ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 6 (3): 468-471, 2007
ISSN 1812-5379

Evaluation of Kostiakov's Infiltration Equation in Furrow Irrigation Design According to FAO Method

[1]Borhan Sohrabi and [2]Abdolkarim Behnia
[1]Iranian Cotton Research Institute, Gorgan, Iran
[2]Faculty of Water Science Engineering, Shahid Chamran University, Ahwaz, Iran

Abstract: According to recommendations by FAO, the estimation of furrow length without any design computations requires the application of the so-called Tn/4 law in order to reduce depth water losses. In other cases where the coefficients in the infiltration equation are known from field measurements and data, other relations may be used on the basis of these coefficients and for given depth water losses. The research was conducted by Agricultural Engineering Institute of Iran through 1992-1997 at four province of Iran. In the investigations carried out in the Sugar Beet Research Station (Karaj) furrow irrigation was used with cut-back. Field analyses revealed differences in the range of 27-38% between the computed parameters in the design stage and farm measurements. The FAO's method was also evaluated at other station in Karaj (Deputy of Infrastructure). In this region, the field measurements and model predictions for infiltration values showed a difference of 1-14%. Evaluation of the FAO model was also performed at Tajrak Agricultural Research Station in Hamedan using the furrow irrigation (without cut-back). The differences in values found at this site were 43-64%. The same differences for Boroujerd Agricultural Research Station were 19-31%. It is easily seen from these observations that theoretical relations, even those proposed by recognized international organizations such as FAO and SCS, cannot establish valid and reliable foundations for designing surface irrigation systems but that at least in large projects, field investigations are required prior to design and evaluation of these systems in order to avoid further water losses.

Key words: Furrow irrigation, Kostiakov equation, furrow length, infiltration rate, advance equation

INTRODUCTION

Furrow irrigation is considered to be one of the best irrigation methods especially for row crops and medium-textured to heavy soils (Zahra, 1986). Accuracy of water advance and depth infiltration equations will have significant effects on the success of irrigation design and management. This has stimulated a lot of research aimed at developing valid equations and technical manuals in order to enhance irrigation efficiency and uniform water distribution along furrows. Agricultural Research Engineering Institute of Iran embarked in 1992 on one such national research project to study and compare a number of universally recognized furrow irrigation methods in order to identify and propose the best for application by executive departments involved. The methods surveyed in this study included the FAO, SCS and volume balance models. The authors worked on the evaluation of the FAO model in Sugar beet Agricultural Research Station (ARS) at Karaj (Tehran Province), Tajrak ARS (Hamedan Province), Boroujerd ARS (Lorestan Province), Cotton ARS at Gorgan (Golestan Province) and Torogh ARS at Mashad (Khorasan Province).

The increasing population and the growing demand for food worldwide are inflicting increasing pressure on natural resources. But even under normal conditions, satisfactory crop yields will not be possible without proper irrigation.

It, therefore, follows that in the Iranian context (water scarcity and abundance of cultivable land) improved water consumption and land use change from dry to irrigated farm will play decisive roles in increasing crop production.

Pressurized irrigation systems are the best in terms of irrigation efficiency. What hinders the application of these systems, though, is their high investment costs that cannot be afforded by small landlords owning small farms with rather low income levels. In response to this state of affairs, experts working in the field have always concentrated their efforts on improving surface irrigation methods or on developing new methods in their attempts

Corresponding Author: Abdolkrim Behnia, Faculty of Water Sciences Engineering, Shahid Chamran University of Ahwaz Ahwaz, Iran Tel: 0098(611)3364055, 0098(912)1955265 Fax: 0098(611)3365670

to increase irrigation efficiency and to increase cultivated land by savings in water consumption. Furrow irrigation is one of the best irrigation methods particularly for row crops, whose success greatly depends on accurate infiltration and advance equations. There are numerous infiltration equations available today but FAO recommends Kostiakov's infiltration equation for furrow irrigation applications.

Furrows must be on consonance with the slope, the soil type, the stream size, the irrigation depth, the cultivation practice and the field length. The impact of these factors on the furrow length is discussed. Applying larger irrigation depths usually means that furrows can be longer as there is more time available for water to flow down the furrows and infiltrate. Sandy soils, water moves faster vertically than sideways. Narrow, deep V-shaped furrows are desirable to reduce the soil area through which water percolates. However, sandy soils are less stable and tend to collapse, which may reduce the irrigation efficiency. In clay soils, there is much more lateral movement of water and the infiltration rate is much less than for sandy soils. Thus a wide, shallow furrow is desirable to obtain a large wetted area to encourage infiltration (Walker and Skogerboe, 1987).

Davis and Fry (1963) carried out an investigation to measure infiltration rates along furrows. Based on tests and findings by other researchers, he found water movement along furrows to depend on distances between furrows; furrow shape and size; water speed along the furrow and the difference between ridge and bed soil densities.

