TARIM BİLİMLERİ DERGİSİ 2006, 12 (3) 267-276
ANKARA ÜNİVERSİTESİ ZİRAAT FAKÜLTESİ
DOI: 10.1501/Tarimbil_0000000464

Estimation of Kostiakov Infiltration Parameters Using Initial Soil Moisture

Abolfazl NASSERI[1] Mohammad Reza NEYSHABORI[2]

Geliş Tarihi: 19.04.2006

Abstract: The Kostiakov equation was extensively used to estimate furrow infiltration but it is unadjusted for different field conditions. The Kostiakov infiltration parameters (*k* and *a*) were therefore developed as a function of initial soil moisture content and irrigation events in current study. The field experiments comprised two types trials. The first was infiltration measuring at 56 sites over the field for the first irrigation event. The second measurements were at the furrows along the same field for five successive irrigation events. Infiltration measurements were taken by blocked furrow infiltrometers. Results showed that the averages of *k* ranged from 272.84 to 733.991 $mlm^{-1}min^{-a}$ and for *a* were from 0.614 to 0.815. The parameter *a* was described as a non-linear function of initial soil moisture content and as a logarithmic function of *k*. The parameter *k* was developed as a non-linear function of initial soil moisture and irrigation events. Cumulative infiltration from five successive irrigation events were correlated to each others and according to the results cumulative infiltration from each irrigation event can be predicted from the other previous irrigation events.

Key Words: Infiltration parameters, Kostiakov parameters, Furrow irrigation

Başlangıç Toprak Nemini Kullanarak Kostiakov İnfiltrasyon Parametrelerinin Tahmini

Öz: Kostiakov eşitliği, farklı tarla koşulları için geçerli olmamasına rağmen uzun bir sure çizi infiltrasyonunutahmin etmede kullanılmıştır. Bu nedenle Kostiakow infiltrasyon parametleri (*k* ve *a*), bu çalışmada başlıngıç toprak nemi içeriği ve sulama uygulamalarının bir fonksiyonu ortaya konulmuştur. Tarla denemeleri iki tip uygulamayı karşılaştırmıştır. Birincisi, ilk sulama uygulaması için 56 bölgede infiltrasyonun ölçülmesidir. İkinci ölçümler ise aynı alanlarda birbirini izleyen 5 sulama uygulaması süresince çizilerde yapılmıştır. İlfiltrasyon ölçümleri bloklu çizi ilfiltrometreleri ile yapılmıştır. Sonuçlar, ortalama k değerinin 272.84-733.991 m/m $-^{1}min^{-a}$ ve a değerinin 0.614-0.815 arasında değiştiğini göstermiştir. *a* parametresi ilk toprak nem kapsamının non-linear bir fonksiyonu ve *k*'nın logartmik fonksiyonu olarak tanımlanmıştır. K parametresi ilk toprak neminin ve sulama uygulamalarının non-linear bir fonksiyonu olarak bulunmuştur. 5 sulama uygulamasındaki kümülatif infiltrasyon diğerleri ile bağlantılıdır. Sonuçlar her sulama uygulamasındaki kümülatif infiltrasyon daha önceki sulama uygulamalarından tahmin edilebileceğini göstermektedir.

Anahtar Kelimeler: İnfiltrasyon parametreleri, Kostiakow parametreleri, çizi infiltrasyonu

Introduction

Infiltration affects the advance of the irrigation streams, recession of water from soil surface, infiltrated and runoff volumes as well as uniformity of water application within the field (Jobling and Turner 1973, Fonteh and Podmore 1993). Consequently, design and management of irrigation systems depend on infiltration characteristics. Furthermore, since furrow infiltration depend on soil and furrow hydraulic properties, initial soil moisture content, permeability changes due to the surface water movement, irrigation events and air entrapment (Walker and Skogerboe 1987), its modeling is somewhat difficult. Nevertheless, empirical opportunity time-based functions are employed for describing furrow infiltration. The most often used is Kostiakov (1932) equation, which has been developed as below:

$$Z = k\,\tau^{a} \qquad (1)$$

where Z and τ are cumulative infiltration and opportunity time, respectively. Exponent *a* and the coefficient *k* known as infiltration parameters or empirical coefficients. Generally, the exponent *a* is greater than zero but less than one. Several

