

Prediction of Soil Infiltration Rate Based on Some Physical Properties of Soil

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Abstract: Soil infiltration rate is perhaps the most crucial process 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 some easily available physical properties of soil. Therefore, a relation between soil infiltration rate and some physical properties of soil is needed. In this study, for predicting soil infiltration rate (IN) based on particle size distribution, viz. sand content (SA), silt content (SI) and clay content (CL) of soil, bulk density (BD), organic matter (OM) and moisture content (MC) of soil, fifty-five multiple-variable linear regression models were suggested. Models were divided into five main classes and the soil infiltration rate was estimated as a function of one, two, three, four and five independent variables. The statistical results of study indicated that in order to predict soil infiltration rate based on some physical properties of soil the one-variable linear regression model $IN = 0.391 SA - 2.917$ with $R^2 = 0.8905$ (as the simplest model) and the five-variable linear regression model $IN = 28.13 - 0.220 SI - 0.518 CL + 4.592 BD - 1.440 OM + 0.022 MC$ with $R^2 = 0.9092$ (as the most complex model) may be strongly recommended.

Key words: Soil • Infiltration rate • Prediction • Modeling • Physical properties

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. Free water at the soil-atmosphere interface is a source of great importance to man. Efficient management of this water will require greater control of infiltration. 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 rate is perhaps the most crucial process affecting surface irrigation uniformity and efficiency as it is the mechanism that transfers and distributes water from the surface to the soil profile. It is essential to predict the cumulative infiltration in order to estimate the amount of water entering the soil 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 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 the large number of measurements generally 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 physical properties of soil. Therefore, the main objectives of this research were to determine optimum soil infiltration rate model(s) based on some physical properties of soil and to verify the model(s) by comparing their results with those of the field tests.

MATERIALS AND METHODS

Experimental Site: Field experiments were carried out at the agricultural fields of Karaj, Alborz Province, Iran. This site is located at latitude of 35°59' N, longitude of 51°6' E and altitude of 1300 m above mean sea level in semi-arid climate (345 mm rainfall annually) in the center of Iran.

Experimental Procedure: Eighty-five soil samples were taken at random from different fields of the experimental site. In order to obtain required parameters for determining soil infiltration rate models, some physical properties of soil such as sand content (SA), silt content (SI), clay content (CL), bulk density (BD), organic matter (OM) and moisture content (MC) 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 measured using a double ring infiltrometer.

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 until the rate of infiltration became constant. Table 1 shows infiltration and physical properties of the eighty-five soil samples used to determine soil infiltration rate models.

Also, in order to verify selected soil infiltration rate models, fifteen soil samples were taken at random from different fields of the experimental site. Again, infiltration rate and physical properties of the soil samples were measured as described before. Table 2 shows infiltration rate and physical properties of the fifteen soil samples used to verify selected soil infiltration rate models.

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

$$Y = k_0 + k_1X_1 + k_2X_2 + \dots + k_nX_n \quad (1)$$

where:

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

X_1, X_2, \dots, X_n = Independent variables, for example sand content (%), silt content (%), clay content (%), bulk density (g/cm³), organic matter (%) and moisture content of soil (%)

$k_0, k_1, k_2, \dots, k_n$ = Regression coefficients

Table 1: Infiltration rate and physical properties of the eighty-five soil samples used to determine soil infiltration rate models

Sample No.	Infiltration rate (mm/h)	Sand content (%)	Silt content (%)	Clay content (%)	Bulk density (g/cm ³)	Organic matter (%)	Moisture content (%)
1	8.82	28	34	38	1.826	1.002	7.376
2	3.63	20	38	42	1.610	1.030	7.897
3	9.14	22	40	38	1.667	0.960	8.181
4	4.61	20	40	40	1.685	1.310	7.446
5	7.45	28	34	38	1.528	1.010	10.47
6	3.15	18	40	42	1.527	1.320	7.442
7	4.12	20	38	42	1.538	1.070	11.88
8	3.28	24	36	40	1.619	1.190	9.048
9	2.03	22	36	42	1.595	1.320	10.45
10	6.79	24	40	36	1.546	0.940	7.076
11	3.60	22	36	42	1.626	1.100	12.22
12	2.50	16	38	46	1.535	1.040	10.53
13	2.20	26	34	40	1.526	1.190	11.25
14	1.70	24	36	40	1.606	1.160	2.620
15	7.46	22	40	38	1.557	1.010	4.272
16	3.30	18	38	44	1.688	1.050	6.683
17	2.90	20	36	44	1.437	1.003	8.904
18	3.10	26	32	42	1.685	1.040	9.040
19	9.32	28	34	38	1.561	1.006	7.874
20	7.06	28	34	38	1.677	1.003	9.738
21	4.30	20	38	42	1.495	1.020	6.193
22	14.8	36	36	28	1.670	0.600	8.770

