TRICKLE IRRIGATION AS A SIMPLE TOOL TO ESTIMATE SATURATED HYDRAULIC CONDUCTIVITY

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ABSTRACT

The saturated hydraulic conductivity of soil is needed for deteriming the agricultural and hydrological processes. The measurement techniques used to estimate such property remain hampered by extensive labor and time constraints. Both emitter discharge rate and steady saturated radius emerged from point source trickle irrigation on the soil surface were used to determine the saturated hydraulic conductivity using Wooding's equation. Field experiments on sandy and sandy loam soils were conducted to estimate the saturated hydraulic conductivity based on point source trickle irrigation. The results showed that predicted saturated hydraulic conductivity values were within 23% and 26 % of measured values as estimated by constant head method under libratory condition.Additionally, the Wooding's equation was found to produce equally or more accurate descriptions of saturated hydraulic conductivity as compared to several published pedotransfer functions (PTFs) used to estimate the saturated hydraulic conductivity.

Keywords: saturated hydraulic conductivity, trickle irrigation, Pedotransfer functions

1. INTRODUCTION

Saturated hydraulic conductivity (K_s) is an important soil property, especially for many soil-water related investigations such as water conservation, irrigation design, drainage and general transport phenomena in the soil.Saturated hydraulic conductivity can be obtained by field or laboratory methods, however, the measurement techniques remain expensive and time consuming. The importance of and demand for K_s data motivated researches to develop indirect method of obtaining K_s. Pedotransfer functions (PTFS) are becoming increasingly popular for estimating saturated hydraulic conductivity from soil physical properties such as soil texture, bulk density, organic matter content, and water retention. The majority of PTFs are completely empirical, although physico-empirical models and fractal theory models have also been developed, Sobieraj et al. [1].

Some physico-empirical approaches to estimate K_s have been proposed based on either geometric mean particle diameter, Campllle [2] or soil water retention curve parameters, Laliberte et al. [3].

However, these methods may be more suitable for predicting near-saturated hydraulic conductivity, excluding macropore effects, Jarvis et al. [4]. Aimrun et al. [5] used a power function based on effective porosity $Ø_e$ to determine saturated hydraulic conductivity for lowland paddy soils. Although the results indicated a strong relationship between K_s and $Ø_e$ it needs to be validated versus other type of soil. Among the advantages of trickle irrigation, the information of flow rate from a point source and the respective saturated water entry radius r_s can be used to estimate the saturated hydraulic conductivity. The size of saturated area under drippers is strongly related to the saturated hydraulic conductivity and the emitter discharge rate. Such relationships were described by Wooding [6], Clothier et al. [7], Shani et al. [8]. This paper present an easy method to estimate the saturated hydraulic conductivity under field condition based on simple obtainable data from point source trickle irrigation experiments. The data used for such estimation were, emitter discharge rate and the saturated radius on the soil surface.

1.1 THEORETICAL CONSIDERATION

Wooding [6] presented an approximate solution for steady-state flow per unit area, q, from a shallow saturated entrance on the soil surface as:

$$q = \frac{Q}{\pi r_s^2} = K_s + \frac{4.K_s}{\pi \alpha} . \frac{1}{r_s} \tag{1}$$

where Q is discharge rate of the point source ($L^3\ T^{-1}$), K_s is the saturated hydraulic conductivity ($L\ T^{-1}$), r_s is the steady-state saturated radius (L), α is a constant characteristic of the soil related to soil sorptive properties and describes the rate reduction in conductivity with matric head (L^{-1}).The reciprocal value of α was identified as a parameter quantifies the importance of capillary forces relative to gravity forces, Philip [9]. In order to reach this solution an exponential relation between the hydraulic conductivity and the hydraulic potential was assumed:

$$k(h) = K_s \exp(\alpha h) \tag{2}$$

According to Equation (1), the saturated radius increases with the increasing of the application rate and with the reducing of the saturated hydraulic conductivity. In addition, the first term on the right side of Equation. (1) represents the contribution of gravity to the flow, and the second term represents the contribution of capillarity and geometry of the source.

