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EVALUATION OF KOSTIAKOV INFILTRATION EQUATION PARAMETERS FROM IRRIGATION ADVANCE IN LEVEL BASINS

Abdul Khaliq, Muhammad Iqbal & Shafiq Anwar
Department of Irrigation & Drainage,
University of Agriculture, Faisalabad

A simple power function with R2 greater than 0.99 was fitted to the measured advance data. A procedure based on volume balance principles that used measured advance, advance exponent and Manning 'n' was formulated to evaluate Kostiakov infiltration equation parameters for level basin irrigation. Using ring infiltrometer-derived and volume balance-derived infiltration parameters, advance curves for level basin irrigation were simulated. The volume balance-derived infiltration parameters produced curves that agreed well to the observed advance curves with a difference of ± 0.1 minutes in the total advance time. In the case of ring infiltrometer-derived infiltration parameters, deviations of -6.9 to ± 19.4 minutes were found in the total advance time. The study concluded that the infiltration characteristics obtained from the advance data represent the field conditions accurately.

INTRODUCTION

Infiltration is the most important soil parameters in the design, evaluation and management of surface irrigation systems (Holzapfel *et al.,* 1988; Clemmens, 1983; Walker and Willardson, 1983). In surface irrigation systems, infiltration affects both advance and recession times during irrigation and therefore, the depth of infiltration and uniformity of water application in the field.

Ring infiltrometer is most commonly used method of infiltration measurement. It is used to obtain infiltration characteristics of the soil at a point where it is installed. A problem with this method is that it does not always result in measured infiltration characteristics that are representative of the entire field. Further, the methods that use static water condition often fail to indicate the typically dynamic field conditions during surface irrigation. Therefore, use of the point-measured infiltration in the design and management of surface irrigation systems becomes critical.

This paper presents a volume balance procedure to evaluate Kostiakov infiltration equation parameters for level basin irrigation systems. In order to assess the accuracy of the volume balance-evaluated infiltration parameters, simulated advance curves have been also compared with the field observed data.

METHODLOGY

Elliott and Walker (1982) presented volume balance approach for determining the parameters of modified Kostiakov infiltration equation for furrow irrigation. Their approach was based on measurements of advance rates, hydraulic X-section and tailwater volume. In this study, the volume balance approach was applied to evaluate the parameters of Kostiakov infiltration equation for level basin irrgation. The following sections explain the formulation of volume balance equations for level basin irrigation and data collection required for the evaluation of the infiltration parameters.

Theory: To maintain volume balance, volume of water applied must equal the volume of water on soil surface plus volume of water infiltrated. For the advance phase of irrigation, volume balance equation for a unit width of basin can be written as:

$$q_0 t_x = V_y + V_z \qquad (1)$$

where

q_0 = unit inflow rate, m^3/min-m

t_x = advance timd to distance X ($0 \le X \le L$), min

L = length of basin, m

V_y = volume of surface water per unit width of a basin, m^3/m

V_z = volume of water infiltrated per unit width of a basin, m^3/m

From epmirical studies, average depth of flow is assumed to be 80% of the flow depth at the inlet of a basin. Therefore, volume of surface water equals the average depth of flow times the advance distance.

$$V_y = 0.80\ y_0 X. \qquad (2)$$

in which y_0 is the flow depth at the inlet of a basin when the water front is at a distance X from the inlet (m).

When applied to the basin inlet in terms of unit width, Manning equation with friction slope equal to the inlet depth divided by the advance distance defines y_0 as:

$$Y_0 = \left(\frac{q^2 n^2}{3600}\right)^{0.23} \qquad (3)$$

in which 'n' is the Manning roughness coefficient.

Volume of water infiltrated per unit width of a basin during advance is found by integrating the point infiltrated depth over the advance distance, which is:

$$V_z = \int_0^X z\,ds \qquad (4)$$

in which 's' is the distance ($0 \le s \le X$) and 'z' is cumulative point infiltration.