Table 1: Continued

Sample No.	Infiltration rate (mm/h)	Sand content (%)	Silt content (%)	Clay content (%)	Bulk density (g/cm ³)	Organic matter (%)	Moisture content (%)
23	2.50	20	40	40	1.677	1.350	8.082
24	1.70	20	38	42	1.546	1.040	6.971
25	6.90	30	36	34	1.628	1.060	5.175
26	6.50	28	38	34	1.481	1.130	11.88
27	11.9	38	36	26	1.698	0.560	5.453
28	9.60	22	40	38	1.596	1.020	5.537
29	6.10	26	38	36	1.594	1.060	3.433
30	7.11	28	34	38	1.574	1.140	7.540
31	2.30	22	36	42	1.690	1.240	6.477
32	3.20	26	36	38	1.693	1.110	5.022
33	9.60	24	40	36	1.743	1.050	6.518
34	8.90	28	36	36	1.555	1.004	4.602
35	2.27	26	36	38	1.583	1.210	4.731
36	23.5	71	7	22	1.843	0.390	3.243
37	26.0	78	5	17	1.845	0.320	4.607
38	22.1	69	10	21	1.923	0.360	6.392
39	25.5	68	12	20	2.032	0.350	5.923
40	25.2	65	15	20	1.832	0.290	4.044
41	22.5	65	15	20	1.839	0.310	3.524
42	24.5	65	15	20	1.935	0.300	2.349
43	22.8	70	11	19	1.919	0.390	7.240
44	26.3	67	9	24	1.980	0.320	1.913
45	23.6	79	9	12	2.070	0.360	3.538
46	24.3	65	10	25	2.181	0.340	3.899
47	27.2	72	9	19	2.181	0.320	3.925
48	28.5	70	10	20	2.038	0.340	1.858
49	26.2	76	13	11	2.016	0.390	4.008
50	27.5	68	14	18	1.904	0.300	3.315
51	22.1	79	5	16	1.872	0.310	1.438
52	23.5	54	16	30	1.718	0.320	6.320
53	6.90	22	46	32	1.722	1.800	12.67
54	7.30	24	44	32	1.572	1.780	13.82
55	7.10	34	38	28	1.698	1.340	14.33
56	9.10	20	48	32	1.463	1.680	13.58
57	9.30	22	48	30	1.500	1.830	15.43
58	6.00	26	42	32	1.678	1.850	7.225
59	7.10	24	44	32	1.524	1.800	8.895
60	7.90	16	52	32	1.639	1.630	12.53
61	5.40	20	48	32	1.473	1.800	15.71
62	6.00	24	50	26	1.424	1.670	16.49
63	8.70	24	46	30	1.423	1.280	13.90
64	8.90	24	44	32	1.336	1.780	13.74
65	9.00	32	38	30	1.700	1.880	14.51
66	6.60	28	42	30	1.452	1.780	16.70
67	8.22	20	48	32	1.472	1.880	14.41
68	6.80	20	48	32	1.684	1.280	11.40
69	7.10	20	48	32	1.575	1.360	3.634
70	7.70	28	42	30	1.671	0.750	5.037
71	7.90	28	40	32	1.593	0.860	7.399
72	6.84	32	38	30	1.612	0.830	6.266
73	7.90	30	44	26	1.727	0.740	8.629
74	6.50	28	42	30	1.628	1.840	5.894
75	9.00	28	40	32	1.652	1.860	5.963
76	8.80	32	40	28	1.594	1.740	4.595
77	8.30	20	48	32	1.567	1.910	7.307
78	7.10	24	46	30	1.621	1.880	5.970
79	8.00	30	44	26	1.599	1.820	3.159
80	9.70	22	46	32	1.619	1.780	4.628
81	7.60	34	38	28	1.476	1.580	3.317
82	7.30	22	46	32	1.486	1.800	5.325
83	8.40	24	44	32	1.650	1.880	3.724
84	7.60	20	48	32	1.608	1.880	3.664
85	6.90	24	44	32	1.551	1.800	3.960

