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Prediction of Soil Infiltration Rate Based on Particle Size Distribution and Bulk Density of Soil

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Abstract: Soil infiltration rate is perhaps the most crucial parameter affecting surface irrigation uniformity and efficiency. It is often determined using laborious and time consuming field tests, but it may be more suitable and economical to develop a method which predicts soil infiltration rate based on easily available physical properties of soil. In this study, eighty-five soil samples were collected randomly from different fields of the experimental site at Karaj, Alborz Province, Iran, for predicting soil infiltration rate (IN) based on soil particle size distribution, viz. silt (SI) and clay (CL) content and bulk density (BD) of the investigated soils, a three-variable linear regression model was suggested. The statistical results of study indicated that in order to predict soil infiltration rate based on particle size distribution and bulk density of soil the three-variable linear regression model IN = 28.38 - 0.274 SI - 0.505 CL + 4.431 BD (R^2 = 0.9071) can be strongly suggested.

Key words: Soil · Infiltration rate · Modeling · Prediction · Silt content · Clay content · Bulk density

INTRODUCTION

Surface irrigation methods are widely used throughout the world [1, 2]. Recent advances in the theoretical description and model simulation of surface irrigation methods permit the evaluation of existing procedures and the development of new technologies of irrigation systems and their management. Efficient management of available water will require greater control of infiltration, where the increased infiltration control would help to solve such wide ranging problems as upland flooding, pollution of surface and ground-waters, declining water tables and inefficient irrigation of agricultural lands [3]. For these reasons, soil infiltration is perhaps the most crucial process affecting not only surface irrigation uniformity but also its efficiency as it is the mechanism that transfers and distributes water from the surface into the soil profile. It is essential to predict the cumulative infiltration in order to estimate the amount of water entering the soil profile and its distribution. Infiltration also affects both the advance and recession processes and thus is important in estimating the optimal discharge that should be directed to the field [4]. The infiltration process depends on the physical, chemical and biological properties of the soil surface, the initial distribution of water in the soil prior to irrigation, the

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movement of water over the surface and the depth of water on the soil surface. These properties and conditions vary over a field and collectively cause infiltration itself to exhibit large variation at the field scale. Therefore, infiltration is difficult to characterize on a field scale because of a large number of measurements is necessary [5].

In the engineering evaluation and design of surface irrigation systems, it has been useful to predict the soil infiltration rate [4]. In general, prediction of the soil infiltration rate involves the adoption of a functional form to be used and the determination of the value of the numerical constants in the adopted equation. Prediction of soil infiltration rate is a major problem in irrigation studies due to proper selection of the technique used to determine the parameters of the empirical infiltration models, the use of empirical infiltration models and its dependence on soil moisture, soil characteristics and surface roughness. Thus, the technique used to determine the soil infiltration characteristics must be appropriate for the purpose of the study [6-8].

Despite the considerable amount of research done, which shows the relationship between soil infiltration rate and soil properties, very limited work has been conducted to predict soil infiltration rate based on particle size distribution and bulk density of soil. Therefore, the main objectives of this research were to determine soil infiltration rate model based on particle size distribution (silt and clay content) and bulk density of soil and to verify the model by comparing its results with those of the field tests.

MATERIALS AND METHODS

Experimental Procedure: Eighty-five soil samples were collected randomly from different fields of the experimental site at Karaj, Alborz Province, Iran (35° 59' N, 51° 6' E and altitude of 1300 m above mean sea level) and recognized as semi-arid climate (345 mm rainfall annually) in the center of Iran. In order to obtain required parameters for determining soil infiltration rate model, silt (SI) and clay (CL) content and bulk density (BD) of the soil samples were measured using laboratory tests as described by the Soil Survey Laboratory Staff [9]. Also, infiltration rate of the soil in all treatments was determined using a double ring infiltrometer method. The infiltrometer was installed in the position of each treatment, filled with water and the initial reading was noted. The depth of water in the infiltrometer was noted after frequent intervals time until the rate of infiltration became constant to obtain basic infiltration rate. Table 1 shows infiltration rate, silt and clay content and bulk density of the eighty-five soil samples used to determine soil infiltration rate model.

