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Temperature dependence of hydraulic conductivity decrease due to biological clogging under ponded infiltration

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Abstract

Decrease in hydraulic conductivity due to microbial biomass accumulation in soil pore, i.e., biological clogging or bioclogging, was studied in laboratory repacked sand columns, and temperature dependence of the bioclogging was observed. Glucose solution of 100 ppm was percolated continuously to laboratory sand columns in ponded condition, and hydraulic conductivity was measured every day. The temperature conditions were 15, 20, 25 and 30℃, and the experimental period was 4, 7 and 10 days. After each experiment, numbers of bacteria and fungi were counted by dilute plate counting method, and the amount of soil organic matter was estimated from the measurement of loss on ignition. Hydraulic conductivity did not change in 15℃ column, while it decreased exponentially with time in 20, 25 and 30℃ columns, and the rate of the decrease was largest at 25℃. Loss on ignition increased with time for all columns, and the rate of the organic accumulation was smallest at 15℃ and largest at 25℃. Exponential relationship was found between the loss on ignition and the relative hydraulic conductivity, which suggests that slime material observed at the inlet of the columns was a primary cause of biological clogging. Increase in the numbers of bacteria was highest at 30℃, while increase in the numbers of fungi was highest at 25℃. This suggests that clogging of soil pore by fungal hyphae also plays important role in biological clogging, although in many studies fungal clogging tends to be neglected and only bacterial clogging has been studied.

Key words *: Bioclogging, Fungi, Temperature dependence, Hydraulic conductivity, Organic Matter*

1. Introduction

While in many studies infiltration rate in the field is smaller in winter than summer (Constantz et al., 1994; Cerda , 1999; Basher and Ross, 2001), because saturated hydraulic conductivity is inversely proportional to viscosity of water, Battikhi and Suleiman (1999) reported that infiltration rate is smaller in summer. This may be because of the effect of biological clogging, or bioclogging, of soil pore, where in long term submergence of water microbial cells and their synthesized products accumulates in soil pore and decrease saturated hydraulic conductivity (Allison, 1947; Baveye et al., 1998).

The purpose of this study is to investigate the temperature dependence of the hydraulic conductivity decrease due to biological clogging.

2. Materials and Methods

Experimental setup is shown in **Fig. 1.** Acrylic column of 5 cm in diameter and 2 cm in height was connected to a Mariotte tank, and the whole system was stored in a constant temperature chamber. Toyoura sand was packed to 1 cm height by hand in saturated condition. The bulk density of the packed sand is 1.52 Mg m^{-3}, which corresponds to the porosity of n=0.424. Glucose solution of 100 g m^{-3} was supplied to this column by a Mariotte tank, and continuous ponded infiltration was maintained throughout flow period.

The experimental condition had 4 kinds of temperature (15, 20, 25, 30℃) and 3 kinds of flow period (4, 7, 10 days), which makes 12 kinds of conditions. Out of the 12 experimental conditions, 11 column experiments was conducted, excluding the condition of 25℃ and 10 days.

Saturated hydraulic conductivity was measured every 24 hours from the measurement of flux and hydraulic gradient. After each time the hydraulic conductivity was measured, the height of the Mariotte tank was changed to alter hydraulic gradient, keeping the flux of 2.55×10^{-5} m s^{-1}, so that pseudo constant flux condition was attained.

After the flow was terminated, sand was sampled from upper, middle and lower layers. Each layer was about 3 mm thickness. For each sampled sand, organic matter content and the numbers of bacteria and fungi were measured as follows. Organic matter was measured by loss on ignition by 800℃ and 6 hours. Numbers of bacteria and fungi was measured by the dilute plate counting method.

3. Results and Discussion

3.1 Temperature dependence of decrease in hydraulic conductivity

Change in the saturated hydraulic conductivity of the longest period runs of each temperature (7 days for 25℃ and 10 days for others) is shown in **Fig. 2.** In all the runs, the hydraulic conductivity increased at the first day, because of the effect of the removal of entrapped air (Allison, 1947). The removal of entrapped air was also visually detected, and it also matches the measurement by Seki et al. (1998).

After the initial increase of hydraulic conductivity by the removal of entrapped air, hydraulic conductivity decreased exponentially in all the columns. At 15℃, hydraulic conductivity did not decrease, and at 20 and 30℃、the rate of the decrease of hydraulic conductivity was almost the same. The rate of the decrease of hydraulic conductivity was largest at 25℃. In Fig. 2, only the result of the longest period runs are shown, but other runs also showed similar trend.

