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Infiltration pattern during flood irrigation using dye tracer test

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<Abstract>

The objective of this study was to examine the infiltration pattern in a soil developed from granite using the nonfluorescent and nontoxic food dye, Brilliant Blue FCF ($C_{37}H_{34}N_2Na_2O_9S_3$) as the dye tracer. A homogeneous matrix flow occurred in the A horizon with weak, medium granular structure and fingering at the interface of finer-textured A horizon and coarser-textured C horizon. Pegmatitic vein originated from the granite and plant root in C horizon induced preferential flow.

key word : dye tracer, Brilliant Blue FCF, homogeneous matrix flow, preferential flow, infiltration.

1. Introduction

The unsaturated zone between land and groundwater has a limited regulatory function for groundwater recharge and discharge and the fate of contaminants on their way to water resources. Soil can act as a filter that can trap contaminants in the soil matrix preventing or reducing the contamination of groundwater, but the preferential flow of water and solute in soil can allow contaminants to bypass the soil matrix and to proceed rapidly to groundwater (Flury et al., 1994; Tindal and Vencill. 1995). Homogeneous matrix flow of water can be easily predicted using numerical models based on Darcian's assumption and field measurement (Warrick et al., 1997). However, preferential flow makes an accurate estimation of hydrological process and contaminant transport difficult.

Dye tracing has also been employed to visualize flow paths and to mimic the transport behavior of solutes. The most commonly used dye tracer to stain flow paths in porous media is the nonfluorescent food dye Brilliant Blue FCF ($C_{37}H_{34}N_2Na_2O_9S_3$). Brilliant Blue FCF has a good visibility in soils and a weak adsorption on soils (Flury and Fluhler, 1995). It also exhibits low toxicity and moderate price, making it a good tracer. The objective of this study was to examine the infiltration pattern in a soil developed from granite.

2. Material and method

The soil profile was developed from an Jurassic granite and located at Daejeon, Korea. Characteristics of the soil are shown in Table 1.

Table 1. Physical, mineralogical and chemical properties of the soils used in this study.

Classification[1]	Parent material	Horizon	Depth (cm)	Color	Texture (clay/silt/sand) (%)	Structure	Mineralogy[2]	pH[3]	EC[4] (μS/cm)	I.L[5] (%)
Typic Dystrudepts	Granite	A	2-30	10YR 4/2	Sandy loam (3.3/30.0/66.7)	Weak, medium granular	Q, F, M, K	4.52	32.9	0.54
		C1	30-54	10YR 6/4	Loamy sand (2.6/20.4/77.0)	Residual rock structure	Q, F, M, K, V	6.07	25.0	0.46
		C2	54-150	10YR 6/4	Loamy sand (2.6/22.4/75.0)	Residual rock structure	Q, F, M, K, V	4.96	9.51	0.21

1: adopted from NIAST and RDA (2000). 2: Q: quartz, F: feldspar, M: mica, K: kaolinite, V: vermiculite. 3 and 4: determined with 1 soil and 10 distiled water method. 5: Ignition loss.

A solution of Brilliant Blue FCF (Neveon Hilton Davis Inc., Cincinati, OH) at a concentration of 5 g/l was used to stain the flow paths (Reichenberger et al., 2002). Acryl square frame (1.0 × 1.0 m) was installed into the ground at 5 cm depth. The framed area was flooded with 150 L of the dye solution and was covered with a vinyl film to prevent evaporation and dilution by rainfall. After 3 days of the flooding, the soil was excavated down to 1.5 m depth at an edge of the frame (Fig. 1). The horizontal views of the soil profile were exposed by removing a layer of 5 cm thick once from the surface to 70 cm depth. The vertical and horizontal images were recoded using a digital camera (Sony Cybershot DSC-F717) under daylight.

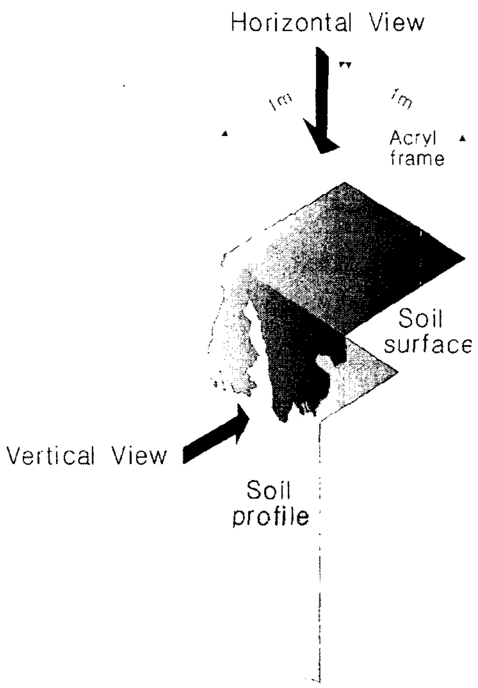

Fig. 1. Schematic presentation of the field dye tracer test.

