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Numerical simulation of wetting zones generated by artificial macropores

SUETSUGU, Atsushi[1*], MORI, Yasushi[1]

[1]Fclt Environ Sci & Tech, Okayama Univ.

Introduction

Soil macropores have been recognized historically (e.g., Schumacher, 1864). Water retention characteristics of the macropores have been described quantitatively by using capillary pressure (e.g., Nelson & Baver, 1940), while transport phenomena through macroporous soils are still a research topic in geological science. Laminar flows in macroporous soils have been estimated by the dual-porosity model (Gerke & van Genuchten, 1993). Rapid flows in macroporous soils have also been characterized with non-destructive techniques for visualization of soil macropores (e.g., Capowiez et al., 2011), quantification of macropore volume (e.g. Nakashima & Kamiya, 2007), and quantitative evaluation of transport parameters for macropores (Elliot et al., 2010). As the tools for the assessment of soil macroporosity being developed, various efforts to utilize the natural processes generated by macropores are being carried out. Shipitalo and Gibbs (2000) suggested a method to dispose wastewater to soils through the network of earthworm burrows. Hirth et al. (2005) developed artificial biopores to introduce seedlings of ryegrass into soils. The authors developed an artificial macropore system to promote flows in subsurface soils. The artificial macropore has narrow (c.a. 1 cm) auger-holes filled with coarse fibrous materials (Mori, 2009). By filling the fibrous materials, erosion of the macropore walls is expected to be reduced. Rapid flows in macropores are moderated by the fillings to extend flow regions in the subsurface layers. The extended flow regions would be effective in leaching of soil contaminants, bioremediation, carbon sequestration, etc. To evaluate the wetting zones generated by the artificial macropores, a numerical simulation with Hydrus2D (PC-Progress, s.r.o.) was conducted at two types of rainfall intensity (2, 20 mm/hr) and three types of inclination (0, 5, 10 degree).

Methods

A surface-crusted loam soil was supposed for remediation with the artificial macropore. Hydraulic conductivity of the crust was set at $5.56*10^{-7}$ m/s (ca. 2 mm/hr). We supposed to use a blasted bamboo for the permeable filling. Saturated hydraulic conductivity of the filling was set at $7.00*10^{-3}$ m/s (obtained by the constant head method). To simulate overland flows with Hydrus2D, two types of approach were employed.

(1) Introducing a virtual layer for ponding water storage in Hydrus2D simulation

A virtual surface layer (Rassam et al., 2003) was set above the real soil surface. Saturated hydraulic conductivity of the layer was set at 5 m/s to avoid retardation of flows. A valley-like geometry was selected as an ideal site for the artificial macropore.

(2) Overland flow calculation with Hydrus2D

The overland flow module for Hydrus2D (Simunek, 2003; Kohne et al., 2011) utilizes the kinematic wave approximation of ponding water change with the empirical Manning hydraulic resistance. The Mannings roughness coefficient was set at 0.030 for forests with sufficient understory vegetation. Geometry of the system was simplified to a single slope for this approach. The hydraulic parameters were re-optimized to maintain water content at positive pressure values.

Results & Discussion

At 20 mm/hr rainfall intensity, the artificial macropore generated a wetting zone around the macropore (Figure 1). For both of the valley system and the single slope system, the width of the wetting zones were ca.140 cm in the inclined (5 and 10 degree) lands. The artificial macropore system was less effective in the horizontal lands. No significant difference was given by installing the artificial macropore at 2 mm/hr rainfall intensity. Base on the results, appropriate spacing of the artificial macropores should be less than 140 cm for the crusted loam soils with moderate inclinations. Inclination enhanced infiltration through the artificial macropores, but precise estimation for more realistic geometries will be conducted with COMSOL software package.

Keywords: artificial macropore, Hydrus, carbon sequestration, leaching, wetting zone, numerical simulation

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