Irrigation system design procedures generally use empirical infiltration functions beeause of their simplicity and adequate representation of soil infiltration (Singh and Yu, 1990; Fok, 1986; Heerman and Duke, 1983; Clemmens, 1983). The most often used function for border and basin irrigation is the Kostiakov infiltration function which is a simple power function of the following form:

$$z = k(t_{os})^a \qquad (5)$$

z = infiltrated depth at point s, m

k = a constant, m/min^a

a = an exponent $\le$ 1

t_{os} = infiltration opportunity time at point s, min

During advance phase, infiltration opportunity time at any point is the total advance time minus advance time to the considered point. Advance time can be found from the known advance function. A simple power advance function was used in this study, which is:

$$x = p\,(t_x)^r \qquad (6)$$

in which 'p' is a constant and 'r' is an exponent ($r \le 1$). The parameters 'p' and 'r' can be found by fitting the function to measure advance data.

Using $t_{os} = (t_x - t_s)$ where t_S is advance time to distance's', the volume of water infiltrated over the distance X per unit width of a bsin can be obtained from the integration of equation (4).

$$V_Z = \phi_z k(t_x)^a X \quad (7)$$

where f_Z is subsurface shape factor, defined as:

$$\phi_z = \frac{a + r(1-a) + 1}{(1 + a)(1 + r)} \quad (8)$$

Substituting the expression for V_y (equation 2) and V_Z (equation 7), equation 1 becomes:

$$q_0 t_x = 0.80 y_0 X + \phi_z k(t_x)^a X \quad (9)$$

To solve for the unknowns 'a' and 'k', equation (9) is applied to the points: one at the middle of a basin and the other is the end of a basin. Therefore, with $X = L/2$ and $t_x = t_{0.5L}$; and $X = L$ and $t_x = t_L$, two volume balance equations are written as:

$$\phi_z k(t_{0.5L})^a = \frac{2 q_0 t_{0.5L}}{L} - 0.80 y_0 = V_{0.5L} \quad (10)$$

After performing logarithmic transformation, equation (10) and equation (11) can be solved simultaneously for the unknown 'a' and 'k':

$$a = \frac{\ln(V_L/V_{0.5L})}{\ln(t_L/t_{0.5L})} \quad (12)$$

$$k = \frac{V_L}{\phi_z (t_L)^a} \quad (13)$$

Field data: Three borders (90 m long and 10 m wide) were constructed at the Postgraduate Agricultural Research Station (PARS), University of Agriculture, Faisalabad. The soil of the basins was characterized as sandy clay loam. Laser-controlled landleveling equipment was used to level the basins at about zero slope.

In order to record the advance rate, stations were marked along the length of basins at an interval of 10 m. The basins were kept bare. As there was no danger of crop wilting, three irrigations were applied at intervals of 21 and 75 days, respectively. Inflow to the basins was maintained at the rate of 2.0, 1.0 and 3.0 lps/m during the first, second and third irrigation events, respectively. the flow rate was monitored with a broad-crested weir and a cut-throat flume installed on the upstream of the field watercourse.

Time when the water front reached the marked stations was recorded. In the case of non-uniform advance, average of the water front was used to record advance time. On the days of irrigation, infiltration measurements were made in each basin with double ring infiltrometers.

A simple power function (equation 6) was fitted to the field advance data. The parameters 'p' and 'r' with their coefficient of determination (R^2) are listed in Table 1. Kostiakov infiltration function was fitted to the ring infiltrometer data. the volume balance procedure with an 'n' value of 0.05 (for bare soil) was used to evaluate parameters 'k' and 'a'. Table 2 lists the ring infiltrometer-derived and volume balance-derived infiltration parameters.

