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Field-Measured Furrow Infiltration Functions

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Abstract: Furrow infiltration varies with different variables and is a complex process for modeling infiltration over the field. This research was conducted to develop empirical relationships between field-wide furrow infiltration and independent variables such as the opportunity time, initial soil water content, flow depth, flow section area, wetted perimeter and wet bulk density. Furrow infiltration was measured by blocked furrow infiltrometers at 48 infiltration sites over a 70 x 130 m field plot. Simple and partial correlations between cumulative infiltration and independent variables were evaluated. The effects of wet bulk density and flow depth on cumulative infiltration were insignificant when the effects of all other variables were removed. However, the effects of other variables such as the opportunity time, wetted perimeter, flow section area and initial soil water content on cumulative infiltration were significant. The results showed that 63.52 % of the variation in cumulative infiltration could be explained by the opportunity time when the other variables were held constant. To describe the field-wide cumulative infiltration as a function of independent variables a model was developed by using least squares regression.

Key Words: Infiltration functions, Infiltration, Furrow irrigation.

Tarla Koşullarında Ölçülmüş Karık İnfiltrasyon Fonksiyonları

Özet: Karık infiltrasyonu farklı değişkenlerin etkisiyle değişir ve tüm tarla yüzey için infiltrasyonun modellenmesi çok karmaşık bir işlemdir. Bu çalışma, tüm tarlayı temsil eden karık infiltrasyonu ile infiltrasyon süresi, başlangıç toprak suyu kapsamı, akım derinliği, akım kesit alanı, ıslak çevre ve hacim ağırlığı gibi bağımsız değişkenler arasında amprik bir ilişki geliştirmek için yapılmıştır. Karık infiltrasyonu, 70 x 130 m genişliğindeki bir tarlada tıkalı karık yöntemiyle 48 noktada ölçülmüştür. Yığışımlı infiltrasyon ile bağımsız değişkenler arasındaki basit ve kısmi bağdaşımlar (korelasyon) değerlendirilmiştir. Tüm diğer degişkenlerin etkileri dikkate alınmadığında, hacim ağırlığı ile akım derinliğinin yığışımlı infiltrasyon üzerine etkileri önemli bulunmuştur. Ancak, infiltrasyon süresi, ıslak çevre, akım kesit alanı, ve başlangıç toprak suyu kapsamı, gibi diğer değişkenlerin de yığışımlı infiltrasyon üzerine etkileri önemlidir. Sonuçlar, diğer değişkenler sabit tutuldugunda, yığışımlı infiltrasyondaki değişmenin % 63.52'sinin infiltrasyon süresi ile açıklanabildiğini göstermiştir. Bağımsız değişkenlerin bir fonksiyonu olarak, tarla ölçekli yığışımlı infiltrasyonu açıklamak için en küçük kareler yöntemi kullanılarak, bir model geliştirilmiştir.

Anahtar Sözcükler: İnfiltrasyon fonksiyonları, İnfiltrasyon, Karık sulama

Introduction

Surface irrigation is the oldest and most widely used method for irrigating agricultural land across the world. Furrow irrigation is one of several methods of surface irrigation. The design, evaluation and management of furrow irrigation depend on infiltration characteristics. Furrow infiltration comprises both local and field–average infiltration, and affects the advance and recession times, runoff and infiltrated volume, and uniformity of water application during an irrigation event (Jobling and Turner, 1973; Fonteh and Podmore, 1993).

Furrow infiltration is a complex and intricate process, and is difficult to model deterministically. Accordingly, most conventional opportunity time-based functions are used to quantify furrow infiltration (Trout, 1992; Fonteh and Podmore, 1993). Most estimation methods of infiltration parameters assume that ,firstly, the entire field has homogeneous soil properties and there is no spatial variability. This assumption can give misleading results when significant trends or changes exist in soil properties. Secondly, it is assumed that the water flow over the surface does not affect the infiltration. This may

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not be a good assumption where soil is eroded by the water flow over the soil surface (Clemmens et al., 2001).

