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Review and Accuracy Comparison of Various Soil Infiltration Models under Field Conditions

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Abstract: Field experiments were conducted to review and compare the accuracy of various soil infiltration models, i.e. Kostiakov (K), Kostiakov-Lewis (KL), Walker (W), Soil Conservation Service (SCS) and Revised Soil Conservation Service (RSCS) models under field conditions and border irrigation method. Two selected fields of 50.0 m long and 7.5 m wide were prepared for sowing of barely by performing primary and secondary tillage operations and considered as treatments in this study. After planking and sowing of barley by seed drill, the cumulative infiltration for each treatment was measured using a double ring infiltrometer. The infiltrometer was installed in the border, filled with water and the depth of water was noted after frequent intervals, until the infiltration rate became constant. From the values of cumulative infiltration and time interval, the constants of the models were determined. Using all the five soil infiltration models, predictions were made for each treatment. The results of the study indicated that the cumulative infiltrations predicted by the K, KL and RSCS models were very close to the field measurements. In addition, the SCS model was able to predict the cumulative infiltration to a reasonable degree of accuracy. However, the W model under predicted the cumulative infiltration. In terms of accuracy, the infiltration models predicted the cumulative infiltration in the order of K > KL > RSCS > SCS > W owing to discrepancies between the predicted and measured results in the reverse order.

Key words: Soil · Infiltration models · Field conditions · Accuracy

INTRODUCTION

Surface irrigation methods are widely used throughout the world [1]. 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. Such developments are now underway for their refinement and adoption of local conditions of soil, climate, crop and economic considerations [2]. The border irrigation is a widely used method of surface irrigation. The surface depths are essentially small in comparison to both length and width of the border [3]. Border irrigation methods make use of parallel ridges to guide a sheet of flowing water as it moves down the field. The strips have zero slopes cross wise but have little or no slope in the direction of length. The former is called the graded border and the later one is the level border irrigation system. It is best suited to soils having low to moderately high intake rate. For close growing crops, the border irrigation method is preferred because of the advantages of border irrigation associated with mechanized agriculture [4].

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 [2].

Besides, soil infiltration 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

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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 [5]. 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 [6].

In the engineering evaluation and design of surface irrigation systems, it has been useful to predict the soil infiltration [5]. In general, predication of the soil infiltration involves the adoption of a functional form to be used and the determination of the value of the numerical constants in the adopted equation [7]. Prediction of soil infiltration 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 [7, 8, 9].

One of the simplest and most commonly used expressions for infiltration has been the Kostiakov equation which can be written for border or basin irrigation as [2, 3, 5]:

$$z = k\,t^{a} \tag{1}$$

where:
z = cumulative depth of infiltration, m
k = an empirical soil constant for infiltration, m/min^{a}
t = intake opportunity time, min
a = an exponent, non-dimensional

When the duration of the water application is relatively short, such as in some border and basin systems, the infiltration rate derived from equation 1 ($I = \partial z/\partial t$) will not significantly underestimate infiltration at the end of irrigation. However, this is not an adequate assumption when the intake opportunity time exceeds 3-4 hour, a situation commonly encountered in furrow irrigation and irrigation of large borders or basins. Thus, a more generally applicable relation is the Kostiakov-Lewis equation which adds a term for final or basic intake rate. The Kostiakov-Lewis function for borders and basins is [5, 10]:

$$z = k\,t^{a} + f\,t \tag{2}$$

where:
f = final or basic intake rate, m/min

In the absence of localized field data, Walker [6] based on Kostiakov-Lewis equation, has often provided sufficient information and general recommendation for preliminary design and evaluation of surface irrigation systems (Walker model).

Since surface irrigation is often applied to the fine or medium textured soils and some of these tend to crack, equation 2 can be extended to include a combined term for cracking and depression storage as [5, 6]:

$$z = k\,t^{a} + f\,t + c \tag{3}$$

The units of c are the same as z, but to date there is no general recommendation for values of this term. One can observe that if f is set to zero, equation 3 has the same form as the original Soil Conservation Service (SCS) intake family equations [5, 6]:

$$z = k\,t^{a} + c \tag{4}$$

However, to more fully utilize advances in procedures for field data collection and analysis as well as the software to automate the hydraulic computations, it has become necessary to revise these intake family equations for local conditions. To develop the Revised Soil Conservation Service (RSCS) intake family equations, revised values of k, a and c can be determined through a least squares regression analysis [5].

