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DETERMINATION OF UNSATURATED HYDRAULIC CONDUCTIVITY BY INTERNAL DRAINAGE ASSUMING A UNIFORM SOIL WATER PROFILE

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ABSTRACT

The internal drainage procedure may be used to measure the soil unsaturated hydraulic conductivity (UHC) by measuring the soil water content and matric potential profiles. However, in some cases this method can not be used due to failure of tensiometer in determination of soil matric potential. Therefore, a simplified procedure may be applied. In the present investigation a modified internal drainage method was used and compared with the original procedure to determine the UHC in three different soils. In this simplified method, it was assumed that a uniform soil water profile or unit hydraulic gradient was assumed. The simplified procedure only requires the soil water profile to be measured by a neutron probe or by the gravitational method. The equation of UHC as a function of soil water content, K(θ), obtained by the two different methods was similar for two of the three soils (Dezful and Mollasani) which contained no gravel. In these

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soils, the soil water profiles were rather uniform and their hydraulic gradients were about 1.0 and 0.92 which are close to unity. Therefore, it may be concluded that the simplified method of internal drainage can be applied to homogeneous soils with a nearly uniform soil water profile and unit hydraulic gradient. The K(θ) for gravelly soil (Jahrom) was different in the two methods due to the nonhomogeniety of soil and non-uniform soil water profile.

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تعیین ضریب هیدرولیکی خاک غیراشباع با روش زهکشی داخلی و نیمرخ یکنواخت آب خاک

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به ترتیب مربی مجتمع آموزشی و پژوهشی رامین-اهواز واستاد بخش آبیاری دانشگاه شیراز.

چکیده

با اندازه گیری نیمرخ ها ی آب خاک وپتانسیل ماتریک خاک می توان ضریب هدایت هیدرولیکی خاک غیراشباع را به روش زهکشی داخلی اندازه گیری کرد. اما در بعضی موارد به علت عدم امکان اندازه گیری پتانسیل ماتریک آب خاک بوسیله مکش سنج نمی توان از این روش استفاده کرد. بنابراین دراین پژوهش روش ساده ای برای زهکشی داخلی پیشنهاد گردیده است. این

روش ساده برای تعیین ضریب هدایت هیدرولیکی غیراشباع سه خاک مختلف به کار رفته و نتایج آن با روش اصلی زهکشی داخلـی مقایسـه شـد. درروش سـاده فـرض گردیـد کـه نیمـرخ آب خـاک یکنواخت بوده و یا دارای شـیب بـارآبی واحـد مـی باشـد. درروش سـاده تنهـا بایسـتی مقـدار آب دراعماق مختلف خاک رابوسیله نوترون متر ویاروش-وزنی اندازه گیری نمود. معادله بیـن ضریـب هدایت هیدرو لیکی خاک غیراشباع ومقدار آب خاک درروش های مذکور برای خاک های دزفـول و ملاثانی که سنگریزه نداشتند، همانند بودند. در این خاک ها، نیمرخ آب خـاک نسبتا یکنواخـت بوده و شیب بار آبی بین ۰/۹۲ تا۱/۰۱ متغیر بود. بنـابراین نتیجـه گـیری مـی شـود کـه روش سـاده زهکشی داخلی را می توان برای تعیین ضریب هدایت هیدرولیکـی خـاک غیراشـباع درخـاک هـای همگـن بکـار بردکـه دارای نیمـرخ آب خـاک یکنواخـت و یـا شـیب بـار آبـی نزدیـک بـــه واحـــد هستند. ضریب هدایت هیدرولیکی خاک غیراشباع درخاک جهرم که بـا روش هـای مختلـف تعییـن گردید متفاوت بود زیرا این خاک ناهمگن بوده و نیمرخ آب خاک غیر یکنواختی دارد.