Equation (1) can be arranged to be in form of linear regression Equationuation of q versus $1/r_s$ as

$$y = a + bx \tag{3}$$

where *a* and *b* represent the intercept and the slope of the linear regression Equation. The saturated hydraulic conductivity can be estimated from the intercept of the linear regression Equation and α is then estimated from

$$\alpha = \frac{4.K_s}{b.\pi} \tag{4}$$

2. MATERIAL AND METHODS

Field experiments were conducted on sand and sandy loam bares soil found at two locations situated 20 km south of Tripoli-Libya along the way to the International Tripoli Airport. The sandy soil was classified as loose, very friable, and highly drained and has very fine roots, while the sandy loam was classified as massive, moderately hard, and fine and medium irregularly shaped of lime concentrations with common fine roots. The main physical characteristics of both soils are given in the Table 1. The experimental procedures to determine these properties were determined as described by Black [10] whereas the texture of soil was determined by the pipette method the bulk density was determined using undisturbed core and the average saturated hydraulic conductivity determined on undisturbed samples using the constant head method The saturated moisture content was taken to be equal to the porosity of soil, Hillel [11].

Table 1. Summary of soil physical properties used in the study

Soil	**Sand %**	**Silt %**	**Clay %**	**Bulk density gm/cm^3**	**Initial and saturated Moisture content (Vol)**	**Ks cm/h**
Sand	98	-	-	1.58	0.05-0.40	20.08
Sandy Loam	73	17	10	1.38	0.06-0.48	5.8

The apparatus of trickle irrigation system used in this investigation was designed to provide uniform water application from a point source at various rates. Essentially, the apparatus consisted of a modified Marriott tube, Yitayew and Waston [12], was used as a reservoir joined to emitters by means of hose 0.75 in ID. The Emitters were calibrated for the application of the required volume at desired rate. The outlets were located on the soil surface where each dripper irrigated a distinct area without any interface with others. Various application rates were chosen between 1.5 and 6 liter per hour for the sand.

In order to evaluate the model more thoroughly, a series of pedotransfer functions (PTFs) in predicting K_s were selected from published data may support the proposed model for determining the saturated hydraulic conductivity. The selected PTFs were developed by Brakensiek et al. [13], Campbell and Shiozawa [14], Cosby et al. [15], Jabro [16], Puckett et al. [17], Dane and Puckett [18] and Saxton et al. [19]. The basis for choosing these PTFs was governed by the available input data i.e., particle size distribution, bulk density and saturated moisture content (Table 2). The differences between these models are more related to the input data.

Table 2: Peodotransfer functions used for estimating saturated hydraulic conductivity*

1. Brakensiek et al. [13]	$K_s(mm/h) = \exp[19.52348ø - 8.96847 - 0.028212(P_{<2}) + 0.00018107(P_{50\text{-}2000})^2 - 0.0094125(P_{<2})^2 - 8.839521 ø^2 + 0.077718(P_{50\text{-}2000}) ø - 0.00298(P_{50\text{-}2000})^2 ø^2 - 0.019492(P_{<2})^2 ø^2 + 0.0000173(P_{50\text{-}2000})^2(P_{<2}) + 0.02733(P_{<2})^2 ø + 0.001434(P_{50\text{-}2000})^2 ø - 0.0000035(P_{<2})^2(P_{50\text{-}2000})]$
2. Campbell and Shiozawa [14]	$K_s(mm/h) = 54 \exp[-0.07P_{50\text{-}2000}-0.167P_{<2}]$
3. Cosby et al. [15]	$K_s(mm/h) = 25.4\times10(-0.6 + 0.012 P_{50\text{-}2000} - 0.0064P_{<2})$
4. Jabro [16]	$Log(K_s)(cm/h) = 9.56 - 0.81 \log(P_{2\text{-}50})-1.09 \log (P_{<2}) - 4.64(BD)$
5. Puckett et al. [17]	$K_s(mm/h) = 156.96 \exp(-0.1975P_{<2})$
6. Dane and Puckett [18]	$K_s(mm/h) = 303.84 \exp(-0.144P_{<2})$
7. Saxton et al. [19]	$K_s(mm/h) = 10 \exp[12.012 - 0.0755P_{50\text{-}2000} + [-3.895 + 0.03671P_{50\text{-}2000} - 0.1103P_{<2} + 0.00087546(P_{<2})^2/\theta_s]$ where $\theta_s = 0.332 - 0.0007251P_{50\text{-}2000} + 0.1276 \log 10(P_{<2})$