Also, in order to verify soil infiltration rate model, fifteen soil samples were selected randomly from different fields of the experimental site. Again, infiltration rate, silt and clay content and bulk density of the soil samples were measured as described before. Table 2 shows infiltration rate, silt and clay content and bulk density of the fifteen soil samples used to verify soil infiltration rate model.

Regression Model: A typical three-variable linear regression model is shown in equation 1:

$$Y = k_0 + k_1X_1 + k_2X_2 + k_3X_3 \qquad (1)$$

where:

Y = Dependent variable, for example soil infiltration rate (mm/h)

X_1, X_2, X_3 = Independent variables, for example silt and clay content (%) and bulk density (g/cm^3) of soil

k_0, k_1, k_2, k_3 = Regression coefficients

In order to predict soil infiltration rate from silt and clay content and bulk density of soil, a three-variable linear regression model was suggested and all the data (Table 1) were subjected to regression analysis using the Microsoft Excel 2007.

Statistical Analysis: A paired samples t-test and the mean difference confidence interval approach were used to compare the soil infiltration rate values predicted by model with the soil infiltration rate values measured by field tests. The Bland-Altman approach [10] was also used to plot the agreement between the soil infiltration rate values measured by field tests with the soil infiltration rate values predicted by model. The statistical analyses were also performed using Microsoft Excel 2007.

Table 1: Infiltration rate, silt and clay content and bulk density of the eighty-five soil samples used to determine soil infiltration rate model

Sample No.	Infiltration rate (mm/h)	Silt content (%)	Clay content (%)	Bulk density (g/cm^3)
1	8.82	34	38	1.826
2	3.63	38	42	1.610
3	9.14	40	38	1.667
4	4.61	40	40	1.685
5	7.45	34	38	1.528
6	3.15	40	42	1.527
7	4.12	38	42	1.538
8	3.28	36	40	1.619
9	2.03	36	42	1.595
10	6.79	40	36	1.546
11	3.60	36	42	1.626
12	2.50	38	46	1.535
13	2.20	34	40	1.526
14	1.70	36	40	1.606
15	7.46	40	38	1.557
16	3.30	38	44	1.688
17	2.90	36	44	1.437
18	3.10	32	42	1.685
19	9.32	34	38	1.561
20	7.06	34	38	1.677
21	4.30	38	42	1.495
22	14.8	36	28	1.670
23	2.50	40	40	1.677
24	1.70	38	42	1.546
25	6.90	36	34	1.628
26	6.50	38	34	1.481
27	11.9	36	26	1.698
28	9.60	40	38	1.596
29	6.10	38	36	1.594
30	7.11	34	38	1.574
31	2.30	36	42	1.690
32	3.20	36	38	1.693
33	9.60	40	36	1.743
34	8.90	36	36	1.555
35	2.27	36	38	1.583
36	23.5	7	22	1.843
37	26.0	5	17	1.845
38	22.1	10	21	1.923
39	25.5	12	20	2.032
40	25.2	15	20	1.832
41	22.5	15	20	1.839
42	24.5	15	20	1.935
43	22.8	11	19	1.919
44	26.3	9	24	1.980
45	23.6	9	12	2.070
46	24.3	10	25	2.181
47	27.2	9	19	2.181
48	28.5	10	20	2.038
49	26.2	13	11	2.016
50	27.5	14	18	1.904
51	22.1	5	16	1.872
52	23.5	16	30	1.718
53	6.90	46	32	1.722
54	7.30	44	32	1.572
55	7.10	38	28	1.698
56	9.10	48	32	1.463

Table 1: Continued

57	9.30	48	30	1.500
58	6.00	42	32	1.678
59	7.10	44	32	1.524
60	7.90	52	32	1.639
61	5.40	48	32	1.473
62	6.00	50	26	1.424
63	8.70	46	30	1.423
64	8.90	44	32	1.336
65	9.00	38	30	1.700
66	6.60	42	30	1.452
67	8.22	48	32	1.472
68	6.80	48	32	1.684
69	7.10	48	32	1.575
70	7.70	42	30	1.671
71	7.90	40	32	1.593
72	6.84	38	30	1.612
73	7.90	44	26	1.727
74	6.50	42	30	1.628
75	9.00	40	32	1.652
76	8.80	40	28	1.594
77	8.30	48	32	1.567
78	7.10	46	30	1.621
79	8.00	44	26	1.599
80	9.70	46	32	1.619
81	7.60	38	28	1.476
82	7.30	46	32	1.486
83	8.40	44	32	1.650
84	7.60	48	32	1.608
85	6.90	44	32	1.551