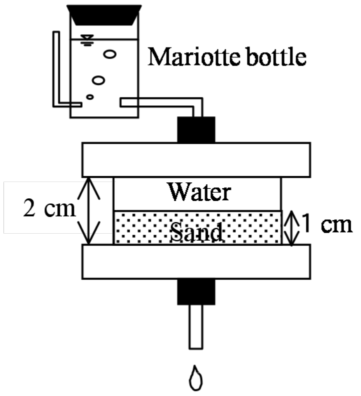

Fig. 1 Diagram of the Permeameter

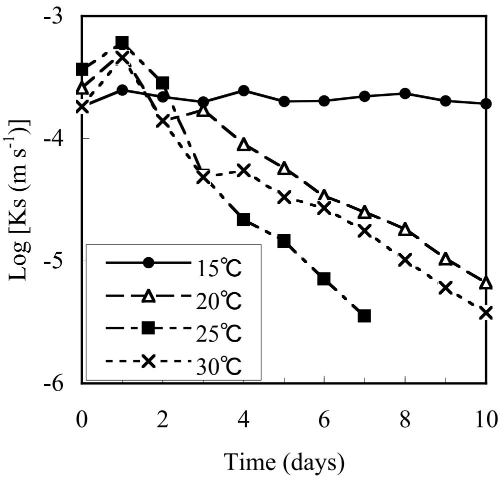

Fig. 2 Change in hydraulic conductivity

3.2 Effect of organic matter on hydraulic conductivity decrease

From careful observation of sand, the particle of the clogged sand was tied with bonding material, which appears to be a gel or slime organic material produced by microbes. The clogged sand with bonding material did not disperse when submerged in water, while the unclogged clean sand easily dispersed in water. The amount of the bonding organic material was estimated by the loss on ignition. For every experiment, the loss on ignition increased with time (data not shown in this except). The increase of the loss on ignition at 15℃ was very small, and the rate of the increase of the loss on ignition was largest at 25℃ in all the three layers. Among three layers, the upper layer always had the largest rate of increase in organic matter. In this way, the temperature dependence of the increasing rate of organic matter corresponds to the temperature dependence of the decrease in hydraulic conductivity.

To show the relationship between the increase in organic matter and the decrease in hydraulic conductivity more clearly, the relationship between the loss on ignition and relative hydraulic conductivity, i.e., the final hydraulic conductivity divided by the largest hydraulic conductivity (the value at 1 day) for all 11 columns, is shown in **Fig. 3**. Hydraulic conductivity decreased exponentially with the loss on ignition. This suggests that the organic matter was responsible for the decrease in hydraulic conductivity. The exact determination of the amount of the amount of organic matter from the loss on ignition remains unclear.

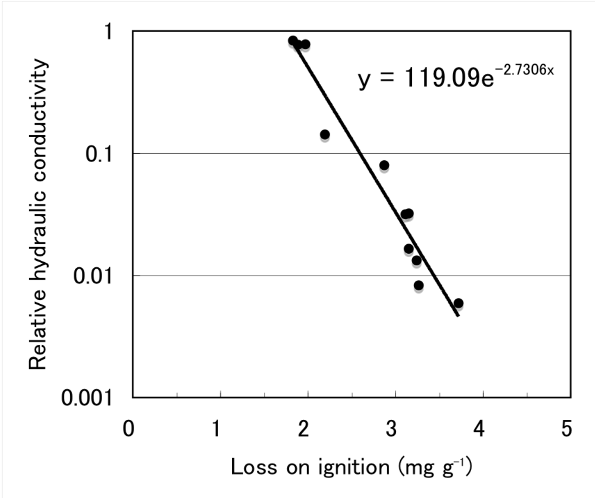

Fig. 3 Relationship between loss on ignition and relative hydraulic conductivity

3.3 Effect of bacteria and fungi on hydraulic conductivity decrease

According to the numbers of bacteria and fungi measured at the end of each studies (data not in this excerpt), they all increased with time in all the conditions of temperature. In all the columns, the upper layer always had largest numbers of bacteria and fungi among three layers. The rate of the increase of numbers of bacteria was smallest for 15℃ and increased with temperature and had largest value for 30℃. In contrast, the decrease of the hydraulic conductivity was most rapid in 25℃. It suggests that the temperature dependence of the biological clogging did not only depend on the temperature dependence of bacterial growth.

The rate of the increase of the numbers of fungi was largest at 25℃. The temperature dependence of the rate of hydraulic conductivity decrease matched with the temperature dependence of fungal growth. This would suggest that fungal hyphae also play some role on biological clogging, as suggested by Seki et al. (1996, 1998).

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