The primary objective of this study is to assess the predictability of Kostiakov (K), Kostiakov-Lewis (KL), Walker (W), Soil Conservation Service (SCS) and Revised Soil Conservation Service (RSCS) models for border irrigation method for border irrigation method and to compare the measured and predicted cumulative soil infiltration using these models.

MATERIALS AND METHODS

Field experiments were carried out at the research site of Tehran Agricultural and Natural Resources Research and Education Center, Varamin, Iran. Two fields of 50.0 m long and 7.5 m wide were selected as treatments

Table 1: Soil physical characteristics for each border irrigation treatment

Treatment	Sand (%)	Silt (%)	Clay (%)	Bulk density (g cm^{-3})
1	19	51	30	1.53
2	7	64	29	1.44

and leveled by laser-guided land leveling equipment. The selected fields were prepared for sowing of barley by performing primary and secondary tillage operations. After planking, barley was planted with the help of seed drill. The soil of the experimental site was a fine, mixed, thermic, Typic Haplacambids clay-loam soil. A summery of soil physical characteristics for each border irrigation treatment is given in Table 1.

The experimental fields were irrigated through field channels developed for the purpose. Irrigations were applied to each experimental field by gravity method (border irrigation) in accordance with irrigation turn (every 25 days). The cumulative infiltration for each treatment was measured using a double ring infiltrometer. The infiltrometer was installed in the border 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. The cumulative infiltration and time data were used to determine the constants of K, KL, W, SCS and RSCS models.

RESULTS

Kostiakov (K) Model: The cumulative infiltration and time data were subjected to non-linear regression analysis ($z = k\,t^a$) using the computer software Microsoft EXCEL (Version 2003) to find the constants of K model. The calculated constants k and a for each border irrigation treatment are given in Table 2.

Kostiakov-Lewis (KL) Model: Using the final or basic intake rate, the cumulative infiltration and time data were subjected to non-linear regression analysis ($z - f\,t = k\,t^a$) by the computer software Microsoft EXCEL (Version 2003) to find the constants of KL model. The calculated constants k, a and f for each border irrigation treatment are also given in Table 2.

Walker (W) Model: The constants of KL model were taken the same as proposed by Walker [6] as a general recommendation for border irrigation under local conditions of the experimental fields. The recommended constants k, a and f for each border irrigation treatment are also given in Table 2.

Table 2: The constants of K, KL and W models for each border irrigation treatment

	Model							
	K		KL			W		
Treatment	*k*	*a*	*k*	*a*	*f*	*k*	*a*	*f*
1	0.0046	0.801	0.0050	0.842	0.00040	0.0021	0.483	0.000143
2	0.0053	0.862	0.0042	0.533	0.00026	0.0026	0.537	0.000193

Table 3: The constants of SCS and RSCS models for each border irrigation treatment

	Model					
	SCS			RSCS		
Treatment	*k*	*a*	*c*	*k*	*a*	*c*
1	0.1064	0.7356	0.6985	0.0034	0.866	0.0025
2	0.1321	0.7572	0.6985	0.0046	0.894	0.0015

Soil Conservation Service (SCS) Model: The original intake Family curves were used to find the constants of SCS model under local conditions of the experimental fields. The recommended constants k, a and c for each border irrigation treatment are given in Table 3.

Revised Soil Conservation Service (RSCS) Model: The constants of RSCS model were determined using the cumulative infiltration and time data through a least squares regression analysis in computer software Microsoft EXCEL (Version 2003). The revised constants k, a and c for each border irrigation treatment are also given in Table 3.

DISCUSSION

For each border irrigation treatment, predictions were made using all the five soil infiltration models and the predicted cumulative infiltrations were compared with the measured cumulative infiltrations as follow:

Treatment 1: The cumulative infiltration curve from the field measurement compared with those predicted by the K, KL, W, SCS and RSCS models for an intake opportunity time of 180 minutes have been plotted in Figs. 1 and 2. From comparison of the curves, it can be concluded that all the models except the W model have reasonable predictions over the measured range.

