infiltration test could be considered identical. Moreover, the topsoil (about 1 cm thick) was removed in order to eliminate the effect of the surface crust. The test consisted of measuring the infiltrated water with time after the supply of a constant volume of water at the soil surface in the ring. The experiment was terminated when the time between two successive supplies was practically constant for at least three supplies. Soil samples collected inside and outside the ring allow the determination of the saturated and initial gravimetric water contents. A third undisturbed soil sample of known volume was collected to measure the bulk density and convert the gravimetric to volumetric water contents. All samples were then sieved to detemine the grain size distribution of the soil.

5. Results and discussion

The solid points on figure 1a show the measured particle size distribution, and the continuous line is the fit of a van Genuchten (1980) type equation on the measurements. Figure 1b shows typical results of ring infiltration. On this figure the solid points are measurements on which the infiltration equation of Brutsaert (1976) was fitted (continuous line).

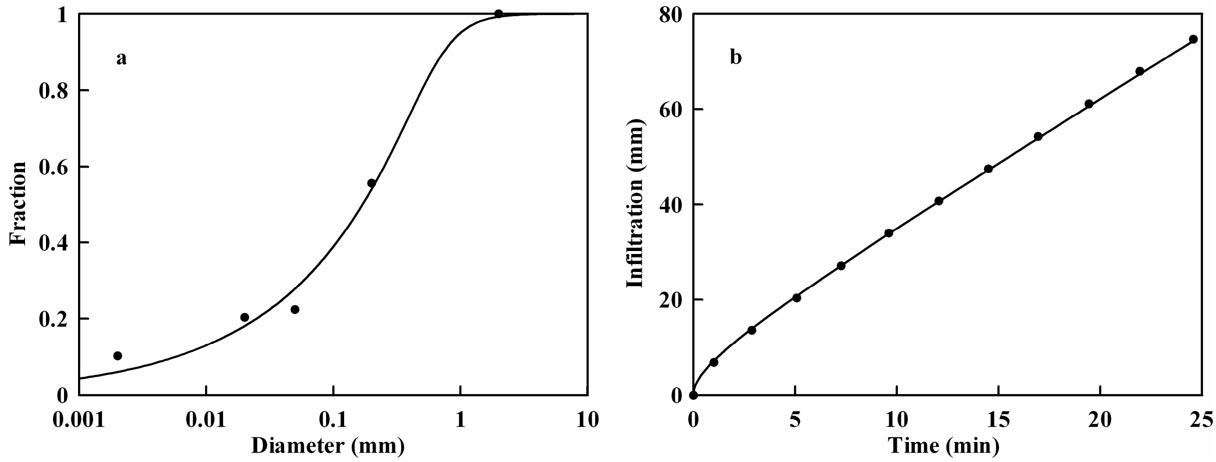

Figure 1 Measured (points) and fitted (continuous curve) grain size distribution (1a) Measured (points) and fitted (continuous line) single ring infiltration test (1b)

The soil water retention and hydraulic conductivity inferred from the above information are shown on figure (2a) and (2b) respectively. Note that the dependence of the hydraulic conductivity on the water pressure is obtained by eliminating the water content between the water retention and hysraulic conductivity relationships.

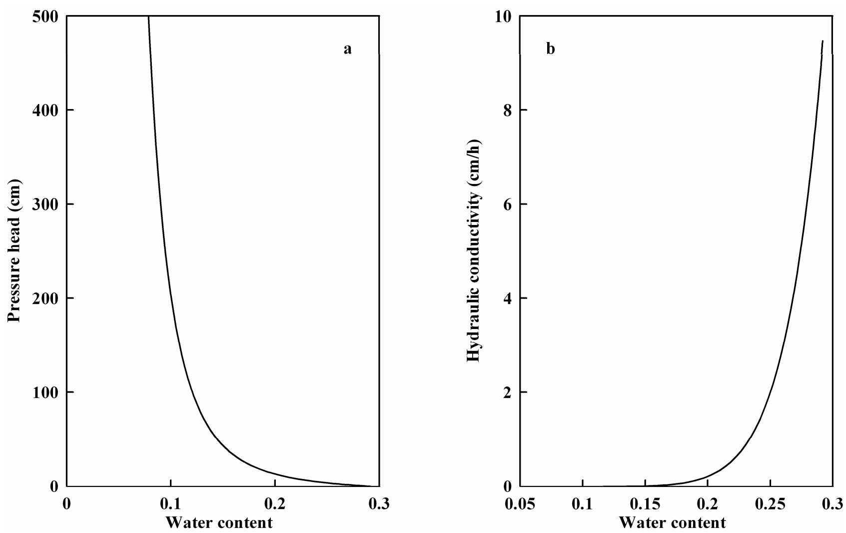

Figure 2 Soil water retention (2a) and hydraulic conductivity (2b) determined from particle size distribution and analysis of single ring infiltration test