[1] Irrigation and Drainage Division, Agricultural Engineering Research Department, East Azarbaijan Research Center for Agriculture and Natural Resources, Tabriz- Iran
[2] Department of soil Science, Faculty of Agriculture, Tabriz University, 51664,Tabriz- Iran

researches were based on water advance data to estimate Kostiakov infiltration parameters (Christiansen et al. 1966, Noroum and Gray 1970, Elliott et al. 1983, Smerdon et al. 1988, Blair and Smerdon 1988, Wallender and Sirjani 1988). Also, Cahoon (1998) used kinematic wave model for estimating the infiltration characteristics from coincidence between observed and predicted advance and runoff. The Kostiakov equation couldn't be adjusted for different field conditions such as initial soil moisture content (θ_o) that affect infiltration (Philip 1957) and this is its major weakness. Philip (1957) showed that increasing θ_o decreases infiltration rate at small opportunity time and there is no influence of θ_o on the final infiltration rate. Recently, Nasseri et al. (2004) presented a regression model indicating cumulative water infiltration at 4 hr as a function of initial soil moisture content. Although the infiltration function changes for each surface irrigation event (Walker and Skogerboe 1987). Childs et al. (1993) found no correlations among cumulative infiltrations from various irrigation events and it was attributed to the changes in cultural practices during the season. The purpose of the present study is to investigate and model of Kostiakov infiltration parameters (*k* an *a*) as a function of initial soil moisture content and irrigation events.

Material and Methods

The field experiments were conducted during the summer of 2002 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 field soil has been classified as loamy, mixed, mesic and typic calcixerept and its physical properties are summarized in Table 1.

Experiments comprised two type trials. The first was furrow infiltration measuring at 56 sites over a 70 X130-m field plot for the first irrigation event. The second experiment was infiltration measuring at the furrows along the same field for five successive irrigation events (IRR1 to IRR5) with seven days intervals. Measurements were taken in the bare field with a furrow spacing of 65 cm and slope of 1.56%.

Cumulative infiltration was measured by blocked furrow method for an 85 cm furrow segment as described by Oyonarte et al. (2002) along the triplicate furrows for 240 min. The middle and two adjacent furrows from each triplicate furrows were considered to be "measure" and "buffer" furrows, respectively. The furrows cross-sections were measured at three locations along the blocked segments using a profilometer. Initial soil moisture content was measured by gravimetry and drying by burning alcohol method (Gardner 1976) for the samples taken from soil surface up to 90 cm depths with 20 cm intervals during five irrigation events (IRR1 to IRR5). More details about the first experiment can be found in Nasseri et al. (2004).

Results and Discussion

Principle statistics for measured initial soil moisture content and acquired Kostiakov infiltration parameters (*k* and *a* in Equation 1) by non-linear regression were presented for experiments 1 and 2 in Table 2. The averages of initial soil moisture content ranged from 4.9 to 12.56 % and from 6.95 to 15.01 % for measurements made over the field (experiment# 1)and during irrigation events (experiment # 2), respectively, and CVs ranged from about 5 to 48%. The average of *k* ranged from 272.84 to 733.991 $mlm^{-1}min^{-a}$ and CVs were relatively high with average of about 53 and 33 % for over the field and irrigation events data. Such variability in *k* could be arose from changeability of soil and furrow hydraulic properties. The average of *a* were from 0.614 to 0.815 and CVs were low with average of about 12 to 14.5% for the experiments 1 and 2 data, respectively. Table 2

Table 1. Soil physical properties for different soil depthes (Jafarzadeh et al.1993).