INTRODUCTION

Unsaturated water movement in soil profile is usually considered in irrigation, drainage, deep percolation and soil water pollution. Measurement of deep percolation in the field is very difficult, but it is required in water balance studies in the root zone of crops and trees to determine evapotranspiration and irrigation application efficiency. Therefore, deep percolation in the field may be estimated by measuring the gradient of soil water potential at depths below the root zone and using unsaturated hydraulic conductivity (UHC) as a function of soil water content and/or water potential. However, in the case of unit hydraulic gradient at depths below the root zone (uniform soil water profile at or below the root zone in homogeneous soil) deep percolation is equal to the UHC (6). The UHC as a function of soil water content, K(θ), has been determined by various laboratory and field procedures (2,3,5,7). Furthermore, UHC function was measured in field by sprinkler infiltration method (14) and by infiltration through an impeding layer (1,4).

Most of the UHC relationships are power or exponential functions. Recently, these functions have been determined by an empirical method (10), numerical solution of Richard's equation (12) and applying the fractal concept in soil moisture retention curve (11).

The theory of internal drainage with a constant flow through a soil profile has been proposed by Rose *et al.* (9) and then was used in laboratory by Watson (13). Hillel *et al.* (6) applied this theory and proposed a procedure for measuring UHC in the field. In their method, water content profile and water potential gradient were determined by neutron probe and tensiometer, (internal drainage method), respectively. However, in some cases this method can not be used, therefore, a simplified procedure may be applied.

In the present investigation a modified internal drainage procedure was developed and compared with the original procedure for measuring the UHC for three different soils.

Theory

The internal drainage method is valid when water table is not present or is located deep enough not to influence the vertical flow of water (6). This method requires that soil volumetric water content (θ) and/or matric potential (h) measurements be made at frequent time intervals (t) and depths (z) while evapotranspiration is prevented. General differential equation for vertical water flow in soil is:

$$\partial \theta / \partial t = \partial (K(\theta) \partial H / \partial z) / \partial z \qquad [1]$$

in which θ is the volumetric soil water content (cm^3 cm^{-3}), t is time (day), z is the soil depth (cm), $K(\theta)$ is the unsaturated hydraulic conductivity (UHC) ($cm\ day^{-1}$) and H is the hydraulic head (sum of matric potential (h) and gravitational potential (z), cm. Integration of equation [1] between z=0 and Z will result in the following equation:

$$(\partial\theta/\partial t)_Z = (K(\theta)\partial H/\partial z)_Z \qquad [2]$$

in which Z is the soil depth at which soil water content is measured. With zero flux of water on the soil surface (no evapotranspiration) the variation of soil water profile is related to downward flux and can be shown as follows:

$$(dw/dt)_Z = q = (K(\theta)\partial H/\partial z)_Z \qquad [3a]$$

$$w = \int_0^Z \theta dz$$

$$q = \int_0^Z (\partial\theta/\partial t)dz \qquad [3c]$$

in which w is the total amount of water in soil profile at depth of zero to Z (cm). When water content and soil matric potentials are measured at different depths and time intervals, (Δz) and (Δt), the downward flux can be obtained as follows:

$$q = \sum_{i=1}^{n}(d\theta/dt)(\Delta z)_i \qquad [4]$$

Therefore, the UHC as a function of soil water content is as follows:

$$K(\theta) = q/((\partial h/\partial z)+1) \qquad [5]$$

in which $\partial h/\partial z$ is the matric potential gradient. Equations [4] and [5] are used to calculate $K(\theta)$ in the original internal drainage method. When variation in soil water content with depth is negligible in a homogeneous soil, $\partial h/\partial z$ is also negligible, and equation [5] will be as follows:

$$K(\bar{\theta}) = q = -[d\bar{\theta}/dt]Z \qquad [6]$$

in which $\bar{\theta}$ is the average soil water content at depths of zero to Z and the $d\bar{\theta}\,dt^{-1}$ has a negative value. equation [6] is suggested to be used to estimate the K(θ) which is simpler than the equations [4] and [5]. Equation [6] only needs the measurements of soil water contents at different depths and times.