Linear regression with zero intercept was performed to verify the validity of each prediction. The cumulative infiltration values predicted using the infiltration models and those measured experimentally were plotted against

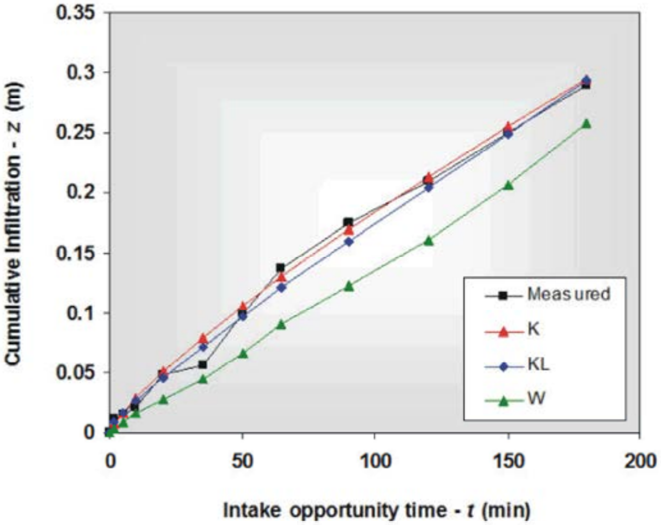

Fig. 1: Cumulative infiltration predicted using K, KL and W models compared with that measured experimentally for treatment 1

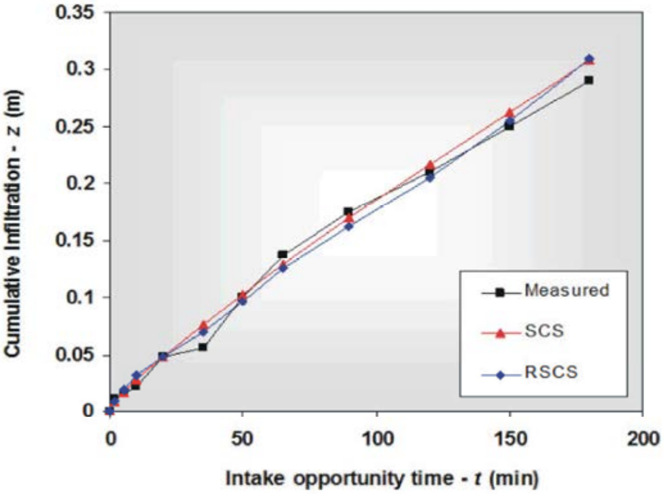

Fig. 2: Cumulative infiltration predicted using SCS and RSCS models compared with that measured experimentally for treatment 1

Table 4: The slope and coefficient of determination (R^2) of the line of best fit for linear regression with zero intercept between predicted and measured cumulative infiltration for treatment 1

Model	K	KL	W	SCS	RSCS
Slope	1.01	0.99	0.80	1.04	1.01
R^2	0.99	0.99	0.98	0.99	0.99

Table 5: Root of mean square errors (RMSE) and mean relative percentage deviation (MRPD) between predicted and measured cumulative infiltration for treatment 1

Model	K	KL	W	SCS	RSCS
RMSE (mm)	8.5	8.7	32.9	9.9	9.9
MRPD (%)	13.0	10.9	31.9	14.3	11.3

Table 6: The slope and coefficient of determination (R^2) of the line of best fit for linear regression with zero intercept between predicted and measured cumulative infiltration for treatment 2

Model	K	KL	W	SCS	RSCS
Slope	1.05	1.05	0.78	0.85	1.07
R^2	0.99	0.99	0.95	0.97	0.99

Table 7: Root of mean square errors (RMSE) and mean relative percentage deviation (MRPD) between predicted and measured cumulative infiltration for treatment 2

Model	K	KL	W	SCS	RSCS
RMSE (mm)	20.1	21.1	57.5	40.9	25.0
MRPD (%)	7.7	7.9	65.8	25.6	9.3