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

ρ_b , FC, AW and TPS are bulk density, field capacity, available water and total pore space, respectively.

Table 2. Principle statistics of initial soil moisture content and Kostiakov infiltration parameters (*k* and *a*) for experiments 1 and 2.

		Experiment #1				Experiment # 2				
		Furrow # 1	Furrow # 2	Furrow # 3	Furrow # 4	IRR1	IRR2	IRR3	IRR4	IRR5
θ_o	Average	12.559	10.491	7.543	4.910	6.945	12.311	13.912	13.532	15.010
(gravimetric	Std. Dev.	2.211	1.587	1.580	1.348	3.341	2.381	1.689	2.146	0.736
%)	Variance	4.889	2.519	2.497	1.818	11.167	5.668	2.856	4.606	0.541
	Skewness	0.159	0.679	0.057	0.290	1.365	-0.999	1.706	0.000	0.000
	CV (%)	17.607	15.129	20.953	27.463	48.119	19.339	12.147	15.859	4.899
k ($mlm^{-1}min^{-a}$)	Average	648.398	701.035	715.240	733.991	665.34	531.449	272.843	467.15	584.929
	Std. Dev.	341.294	435.365	300.505	394.22	273.87	183.615	99.515	69.616	227.035
	Variance	116481.6	189542	90303.2	155414.9	75009	33714.46	9903.214	4846.409	51545.130
	Skewness	0.714	1.707	1.394	1.895	-1.731	0.251	1.584	0.000	0.785
	CV (%)	52.636	62.102	42.014	53.710	41.16	34.55	36.47	14.90	38.814
a	Average	0.729	0.675	0.746	0. 815	0.734	0.745	0.639	0.812	0.614
	Std. Dev.	0.103	0.082	0.078	0.082	0.032	0.077	0.145	0.174	0.084
	Variance	0.011	0.007	0.006	0.006	0.001	0.006	0.021	0.030	0.007
	Skewness	1.053	-0.509	-0.815	0.541	-1.721	0.420	0.072	0.000	0.000
	CV (%)	14.164	12.163	10.526	10.123	4.387	10.326	22.644	21.458	13.631

showed that the Kostiakov coefficient *k* had positive skewness (except for IRR1) with average of 0.73 indicating that the *k* has a distribution with a long right tail. The exponent *a* with average of –0.11 had both positive and negative skewness.

Frequency distribution and normal curves of *k* and *a* for cumulative infiltration measured at the four furrows and over the field as well as during five irrigation events were shown in Figures1 and 2. The most frequency acquired *k* ranged from 600 to 800 and was 600 $mlm^{-1}min^{-a}$ for the four furrow and field-wide data, respectively (Figure.1). Corresponding figure was 400 $mlm^{-1}min^{-a}$ for all five irrigation events (Figure1). The most frequency obtained *a* ranged from 0.65 to 0.78 and was 0.76 for the four furrow and field-wide data, respectively (Figure 2). Corresponding figure was 0.72 for all five irrigation events (Figure 2).

For describing *k* and *a* as a function of measured θ_o and irrigation events (IRR), as well as *a* as a function of *k* from cumulative infiltration data measured over the field and during five irrigation events, non-linear regression were applied using the least squares regression procedure (Kohler 2002) and results were presented in Table 3. Coefficient of determination (R^2), t-statistics and F-ratio (Kohler 2002) were used as criteria in selecting the models (Table 4). Results showed that the exponent *a* was worked out as a function of $\theta_o^{-0.10}$ with average coefficient of 0.908. The exponent was also developed as a function of log (*k*) with average coefficient of 0.1145. Infiltration parameter *k* acquired as a function of $\theta_o^{-0.85}$ for field-wide data. It also was as a function of $\theta_o^{-0.85}$ and IRR^2 for irrigation events data. R-squared of the models were high (except for *k* (θ_o) at the first experiment) indicating that the acquired models explains more than 94% of the variability in *k* and *a*. Since the P- values of parameters and the models were less than 5% rejection level (Tables 4 and 5), there is a statistically significant relationship between the variables at the 5% level ($p \leq 0.05$). Kostiakov infiltration parameters (*k* and *a*) from measured cumulative infiltration over the field and during irrigation events were compared with predicted values (from Table 3) in Figure 3. The agreements were satisfactory.