Table 2: Infiltration rate and physical properties of the fifteen soil samples used to verify selected soil infiltration rate models

Sample No.	Infiltration rate (mm/h)	Sand content (%)	Silt content (%)	Clay content (%)	Bulk density (g/cm ³)	Organic matter (%)	Moisture content (%)
1	9.25	32	36	32	1.666	1.050	7.175
2	3.79	26	32	42	1.473	1.170	8.114
3	8.50	28	32	40	1.732	1.003	6.611
4	3.95	22	38	40	1.541	1.010	11.37
5	6.01	22	38	40	1.441	1.080	5.270
6	26.8	76	10	14	1.986	0.390	6.316
7	28.4	72	12	16	2.065	0.320	3.995
8	21.5	68	13	19	1.836	0.370	3.392
9	6.34	20	46	34	1.587	1.880	13.16
10	7.61	22	46	32	1.659	1.710	13.09
11	6.58	20	48	32	1.544	1.800	14.18
12	8.73	28	44	28	1.535	1.270	5.101
13	8.50	28	44	28	1.578	1.880	6.560
14	6.09	24	44	32	1.554	1.860	4.875
15	10.0	36	38	26	1.557	1.580	4.108

Table 3: Fifty-five multiple-variable linear regression models categorized in five classes based on the number of independent variables

Model class	Model No.	Model
First	1	$IN = k_0 + k_1 SA$
	2	$IN = k_0 + k_1 SI$
	3	$IN = k_0 + k_1 CL$
	4	$IN = k_0 + k_1 BD$
	5	$IN = k_0 + k_1 OM$
	6	$IN = k_0 + k_1 MC$
Second	7	$IN = k_0 + k_1 SA + k_2 SI$
	8	$IN = k_0 + k_1 SA + k_2 CL$
	9	$IN = k_0 + k_1 SA + k_2 BD$
	10	$IN = k_0 + k_1 SA + k_2 OM$
	11	$IN = k_0 + k_1 SA + k_2 MC$
	12	$IN = k_0 + k_1 SI + k_2 CL$
	13	$IN = k_0 + k_1 SI + k_2 BD$
	14	$IN = k_0 + k_1 SI + k_2 OM$
	15	$IN = k_0 + k_1 SI + k_2 MC$
	16	$IN = k_0 + k_1 CL + k_2 BD$
	17	$IN = k_0 + k_1 CL + k_2 OM$
	18	$IN = k_0 + k_1 CL + k_2 MC$
	19	$IN = k_0 + k_1 BD + k_2 OM$
	20	$IN = k_0 + k_1 BD + k_2 MC$
	21	$IN = k_0 + k_1 OM + k_2 MC$
Third	22	$IN = k_0 + k_1 SA + k_2 SI + k_3 BD$
	23	$IN = k_0 + k_1 SA + k_2 SI + k_3 OM$
	24	$IN = k_0 + k_1 SA + k_2 SI + k_3 MC$
	25	$IN = k_0 + k_1 SA + k_2 CL + k_3 BD$
	26	$IN = k_0 + k_1 SA + k_2 CL + k_3 OM$
	27	$IN = k_0 + k_1 SA + k_2 CL + k_3 MC$
	28	$IN = k_0 + k_1 SA + k_2 BD + k_3 OM$
	29	$IN = k_0 + k_1 SA + k_2 BD + k_3 MC$
	30	$IN = k_0 + k_1 SA + k_2 OM + k_3 MC$
	31	$IN = k_0 + k_1 SI + k_2 CL + k_3 BD$
	32	$IN = k_0 + k_1 SI + k_2 CL + k_3 OM$
	33	$IN = k_0 + k_1 SI + k_2 CL + k_3 MC$
	34	$IN = k_0 + k_1 SI + k_2 BD + k_3 OM$
	35	$IN = k_0 + k_1 SI + k_2 BD + k_3 MC$
	36	$IN = k_0 + k_1 SI + k_2 OM + k_3 MC$
	37	$IN = k_0 + k_1 CL + k_2 BD + k_3 OM$
	38	$IN = k_0 + k_1 CL + k_2 BD + k_3 MC$
	39	$IN = k_0 + k_1 CL + k_2 OM + k_3 MC$
	40	$IN = k_0 + k_1 BD + k_2 OM + k_3 MC$