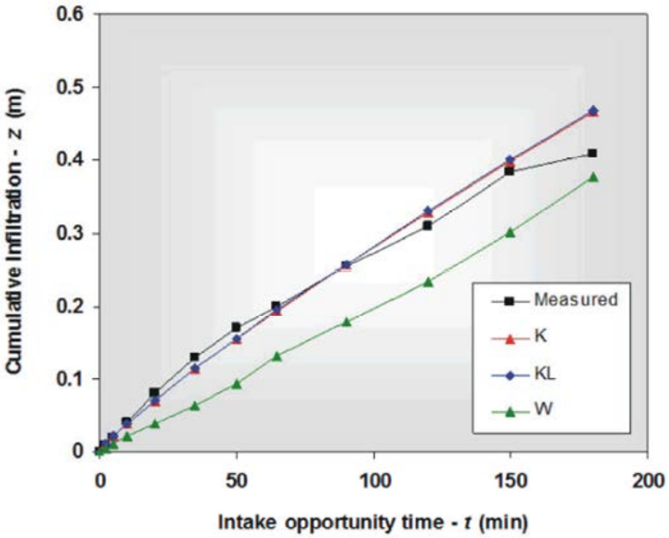

Fig. 3: Cumulative infiltration predicted using K, KL, and W models compared with that measured experimentally for treatment 2

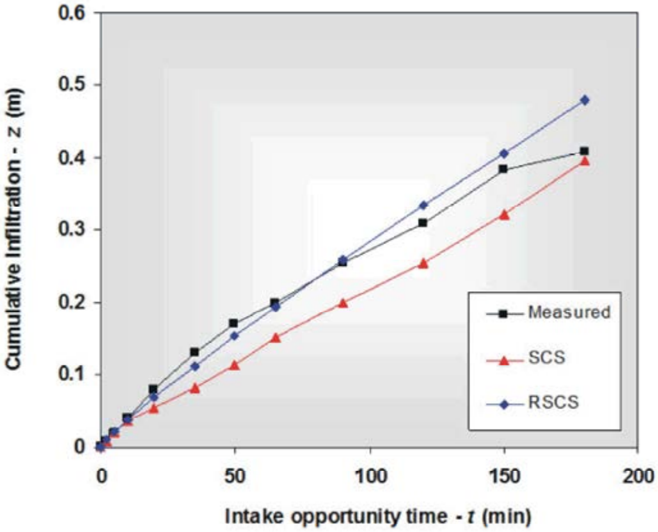

Fig. 4: Cumulative infiltration predicted using SCS and RSCS models compared with that measured experimentally for treatment 2

each other and fitted with a linear equation with zero intercept. The slope of the line of the best fit and its coefficient of determination for each model are given in Table 4. To check the discrepancies between the predicted and measured results, Root of mean square errors (RMSE) and mean relative percentage deviation (MRPD) were used. The amounts of RMSE and MRPD for each model are given in Table 5.

Statistical results indicated that the K, KL, SCS and RSCS models satisfactorily predicted the cumulative infiltration. However, the W model noticeably under predicted the cumulative infiltration. In terms of accuracy, the infiltration models predicted the cumulative infiltration in the order of K > KL > RSCS > SCS > W owing to discrepancies between the predicted and measured results in the reverse order.

Treatment 2: Again, the cumulative infiltration curve from the field measurement compared with those predicted by the K, KL, W, SCS and RSCS models for an intake opportunity time of 180 minutes have been plotted in Figs. 3 and 4. From comparison of the curves, it can be concluded that the cumulative infiltrations predicted by the K, KL and RSCS models were very close to the field measurements.

As before, linear regression with zero intercept was performed to verify the validity of each prediction. The cumulative infiltration values predicted using the infiltration models and those measured experimentally were plotted against each other and fitted with a linear equation with zero intercept. The slope of the line of the best fit and its coefficient of determination for each model are given in Table 6. Once more, RMSE and MRPD were used to check the discrepancies between the predicated and measured results. The amounts of RMSE and MRPD for each model are given in Table 7.

Statistical results indicated that the K, KL and RSCS models satisfactorily predicted the cumulative infiltration. Moreover, the SCS model was able to predict the cumulative infiltration to a reasonable degree of accuracy. However, the W model markedly under predicted the cumulative infiltration. In terms of accuracy, the infiltration models predicted the cumulative infiltration in the order of K > KL > RSCS > SCS > W owing to discrepancies between the predicted and measured results in the reverse order.

CONCLUSION

Among the five soil infiltration models, the K, KL and RSCS models satisfactorily predicted the cumulative infiltration. In addition, the SCS model was able to predict the cumulative infiltration to a reasonable degree of accuracy. However, the W model noticeably under predicted the cumulative infiltration.

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