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Hydraulic properties of soils in Tanggula Mountains

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Abstract

Hydraulic properties of soils in Tanggula Mountains, that comprise soil-moisture characteristic curve and saturated-unsaturated hydraulic conductivity, were measured by laboratory methods. Soil properties in Tanggula Mountains are characterized qualitatively using Brooks and Corey equations. Compared with soils in other areas, effective water content and saturated hydraulic conductivity seem to be low due to poor biological activity in severe climate conditions.

1. Introduction

Hydraulic properties of soils, that comprise soil-moisture characteristic curve and saturated-unsaturated hydraulic conductivity, are essential to investigate not only movements of water and energy within soils, and also land surface interactions between soil and atmosphere. Moreover, these properties have been directly involved in GCMs as important parameters. There have been few studies about hydraulic properties of soils in Tibetan Plateau. In this study, soil properties in Tanggula mountains have been measured by laboratory methods and quantified using a set of equations proposed by Brooks and Corey(1964). Though laboratory measurements have not finished, we report the primary and tentative results of laboratory measurements and discuss some characteristics of soils in Tanggula Mountains.

2. Functional expressions of hydraulic properties of soils

Water movement in soil with vertical, one-dimensional saturated-unsaturated condition is written as below,

$$C(\Psi)\frac{\partial\Psi}{\partial t}=\frac{\partial}{\partial z}\left\{K(\Psi)\left(\frac{\partial\Psi}{\partial z}+1\right)\right\} \tag{1}$$

$$C(\Psi)=\frac{\partial\theta}{\partial\Psi} \tag{2}$$

where Ψ is pressure head, θ is volumetric water content, $C(\Psi)$ is specific water content, z is vertical axis, t is time, and $K(\Psi)$ is hydraulic conductivity.

Equation (1) is the combination of Darcy's law extended to unsaturated flow by Richards(1931) and the equation of continuity. Here, $C(\Psi)$, the relationships between water content and pressure head, is called specific water content or soil-moisture characteristic curve. $K(\Psi)$ is the relationship between pressure head and hydraulic conductivity. Water movement in soil is characterized by these two relationships. There are many functional forms expressing these relationships. We employ a set of equations proposed by Brooks and Corey(1964) because of their simplicity and physical basis. The equations have been employed by some GCMs such as the SiB-GCM(Sellers *et. al.*, 1986).

Brooks and Corey equations are expressed as below. The hydraulic conductivity equations are

$$\begin{cases} K(\Psi)=K_s & \Psi \geqq \Psi_b \\ K(\Psi)=K_s\left(\frac{\Psi_b}{\Psi}\right)^{\eta} & \Psi < \Psi_b \end{cases} \quad (3)$$

where K_s is saturated hydraulic conductivity, Ψ_b is bubbling pressure, and η is pore-size distribution index in the relationship between pressure head and hydraulic conductivity.

The equations for soil-moisture characteristic curve are

$$\begin{cases} \theta=\theta_s & \Psi \geqq \Psi_b \\ \theta=(\theta_s-\theta_r)\left(\frac{\Psi_b}{\Psi}\right)^{\lambda}+\theta_r & \Psi < \Psi_b \end{cases} \quad (4)$$

where θ_s is saturated water content, θ_r is residual water content, and λ is pore-size distribution index in the relationship between water content and pressure head. (θ_s-θ_r) means content of movable water by gravity force. It is called effective water content. It is commonly said that there is a relationship between λ and η, expressed as $\eta=2+3\lambda$. Consequently, water movement within soil should be characterized by θ_s, θ_r, K_s, Ψ_b, λ and η. Note that Ψ_b can be determined as parameters in both relationships independently. Values of Ψ_b in both relationships of the same sample are usually similar.