Cumulative infiltrations from IRR1 to IRR4 against CI from the other irrigation events for the first replication were displayed in Figure 4, for instance. Their relationships can be expressed as linear functions. Accordingly cumulative infiltrations from IRR1 to IRR4 were linearly regressed against CI from the successive irrigations (IRR2 to IRR5). Results including linear regression line slops (LRLS) and R^2 were presented in Table 6. The coefficient of determinations with average of 0.997 were highly statistically significant; implying that cumulative infiltration for each irrigation event can be predicted from the other previous irrigation events

Conclusion

The Kostiakov infiltration parameters were adjusted for initial soil moisture content and irrigation events in the present study. Modeling was based on measured CI from 56 blocked segments over the field and from five irrigation events. According to this modeling, the infiltration parameters *k* and *a* can be only estimated from initial soil moisture content and irrigation event. The most frequency for *k* and *a* acquired from field-wide data were 600 $mlm^{-1}min^{-a}$ and 0.76, respectively. The correlation between cumulative infiltration from five successive irrigation events found to be significant. For CI data from IRR1 vs. IRR2, IRR2 vs. IRR3 and IRR3 vs. IRR4, Childs et al. (1993) found R-squared of regression models to be 0.04, 0.34 and 0.64, respectively. Lack of correlation among irrigation events especially between IRR1 and IRR2 were attributed to different cultural practices that affect infiltration. The current study finding is however conflict with those reported by Childs et al. (1993) but is accordance with Walker and Skogerboe (1987). According to current finding, CI for IRR5 can be predicted based on CI from other irrigation events even from IRR1.In this case, it will cause to save up on time and cost.

Table 3. Regression models to estimate *k* and *a* as a function of initial soil moisture content and irrigation events.

For CI measured over the field (Experiment #1)	R^2
$a = 0.913\ \theta_o^{-0.10}$	0.98
$a = 0.114 \log(k)$	0.96
$k = 3492.27\ \theta_o^{-0.85}$	0.71
For CI measured during irrigation events (Experiment #2)	**R^2**
$a = 0.903\ \theta_o^{-0.10}$	0.98
$a = 0.115 \log(k)$	0.98
$k = 8.4917\ IRR^2 + 3138.45\ \theta_o^{-0.85}$	0.94