According to Booher (1974), the law of Tn/4 was first proposed by Kradel *et al.* (1956). Kradel had shown that in order to achieve more uniform distribution and to reduce losses due to depth infiltration, the water advance along the furrow must reach the end of the furrow in ¼ of the time required for the net infiltration of the irrigation water. In this way, he maintained, depth water losses would reduce by 5% (Amin, 1994). These studies and findings form the basis of recommendations by FAO for designing furrow lengths. However, in cases where the power value in Kostiakiov's equation is any value other than 0.5, other relations must be used (Amin, 1994).

Fangmeier and Ramsey (1978) evaluated Philip's and Kostiakov's equations for sand-loamy soils. Inflow and outflow rates, advance and recession times, were measured and recorded. Their results showed the higher accuracy of Philip's equation as compared to Kostiakov's.

Elliot and Walker (1982) recommend the two-point method for determining water advance equation. Their water advance equation is an indexical one and is in good agreement with field observations.

Walker and Skogerboe (1987) reviewed different methods to recommend the two-point method and the indexical function for determining the water advance equation in furrows.

The American Soil Conservation Service (SCS) used Kostiakov's relation and the flow hydraulic relations governing open channels to develop a special method for determining infiltration and advance equations for furrows. Their method is theoretical in nature and is used in designing furrow irrigation systems.

MATERIALS AND METHODS

In our experiments, gated pipes including water pumps, pressure control tanks, water transfer pipes, were used. The water delivery pipe was installed at one end of the farm and a sluice valve was mounted for each furrow to maintain a constant stream size throughout the experiment. Then the following steps were taken:

- Land preparation for planting the dominant crop in the region:
- Making furrows according to the conditions required for the main crop of the region
- Determining the slopes of the furrow along and across the furrow (S).
- Calculation of the maximum non-erosion flow using the empirical relation
- $Q_{max} = 0.6/S$
- Testing different flow rates around the empirical flow to determine maximum (practical) farm non-erosion flow rate
- Performing the inflow-outflow tests (at least six replications) in 30 m furrows to derive Kostiakov's infiltration equation
- Plotting the cumulative infiltration and time curves in logarithmic scale and deriving Kostiakov's relation

$$D = aT^b$$

Where:

D = Cumulative infiltration (mm),
T = Cumulative time (Min),
a, b = Coefficients

- Computation of the net irrigation depth based on soil tests or on meteorological statistics:

$$Fn = MAD\ (Fc-Pw_p) * D * A_s / 100$$

Where:

Fn = Net irrigation depth,
MAD = Management coefficient,

Fc = Moisture percentage of at field capacity,
Pwp = Moisture percentage at permanent wilting point,
D = Rooting depth and
As = Apparent soil specific gravity

- Computation of advance time required for infiltration of net irrigation depth:

$$T_n = (F_n /a)^{1/b}$$

T_n = Time required for infiltration of net irrigation depth (min)

- Computation of advance time according to FAO recommendations:

$$T_t = T_n/4$$

Tt = Advance time (min)

- Testing design flow in long furrows to record advance time and advance equation:

$$x = pT_t^r$$

x = furrow length (m)

- Determining furrow length based on the last two computations above
- Performing the experiment using the inflow-outflow method along the design length in order to perform evaluations according to FAO recommendations.

RESULTS AND DISCUSSION

The Sugar beet research station is located in the west of Karaj (Tehran Province). The soil texture of this Station is Silty Clay Loam. The field experiments were performed by Cut-Back method with first flow 1 L sec^{-1} and second flow 0.5 L sec^{-1} Length of furrow to determine the infiltration equation were 30 m, but 115 m for evaluation. The analysis of data shows that there is a difference of 27-38% between the soil water and which is calculated by kostiakov equation. In other words, the kostiakov equation shows 33% more than its real value in saved water value. The main reason of this difference should be searched in relatively wide furrow and ignorance of the effect of it wetted area. The results of this area are shown in Table 1 and 2 (Hamid *et al*., 1994).

The results of experiments in the field of infrastructural assistance in Karaj (Tehran province) are the same as above. The soil texture of this station is silty loam and experiments were performed by cut-back method (first flow 1 L sec^{-1} and second flow 0.5 L sec^{-1}).

According to the reduction of the furrow width in this area, the difference between the average of leaked water depth in design level and average leaked water depth in the experiment, was decreased to 10% (6-14%) (Table 1 and 2).

The agricultural research station in Tajrak is located at the distance of 45 km near Hamedan and is one of the biggest research stations in Iran. The soil at Tajrak station is silty-clay-loam. A large portion of the Land at this station dedicated to growing potato. A maximum non-erosion flow rate of 1.2 L sec^{-1}, furrows of 30 m and a

Table 1: Infiltration and advance rate equation

	Furrow length (m)				Inflow rate (L sec^{-1})			
Station	F1	F2	Furrow width (m)	Soil texture	Q1	Q2	Inf. Eq.	Advance Eq.
1	30	115	0.8	SCL	1	0.5	$D = 2.263T^{0.801}$	$X = 12.37\ T^{0.685}$
2	30	190	0.55	SCL	1	0.5	$D = 2.660T^{0.580}$	$X = 12.37\ T^{0.557}$
3	30	95	0.6	SL	1.2	-	$D = 3.16T^{0.586}$	$X = 12.95\ T^{0.686}$
4	30	110	0.6	SL	0.5	-	$D = 1.358T^{0.682}$	$X = 13.06\ T^{0.593}$