*Note: Particle sizes in these PTF equations are listed as $P_{<2}$ (clay), $P_{2\text{-}50}$ (silt), and $P_{50\text{-}2000}$ (sand). In addition, BD = bulk density, ø = porosity, and θ_s = saturated moisture content.

These differences create advantages which could help for verification purpose. The details of these experiments were discussed extensively in the literature y soil and 1 to 4 liter per hour for the sandy loam soil. During each experiment, the movement of saturated water entry radius was recorded periodically. The experiments were replicated five times, each one with various application rates.

3. RESULTS AND DISCUSSION

Close observations indicated that the actual water source did not behave as an ideal point source, but the water was spaced over a finite circular water saturated area. The border of saturated area was determined visually as the point where the free-water indicated by glistening surface zone ended on the soil surface. It was also noted that the saturated zone various according to discharge rate. Figure (1) displays the final saturated radius versus emitter discharge rate for sandy and sandy loam soil. For sandy soil the steady radius values were achieved after about 25 minutes. It is clear from the figure that the saturated radius increased as the discharge rate increased where the maximum value of the saturated radius 7 cm was found under 6 l/h application rate. In case of sandy loam soil, the steady value of the saturated radius reached about 30 minutes. The maximum values of saturated radius ranged from 4 to 9 cm. However, many studies assured that the rate of increase and limiting extent of the central saturated radius is a function of soil type and application rate (Clothier and Wooding [7], Shani et al. [8], Yitayew et al. [20]).

Figure 2 depicts the relationship of flux densities, q, versus the reciprocal of steady state radii 1/rs, produced by the point source for sandy and sandy loam soil, respectively. It can be noted, as expected, the saturated hydraulic conductivity K_s (the intercept) and the values of α increased as the soil texture is coarser. These results agree with what reported by Amoozegar-Fard et al. [21]. The values of K_s and α are displayed in Figure 2.