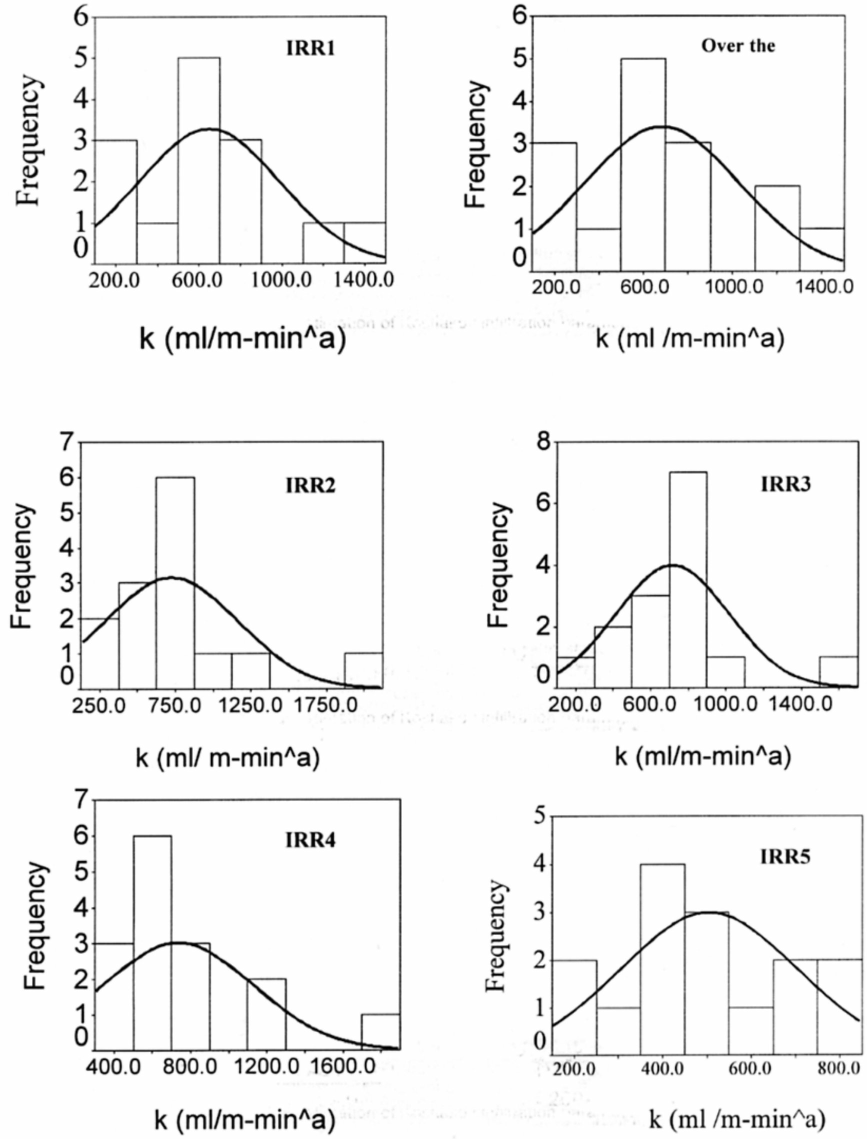

Figure 1. Frequency distribution of *k* for cumulative infiltration measured over the field and for five irrigation events.