Typical results of rain simulation are shown on figure 3a. The dotted broken line is the cumulative amount of supplied rain, and the solid points represent the corresponding measured runoff. This figure shows that the runoff rate during the last rain, 90 mm/h intensity, is practically constant. Thus it is realistic to consider that infiltration is steady. The runoff rate, determined by linear regression between for $93 \leq t \leq 100$ minutes (with a coefficient of determination $r^2 > 0.99$) is 75.1 mm/h. Thus, the steady infiltration rate is 14.9 mm/h, to be compared with the soil saturated conductivity determined from the single ring infiltration test: 96.8 m/h.

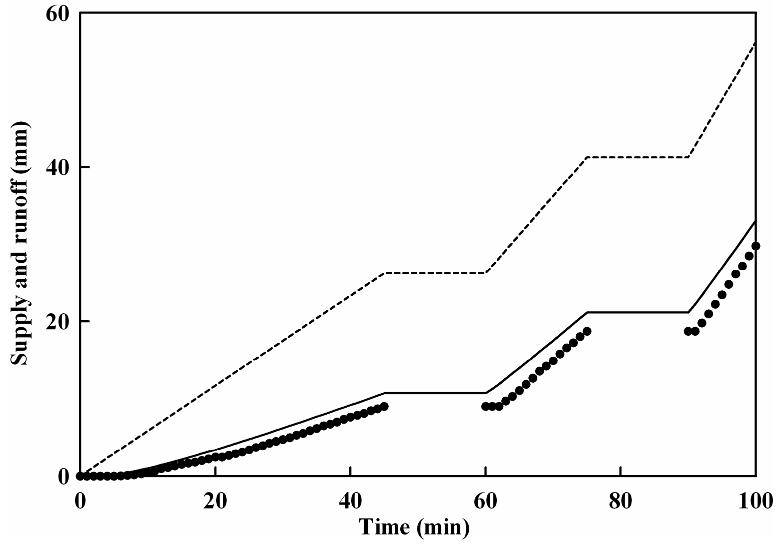

Figure 3 Cumulative rain supplied (dotted line) and measured runoff (solid points)
The continuous curve is the computed runoff

The crust resistance determined from the ratio of the steady state infiltration rate to the correspondent pressure haed and the soil properties determined previously were supplied as inputs to a numerical model. The objective was to reproduce the rain simulation experiment numerically and test the relevance of the determined crust resistance. The results are shown by the continuous curve in figures 3 and 4. Figure 3 compares the computred runoff with observation, while figure 4 presents a comparison between the actual and computed infiltrations. The difference between observations and numerical results being limited to 15%, prove that this method is satisfactory to determine the crust resistance in situ.

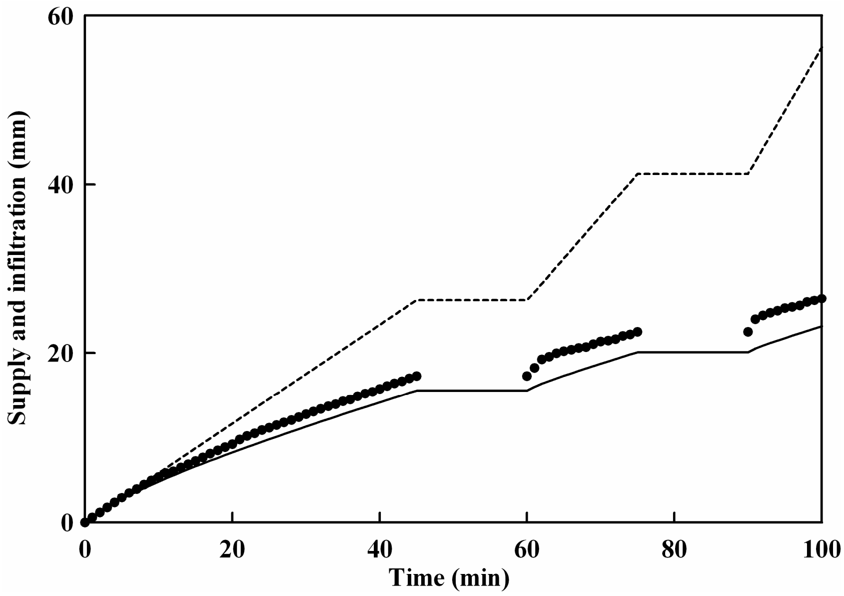

Figure 4 Cumulative rain supplied (dotted line) and measured infiltration (solid points)
The continuous curve is the computed infiltration

6. References

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