Spatial Variability of Hydraulic Properties of Forest Soils

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1. Introduction

Many studies on spatial variability of soil hydraulic properties have been done (Mahonty et al., 1994; Hopmans, 1993; Clausnitzer et el., 1992; Peck et al., 1977; Hills et al., 1989; Nielson et al., 1973 and so on). Most of those studies were for agriculture soils. The spatial variability of hydraulic properties of forest soils in a hill slope is still rarely known. In this study, the hydraulic properties of forest soil in a trench of a hill slope from the crest to the foot slope were measured to observe its spatial variability.

Scaling factors (α_i) were determined to reduce the number of parameters needed to describe the spatial variation of hydraulic properties. The pressure head (ψ)-effective saturation (S_e) and hydraulic conductivity (K)-S_e relationships were scaled separately as well as simultaneously. The Kosugi's model (1996) called lognormal (LN) model was used to express the ψ-S_e and K-S_e relationships.

2. Experimental Site

Hydraulic properties were measured in laboratory using large soil sample column of 19.5 cm in diameter and 60 cm long. The soil samples were taken from six sites in a hill slope from the crest to the foot slope, in the upper stream of the Sumiyoshi River Basin. The Basin is located on the western slope of Mount Nishiotafuku, in Rokko Mountain range, Hyogo Prefecture. The area is covered with dense deciduous broad-leaved forest. The hydraulic properties of soil samples were measured in every 10 cm interval down to 50 cm below soil surface.

3. Method

3.1 Hydraulic properties measurement

The hydraulic properties measurement method is the same principally as the method proposed by Hendrayanto et al. (1998). In this study the soil sample was put on a sand column. To measure the saturated hydraulic conductivity (K_s), the saturated steady flow was created in the soil samples column by supplying water using rainfall simulator. The water head level at soil surface was kept constant by applying the constant rainfall. The position of water surface in the overflow tank (the bottom steady boundary condition) was set up at three difference positions. The methods to calibrate TDR, and to calculate unsaturated water retention and unsaturated hydraulic conductivity are explained in detail by Hendrayanto et al. (1998).

3.2 Scaling hydraulic properties.

Scaling factor α_i defined by Peck et al. (1977) was applied to the LN model. The scaled $\psi(S_e)$ and $K(S_e)$ are:

$$\psi(S_e) = \frac{\hat{\psi}_m}{\alpha_{\psi,i}} exp\left[\hat{\sigma} Q^{-1}(S_e)\right] \quad \text{.................} \quad (1)$$

$$K(S_e) = \alpha_{K,i}^2 \hat{K}_s S_e^{0.5} Q^2 \left[Q^{-1}(S_e) + \hat{\sigma}\right] \cdots\cdots\cdots \quad (2)$$

$\alpha_{\psi,i}$ and $\alpha_{K,i}$ were determined separately as well as simultaneously. The non-linear least squares optimization method, provided in spread sheet program EXCELL® (Wraith and Or, 1997) was used to determined $\alpha_{\psi,i}$ and $\alpha_{K,i}$ in eq. [1] and [2].

4. Results

Figure 1 shows the measured water content (θ)–pressure head (ψ) and unsaturated (K)-ψ relationships of 30 samples. Fig.1 shows that θ–ψ and K-ψ relationships vary in a trench of a forested hill slope. Further observations show that hydraulic properties vary vertically (down to – 50cm from the surface) as well as horizontally (from the crest to the foot slope). Hydraulic properties are more variable in horizontal direction than vertical direction.

Table 1 shows the statistics of hydraulic properties parameters which are used in the LN model that can express the θ-ψ and K-ψ relationships very well. Those parameters show significant variability. The coefficient of variance (CV) of those parameters are larger than 15%.

