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FLOW IN SOILS WITH MACROPORES

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1 Introduction

Flow of water in soil has been discussed for the 1983 course by Dr. H. Verplancke of the Dept. of Soil Physics, Faculty of Agricultural Sciences, State University of Ghent in Belgium. His excellent lecture notes will also be used for this course in 1985. In addition I will present here a discussion of bypass flow, which is the movement of free water along macropores through an unsaturated soil matrix. Bypass flow is important under field conditions, but it has, so far, received very little attention in soil physical literature. Macropores can also have a significant effect on the upward unsaturated flow of water from the water-table to the rootzone, when they occur as horizontal air-filled cracks. The various aspects will now be discussed in the form of a series of case-studies. Literature references are provided to obtain further information.

Case study 1: Infiltration of sprinkler-irrigation in a dry clay soil. The important process of "bypass-flow" (earlier called: "short-circuiting") is being characterized here. This process describes vertical infiltration of free water through unsaturated soil horizons. A solution of methylene blue in water was used for sprinkling irrigation on a dry, cracked clay soil (Bouma and Dekker, 1978). Soil below the experimental plot (1.0 x 0.5 m) was excavated and visual observations were made of the infiltration patterns of the water, which consisted of 5 to 7 mm wide vertical bands on ped faces.

The total number and surface area of bands were determined in soil below the 0.5 cm^2 plot for each 10 cm depth increment down to 100 cm below surface. Five sprinkling intensities were tested in four different clay soils. The total surface area of bands, to be called "contact area" (S) hereafter, is an important characteristic as it defines the area which is available for lateral infiltration into the (dry) peds. The contact area increase up to 200 cm^2 as sprinkling intensity became higher (Bouma and Dekker, 1978), but the stained fraction of the total vertical surface area of cracks remained low in alle cases. A coarse prismatic structure with peds of 10 cm cross section has (per 10 cm thickness increment) a contact area of 20 000 cm^2 in a plot of 0.5 m^2. The maximum stained contact of 200 cm^2 represents, therefore, only 1% of the potentially available vertical surface of infiltration.

Measuring bypass flow.

Undisturbed cylindrical soil samples of surface soil are taken in plastic cylinders and are subjected to sprinkling irrigation (Fig. 1). Bypass flow is directly measured in eight samples. The size of these samples (6 litres) is high compared with standard samples sizes. They often do, however, not contain twenty peds.

Correct placement of the cylinders in the soil, when sampling, is therefore crucial and a structure description should always be made before sampling. The reader is referred to Bouma et al. (1981) and Dekker and Bouma (1984) for further details.

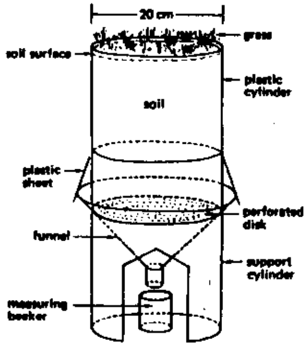

Fig. 1 Measurement of short-circuiting in a large core of undisturbed surface soil

Case study 2: Effects of horizontal cracking on upward, unsaturated flow.

Vertical cracks may result in bypass flow. However, soil shrinkage also causes the formation of horizontal cracks which strongly impede upward flow of water in unsaturated soil (Bouma and De Laat, 1981). A method was devised to stain air-filled horizontal cracks at different moisture contents and corresponding (negative) pressure heads. A cube of soil (30 cm x 30 cm x 30 cm) is carved-out in situ (Figure 2). The cube is encased in gypsum and is turned on its side. The upper and lower surface are opened and two sidewalls of the turned cube are closed. Methylene blue in water is poured into the cube and will stain the air-filled cracks. The surface area of these stained cracks is counted after returning the cube to its original

position. A separate cube is needed for each (negative) pressure head. The K-curve for the peds (Figure 3) is "reduced" for each pressure head measured in a cube. When, for example, 50% of the horizontal cross sectional area is stained, K_{unsat} for upward flow is 50% of the K_{unsat} at the same pressure head in the peds. The reduced K curve is called: K macro.

