Determination of Soil Hydraulic Properties in Non-Level Landscapes

W. L. Bodhinayake and B. C. Si
Department of Soil Science, University of Saskatchewan, Saskatoon, SK, S7N 5A8

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Abstract

Majority of the landscapes in Saskatchewan are non-level. However, specifically designed instruments are not available for the estimation of hydraulic properties of surface soils in non-level landscapes. The purpose of this study was to evaluate the suitability of available tools (tension infiltrometer and double ring infiltrometer) for the estimation of surface soil hydraulic properties in non-level lands. A field experiment was conducted in a loamy soil in Laura, Saskatchewan. Soil surface was prepared to represent 0, 7, 15 and 20% slopes. Infiltration rates were measured using a tension infiltrometer and a double ring infiltrometer. Hydraulic properties were estimated. Steady infiltration rates measured using double ring infiltrometer were not significantly different among slopes ($p < 0.05$). Saturated hydraulic conductivity and inverse macroscopic capillary length scale predicted from tension infiltrometre were not statistically different ($p < 0.05$) among the slopes tested indicating that these instruments are suitable for characterization of surface hydraulic properties in hummocky landscapes in Saskatchewan. A computer simulation is planned for further confirmation of these results.

Introduction

In Saskatchewan, there are level (slope < 1%) as well as non-level landscapes. Majority of the landscapes are non-level, which includes undulating, rolling, hilly, hummocky etc. (Soil Survey Report No. 12, 1962; Pennock et al., 1987). It has been shown by various researches that the type of landscape influences soil properties including soil hydraulic properties such as infiltration rate, saturated hydraulic conductivity and unsaturated hydraulic conductivity as a function of water content and matric potential (Zebarth et al., 1989; Zebarth and de Jong, 1989). These properties are important for understanding water balance, irrigation and transport processes (Si et al., 1999). Moreover, hydraulic properties of surface soils affect the partition of rainfall and snowmelt into runoff and soil water storage. Hence, knowledge on surface soil hydraulic properties in non-level lands is needed for efficient soil and water management in prairies.

In situ measurement of soil hydraulic properties is quite difficult. Therefore, infiltration based methods are recognized as valuable and convenient methods in investigating soil hydraulic properties (Angulo Jaramillo et al., 2000). Double ring infiltrometer and tension infiltrometer have been widely used for efficient measurements of soil hydraulic properties under saturation and unsaturated conditions, respectively (Bower, 1986; Angulo-Jaramillo et al., 2000; Reynolds and Elrick, 1991). Double ring infiltrometer and tension infiltrometer have been extensively used to obtain soil hydraulic properties in non-level lands. Watson and Luxmoore (1986) and Wilson and Luxmoore (1988) used these instruments for measuring infiltration rates and macro pore flow in forest watersheds with slopes up to 20%. Using a single ring infiltrometer, Elliott and Efetha (1999) measured infiltration rates in conventionally tilled and zero-tilled fields with slopes ranging from 6-30% in a rolling landscape, Canada. However, Harr (1987) showed that even a slight change in soil water pressure head due to slope changed both magnitude and direction of water flux. As a consequence, the infiltration rate, which is the basic measurement used in estimating hydraulic properties would vary between level and non-level lands. Therefore, use of double ring infiltrometer and tension infiltrometer in sloppy lands would give erroneous results. So far no attempt has been made to evaluate the suitability of these instruments for sloppy lands, to the best of our knowledge. Hence, there is a great need for evaluating the use of double ring infiltrometer and tension infiltrometer for sloppy lands as no specifically designed instruments are available for the measurement of soil hydraulic properties in non-level lands.

Objective

The objective of this study was to evaluate the suitability of double ring infiltrometer and tension infiltrometer for the estimation of surface soil hydraulic properties in non-level lands.

Materials and Methods

This study was carried out at Laura farm (about 50 km west of Saskatoon), Saskatchewan, Canada. The soil of the area is classified as Orthic Dark Brown Chernozems with the surface soil of silty loam in texture.