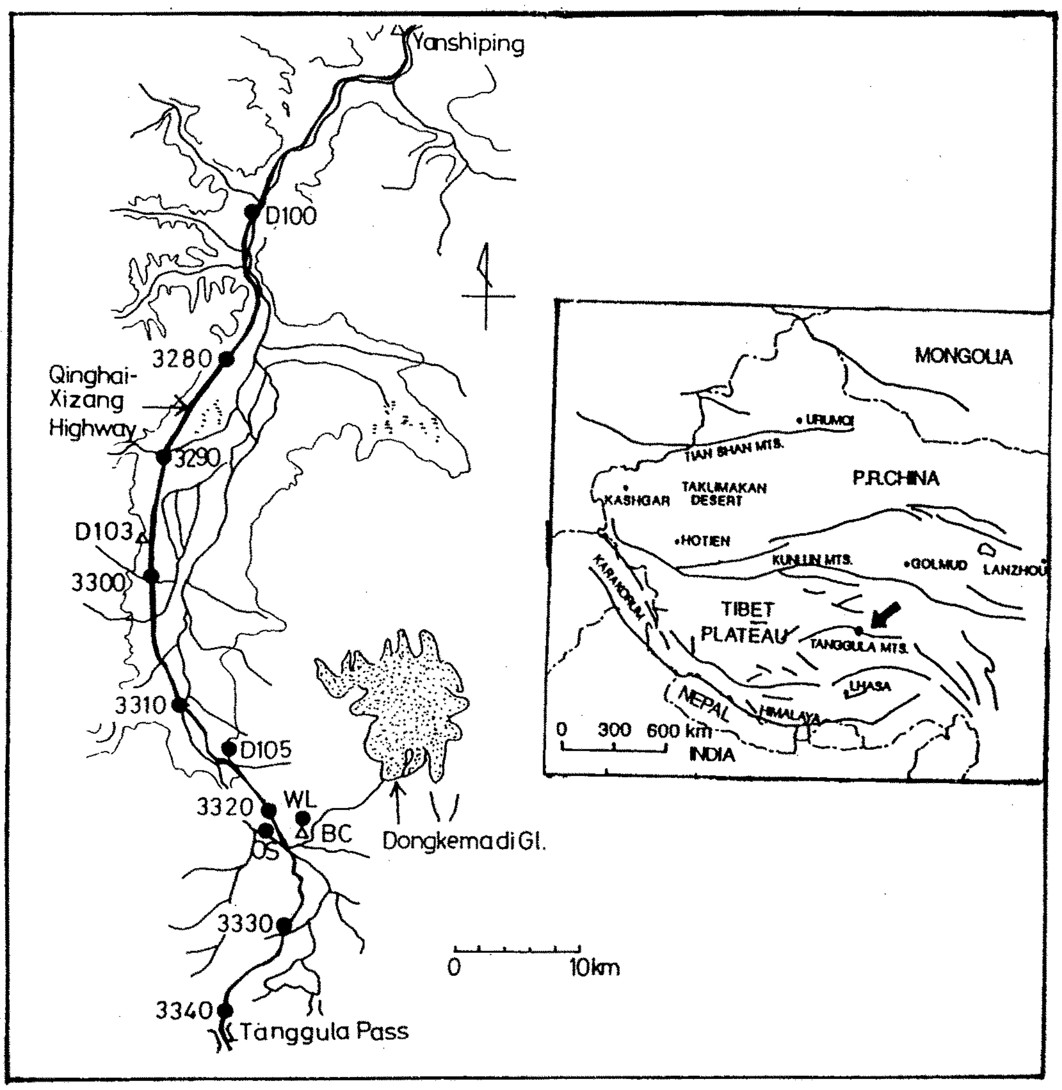

Fig. 1. The map of the study area, Tanggula Mountains.

3. Sampling sites and methods

3.1. Sampling sites and sampling method

Soils for laboratory measurements were sampled in October 1990, October 1992 and May 1993. Figure 1 shows sampling sites in Tanggula mountains. D100, D105 and WL(Wet Land) are the places where automatic data loggers of soil moisture, soil temperature and other meteorological instruments are set. Numbers such as 3280 indicate the milestones along the Qinghai-Xizang Highway. We used the milestones as the indicators of measuring points. These places are also the measuring points of soil moisture distribution at large scale. OS indicates the former weather station from 1989 to 1990 near D105.