Table 3:Continued

Model class	Model No.	Model
Forth	41	$IN = k_0 + k_1 SA + k_2 SI + k_3 BD + k_4 OM$
	42	$IN = k_0 + k_1 SA + k_2 SI + k_3 BD + k_4 MC$
	43	$IN = k_0 + k_1 SA + k_2 SI + k_3 OM + k_4 MC$
	44	$IN = k_0 + k_1 SA + k_2 CL + k_3 BD + k_4 OM$
	45	$IN = k_0 + k_1 SA + k_2 CL + k_3 BD + k_4 MC$
	46	$IN = k_0 + k_1 SA + k_2 CL + k_3 OM + k_4 MC$
	47	$IN = k_0 + k_1 SA + k_2 BD + k_3 OM + k_4 MC$
	48	$IN = k_0 + k_1 SI + k_2 CL + k_3 BD + k_4 OM$
	49	$IN = k_0 + k_1 SI + k_2 CL + k_3 BD + k_4 MC$
	50	$IN = k_0 + k_1 SI + k_2 CL + k_3 OM + k_4 MC$
	51	$IN = k_0 + k_1 SI + k_2 BD + k_3 OM + k_4 MC$
	52	$IN = k_0 + k_1 CL + k_2 BD + k_3 OM + k_4 MC$
Fifth	53	$IN = k_0 + k_1 SA + k_2 SI + k_3 BD + k_4 OM + k_5 MC$
	54	$IN = k_0 + k_1 SA + k_2 CL + k_3 BD + k_4 OM + k_5 MC$
	55	$IN = k_0 + k_1 SI + k_2 CL + k_3 BD + k_4 OM + k_5 MC$

In order to predict soil infiltration rate from sand content, silt content, clay content, bulk density, organic matter and moisture content of soil, fifty-five multiple-variable linear regression models were suggested and all the data (Table 1) were subjected to regression analysis using the Microsoft Excel 2007. All the multiple-variable linear regression models are shown in Table 3.

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 selected model(s) 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 infiltrations rate values predicted by selected model(s). The statistical analyses were also performed using Microsoft Excel 2007.

RESULTS

A total of fifty-five multiple-variable linear regression models have been categorized in five classes based on the number of independent variables (Table 3). The p-value of independent variables and coefficient of determination (R^2) for the fifty-five multiple-variable linear regression models are shown in Table 4.

First Class Models: In the first class models, soil infiltration rate can be predicted as a function of one independent variable. As indicated in Table 4, among the first class models (models No. 1-6), model No. 1 where sand was considered as independent variable had the highest R^2 value (0.8905) and the lowest p-value

(1.29E-41). Thus, based on the statistical results model No. 1 was selected as the best model of first class models, which is given by equation 2.

$$IN = 0.391 SA - 2.917 \quad (2)$$

Second Class Models: In the second class models, soil infiltration rate can be predicted as a function of two independent variables. As indicated in Table 4, among the second class models (models No. 7-21), model No. 12 where silt and clay were considered as two independent variables had the highest R^2 value (0.9042) and the lowest mean p-value (3.82E-20). Therefore, based on the statistical results model No. 12 was selected as the best model of second class models, which is given by equation 3.

$$IN = 37.87 - 0.315 SI - 0.527 CL \quad (3)$$

Third Class Models: In the third class models, soil infiltration rate can be predicted as a function of three independent variables. As indicated in Table 4, among the third class models (models No. 22-40), model No. 31 where silt, clay and bulk density were considered as three independent variables had the highest R^2 value (0.9071) and the lowest mean p-value (2.39E-10). Thus, based on the statistical results model No. 31 was selected as the best model of third class models, which is given by equation 4.

$$IN = 28.38 - 0.274 SI - 0.505 CL + 4.431 BD \quad (4)$$

Forth Class Models: In the forth class models, soil infiltration rate can be predicted as a function of four independent variables. As indicated in Table 4, among the