Spatial and temporal variability of soil properties, and spatial variability of opportunity time over the field cause field-average infiltration functions to be used in computations instead of local infiltration functions, although the former are often more complicated. Many investigations have indicated that furrow infiltration varies with different variables. Fangmeier and Ramsey (1978) showed that intake rate was linearly correlated with wetted perimeter in precision-made furrows. Izadi and Wallender (1985) found that in both stagnant and flowing blocked furrow tests infiltration rates were positively correlated with wetted perimeter while cumulative infiltration was correlated with wetted perimeter only in the stagnant tests. They found that wetted perimeter variability contributed one-third of infiltration variability, while the remaining two-thirds arose from measurement error and soil variability. They did not quantify the contribution of other variables such as opportunity time (Tarboton and Wallender, 1989) and initial soil water content. The extended Kostiakov infiltration equation assumes that the wetted perimeter is constant. For the computation of intake as a fuction of local wetted perimeter, Strelkoff and Souza (1984) developed a simple procedure. In order to compute intake with a zero-inertia simulation model, Schwankl and Wallender (1988) used the extended Kostiakov equation and the infiltration equations developed by Strelkoff and Souza (1984). They concluded that the extended Kostiakov equation would result in overprediction of advance times. When wetted perimeter was constant, less water infiltrated near the upstream end of the furrow and more near the downstream end with respect to assuming a variable wetted perimeter (Bautista and Wallender, 1993). Childs et al. (1993) found that when the infiltration parameters were variable and the opportunity time was constant, the infiltration depth coefficient of variation was between 1.5 and 5 times greater than when the parameters were constant and the opportunity time was variable. Enciso-Median et al. (1998) indicated that the soil water content and development of surface seals influence infiltration. Recently, Abbasi et al. (2003) showed that flow depth in furrows played a major role in water flow and solute distribution below the furrows.

The above-cited studies have not investigated the effects of different variables such as the opportunity time, initial soil water content, flow depth, flow section area, wetted perimeter and soil bulk density on field-wide furrow infiltration. Therefore, the main objective of the present study is to develop empirical relationships that may express field-wide furrow infiltration as a function of the above variables.

Materials and Methods

The field experiments were conducted during the spring and summer of 2002 in an experimental field measuring 70 x 130 m located at the Karkaj Research Station of Tabriz University, Iran (latitude 38° 5' N, longitude 46° 17' E, and 1360 m above mean sea level). The soil of the experimental area has been classified as loamy, mixed, mesic and typic calcixerept, and was kept bare during the test. Field slope and furrow spacing were 1.56% and 65 cm, respectively. The soil's physical characteristics and the field layout are shown in Table 1 and Figure 1, respectively. Along the width of the experimental field plot 4 sets of triplicate furrows were selected, as illustrated in Figure 1. The middle and the 2 adjacent furrows were treated as the "measure furrow" and "buffer furrows", respectively. In each set, the 130 m middle furrow (or measure furrow) was divided into twelve 10 m sections and an infiltration trial was carried out at each section. Soil moisture content, wet bulk density, and furrow cross section were also measured prior to the infiltration test. Gravimetry with drying by the burning alcohol technique (Gardner, 1976) was employed for moisture content measurement at the 0-20 cm surface layer. Gross irrigation depth was computed on the basis of soil and soil water properties and crop rooting depth.

The furrow cross sections were measured by using a profilometer with moveable rods with 2 cm spacing and graduated in millimeters. Flow section area and wetted perimeter were obtained graphically from furrow cross sectional profiles that were measured at 3 locations in each test section (Walker, 1989).

Furrow infiltration was measured with blocked furrow infiltrometers as described by Tarboton and Wallender (1989), Walker and Skogerboe (1987), Walker (1989), Trout (1992) and Oyonarte et al. (2002). Measurments were conducted for 240 min at each test site and infiltrated water volume versus time values were recorded. This procedure was repeated for 48 infiltration tests site over the experimental field plot.

