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A linear source method for soil infiltrability measurement and model representations

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Summary Soil infiltrability determines the fraction of applied irrigation and/or rainfall water transferred into the soil and the surface runoff. A new method is advanced to measure soil infiltrability with linear distributed water flow on hill-slope. The experimental procedures were outlined for this purpose. Algorithms for estimating infiltrability from the experimental data were also formulated. An experimental system was developed, including a Mariotte bottle for water supply, a special outlet unit for linear distribution of water flow at the soil surface and a scaled flume. A digital camera was used to record the increase in wetted soil surface area as a function of time. Mathematical models were derived to compute the soil infiltrability-time function from the recorded changes in wetted soil surface area. Laboratory experiments using an air-dry loam were conducted with in flow rate of 4.4 l/h and slopes of 5° and 15° in 3 replicates. The infiltrability results of the new method were compared with the double-ring results obtained on the similar soil. The experimental results showed that the advances in wetted areas as function of time were well fitted with a given function, with determination coefficients (R^2) greater than 0.89. Some existing infiltration models were also applied to the measured infiltration rates to illustrate how the model parameters were determined and how well the measured infiltrability curves were represented by the models. These models, including Philip's, Kostiakov's and several modified Kostiakovs' with different constant infiltration rates, agreed well with the measured data, with determination coefficients (R^2) equal or greater than 0.95. The dynamics of the infiltration curve represented the infiltrability of a soil conceptually. Very little water is needed to make a measurement of a complete infiltrability

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curve. Comparison of the cumulative infiltrated water with the total supplied water indicated that the relative estimation errors were 17.3–7.51% for this new method, demonstrating a very high accuracy of the method. The results validate the rationale of this new method, the computational models and the experimental procedures. This method is convenient for fast field determination of soil infiltrability with much less water required than in conventional methods.

Introduction

The process of water penetrating into soil, referred to as soil water infiltration, plays an important role in hydrological circulation of water. It determines the fraction of irrigation or rain water entering into the soil and the amount of runoff responsible for soil erosion.

Infiltrability is a term used to quantify the capacity of water infiltrating into the soil under abundant water supply. Sometimes the cumulative infiltration is also used to quantify the total infiltrated water volume of a unit area within a certain period of time.

The change in infiltrability with time is described as the change in infiltration rate which is initially high, decreases with time and eventually reaches a final constant value called the steady infiltration rate, which is closely related to the saturated hydraulic conductivity.

There are few direct and indirect methods to determine soil infiltration rate. Few examples are the double-ring method, the Mariotte double-ring method, the rainfall simulator, the disc permeameter, etc.

The double-ring, Mariotte double-ring and the disc permeameter cannot be used for measurements of infiltration rate on the hill-slope. Surface soil structure is disturbed when the two rings are stroke into the soil. Surface soil structure may be destroyed by fast wetting (Levy et al., 1997; Mamedov et al., 2001) when high flow rate of water is poured into the rings in order to measure the very high initial infiltration rate. Fast wetting of soil aggregates causes their breakdown and much lower infiltration rate than the original soil has. Infiltration in a double-ring is a process under a certain hydraulic pressure, and is limited by the water supply capability of the flow pipe orifice (Lei et al., 2006a). Under such conditions, the very high initial soil infiltrability cannot be measured accurately.

Rainfall simulator simulates the actual rainfall conditions. Water is sprayed onto the infiltrating surface with sprinkler(s) (Peterson and Bubenzer, 1986; Ogden et al., 1997; Yuan et al., 1999). Limited by the rainfall intensity, the very high initial infiltrability cannot be measured (Hillel, 1998; Scott, 2000). Only when the soil infiltrability is below the rainfall intensity and runoff is produced, the infiltrability can be measured and/or calculated. If a very high rainfall intensity is applied, in order to measure the very high initial soil infiltrability, the high rate of surface soil wetting and the impact of raindrops induce crust formation (Levy et al., 1994; Morin and van Winkel, 1996; Levy et al., 1997) and surface sealing which produced much lower infiltration rate and final steady infiltration rate (Lei et al., 2006b). The importance of the high initial infiltration rate measurement could be summarized as follows: (1) It is an important part of the soil infiltrability which is important for understanding the soil infiltration behavior as a whole more clearly; (2) As mentioned by William and Robert (2004), without knowing the soil infiltrability, it is not easy to estimate the time when runoff begins from a dry soil surface exposed to prolonged rainfall. Upon knowing the complete soil infiltrability, it is very easy to find this time by comparing soil infiltrability with the actual rainfall intensity; (3) According to Horton's infiltration concept (Philip and Wayne, 2002), the runoff volume is derived from the actual infiltrability and the rainfall intensity. Lei et al. (2006a) suggested a method to measure soil infiltrability using a rainfall simulator with part of the upper slope covered with water-impermeable material to produce runoff. The advance of water flow produced from the impermeable part at the upper slope, which flows on the soil surface at the lower part of the slope, as functions of time, was used to estimate the infiltrability (Lei et al., 2006a). This method is capable of measuring the very high initial infiltrability of sloping soil with relatively small amount of water. It is based on the assumption that the infiltrability values at all locations along the hill-slope are similar, though the differences of runon water arrivals. This assumption needs further clarifications.

Besides these measurement methods, there are many infiltration models frequently used to describe soil infiltration process. Among these infiltration models, Kostiakov infiltration equation (1932) and Philip infiltration Model (1957) are two of the most popular ones. The Kostiakov infiltration equation was based on experimental data. The parameters contained in this equation have no physical meanings. The Philip model is a physical one. The parameters contained in this model have their physical meanings. In this study, some comparisons are made between the mathematical models formulated for the new method of infiltrability measurements and these two infiltration models.

The objectives of this study were: (1) to suggest and describe in detail the experimental procedures of a new method for measuring soil infiltrability; (2) to formulate the mathematical model for computing the soil infiltration capacity from the data obtained in the new method; (3) to compare the results of the new method with presently-existing infiltration models and (4) to estimate the measurement error using the water/mass balance.

Materials and methods

Experimental methodology and materials

Experimental materials

The laboratory system consists of a flume with a measuring tape (Fig. 1), a specially-designed linearly water dis-