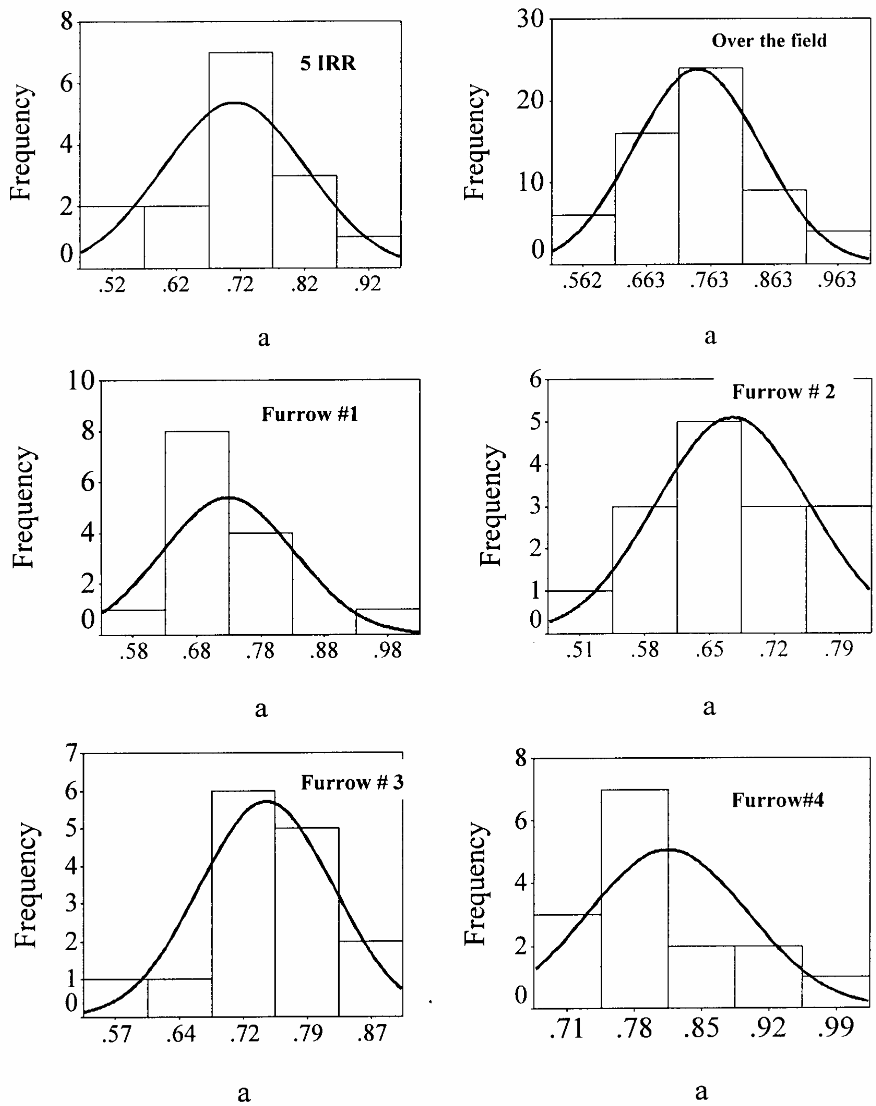

Figure 2. Frequency distribution of *a* for cumulative infiltration measured over the field and for all irrigation events.

Table 4. Multiple regression analysis for *k* and *a* as dependent variables

	Variables	Estimate	Standard error	t-statistic	P-value
	Dependent variable: *k*				
Experiment # 1	Independent variable:				
Experiment # 2	$\theta_o^{-0.85}$	3492.27	310.798	11.236***	0.00
	IRR^2	8.492	3.895	2.180*	0.05
	$\theta_o^{-0.85}$	3138.45	336.606	9.324***	0.00
	Dependent variable: *a*				
	Independent variable:				
Experiment # 1	$\theta_o^{-0.10}$	0.913	0.016	55.08***	0.00
Experiment # 2	$\theta_o^{-0.10}$	0.903	0.038	23.581***	0.00
	Dependent variable: *a*				
	Independent variable:				
Experiment # 1	Log (*k*)	0.114	0.003	35.87***	0.00
Experiment # 2	Log (*k*)	0.115	0.005	23.72***	0.00

*: P<0.05, ***: P<0.001

Table 5. Analysis of variance for acquired models to estimate *k* and *a*.

		Sum of squares	DF	Mean squares	F-ratio	P-value
	Dependent variable: *k*					
	Source:					
Experiment #1	Model	2.3569E7	1	2.3569E7	126.26***	0.00
	Residual	9.5203E6	51	186673.0		
	Total	3.30893E7	52			
Experiment #2	Model	3.58	2	1.79	84.88***	0.00
	Residual	232039.00	11	21094.50		
	Total	3.81	13			
	Dependent variable: *a*					
	Source:					
	Model	28.533	1	28.533	3033.99***	0.00
Experiment #1	Residual	0.479	51	0.009		
	Total	29.012	52			
	Model	6.54	1	6.54	556.09***	0.00
Experiment #2	Residual	0.14	12	0.01		
	Total	6.68	13			
	Dependent variable: *a*					
	Source:					
	Model	27.9066	1	27.907	1287.05***	0.00
Experiment #1	Residual	1.10581	51	0.022		
	Total	29.0124	52			
	Model	6.54	1	6.54	562.64***	0.00
Experiment #2	Residual	0.139	12	0.01		
	Total	6.68	13			

***: P<0.001

Table 6. Linear regression line slop and Correlation coefficient between cumulative infiltration set from IRR1 to IRR5