Table 4: The p-value of independent variables and coefficient of determination (R^2) for the fifty-five multiple-variable linear regression models

Model No.	p-value						R^2
	SA	SI	CL	BD	OM	MC	
1	1.29E-41	---	---	---	---	---	0.8905
2	---	7.62E-25	---	---	---	---	0.7229
3	---	---	9.21E-26	---	---	---	0.7366
4	---	---	---	2.36E-20	---	---	0.6449
5	---	---	---	---	1.74E-13	---	0.4819
6	---	---	---	---	---	2.79E-05	0.1916
7	1.79E-20	0.000980	---	---	---	---	0.9034
8	1.09E-19	---	0.000967	---	---	---	0.9042
9	8.54E-23	---	---	0.410591	---	---	0.8914
10	1.38E-29	---	---	---	0.353796	---	0.8916
11	2.23E-37	---	---	---	---	0.675083	0.8907
12	---	1.09E-19	1.34E-20	---	---	---	0.9042
13	---	2.90E-08	---	0.001152	---	---	0.7566
14	---	5.88E-13	---	---	0.347104	---	0.7258
15	---	9.27E-21	---	---	---	0.896183	0.7229
16	---	---	7.58E-16	7.46E-11	---	---	0.8424
17	---	---	2.07E-26	---	2.75E-14	---	0.8705
18	---	---	5.56E-24	---	---	0.001158	0.7686
19	---	---	---	4.71E-10	0.004667	---	0.6781
20	---	---	---	2.54E-16	---	0.716416	0.6455
21	---	---	---	---	4.55E-10	0.107647	0.4981
22	1.29E-18	0.000393	---	0.115361	---	---	0.9071
23	1.25E-20	0.000539	---	---	0.150402	---	0.9066
24	2.26E-20	0.001114	---	---	---	0.832590	0.9042
25	9.19E-11	---	0.000393	0.115361	---	---	0.9071
26	2.94E-07	---	0.000539	---	0.150402	---	0.9066
27	3.49E-17	---	0.001114	---	---	0.832590	0.9042
28	4.55E-21	---	---	0.305573	0.267372	---	0.8930
29	1.35E-22	---	---	0.340227	---	0.519770	0.8919
30	1.07E-28	---	---	---	0.389882	0.800859	0.8917
31	---	9.19E-11	1.29E-18	0.115361	---	---	0.9071
32	---	2.94E-07	1.25E-20	---	0.150402	---	0.9066
33	---	3.49E-17	2.26E-20	---	---	0.832590	0.9042
34	---	1.19E-06	---	0.001093	0.294047	---	0.7599
35	---	3.17E-08	---	0.001043	---	0.565557	0.7575
36	---	2.93E-12	---	---	0.342849	0.834986	0.7260
37	---	---	4.84E-20	0.001076	3.46E-07	---	0.8866
38	---	---	3.26E-16	1.33E-08	---	0.368596	0.8450
39	---	---	9.42E-26	---	4.95E-12	0.331568	0.8720
40	---	---	---	2.22E-09	0.005258	0.910308	0.6782
41	1.55E-18	0.000331	---	0.147446	0.193264	---	0.9090
42	2.45E-18	0.000526	---	0.119554	---	0.890689	0.9071
43	2.20E-20	0.000601	---	---	0.156618	0.927714	0.9066
44	2.87E-05	---	0.000331	0.147446	0.193264	---	0.9090
45	1.79E-10	---	0.000526	0.119554	---	0.890689	0.9071
46	5.62E-07	---	0.000601	---	0.156618	0.927714	0.9066
47	7.08E-21	---	---	0.270391	0.306289	0.623545	0.8933
48	---	2.87E-05	1.55E-18	0.147446	0.193264	---	0.9090
49	---	1.79E-10	2.45E-18	0.119554	---	0.890689	0.9071
50	---	5.62E-07	2.20E-20	---	0.156618	0.927714	0.9066
51	---	1.23E-06	---	0.001054	0.316601	0.622990	0.7606
52	---	---	8.19E-20	0.001900	6.14E-07	0.902567	0.8866
53	2.78E-18	0.000399	---	0.145962	0.191947	0.823075	0.9091
54	3.17E-05	---	0.000399	0.145962	0.191947	0.823075	0.9091
55	---	9.42E-05	2.36E-18	0.111719	0.157132	0.786337	0.9092

forth class models (models No. 41-52), model No. 48 where silt, clay, bulk density and organic matter were considered as four independent variables had the highest R^2 value (0.9090) and the lowest mean p-value (1.06E-06). As a result, based on the statistical results model No. 48 was selected as the best model of forth class models, which is given by equation 5.