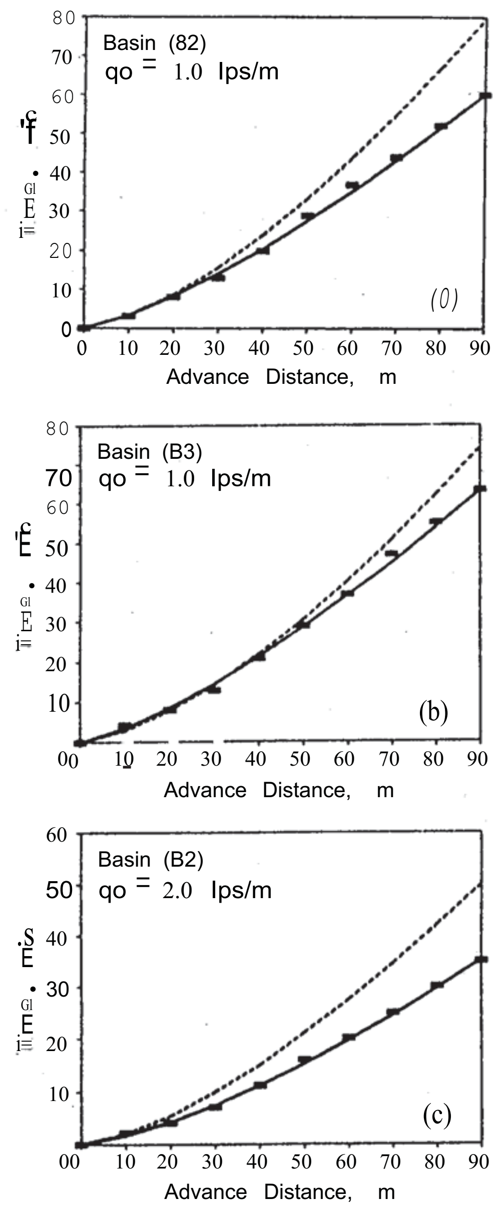
RESULTS AND DISCUSSION

A regression analysis performed on the field advance data demonstrated the ability of the power function (equation 6) to fit the measured advance rates as shown by the large values of R^2. The advance function parameters "p' and er' with corresponding R^2 are listed in Table 1. In the nine set of data (3 basins x 3 irrigations) examined, R^2 found was greater than 0.99.

Table 1. Constant (p) and exponent (r) of Power Advance Function

Basin	p	r	R2
	qo = 1.0 lps/m		
B1	2.4229	0.8708	0.9972
B2	4.2261	0.7433	0.9986
B3	4.2975	0.7307	0.9985
	qo = 2.0 lps/m		
B1	3.8589	0.8653	0.9980
B2	7.1930	0.7087	0.9990
B3	3.9906	0.8764	0.9983
	qo = 3.0 lps/m		
B1	3.8165	0.8928	0.9988
B2	4.8581	0.8248	0.9931
B3	4.8581	0.8248	0.9931

Based on the field advance data, advance exponent and an en'. value of 0.05, infiltration parameters were evaluated using the volume balance approach coupled with the two-point method. Table 2 shows the volume balance-derived and ring infiltrometer-derived infiltration parameters. For the basin (B1), it can be seen from Table 2 that the infiltration exponent was negative for the all three irrigation events. The reason for the negative exponent was found to be the slope in the direction of irrigation which facilitated relatively linear advance. Since the two-point method uses information at two-points, errors/deviations at the measurement points may cause substantial errors in assessing



Rg. 1. Advance Curves for Level Basin Irrigation: observed (filled rectangle); simulated with volume balance-derived k and a (solid line); simulated with ring infiltrometer-derived k and a (dashed line).

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infiltration or may result in failure of the method. Because of the negative infiltration exponent, basin (B1) was dropped off from further analysis.

As Kostiakov infiltration equations is an empirircal one, no physical meanings are attached to its associated parameters. Consequently, it was difficult to judge the accuracy of the two sets of infiltration parameters to represent the field infiltration characteristics. Therefore, the infiltration parameters were compared on the basis of advance time. Using the infiltration parameters in volume balance equation (equation 9), advance trajectories were simulated. Figure 1 compares the simulated and field observed advance curves.

the volume balance-derived infiltration parameters agreed very well with the observed advance curves. On the other hand, considerble deviation can be noticed between the simulated advance curves associated with the ring infiltrometer-derived parameters and field observed advance curves.

Table 3 lists the advance time to the end of the basins. In the case of volume balance-derived parameters, a maximum difference of 0.1 minute in the advance time was observed. On the other hand, deviations of -6.9 minutes to + 19.4 minutes in advance time were found in the case of using ring infiltrometer-derived parameters.