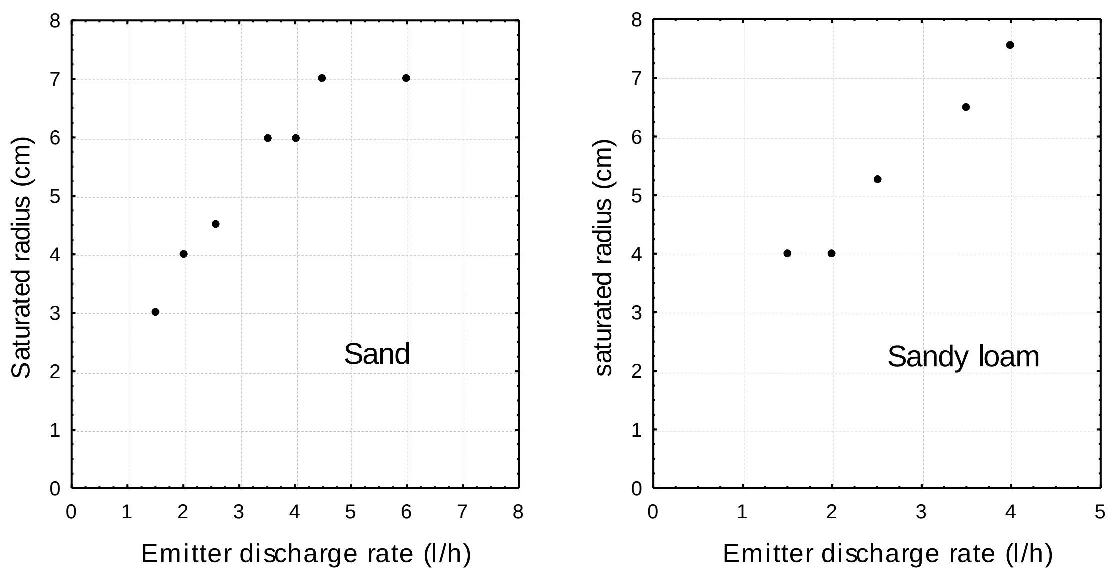

Figure (1) the final saturated radius as related to the emitter discharge rate

The determination coefficient of the linear regression describing the relation between q and 1/r are relatively good 0.72 and 0.75 for sandy and sandy loam, respectively. There is good agreement between K_s values as produced by the point source method and that produced by constant head method (differences of 26% and 23% for sandy and sandy loam, respectively). The discrepancies maybe attributed to the impact of surface topography where there was no guarantee that point source infiltration area would be exactly circular. Moreover, a wide range of discharge rates can be useful and help to minimize error in estimation of saturated hydraulic conductivity.

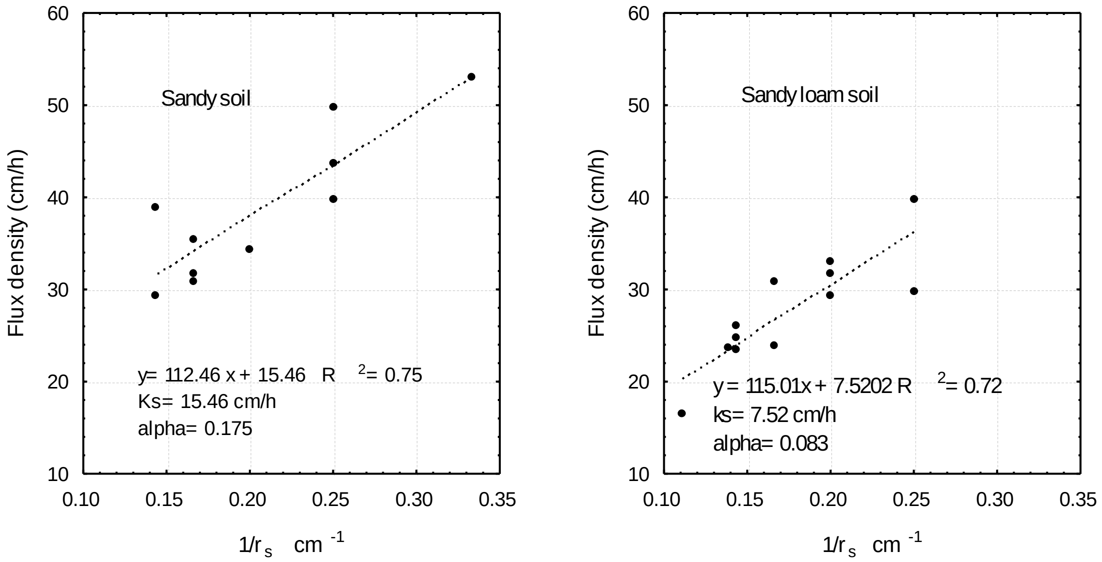

Figure (2) the relationship of flux densities, q, versus the reciprocal of steady-state radii, 1/rs for sandy and sandy loam soil

Table 3 shows the values of K_s for sandy and sandy loam soil as estimated, by constant head method, Wooding's equation and pedotransfer functions (PTFs). The saturated hydraulic conductivity as measured by head method was chosen for comparison purpose. Among PTFs models, one sees that Saxton, Dane and Cosby functions give a high accuracy to predict the saturated hydraulic conductivity. This suggests that the values of saturated moisture content and the percentage of sand, silt and clay can be used to determine K_s. On the other hand, it can be noted from Figure (3) that the discrepancies between measured and simulated saturated hydraulic conductivity is generally smaller with Wooding's equation as compared to the most PTFs findings.