		IRR2	IRR3	IRR4	IRR5
IRR1					
	LRLS†	1.046 ± 0.723*	0.268 ± 0.058	0.971 ± 0.844	0.398 ± 0.586
	R^2‡	0.998 ±0.000	0.997 ± 0.004	0.997 ± 0.002	0.995 ± 0.003
IRR2					
	LRLS	1.000	0.407 ± 0.371	2.195 ± 0.000	0.861 ± 0.928
	R^2	1.000	0.996 ± 0.000	0.995 ± 0.002	0.993 ± 0.008
IRR3					
	LRLS		1.000	3.122 ± 2.430	1.281 ±0.784
	R^2		1.000	0.997 ± 0.002	0.998 ± 0.000
IRR4					
	LRLS			1.000	0.466 ± 0.098
	R^2			1.000	0.997 ± 0.005
IRR5					
	LRLS				1.000
	R^2				1.000

†: Linear regression line slope. ‡: Coefficient of determination. * : Figures in the Table are mean ± S. Dev.

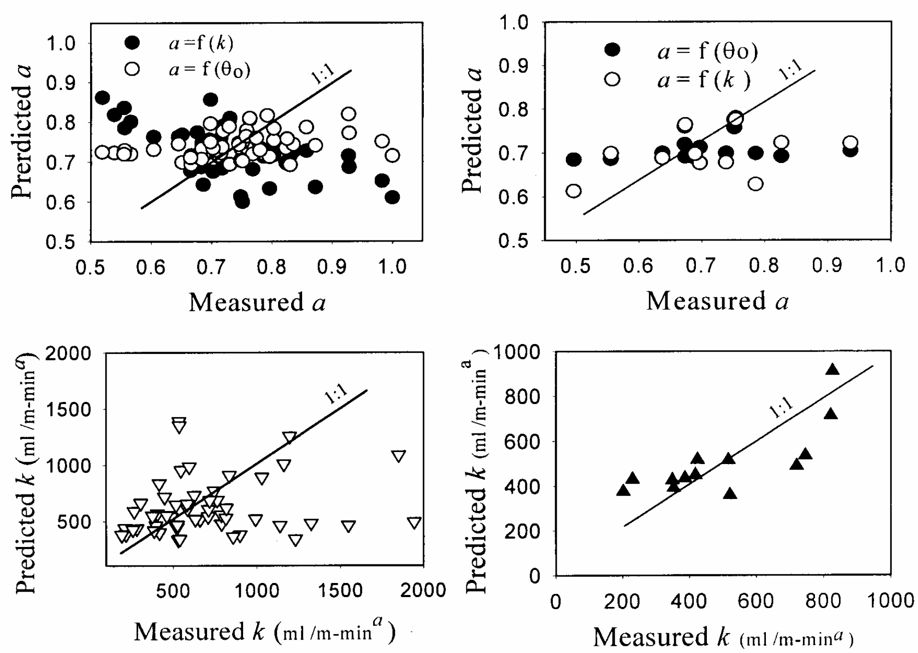

Figure 3. Measured Kostiakov infiltration parameters versus predicted values for over the field and five irrigation events.