The relationship between K(θ) and θ may be presented as follows:

$$K(\theta) = a\,Exp[\,b\,(\theta)\,] \qquad [7]$$

in which a and b are constants depending on the soil properties. To calculate $K(\bar{\theta})$ from eqation [6], the slope of $\bar{\theta}$ as a function of time should be determined accurately. To do this, the following empirical equations may be obtained from the measured θ at various times (t) by regression analysis:

$$\ln t = p+q\,(\bar{\theta}) \qquad [8a]$$

or

$$t = Exp\,[p+q\,(\bar{\theta})] \qquad [8b]$$

and

$$\bar{\theta} = A + B\ln t \qquad [8c]$$

Further , it is assumed that the soil water content is relatively constant at different depths. Differentiating equation [8c] results in :

$$d\bar{\theta}/dt = B/t \qquad [9]$$

Substitution of equations [9] and [8b] in equation [6] results in:

$$K(\bar{\theta}) = -B\,Z\,Exp\,[-p-q\,(\bar{\theta})] \qquad [10]$$

which is similar to equation [7] with a = -B Z Exp (-p) and b= -q .

MATERIALS AND METHODS

Measurements were made at Agricultural Experiment Stations at Mollasani, Dezful (Khuzestan province) and Jahrom (Fars province) in

Iran. Some physical properties of the soils are shown in Table 1(8). The water tables at Jahrom and Dezful regions were very deep and it was deeper than 3.5 m at Mollasani region.

Table 1. Some physical properties of the soils studied.

Sites	Soil depth cm	Sand %	Silt %	Clay %	Gravel %	Apparent bulk density g cm^{-3}
Jahrom	0-60	38.0	38.5	11.9	11.6	1.48
Dezful	0-60	20.0	49.0	31.0		1.47
Mollasani	0-60	30.6	43.0	26.4		1.53

An iron cylinder (1.5 m I.D.) was driven in soil at Jahrom and a neutron tube was placed in the middle of it to a depth greater than 70 cm. Water was applied to the soil to make it nearly saturated to a depth of 70 cm. Soil water content was measured by neutron probe at depth intervals of 10 cm at 0, 1, 2, 5, 9, and 25 days after wetting. Basins of 10x10 m^2 were nearly saturated at Mollasani and Dezful sites to a depth of 90 and 120 cm, respectively. Soil water contents in the middle of the basins were determined at depth intervals of 20 cm by neutron probe at Mollasani and by gravitational procedure at Dezful site. The measurements were made on day 0, 1, 2, 13, and 24 after wetting at Dezful and on day 0, 1, 2, 5, 10, and 25 at Mollasani. At all three sites, tensiometers were placed at depths of 30, 60, and 90 cm near the neutron tube or at the soil sampling sites for soil water content in Dezful. In addition, one more tensiometer was located at the depth of 20 cm at Dezful site. The tensiometer readings were recorded concurrently with the soil water content measurements. Soil surfaces were sprayed by herbicide to prevent weed growth and were covered by plastic sheets to prevent surface evaporation.

RESULTS AND DISCUSSION

The variations of soil water content and hydraulic head with respect to depth for different sites (soils) are shown in Figs. 1 and 2. The soil water profiles were rather uniform for Dezful and Mollasani sites, but it was not uniform for Jahrom due to lighter soil and presence of different amounts of gravel at various depths (Fig. 1). Slopes of the hydraulic head with respect to soil depth (hydraulic gradient) for soils of Dezful and Mollasani were 1.0 (0.87-1.33) and 0.92 (0.67-1.25) which are close to unity while the hydraulic gradient for the soil at Jahrom was less than one with an average of 0.12.

The calculated values of $K(\theta)$ based on equations [4] and [5] (original internal drainage) were correlated with θ and the values of a and b of equation [7] were obtained. The values of a and b in equation[10] (simplified method) were also calculated (Table 2). The values of b are similar in two different methods (original and simplified internal drainage) of $K(\theta)$ determination for soils of Dezful and Mollasani sites with relative values of

Table 2. The values of a and b obtained by original and simplified methods for different soils.