All image processing was conducted using a geographic image processing software, ER Mapper, Version 6.2 (Earth Resource Mapping Corporate, Australia). Because any arbitrary color can be represented as a composition of the three spectral densities in the red (R), green (G), and blue (B) range, only Red-band of these colors selected and saved in a separate image plane with 256 gray values. After using median filtering command of the program, the processed image was converted to black and white image plane, and finally the dye stained pixel was classified.

3. Results and discussion

Fig. 2 shows that the stain images of vertical cross section for the soil. A homogeneous matrix flow occurred in the A horizon and a wavy front (fingering) of the matrix flow extended into C horizon. The preferential flow was observed along the vein and plant root in C horizon. The front of the matrix flow was apparently match with the boundary of A and C horizons.

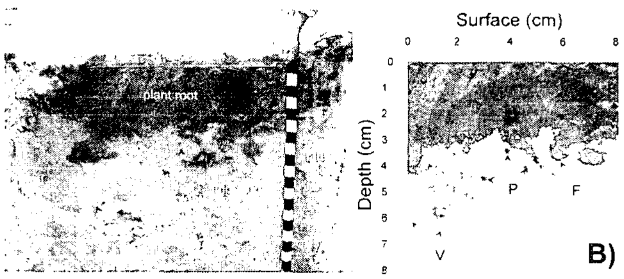

Fig. 2. The digital photograph of stained soil profile (A) and selected area for image analysis of vertical section. P represents for plant root in the figure; F for fingering; V for vein; I for interpedal face.

When the wetting front arrives at the interface of finer textured A horizon and coarser textured C horizon, the downward movement of the wetting front temporary stops at the interface due to the higher suction of A horizon and a lateral movement of the front may occur until the downward movement restarts (Baker and Hillel, 1990).

The calculated dye coverage with depth for the vertical section of the three soils shows in Fig. 3. The dye coverage matches well with the visual observation of the vertical section. Matrix flow in surface soils showed dye coverage of greater than 90 %. A sharp decrease of dye coverage with depth showed just below the boundary of matrix flow and preferential flow.

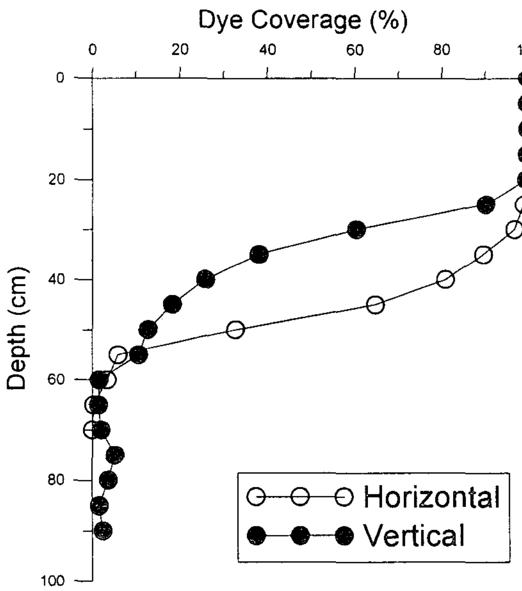

Fig. 3. Dye coverage of the vertical and horizontal sections with depth.

The dye infiltration into the surrounding matrix of the vein and the coarse plant root was also observed in horizontal cross section. The dye coverage of the horizontal sections had the very similar pattern with the dye coverage of the vertical sections. The dye coverage data strongly supports that the homogeneous matrix flow occurred in A horizon and the preferential flow in C horizon.

4. Conclusion

A homogeneous matrix flow occurred in the A horizon with weak, medium granular structure and fingering at the interface of finer textured A horizon and coarser textured C horizon. Pegmatitic vein originated from the granite and plant root in C horizon induced preferential flow.

Acknowledgements

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