Using a spade, loose (ploughed) soil was scraped off from an area of about 4 m^2. Soil surface was prepared artificially to represent 0% (level), 7%, 15%, and 20% slopes (treatments). Undisturbed soil core samples (0.05 m in diameter × 0.05 m in height) were taken from surface soil adjacent to the measurement locations for the determination of bulk density. Antecedent soil moisture content was measured using a time domain reflectometry (TDR) that had two 0.15 m length wave guides and inserted horizontally 2-3 cm below the center of the disc, just before the commencement of infiltration measurements. Total porosity was calculated using soil bulk density and particle density.

Using tension infiltrometer (Soil Moisture Measurement Systems, Tuscon, AZ) with 0.2 m diameter disc, infiltration measurements were made at six tensions namely 2.2, 1.7, 1.3, 1.0, 0.6, and 0.3 kPa. Measurements were continued at each tension until steady state is achieved. After the steady infiltration rate is attained at 0.3 kPa tension TDR reading was taken to determine soil moisture content. Macroporosity was calculated as the difference between total porosity and volumetric moisture held at 0.3 kPa tension. Double ring infiltrometer method with inner and outer ring of 0.2 m and 0.3 m in diameter, respectively, and 0.3 m constant head at the center of the inner ring was used to determine steady state infiltration rates (Bower, 1986) on all the locations parallel to the tension infiltrometer measurements. Treatments were replicated five times and arranged in a randomized complete block design.

For Gardner's (1958) exponential hydraulic conductivity function

$$K(h) = K_s \exp(\alpha h) \tag{1}$$

Wooding (1968) derived the following approximate solution for steady state infiltration rate under a shallow disc:

$$q_\infty(h) = \left(1 + \frac{4}{\alpha \pi r_d}\right) K_s \exp(\alpha h) \tag{2}$$

where $q_\infty(h)$ is the steady state infiltration rate corresponding to the water supply tension *h*, K_s is the saturated hydraulic conductivity, α is the inverse macroscopic capillary length scale, and r_d is the radius of the disc. Equation (2) has two unknown parameters, K_s and α. These parameters were estimated through non-linear regression of q_∞ as a function of *h*.

Results and Discussion

Average bulk density and macro porosity between level (0% slope) and non-level lands were not significantly different at 5% significance level (Table 1). The infiltration rate is a function of the morphology of the pore system, which is controlled by the texture and structure of the soil, its continuity to the soil surface and the potential forces applied to the water (Hillel, 1998). All the experimental units had silty loam soil texture. Hence, as there is no difference in bulk density and macro porosity among slopes, any difference in infiltration rates and estimated hydraulic properties from infiltration rates should be due to the treatment effect (slope of the surface).

Table 1. Bulk Density, Macro- porosity, Steady Infiltration Rate (Measured From Double Ring Infiltrometer) and Saturated Hydraulic Conductivity (Ks) and Inverse Capillary Length Scale (α) Estimated From Tension Infiltrometer Measurements for Different Slopes.

Parameter	Slope (%)				LSD	CV
	0	7	15	20	(0.05)	(%)
Bulk density (g cm^{-3})	01.26	1.25	1.26	1.27	0.06	3.32
Macro porosity (%)	14.54	13.99	15.02	15.78	6.44	31.51
Infiltration rate (cm min^{-1})	0.072	0.096	0.076	0.093	0.05	43.79
Ks (cm min^{-1})	0.013	0.016	0.011	0.013	0.01	60.39
α (cm^{-1})	0.071	0.077	0.055	0.062	0.03	35.23

The inverse macroscopic capillary length scale (α) is a shape parameter of hydraulic conductivity-tension relationship and is a measure of the relative importance of gravitational and capillary forces during water movement in unsaturated soils. The α values as well as saturated hydraulic conductivity values among slopes estimated from tension infiltrometer measurements were not significantly different at 95% probability level. Steady infiltration rates obtained from double ring infiltrometers were also not significant at 5% significance level (Table 1). These results indicate that both tension infiltrometer and double ring infiltrometer are suitable for the measurement of surface soil hydraulic properties in level lands as well as non-level lands up to the slopes of 20%.

Conclusions

Double ring infiltrometer and tension infilrometer are suitable for characterization of surface soil hydraulic properties in non-level lands with slopes up to 20%. As majority of the cultivated lands are below 15% slope, these instruments can be used to estimate saturated and unsaturated hydraulic conductivity of most of the cultivated lands in Saskatchewan.

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