The 100cc cylindrical sampler with 5 cm diameter was used for all the measurements. The sampler made of stainless steel was carefully driven into the soil with vertical direction, ensuring not to disturbing the soil within the sampler. The soil samples were carried into Japan after usual sterilizing treatments with high temperature and high pressure. There might have been some influences on soil structure due to the sterilizing treatment, but we think the disturbances are not so significant.

3.2. Method of measurements

For measurements of saturated-unsaturated hydraulic conductivity of soils, the steady-state head control method improved by Kobiyama and Kubota(1994), referring Klute(1986) was used in this study. Figure 2 shows a schematic diagram of the experimental apparatus. The hydraulic head distribution in the sample was controlled by the Marriotte bottle and the drip point through ceramic filters at both ends of the sample. Using the outlet rate of water at the drip point and the pressure heads of tensiometers, hydraulic conductivity was calculated. The relationship between pressured head and hydraulic conductivity was mapped proceeding through a series of steady-state flows with progressively decreasing pressure head, beginning with pressure head approximately equal to 0. The values of $K(\Psi)$ measured when $0 \geqq \Psi \geqq \Psi_b$ are considered K_s(saturated hydraulic conductivity).

For measurements of soil-moisture characteristic curve of soils in Tanggula, we used the soil column method in lower pressure range and the pressure plate

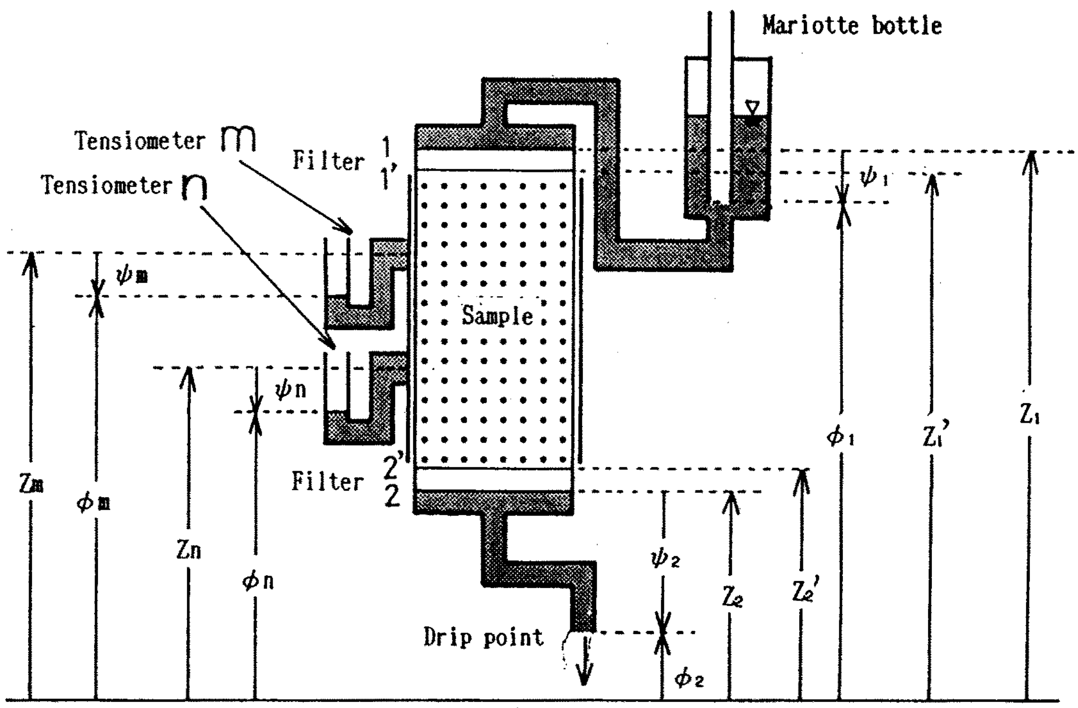

Fig. 2. A schematic diagram of the experimental apparatus for measuring hydraulic conductivity.

method in higher pressure range. Both are popular methods. The relationship between pressured head and volumetric water content was mapped with progressively decreasing pressure head.