Sugar beet Research Station at Karaj(Tehran Province), Infrastructural assistance Site in Karaj (Tehran province), Tajarak Agricultural Research Station (Hamedan Province), Borojerd Agricultural Research Station (Lorestan Province), Q1 and Q2 : first inflow rate and second inflow rate at cutback method

Table 2: Comparison of the results from field measurements and predicted values

	T_t (min)					Fo-x(mm)		
Station	Dis.	Eva.	Fn (mm)	Method	T_a (min)	Dis.	Eva.	Difference (%)
1	27	31	100	cutback	241	109	79	-27
1	27	35	100	Cutback	223	110	73	-34
2	42	35	75	Cutback	475	80	75	-6
2	27	22	75	Cutback	262	77	66	-14
3	19	23	40	usual	99	46	64	39
3	31	23	53	usual	146	61	88	44
4	57	33	83.6	usual	260	93	68	-27
4	39	33	62.7	usual	189	73	44	-40

T_t = Water advance time, F_n = Net irrigation depth, Dis. = At design phase, T_a = Total irrigation time, Eva. = At evaluation phase Fo-x = Average infiltration depth

WSC flume (manufactured and calibrated at the Agricultural Engineering and Technical Research Institute) were used to derive the infiltration equation. Kostiakov's equation was derived by plotting the measured values obtained from inflow-outflow experiments in logarithmic scale. However, due to the presence of coarse qravel and pebbles, soil penetrability is beyond normal while it's moisture retention capacity is less than expected. Design and evaluations had to be based on normal open-end irrigation furrow with maximum non-erosion flow conditions. This strategy causes increased advance time and, ultimately, the likelihood of selecting longer furrows; however, the increased runoff at the end of the furrow will make provisions for the runoff reuse inevitable.

In order to determine the water advance equation in furrow, various experiments were done. Water advance equation in furrow was determined by two methods: Regression method and two-point method. Cross-section, wetted surface and wetted area of the furrow were also measured through profile meter. Against the other result from other parts of Iran, the average of penetrated water along the furrow was 40% more than the predicted value in design level (Table 1 and 2). The suitable furrow length in this area was calculated but in order to reduce the deep penetration losses 120 m length furrows and 360 m farming plots are better and also it's better to use runoff again.

The Borojerd Agricultural research station with the area of 89 ha is located at the distance of 18 km near Borojerd. Its annual rainfall average is 45 mm and the largest plain in Lorestan province (Seilakhor plain) is in this area. According to Amberotermic curve, the aridity period in this area from the middle of Ordibehesht (May) to the middle of Mehr (Oct.). The acceptable yield harvest without irrigation is impossible. In order to determine a suitable furrow length, a common furrow irrigation with open-end method was used with the furrow slope of 0.9%, 0.6 m width and the 110 m final length. Because of a heavy soil tissue and high runoff, 0.5 L sec^{-1} flow was used instead of 0.7 L sec^{-1} non-erosion flow to perform the experiments. The analysis of performed experiments in this area shows a difference of 19-31% between the average depth of penetrated water in designing and the experiment (Table 1 and 2).

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Mr. Keshavarz, the Head of Agricultural Engineering Research Institute of Iran (AERI); Mr. Shahabifar (Soil and Water Institute of Iran), Dr. Farhad Mousavi (Prof. of Isfahan University of Technology), Eng. Hamid Soltanzadeh, Dr. Shahram Ashrafi (AERI), Eng. Saati (Hamedan Agr. Re. Center) and Mr. Soltani (Driver) for their support and help without whom this study would not come into existence. The authorities all agricultural research stations those not named here but who offered their valuable contributions also deserve our special thanks.

REFERENCES

Amin, A., 1994. Principles of Irrigation System Design. Imam Reza University Press.

Booher, L.J., 1974. Surface Irrigation. FAO, Agricultural Development Paper No. 95, pp: 111-132.

Davis, J.R. and A.W. Fry, 1963. Measurement of infiltration rates in irrigated furrow. Trans. ASAE., 6: 318-319.

Elliot, R.L. and W.R. Walker, 1982. Field evaluation of furrow infiltration and advance function. Trans. ASAE, 25: 396-400.

Fangmeier, D.D. and M.K. Ramsey, 1978. Intake characteristics of irrigation furrow. Trans. ASAE., 21: 696-699.

Hamid, S., B. Sohrabi and S.H. Sadr-Ghaen, 1994. Final Report on Evaluation and Comparison of Different Methods of Furrow Irrigation Design Methods and Selection of Best Methods. (In Persian), Agricultural Research Organization Publications, Issue No. 10.

Walker, W.R. and G.V. Skogerboe, 1987. The Theory and Practice of Surface Irrigation.

Zahra, P., 1986. Manuscript on irrigation system design (In Persian); College of Agriculture, University of Tehran.