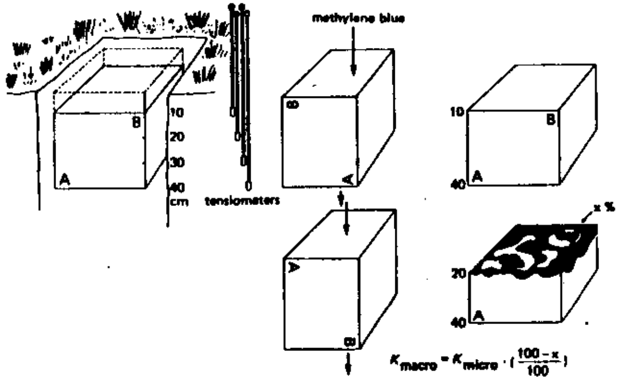

Fig. 2 Measurement of the surface area occupied by air-filled horizontal cracks in a clay soil

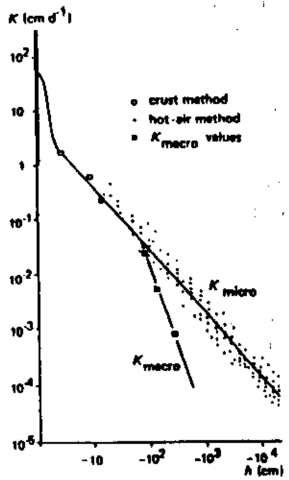

Fig. 3 K curve for the peds (K_{micro}) and K curve for calculating upward unsaturated flow (K_{macro}) in a heavy clay soil. The latter was measured with the procedure shown in Figure 2.

Simulation models

Complex flow processes in bi-porous soils with macropores become simpler when submodels are distinguished, which can be defined by using soil morphological data. Three submodels for infiltration are distinguised in Figure 4 .

1) vertical infiltration at the upper soil surface between the macropores (i_1),
2) flow of water from the surface into the macropores, after filling of microdepressions at the soil surface.
3) partial or complete filling of the macropores and lateral infiltration into the (unsaturated) soil matrix (i_2).

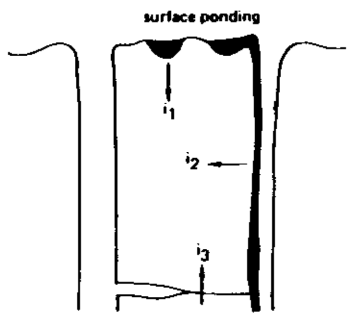

Figure 4. A schematic representation of water infiltration into bi-porous soil, showing surface ponding of water, vertical infiltration (i_1), lateral infiltration along ped faces into the peds (i_2) and upward flow (i_3).

A separate submodel for upward unsaturated flow (i_3 in Figure 4) is based on the staining-method to characterize the effect of horizontal cracks, as discussed earlier. Vertical and lateral infiltration can be characterized by Darcy's equation with the

continuity equation. The reader is referred to any current soil physics textbook for specific details. Computer simulation, using CSMP or other user-friendly subroutines, becomes very attractive for the applications being discussed here. Four cases studies in which these techniques were applied will now be reviewed briefly.

Case study 1: sprinkling irrigation in a clay soil.

A model, composed of three submodels as outlined in Figure 4, was used to predict the infiltration of water during sprinkling irrigation in a dry, cracked soil (Hoogmoed and Bouma, 1980). They used measured K-h, D-θ and h-θ functions, as well as independantly measured data for the contact area S at two sprinkling intensities. The extent of surface ponding was estimated. The high percentage of bypass flow (expressed as a percentage of sprinkling rate) was due to relatively low surface ponding but, particularly, to low S values. Simulation of conditions in which all vertical ped faces would be available for lateral infiltration, ($S = 20\,000$ cm^2) resulted in lack of bypass flow because water was absorbed within 2 cm below surface.

Case study 2: Flooding of dry, cracked clay soil.

Cracks were not filled with water in the previous example, where water moved as narrow bands on the vertical walls of air-filled cracks. On the contrary, ponding of water results in filling of the cracks. The number of cracks per unit surface area, and their width and depth determine the available volume for storage. Infiltration occurs into the upper soil surface, and laterally from the filled cracks. A field study was made in which these various flow processes were combined (Bouma and Wösten, 1984). The volume of air-filled cracks, available for storage of water, could be reliably estimated by making counts of gypsum filled cracks. Lateral infiltration onto the peds was simulated by using a measured D-θ function in a simulation model, which also needed the total length of cracks within a given horizontal cross-sectional area.

Case study 3: Flooding of soils with worm-channels.
Flooding of soils with worm-channels results a deep penetration of water in a short period of time. A field study was made in which vertical infiltration at the soil surface, filling of the worm-channels and lateral infiltration into the soil matrix from the filled channels, was simulated (Bouma et al., 1982). Due to the irregular morphology of the worm-channels, measured infiltration rates into the channels were used as input data for the overall model, rather than calculated infiltration rates assuming channels of perfect cylindrical shape (e.g. Edwards et al., 1979).

Case study 4: Upward, unsaturated flow in cracked clay soil.
Using the staining technique described earlier, a K_{macro} curve (Figure 2) was applied to calculate fluxes in a heavy clay soil from the water-table to the rootzone in the growing season. Good agreement between simulated data and field measurements was found (Bouma and De Laat, 1981) while results were unrealistic when using the K-curve for the peds for calculating these upward fluxes.

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