Table 3: Observed and predicted saturated hydraulic conductivity (cm/h) for sand and sandy loam soil

Method	Sandy soil	Sandy loam soil
Braken	52.26	15.46
Campbell	0.0047	0.006
Jabro	15.8	11.74
Puckett	12.88	2.177
Dane	26.30	7.198
Saxton	21.19	4.88
Cosby	14.46	5.38
Constant head method	20.08	5.79
Wooding	15.46	7.52

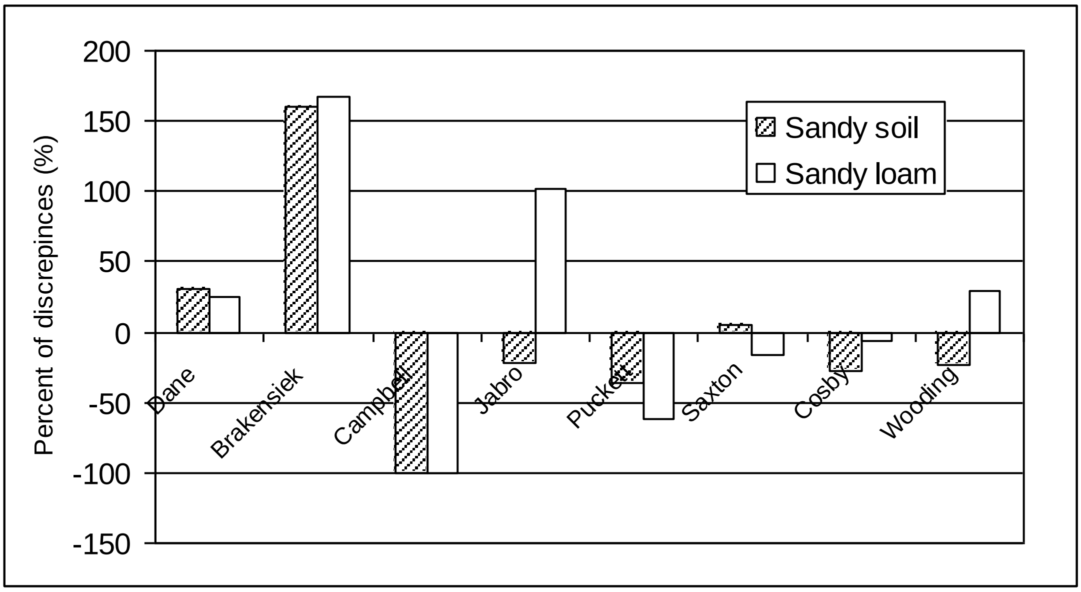

Figure (3) the discrepancies (in percent) between the several predicted methods (as compared to the constant head method) for predicting saturated hydraulic conductivity for sand and sandy loam soil

4. CONCLUSIONS

The aim of this paper has been to examine how the point source trickle irrigation can help to estimate the saturated hydraulic conductivity. A simple method based on Wooding equation, [6], was used to estimate the saturated hydraulic conductivity. The results showed that the trickle application rate controls the saturated radius on the soil surface. The saturated radius reaches steady values in sandy soil faster than sandy loam soil. The saturated hydraulic conductivity as predicted by l for steady- state infiltration from circular ponded area matched with the measured values (23-26% variation). Moreover, the Wooding's equation was found to produce equally or more accurate descriptions of saturated hydraulic conductivity as compared to several published pedotransfer functions (PTFs) used to estimate the saturated hydraulic conductivity. It is interesting to assure that the Wooding method is simple and suitable for determining the saturated hydraulic conductivity where no sophisticated instruments are required, only multiple emitters (at different rates), reservoir with enough capacity, a ruler for measuring distance, a timer and calibrated container to calibrate emitter discharge rate. This method also is not destructive so it can be adapted to measuring changes in soil hydraulic properties with time at the same sampling site. Further more, labor and operating cost are lower. A wide range of discharge rates may useful and helps to minimize error in estimation of saturated hydraulic conductivity.

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