Table 1. The statistics of hydraulic property parameters

	θ_s	θ_r	ψ_m	σ	l	K_s
mean	0.6084	0.3035	-18.7893	1.2295	0.5009	0.1520
St.dev•	0.1164	0.0902	14.7679	0.3219	2.2474	0.1371
CV	0.1913	0.2970	-0.7860	0.2618	4.4870	0.9020
Max	0.8457	0.4111	-4.5258	1.9717	9.9524	0.4200
Min	0.4042	0.0535	-58.8480	0.3362	-1.5400	0.0006

Notes: θ_s: saturated water content; θ_r : residual water content; ψ_m: median of pore radius distribution; σ: standard deviation of log transformed soil pore radius; l: tortuosity factor; K_s: saturated hydraulic conductivity.

Separate as well as simultaneous scaling approach succeed to scale the hydraulic properties. The residual sum of square (RSS) of scaled $\psi(S_e)$ and scaled $K(S_e)$ were reduced 95% and 82%, respectively, by separate scaling, and 79% and 73%, respectively, by simultaneous scaling. The coefficient of determinant (R^2) of de-scaled vs original S_e and de-scaled vs original log K were 0.96 and 0.86, respectively (separate scaling) and 0.92 and 0.65, respectively (simultaneous scaling). Separate scaling gave better results than simultaneous scaling, but it resulted in two sets of scaling factors. Fig.2 shows the de-scaled vs original S_e and de-scaled vs original log K relationship obtained by simultaneous scaling.

Scaling factor, α_i obeyed the lognormal distribution rather than normal distribution (Figure 3). α_i was smaller for the upper part than the lower part of the hill slope. This indicates that soils in the upper part of the hill slope have smaller median pore radius than soils in the lower part of the hill slope. The variability of the scaling factor in the soil surface in horizontal direction was large, compare to the variability in the subsurface soil (Figure 4). The variance of lnα_i $\left(\sigma^2_{\ln\alpha_i}\right)$ was 0.94.

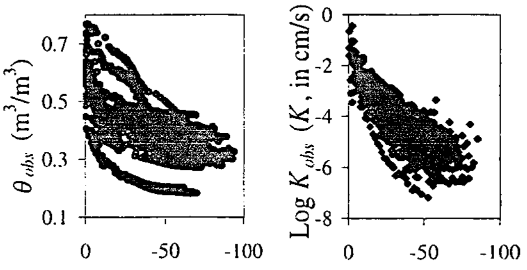

Figure 1

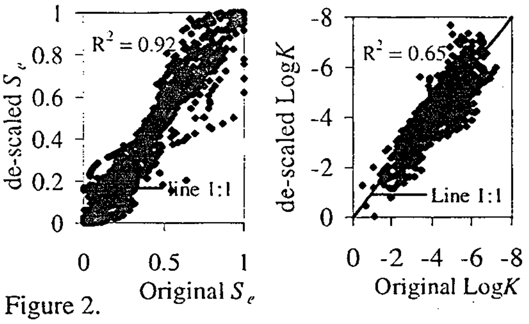

Figure 2.

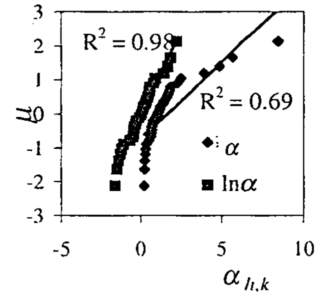

Figure 3.

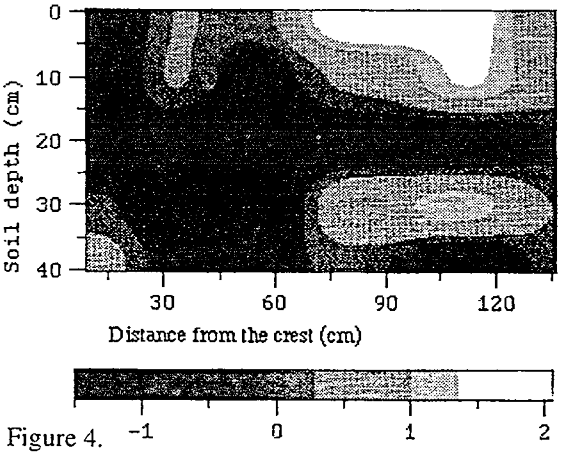

Figure 4.

References

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