Parameters of all samples in both equations are determined by eye-fitting.

4. Results and discussion

4.1. Soil moisture characteristic curve

Table 1 shows the results of all the measurements for soil-moisture characteristic curve. Figure 3 shows some examples of fitting results by Brooks and Corey equations (4). It is clear that Brooks and Corey equations (4) show good applicability for measured relationships. At D105, most values of effective water content ($\theta_s-\theta_r$) are less than 0.2. Some measurements of soils in forested areas in Japan show that effective water contents of soils in forested area in Japan often exceed 0.3, especially in top-soil layers(Shinomiya, 1993). There is not any significant tendency of effective water content changing with depth. That means poor biological activity in severe climate conditions has delayed soil-formation processes. At OS, values of effective soil moisture content exceed 0.4 except No.22. The sampling point of OS was covered with short grasses, like so-called earth-hummock.

Table 1. Parameters in the equation (4) of soil-moisture characteristic curve.

No.	θ_s	θ_r	θ_s-θ_r	ψ_b(cm)	λ	site	depth(cm)
1	0.42	0.32	0.10	-3.0	0.20	D105	5cm
2	0.36	0.22	0.14	-5.0	0.25	D105	10cm
3	0.38	0.18	0.16	-6.0	0.45	D105	20cm
4	0.38	0.18	0.20	-5.0	0.40	D105	30cm
5	0.37	0.18	0.19	-5.0	0.30	D105	45cm
6	0.35	0.20	0.15	-6.0	0.30	D105	60cm
7	0.35	0.12	0.23	-3.0	0.30	D105	60cm
8	0.40	0.20	0.20	-3.0	0.30	D105	70cm
9	0.32	0.15	0.17	-2.0	0.20	D105	80cm
10	0.38	0.12	0.16	-2.0	0.30	D105	100cm
11	0.32	0.18	0.14	-4.0	0.30	D105	100cm
12	0.40	0.10	0.30	-4.0	0.35	3280km	0-4cm
13	0.41	0.18	0.23	-7.0	0.35	3290km	0-4cm
14	0.40	0.12	0.28	-2.5	0.35	3300km	0-4cm
15	0.40	0.20	0.20	-10.0	0.40	3310km	0-4cm
16	0.52	0.45	0.07	-4.0	0.90	3320km	0-4cm
17	0.32	0.07	0.25	-2.0	0.40	3330km	0-4cm
18	0.42	0.32	0.10	-2.0	0.25	3340km	0-4cm
19	0.35	0.18	0.17	-4.0	0.45	Tanggula pass	0-4cm
20	0.49	0.07	0.42	-3.0	0.40	OS	5cm
21	0.48	0.05	0.43	-36.0	0.70	OS	5cm
22	0.44	0.16	0.28	-13.0	0.60	OS	30cm
23	0.50	0.09	0.41	-8.5	0.59	OS	30cm

4.2. Saturated-unsaturated conductivity

Table 2 shows the results of all the measurements for saturated-unsaturated conductivity and Fig. 4 shows some examples of fitting results by Brooks and Corey equations (3). It is also clear that Brooks and Corey equations (3) are effective for expressing measured relationships. It seems that saturated hydraulic conductivities at shallow layers are not so high.

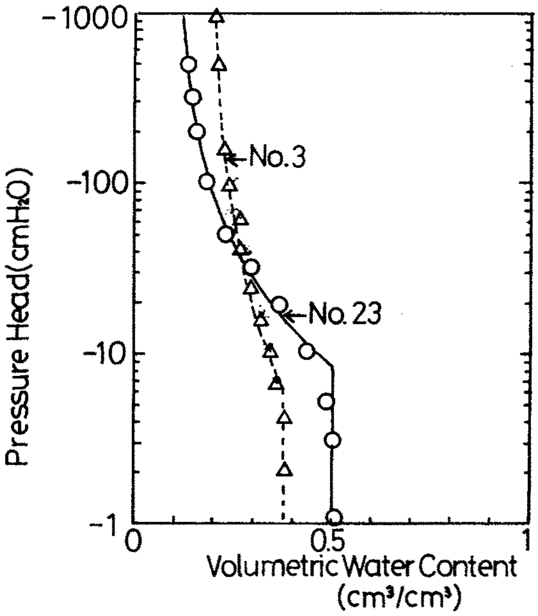

Fig. 3. Examples of soil-moisture characteristic curve. Lines in the figure indicate equation (4).