$$IN = 29.29 - 0.227 SI - 0.521 CL + 4.074 BD - 1.271 OM \quad (5)$$

Fifth Class Models: In this class, soil infiltration rate can be predicted as a function of five independent variables. As indicated in Table 4, among the fifth class models (models No. 53-55), model No. 55 where silt, clay, bulk density, organic matter and moisture content were considered as five independent variables had the highest R^2 value (0.9092) and the lowest mean p-value (1.98E-05). Therefore, based on the statistical results model No. 55 was selected as the best model of fifth class models, which is given by equation 6.

$$IN = 28.13 - 0.220 SI - 0.518 CL + 4.592 BD - 1.440 OM + 0.022 MC \quad (6)$$

DISCUSSION

Among the selected models, i.e. models No. 1, 12, 31, 48 and 55, model No. 1 was chosen as the simplest model and model No. 55 was chosen as the most complex model and a paired samples t-test and the mean difference confidence interval approach were used to compare the soil infiltration rate values predicted using models No. 1

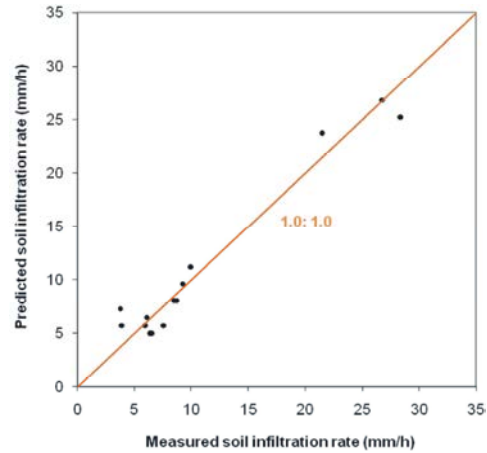


Fig. 1: Soil infiltration rate values measured using field tests (Measured soil infiltration rate) and soil infiltration rate values predicted using model No. 1 (Predicted soil infiltration rate) with the line of equality (1.0: 1.0)

and 55 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 using models No. 1 and 55.

Comparison of Model No. 1 with Field Tests: The soil infiltration rate values predicted by model No. 1 were compared with the soil infiltration rate values measured by field tests and are shown in Table 5. Also, a plot of the soil infiltration rate values determined by model No. 1 and field tests with the line of equality (1.0: 1.0) is shown in Fig. 1. The mean soil infiltration rate difference between

Table 5: Physical properties of the fifteen soil samples used to verify selected soil infiltration rate models No. 1 and No. 55

Sample No.	Soil physical properties						Infiltration rate (mm/h)		
	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm ³)	Organic matter (%)	Moisture content (%)	Field tests	Model No. 1	Model No. 55
1	32	36	32	1.666	1.050	7.175	9.25	9.59	9.93
2	26	32	42	1.473	1.170	8.114	3.79	7.24	4.58
3	28	32	40	1.732	1.003	6.611	8.50	8.02	7.02
4	22	38	40	1.541	1.010	11.37	3.95	5.68	4.91
5	22	38	40	1.441	1.080	5.270	6.01	5.68	4.22
6	76	10	14	1.986	0.390	6.316	26.8	26.8	27.4
7	72	12	16	2.065	0.320	3.995	28.4	25.2	26.3
8	68	13	19	1.836	0.370	3.392	21.5	23.7	23.4
9	20	46	34	1.587	1.880	13.16	6.34	4.90	5.27
10	22	46	32	1.659	1.710	13.09	7.61	5.68	6.88
11	20	48	32	1.544	1.800	14.18	6.58	4.90	5.80
12	28	44	28	1.535	1.270	5.101	8.73	8.02	9.28
13	28	44	28	1.578	1.880	6.560	8.50	8.02	8.63
14	24	44	32	1.554	1.860	4.875	6.09	6.46	6.44
15	36	38	26	1.557	1.580	4.108	10.0	11.2	11.3