Sites	Methods	a (cm d^{-1})	b	Correlation coefficients
Dezful	Original	1.4×10^{-5}	35.1	0.810
	Simplified	4.0×10^{-6}	38.4	0.960
Jahrom	Original	2.4×10^{-3}	21.9	0.892
	Simplified	7.1×10^{-5}	27.3	0.991
Mollasani	Original	2.2×10^{-4}	31.4	0.842
	Simplified	5.2×10^{-4}	29.6	0.990

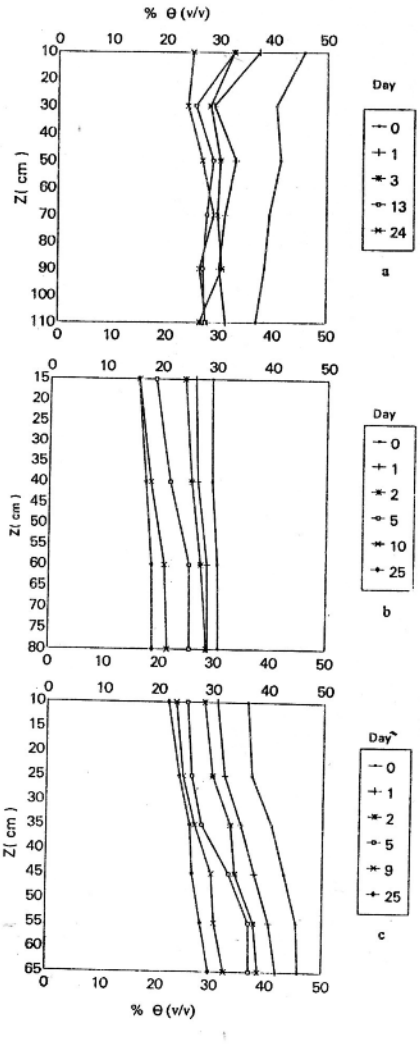

Fig. 1. Soil water content as a function of depth at various times, a: (1-24 days at Dezful site), b: (1-25 days at Mollasani site), c: (1-25 days at Jahrom site).

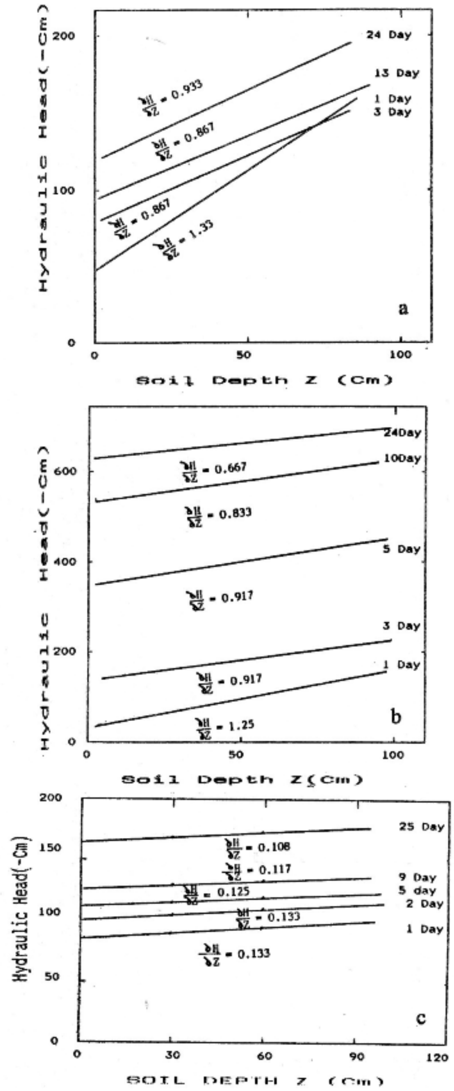

Fig. 2. Hydraulic head as a function of soil depth at various times, a: (1-24 days at Dezful site), b: (1-25 days at Mollássani site), c: (1-25 days at Jahrom site).