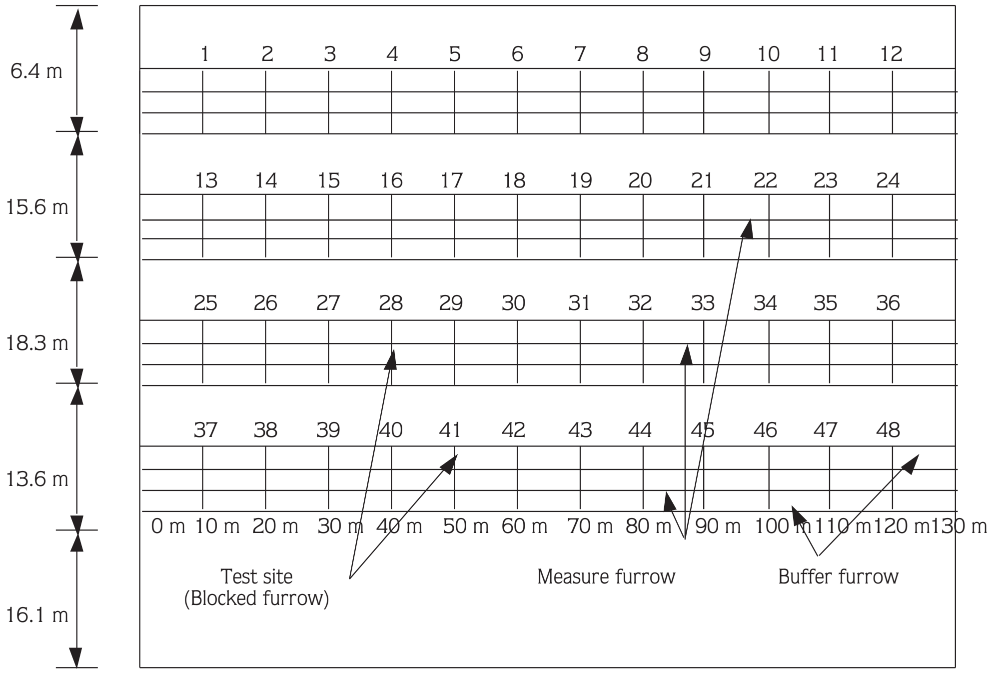

Figure 1. A plan view showing the general layout of the experimental field.

Table 1. Soil physical properties (Jafarzadeh et al.,1993).

Depth Texture (cm)	Gravel	Sand	Silt	Clay	Bulk density ($g\ cm^{-3}$)	FC	TAW	TPS (%)
	(%)					(gravimetric %)		
0-25 Sandy loam	8.4	69.5	24.0	6.5	1.61	12.2	10.7	35.6
25-38 Sandy loam	14.3	55.5	29.7	14.8	1.37	18.2	12.9	46.5
38-65 Sandy loam	00.0	63.8	27.8	8.4	1.28	23.2	17.1	50.0
65-90 Loamy sand	12.0	80.4	16.2	3.4	1.57	17.1	16.7	37.2

FC, TAW and TPS are field capacity, total available water and total pore space, respectively.

In the present study, the dependent variable was cumulative infiltration (volume of water infiltrated per unit length of furrow at time t, $l\ m^{-1}$) that was measured at each test site. Independent variables were opportunity time (min), initial soil water content ($g\ g^{-1}$), wet bulk density ($g\ cm^{-3}$), flow depth (cm), flow section area (cm^2) and wetted perimeter (cm).

Results and Discussion

The soil physical properties over the experimental area are shown as average values in Table 1. Results of independent variables (not including opportunity time) measured in 48 infiltration tests over the field are summarized as their mean and the standard deviation in Table 2. The standard deviation values for wet bulk density and flow depth were small relative to those of other variables.

In order to explain cumulative infiltration based on measured independent variables, the models presented in Table 3 (i.e. a to f) were calculated. The relationships between cumulative infiltration and independent variables were statistically significant at the 5% level ($P \leq 0.05$). Field-wide and field-average cumulative infiltration as a function of the opportunity time in models (a-1, a-2) and their predicted values are shown in Figure 2. Models (b)

Table 2. The mean and standard deviation of measured independent and dependent variables.

	Wo (gravimetric %)	Rb (g cm^{-3})	Dg (cm)	A (cm^2)	Wp (cm)
Mean	8.606	1.422	2.469	10.962	11.042
Std. dev.	3.449	0.081	0.832	5.858	4.251

Wo, Rb, Dg, A and Wp are initial soil water content, wet bulk density, flow depth, flow section area and wetted perimeter, respectively.

Table 3. The relationships between cumulative infiltration and independent Variables.