Table 2. Parameters in the equation (3) of hydraulic conductivity.

No.	K_s (※ 1)	ψ_b(cm)	η	site	depth(cm)
1	1.00	-3.7	2.72	D100	10cm
2	1.05	-3.0	2.51	〃	10cm
3	0.80	-5.8	2.71	〃	20cm
4	1.90	-2.2	1.43	〃	20cm
5	0.60	-5.0	1.21	WL	10cm
6	2.00	-2.0	1.15	〃	20cm
7	0.40	-5.0	2.20	〃	20cm
8	0.65	-4.6	2.26	〃	40cm
9	0.87	-3.8	2.69	〃	40cm
10	0.015	-24.0	2.26	〃	80cm

※ 1 Unit of Ks : 10^{-3}cm/sec

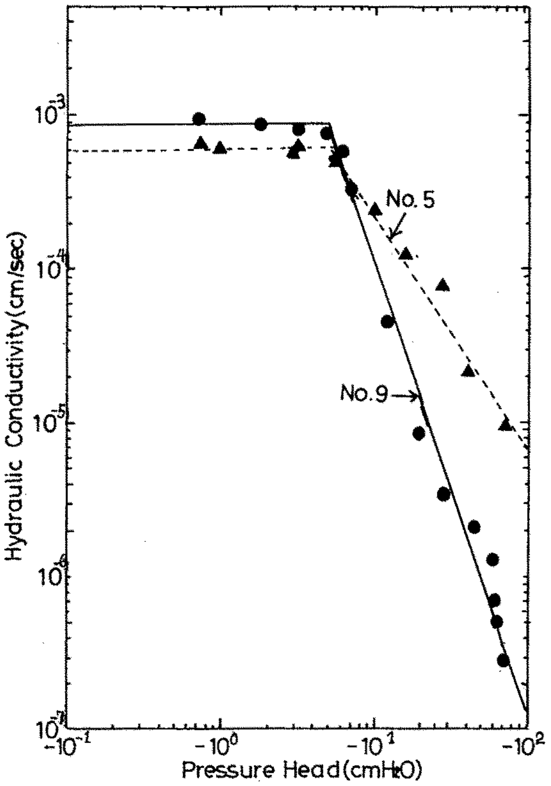

Fig. 4. Examples of hydraulic conductivity. Lines in the figure indicate equation (3).

The hydraulic conductivity at 80 cm depth in WL is very low. That suggests the soil layers that have low hydraulic conductivities like the 80 cm depth in WL could be inactive in terms of water movement even if the depth of active layer exceeds it.

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References

1. Brooks, R. H. and Corey, A. T. (1964) : Hydraulic properties of porous media. Hydrology Paper, No. **3**, Colorado State University, Fort Collins, Colorado, 1–27.
2. Klute, A. (editor) (1986) : Method for soil analysis. 1. Physical and mineralogical methods, 2nd edition. Agronomy Monograph **9**, Am. Soc. Agron., Madison, 1188pp.
3. Kobiyama, M. and Kubota, J. (1994) : Hydraulic properties of soils with macropores in low suction zone. (submitted to Wat. Resour. Res.)
4. Richards, L. A. (1931) : Capillary conduction of liquids in porous mediums. Physics **1**, 318–333.
5. Sellers P. J., Mintz, Y., Sud Y. C. and Dalcher, A. (1986) : A simple biosphere model (SiB) for use within General Circulation Models. J. Atmos. Sci., **43**, 505–531.
6. Shinomiya, Y. (1993) : Formation processes of soil-moisture characteristics in forested slopes (in Japanese). Master of Agriculture thesis, Tokyo Univ. of Agric. and Tech., 155pp.