Table 6: 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 No. 1 vs. field tests	-0.07	1.71	0.8732	-1.02, 0.88
Model No. 55 vs. field tests	-0.05	1.20	0.8710	-0.71, 0.61

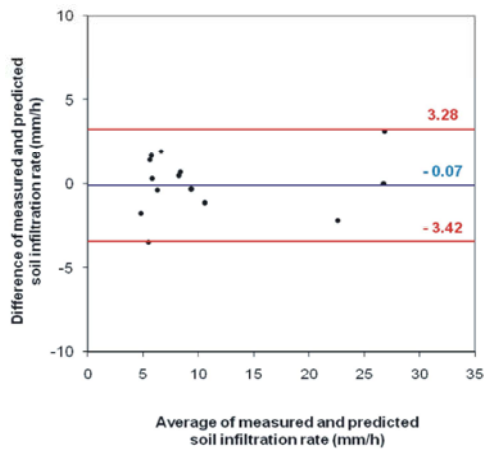


Fig. 2: Bland-Altman plot for the comparison of soil infiltration rate values measured using field tests (Measured soil infiltration rate) and soil infiltration rate values predicted using model No. 1 (Predicted soil infiltration rate); the outer lines indicate the 95% limits of agreement (-3.42, 3.28) and the center line shows the average difference (-0.07)

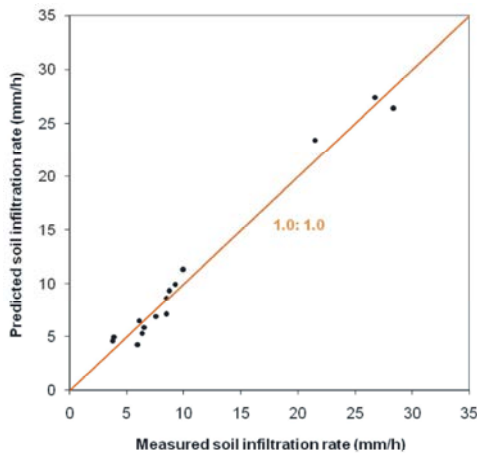


Fig. 3: Soil infiltration rate values measured using field tests (Measured soil infiltration rate) and soil infiltration rate values predicted using model No. 55 (Predicted soil infiltration rate) with the line of equality (1.0: 1.0)

two methods was -0.07 mm/h (95% confidence interval: -1.02 and 0.88 mm/h; $P = 0.8732$). The standard deviation of the soil infiltration rate differences was 1.71 mm/h. The paired samples t-test results showed that the soil

infiltration rate values predicted with model No. 1 were not significantly different than the soil infiltration rate values measured with field tests (Table 6). 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 $\mu - 1.96\sigma$ and $\mu + 1.96\sigma$, known as 95% limits of agreement [10]. The 95% limits of agreement for comparison of soil infiltration rate determined with field tests and model No. 1 were calculated at -3.42 and 3.28 mm/h (Fig. 2). Thus, soil infiltration rate predicted by model No. 1 may be 3.42 mm/h lower or 3.28 mm/h higher than soil infiltration rate measured by field tests. The average percentage differences for soil infiltration rate prediction using model No. 1 and field tests was 18.4%. These results are in line with those of Smerdon *et al.* [1], Mustafa and. [3], Walker [5] and Walker & Busman [7], who reported that soil texture was the most important factor which affected the soil infiltration rate.

Comparison of Model No. 55 with Field Tests: The soil infiltration rate values predicted by model No. 55 were compared with the soil infiltration rate values measured by field tests and are shown in Table 5. In addition, a plot of the soil infiltration rate values determined by model No. 55 and field tests with the line of equality (1.0: 1.0) is shown in Fig. 3. The mean soil infiltration rate difference between two methods was -0.05 mm/h (95% confidence interval: -0.71 and 0.61 mm/h; $P = 0.8710$). The standard deviation of the soil infiltration rate differences was 1.20 mm/h. Again, the paired samples t-test results showed that the soil infiltration rate values predicted with model No. 55 were not significantly different than the soil infiltration rate values measured with field tests (Table 6). 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 $\mu - 1.96\sigma$ and $\mu + 1.96\sigma$, known as 95% limits of agreement [10]. The 95% limits of agreement for comparison of soil infiltration rate determined with field tests and model No. 55 were calculated at -2.40 and 2.30 mm/h (Fig. 4). Therefore, soil infiltration rate predicted by model No. 55 may be 2.40 mm/h lower or 2.30 mm/h higher than soil infiltration rate measured by field tests. The average percentage differences for soil infiltration rate prediction using model