Table 2. Constant (k) and Exponent (a) of Kostiakov Infiltration Function

Basin	Volume balance		Ring Infiltrometer	
	k (m/mina)	a	k (m/mina)	a
		qo = t.O lps/m		
Bl	0.02891	-0.1585*	0.00667	0,450
B2	0.00495	0.3528	0.00485	0.480
B3	0.00533	0,3591	0.00362	0,530
		qo = 2.0 lps/rn		
B1	0.03924	-0.3901*	0.00507	0,490
B2	0.00167	0.7209	0.00619	0,519
B3	0.00898	0.1677	0.00367	0,500
		qo = 3.0Ips/m		
B1	0.03523	-0.0796*	0.00499	0,410
B2	0.02606	0.0104	0.00775	0.370
B3	0.02606	0.0104	0.00345	0,510

*Volume balance approach coupled with two-point method failed to evaluate infiltration parameters.

As can be seen from Figure 1 that the simulated advance curves associated with

Since, the variables except infiltration parameters were kept constant in the sim-

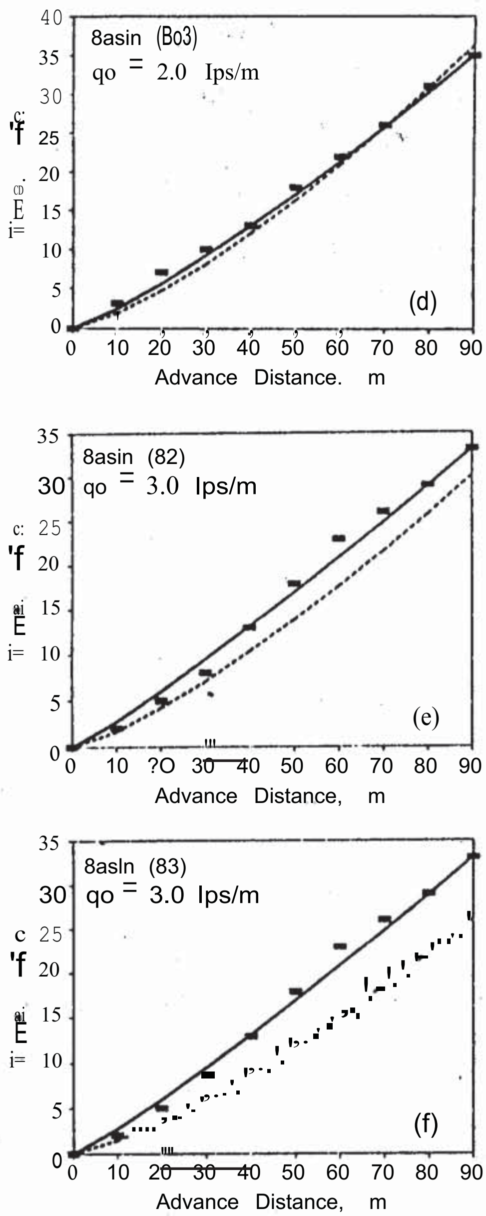

Fig. 1. Advance Curves for Level Basin Irrigation: observed (filled rectangle); simulated with volume balance-derived k and a (solid line); simulated with ring infiltrometer-derived k and a (dashed line).

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ulation of advance, errors (if any) in the infiltration parameters are reflected in the associated advance curves. From the comparison of advance curves (Fig. 1) and total advance time (Table 3), it is obvious that the volume balance-derived infiltration parameters represented the field infiltration characteristics accurately than did the ring infiltrometer-derived parameters.

Table 3. Advance Time to the End of Basins (minutes)

	1.0 lps/m	2.0 lps/m	3.0 lps/m
Basin 2			
t_L (obs.)	60.0	35.0	33.0
t_L (vol.)	59.9	35.1	33.1
t_L (ring)	79.4	50.1	30.1
Basin 3			
t_L (obs.)	63.0	35.0	33.0
t_L (vol.)	62.9	35.1	33.1
t_L (ring)	73.9	36.3	26.1

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