Model order	Model format	Standard error	Correlation coefficient
(a-1)	$Z = (1158854.267 + 296604\ T^{0.879}) / (896.40 + T^{0.879})$	150.933	0.999
(a-2)	$Z = (765690.310 + 415997.2\ T^{0.826}) / (850.658 + T^{0.826})$	10464.5	0.760
(b)	$\check{Z} = 8.375\ Dg^{-1.1105}\ 2.6232^{Dg}$	12.081	0.786
(c)	$\check{Z} = 103.957 - 11.841 Wo + 0.4235\ Wo^2$	12.163	0.782
(d)	$\check{Z} = (30279.155 + 55.473\ A^{3.485}) / (1779.017 + A^{3.485})$	15.029	0.649
(e)	$\check{Z} = 12.294 + 2.445\ Wp$	15.831	0.573
(f)	$\check{Z} = -1369.766 + 2059.273\ Rb - 748.61649\ Rb^2$	17.666	0.427

Z and $\check{Z}$ are field–wide cumulative infiltration over and at 240 min, respectively.

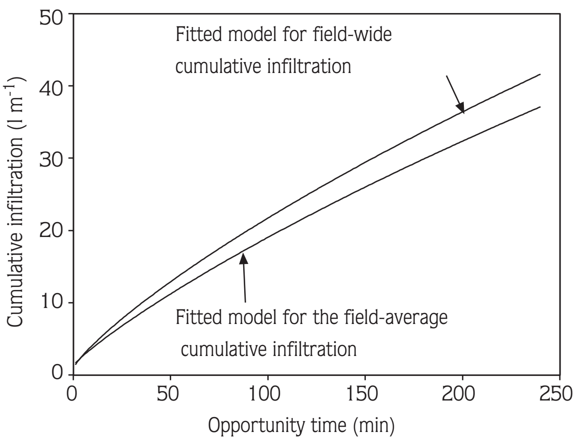

Figure 2. Cumulative infiltration versus opportunity time.

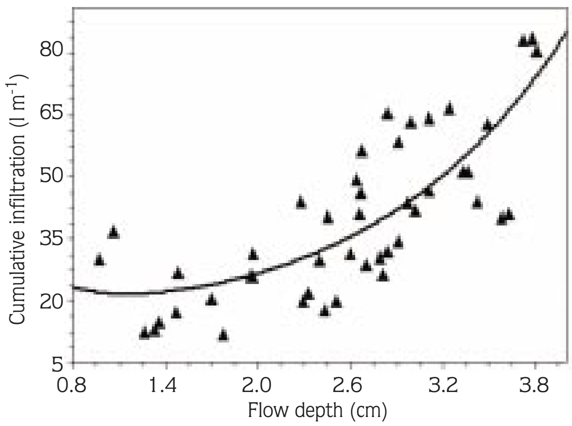

Figure 3. Cumulative infiltration versus flow depth.

to (f) were derived based upon measured values at 240 min. The observed and predicted values of models (b) to (f) are depicted by Figures 3 to 7. There seems to be good agreement between the observed and predicted values of cumulative infiltration by models (a) to (f).

Models (a-1) and (a-2) imply that the opportunity time explains 99.8% and 57.76% of the field-wide and the field-average cumulative infiltration (Z) variability. Models (b) to (f) indicate that 61.77, 61.15, 42.12, 32.83 and 18.23% of the cumulative infiltration variability 240 min ($\check{Z}$) are explained by flow depth, initial soil water content, flow section area, wetted perimeter and wet bulk density, respectively.

The simple correlation coefficients between independent and dependent variables are shown in Figure 8. The correlations are statistically significant at the 10% level ($P \leq 0.10$).

The dependence directions of Z, A and Wp as dependent variables on T, Wo, Dg and Rb are depicted in Table 4.

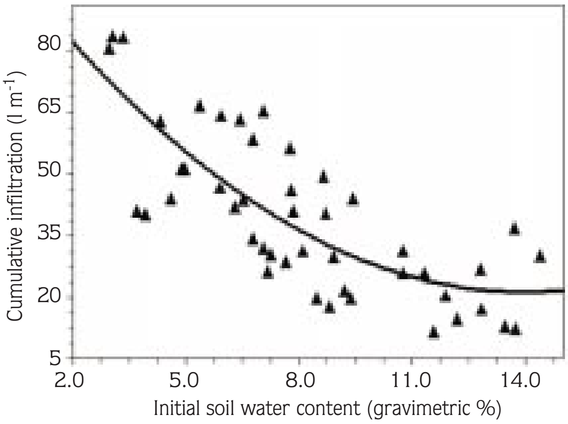

Figure 4. Cumulative infiltration versus initial soil water content.