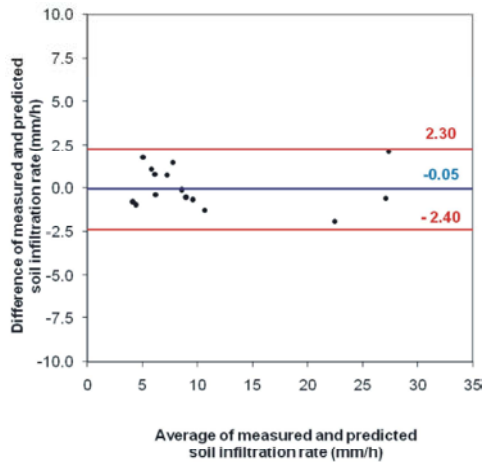


Fig. 4: Bland-Altman plot for the comparison of soil infiltration rate values measured using field tests (Measured soil infiltration rate) and soil infiltration rate values predicted using model No. 55 (Predicted soil infiltration rate); the outer lines indicate the 95% limits of agreement (-2.40, 2.30) and the center line shows the average difference (-0.05)

No. 55 and field tests was 12.2%. These results are in agreement with those reported by Rashidi & Seyfi [2], Walker *et al.* [4] and Holzapfel *et al.* [6], who also reported that physical properties of soil had significant effect on the soil infiltration rate.

CONCLUSIONS

Multiple-variable linear regression models were used to predict soil infiltration rate. The soil infiltration rate values predicted using selected models were compared to the soil infiltration rate values measured by field tests. Statistical results of the study indicated that the difference between soil infiltration rate values predicted by models and measured by field tests were not statistically significant. Therefore, multiple-variable linear regression models provide an easy, economic and brief methodology to predict soil infiltration rate. Results of the study also indicated that sand content of soil is the most important factor which affects soil infiltration rate.

REFERENCES

1. Smerdon, E.T., A.W. Blair and D.L. Reddel, 1988. Infiltration from irrigation advance data II experimental. *Journal of Irrigation and Drainage Engineering*, 114: 4-17.
2. Rashidi, M. and K. Seyfi, 2007. Field comparison of different infiltration models to determine the soil infiltration for border irrigation method. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 2(6): 628-632.
3. Mustafa, O.S., M. Arshad, I. Sattar and S. Ali, 2003. Adoption of Kostiakov model to determine the soil infiltration for surface irrigation methods under local conditions. *International Journal of Agriculture and Biology*, 5(1): 40-42.
4. Walker, W.R., C. Prestwich and T. Spofford, 2006. Development of the revised USDA-NRCS intake families for surface irrigation. *Agricultural Water Management*, 85(1-2): 157-164.
5. Walker, W.R., 2004. *Surface Irrigation Simulation, Evaluation and Design: Guide and Technical Documentation*. Department of Biological and Irrigation Engineering. Utah State University, Logan, Utah.
6. Holzapfel, E., M. Marino, A. Valenzuela and F. Diaz, 1988. Comparison of infiltration measuring methods for surface irrigation. *Journal of Irrigation and Drainage Engineering*, 114(1): 130-142.
7. Walker, W.R. and J. Busman, 1990. Real time estimation of furrow irrigation. *Journal of Irrigation and Drainage Engineering ASCE*, 116: 299-317.
8. Fekersillassie, D. and D.E. Einsenhauer, 2000. Feedback-controlled surge irrigation. I. Model development. *Transactions of the ASAE*, 43(6): 1621-1630.
9. Soil Survey Laboratory Staff, 1996. *Soil Survey Laboratory Methods Manual*. Version 3.0. The United States Government Printing Office, Washington, DC.
10. Bland, J.M. and D.G. Altman, 1999. Measuring agreement in method comparison studies. *Statistical Methods in Medical Research*, 8(2): 135-160.