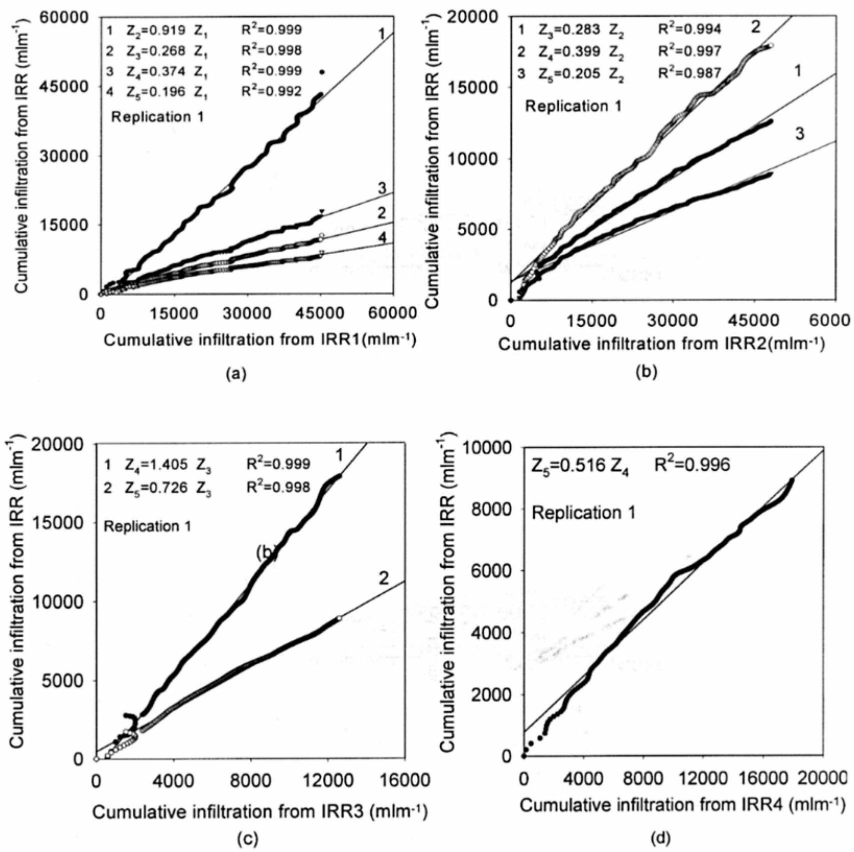

Figure 4. Cumulative infiltration from IRR1 to IRR4 versus cumulative infiltration from the other irrigation events for the first replication.

References

Blaier, A. W. and E. T. Smerdon. 1988. Infiltration from irrigation advance data, II:Experimental .J. Irrig. and Drain.Engrg. 114:18-30.

Cahoon, J. 1998. Kostiakov infiltration parameters from kinematic wave model. J. Irrig. and Drain. Engrg. 124:127-130.

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.

Christiansen, J. E., A. A. Bishop, F. W. Jr. Kiefer and Y. Fok. 1966. Evaluation intake rate constants as related to advance of water in surface irrigation. Trans. ASAE 9:671-674.

Elliott, R. L., W. R. Walker and G. V. Skogerboe.1983. Infiltration parameters from furrow irrigation advance data.Trans. ASAE 26:1726-1731.

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.

Jafarzadeh, A. A., R. Kasraei and M. R. Neyshabori. 1993. Detailed study of 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.

Kostiakov, A.V. 1932. On the dynamics of the coefficient of water percolation in soils and on the necessity for studying it from a dynamics point of view for purposes of amelioration. Transactions of the Sixth Commission of International Society of Soil Science, part A, pp: 17-21.

Nasseri, A., M. R. Neyshabori, A. Fakheri fard, M. Mogaddam and A. H. Nazemi. 2004. Field-measured furrow infiltration functions. Turkish journal of Agriculture and Forestry 28: 93-101.

Norum, D. I. and D. M. Gray. 1970. Infiltration equations from rate-of-advance.J. Irrig. and Drain.Div. 96:111-119.

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

Philip, J. R. 1957.The theory of infiltration: 2.The profile at infinity. Soil83.Sci : 43 448.

Smerdon, E. T., A. W. Blair and D. L. Reddell. 1988. Infiltration from irrigation and advance data.I.Theory.J. Irrig. and Drain. Engrg.114:4-17.

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

Wallender, W. W. and F. Sirjni. 1988. Stochastic infiltration from advance in furrows. ASAE paper No.88-2019, ASAE, ST. Joseph, Mich.

İletişim adresi:
Abolfazi NASSARI
Irrigation and Drainage Division, Agricultural Engineering Research Department, East Azarbaijan Research Center for Agriculture and Natural Resources, Tabriz- Iran