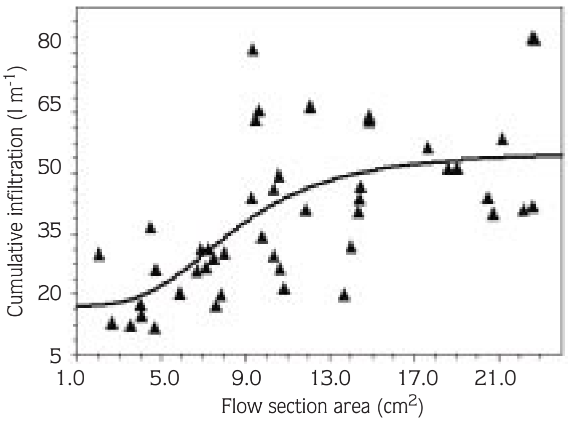

Figure 5. Cumulative infiltration versus flow section area.

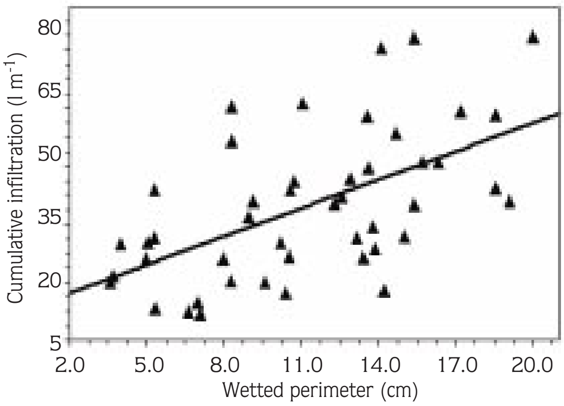

Figure 6. Cumulative infiltration versus wetted perimeter.

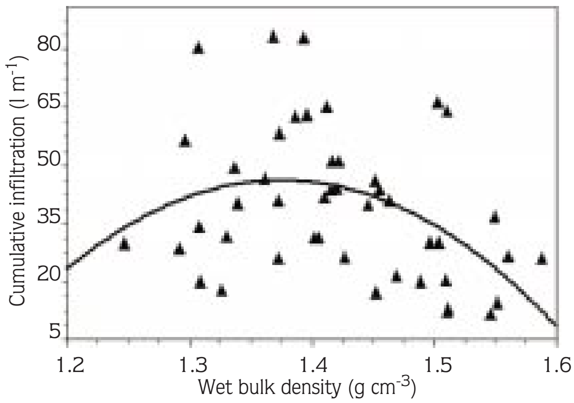

Figure 7. Cumulative infiltration versus wet bulk density.

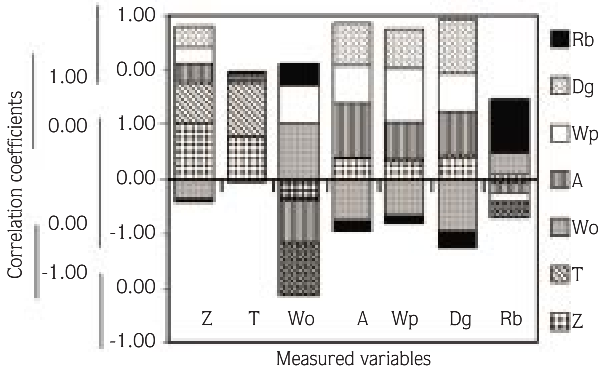

Figure 8. The correlation coefficients between measured variables.

Table 4. Positive and negative correlations between variables.

	T (min)	Dg (cm)	Wo (gravimetric %)	A (cm^2)	Rb (g cm^{-3})
Z (l m^{-1})	P	P	N	P	
A (cm^2)		P	N		N
Wp (cm)		P	N	P	N

P and N represent positive and negative correlations, respectively.