0.91 and 1.06. However, the ratio value of b at two different methods was 0.8 for soil at Jahrom. The a values are in the same order of magnitude at two different methods of K(θ) determination for soils of Dezful and Mollasani (Table 2), while their values for soil at Jahrom differs one order of magnitude at two different methods. These results indicated that the values of K (θ) for soil at Jahrom, based on simplified procedure of internal drainage are not compatible with those obtained from the original procedure of internal drainage.

Comparison of calculated K(θ) from the two different procedures (the original and the simplified internal drainage, Fig. 3) indicated that the average differences between them at soil water contents from less than field capacity to near saturation were about 19, 82, and 33% for soils at Dezful, Jahrom and Mollasani sites, respectively. The main reason for the large difference for Jahrom site is non-uniformity in soil water content with depth (Fig. 1). Therefore, the simplified procedure of internal drainage can be used to estimate K (θ) in homogeneous soils with uniform soil water profile.

The variations in soil water content with respect to depth below 25 cm are 4.0, 2.5, and 9.9 % for soils at Dezful, Mollasani and Jahrom sites, respectively, which resulted in average hydraulic gradients of 1.0, 0.92, and 0.12, respectively. Differences in hydraulic head gradient may be due to differences in soil moisture retention curves of these soils. It is evident that the hydraulic head gradient in soil at Jahrom site is much less than unity. Similar results were reported by Hillel *et al.* (6) in which, with a 10% variation in soil water content at a depth of 0-135 cm, a hydraulic head gradient of about 0.26 was obtained which is less than unity.

CONCLUSION

The internal drainage method is a valuable procedure for field measurement of vertical unsaturated hydraulic conductivity as a function of

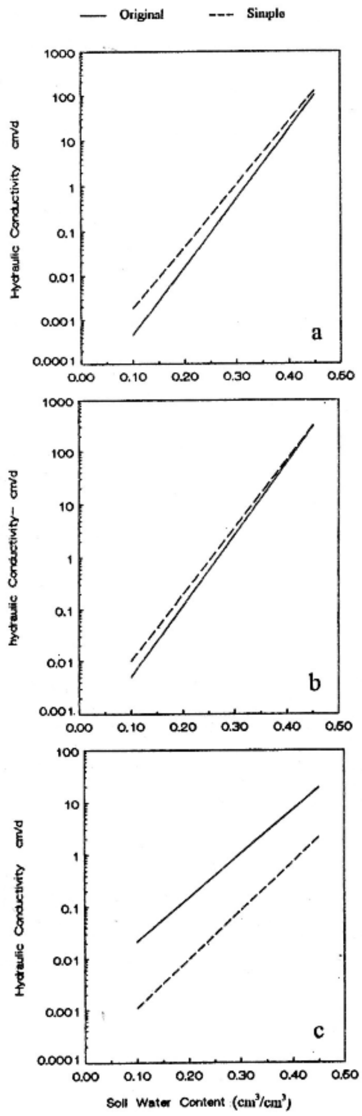

Fig. 3. Hydraulic conductivity as a function of soil water content, a: (Dezful site), b: (Mollasani site), c: (Jahrom site).

soil water content , K(θ), by using tensiometers and neutron probe. However, in some cases, tensiometers fail to function or the soil matric potentials fall below 0.08 MPa (functional limit of tensiometer). Therefore, the original procedure of internal drainage equation [5] can not be used to estimate K(θ). In such cases , the simplified internal drainage method (equation [6] or [10]) can be applied as it only requires that the soil water profile be measured by a neutron probe or by the gravitational procedure. However, the simplified method of internal drainage was shown to be applicable only to soils with a nearly uniform soil water profile or a nearly unit hydraulic gradient, but not to gravelly soils which may not be homogeneous.

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