Table 2: Infiltration rate, silt and clay content and bulk density of the fifteen soil samples used to verify soil infiltration rate model

Sample No.	Infiltration rate (mm/h)	Silt content (%)	Clay content (%)	Bulk density (g/cm^3)
1	9.25	36	32	1.666
2	3.79	32	42	1.473
3	8.50	32	40	1.732
4	3.95	38	40	1.541
5	6.01	38	40	1.441
6	26.8	10	14	1.986
7	28.4	12	16	2.065
8	21.5	13	19	1.836
9	6.34	46	34	1.587
10	7.61	46	32	1.659
11	6.58	48	32	1.544
12	8.73	44	28	1.535
13	8.50	44	28	1.578
14	6.09	44	32	1.554
15	10.0	38	26	1.557

RESULTS AND DISCUSSION

The three-variable linear regression model, p-value of independent variables and coefficient of determination (R^2) of the model are shown in Table 3. In this model, soil infiltration rate (IN) can be predicted as a function of silt (SI) and clay (CL) content and bulk density (BD) of soil. The p-value of independent variables (SI, CL and BD) and R^2 of the model were 9.19E-11, 1.29E-18, 0.115361 and 0.9071, respectively. Thus, based on the statistical results, the three-variable linear regression model was initially accepted, which is given by equation 2.

Table 3: Three-variable linear regression model, p-value of independent variables and coefficient of determination (R^2) of the model

Model	p-value			R^2
	SI	CL	BD	
IN = 28.38 - 0.274 SI - 0.505 CL + 4.431 BD	9.19E-11	1.29E-18	0.115361	0.9071

Table 4: Silt and clay content and bulk density of the fifteen soil samples used to verify soil infiltration rate model

Sample No.	Silt content (%)	Clay content (%)	Bulk density (g/cm^3)	Infiltration rate (mm/h)	
				Field tests	Model
1	36	32	1.666	9.25	9.74
2	32	42	1.473	3.79	4.93
3	32	40	1.732	8.50	7.09
4	38	40	1.541	3.95	4.60
5	38	40	1.441	6.01	4.15
6	10	14	1.986	26.8	27.4
7	12	16	2.065	28.4	26.2
8	13	19	1.836	21.5	23.4
9	46	34	1.587	6.34	5.64
10	46	32	1.659	7.61	6.97
11	48	32	1.544	6.58	5.91
12	44	28	1.535	8.73	8.99
13	44	28	1.578	8.50	9.18
14	44	32	1.554	6.09	7.05
15	38	26	1.557	10.0	11.7

Table 5: Paired samples t-test analyses on comparing soil infiltration rate determination methods

Determination methods	Average difference (mm/h)	Standard deviation of difference (mm/h)	p-value	95% confidence intervals for the difference in means (mm/h)
Model vs. field tests	0.05	1.25	0.8704	-0.64, 0.74

$$IN = 28.38 - 0.274\ SI - 0.505\ CL + 4.431\ BD \quad (2)$$

A paired samples t-test and the mean difference confidence interval approach were used to compare the soil infiltration rate values predicted using the model with the soil infiltration rate values measured by field tests. The Bland-Altman approach [10] was also used to plot the agreement between the measured soil infiltration rate values by field tests with the predicted soil infiltration rate values using the model.