The correlations between cumulative infiltration and every particular independent variable when the others are held constant, e.g., partial correlation coefficients, were estimated. The partial correlations of cumulative infiltration (Z) were statistically significant at the 10% level ($P \leq 0.10$) for opportunity time (T), wetted perimeter (Wp), flow section area (A), and at the 5% level ($P \leq 0.05$) for initial soil water content (Wo), but were not significant for wet bulk density (Rb), and flow depth (Dg). This result implies that 63.52% of the variation in cumulative infiltration is explained by the opportunity time when all the other variables are held constant. In other words, the variation in field-wide cumulative infiltration may be explained solely by the opportunity time, assuming that there are no spatial and temporal variabilities of the other affecting variables. However, this is due to the high correlation between cumulative infiltration and opportunity time, although this assumption may produce incorrect results in field-wide evaluations. For instance, Bautista and Wallender (1993) found that with respect to the variable wetted perimeter, less water infiltrated near the upstream end of the furrow and more near the downstream end when the wetted perimeter was constant.

In order to develop an empirical model relating field-wide cumulative infiltration to the 6 different variables, opportunity time, initial soil water content, flow section area, wetted perimeter, gross depth of water and wet bulk density of soil, multiple regressions were performed using the least squares regression procedure (Moghaddam, 1999; Kohler, 2002).

The obtained model reads

$$Z = 470.318T^{0.33}\ Wp - 4.2813\ Wo\ Dg\ A\ Rb \qquad (1)$$

The R squared of the model is 0.82 and this statistic indicates that the model as fitted explains 82% of the variability in cumulative infiltration over the field. The standard error of the estimate shows the standard deviation of the residuals to be 11173.4. Table 4 shows the analysis of variance for the estimated cumulative infiltration by the obtained model. Since the P value in the following table is less than 0.01, there is a statistically significant relationship between the variables at the 10% level ($P \leq 0.10$). Cumulative infiltrations predicted from the model were plotted against the measured values and are shown in Figure 9 for opportunity times of 60, 120, 180 and 240 min. The calibration linear models were obtained as in Table 6 for predicted and measured values.

It is clear that there are satisfactory agreements between the measured and predicted values for cumulative infiltration.

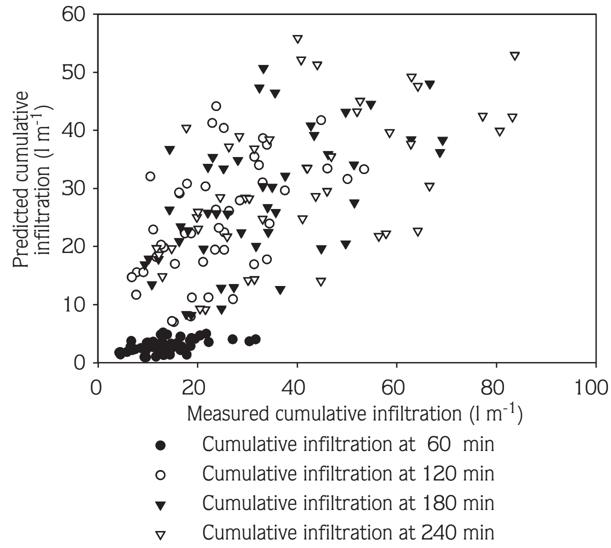

Figure 9. Measured cumulative infiltration versus predicted cumulative infiltration.

Table 6. The calibration models for cumulative infiltration.

Calibration models		R^2
(g)	$Z_{60pred} = 0.18961\ Z_{60}$	84.90
(h)	$Z_{120pred} = 0.9254\ Z_{120}$	85.24
(i)	$Z_{180pred} = 0.7682\ Z_{180}$	85.69
(j)	$Z_{240pred} = 0.6898\ Z_{240}$	85.59

Z_{60}, Z_{60pred}, Z_{120}, $Z_{120pred}$, Z_{180}, $Z_{180pred}$, Z_{240} and $Z_{240pred}$ are measured and predicted cumulative infiltration at 60, 120, 180 and 240 min, respectively.

Conclusion

Simple correlation coefficients between cumulative infiltration and independent variables were evaluated. The correlations between cumulative infiltration and every particular independent variable when the other variables were held constant were evaluated. The effects of wet bulk density and flow depth on cumulative infiltration were not significant, when the effects of all the other variables were removed, while the effects of other

Table 5. Analysis of variance for estimation of cumulative infiltration.