The soil infiltration rate values predicted by model were compared with the soil infiltration rate values measured by field tests and are shown in Table 4. Also, a plot of the determined soil infiltration rate values by model and field tests with the line of equality (1.0: 1.0) is shown in Fig. 1. The mean soil infiltration rate difference between two methods was 0.05 mm/h (95% confidence interval: 0.64 and 0.74 mm/h; P = 0.8704). The standard deviation of the soil infiltration rate differences was 1.25 mm/h. The paired samples t-test results showed that the predicted soil infiltration rate values with model were not significantly different than the measured soil infiltration rate values with field tests (Table 5). The soil infiltration rate differences between these two methods were normally distributed and 95% of the soil infiltration rate differences were expected to lie between μ-1.96σ and μ+1.96σ, known as 95% limits of agreement [10]. The 95% limits of agreement for comparison of soil infiltration rate determined with field tests and model were calculated at -2.40 and 2.50 mm/h (Fig. 2). Thus, predicted soil infiltration rate by model may be 2.40 mm/h lower or 2.50 mm/h higher than measured soil infiltration rate by field tests. The percentage of average difference for prediction soil infiltration rate using model and field tests was 12.8%. These results are in line with those of obtained by Smerdon *et al.* [1], Rashidi and Seyfi [2], Mustafa *et al.* [3], Walker *et al.* [4], Walker [5], Holzapfel *et al.* [6] and Walker and Busman [7], who reported that particle size distribution of soil was the most important factor which affected the soil infiltration rate. They also reported that bulk density of soil had significant effect on the soil infiltration rate.

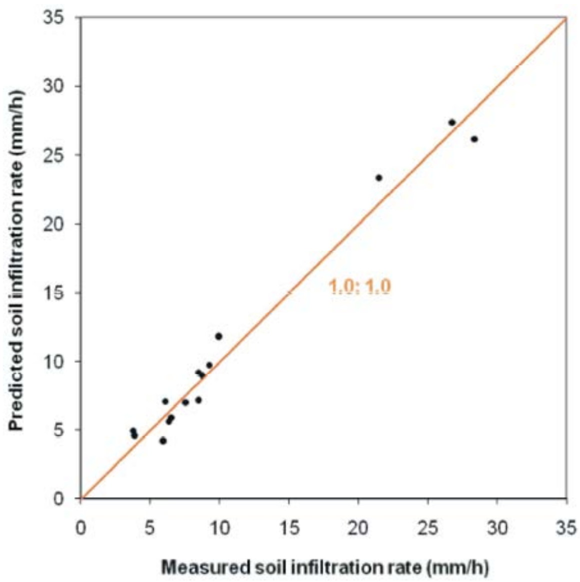

Fig. 1: Soil infiltration rate values measured using field tests (Measured soil infiltration rate) and soil infiltration rate values predicted using the model (Predicted soil infiltration rate) with the line of equality (1.0: 1.0)

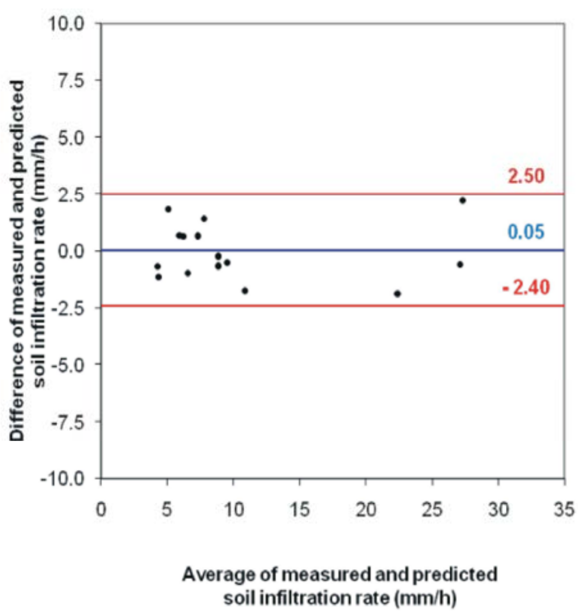

Fig. 2: Bland-Altman plot for the comparison of soil infiltration rate values measured using field tests (Measured soil infiltration rate) and soil infiltration rate values predicted using the model (Predicted soil infiltration rate); the outer lines indicate the 95% limits of agreement (-2.40, 2.50) and the center line shows the average difference (0.05)

CONCLUSIONS

A three-variable linear regression model was used to predict soil infiltration rate (IN) based on silt (SI) and clay (CL) content and bulk density (BD) of soil. The soil infiltration rate values predicted using the model was compared to the soil infiltration rate values measured by field tests. Results of study indicated that the difference between the soil infiltration rate values predicted by model and measured by field tests were not statistically significant. Therefore, the three-variable linear regression model IN = 28.38 - 0.274 SI - 0.505 CL + 4.431 BD (R^2 = 0.9071) provide an easy, economic and brief method to predict soil infiltration rate.

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