Source	Sum of squares	Df	Mean square	F ratio	P value
Model	1.30702E12	2	6.53509E11	5234.53	0.0000
Residual	2.86646E11	2296	1.24846E8		
Total	1.59366E12	2298			

variables such as opportunity time, wetted perimeter, flow section area, and initial soil water content, on cumulative infiltration were significant. The results showed that 63.52% of the variation in Z could be explained by the opportunity time when the other variables were held constant. To describe the field-wide cumulative infiltration as a function of independent variables such as opportunity time, initial soil water content, flow section area, wetted perimeter, gross depth of water and wet bulk density of soil, a model was worked out using least squares regression. The fitted model explains 82.01% of the variability in cumulative infiltration over the field.

References

Abbasi, F., F.J. Adamsen, D.J. Hunsaker, J. Feyen, P. Shouse and M.Th. van Genuchten. 2003. Effects of flow depth on water flow and solute transport in furrow irrigation: Field data analysis. J. Irrig. Drain. Eng. 129: 237-246.

Bautista, E. and W.W. Wallender. 1993. Numerical calculation of Infiltration in furrow irrigation simulation models. J. Irrig. Drain. Eng. 119: 286-294.

Childs, J.I., W.W. Wallender and J.W. Hopmans. 1993. Spatial and seasonal variation of furrow irrigation. J. Irrig. Drain. Eng.119:74-90.

Clemmens, A.J., D.E. Eisenhaure and B.I. Maheshwari. 2001. Infiltration and roughness equations for surface irrigation: How form influences estimation. ASAE Annual International Meeting.

Enciso-Median, J., D. Martin and D. Eisenhauer. 1998. Infiltration model for furrow irrigation. J. Irrig. Drain. Eng.124: 73-80.

Fangmeier, D.D. and M.K. Ramsey. 1978. Intake characteristics of irrigation furrows. Trans. ASAE, 21: 696-700.

Fonteh, M.F. and T. Podmore, 1993. A physically based infiltration model for furrow irrigation. Agric. Water Manage. 23: 271-284.

Gardner, W.H. 1976. Water content. In: Methods of Soil Analysis. Part 1: Physical and Mineralogical Properties. 4th ed., (Ed. C.A. Black, D.D. Evans, L.E. Ensminger, J.L. White, F.E. Clark, and R.C. Dinauer). Madison, WI.: Agronomy Society. 82-127.

Izadi, B. and W.W. Wallender. 1985. Furrow hydraulic characteristics and infiltration. Trans. ASAE. 28: 1901-1908.

Jafarzadeh, A., A., R. Kasraei and M.R. Neyshabori. 1993. Detailed study of Karkaj farms soils. Tabriz University. Tabriz (in Farsi).

Jobling, G.A. and A.K. Turner. 1973.Physical model study of border irrigation. J. Irrig. Drain. Eng. 99:493-510.

Kohler, H. 2002. Statistics for Business and Economics. Thomson Learning Inc. 1226pp.

Moghaddam, M. 1999. Advanced engineering statistics. Faculty of Agriculture, Tabriz University (in Farsi).

Oyonarte, N.A., L. Mateos and M.J. Palomo. 2002. Infiltration variability in furrow irrigation. J. Irrig. Drain. Eng. 128: 26-33.

Schwankl, L. J. and W.W. Wallender. 1988. Zero-inertia furrow modeling with variable infiltration and hydraulic characteristics. Trans. ASAE. 31: 1470-1475.

Strelkoff, T. and F. Souza, 1984. Modeling effect of depth on furrow infiltration. J. Irrig . Drain. Eng. 110: 375-387.

Tarboton, K.C. and W.W. Wallender. (1989). Field-wide furrow infiltration variability. Trans. ASAE. 32: 913-918.

Trout, T.J. 1992. Flow velocity and wetted perimeter effects on furrow infiltration. Trans. ASAE. 35: 855-862.

Walker, W.R. 1989. Guidelines for designing and evaluating surface irrigation systems. Irrigation and Drainage, Paper No. 45, FAO, Rome, Italy, 137pp.

Walker, W.R. and G.V. Skogerboe. 1987. Surface irrigation: Theory and Practice. Prentice-Hall, Inc., New Jersey, 386 pp.