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Using Empirical Equations to Determine Appropriate Furrow Length Under Field Condition

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Abstract: In this study, some of the empirical methods such as USDA-SCS and volume balance equations were used for determining furrow length. The main purpose was proving empirical equations application possibility. According to results, USDA-SCS and Volume Balance Equations can be used for determining furrow length at the Bafra Plain, Turkey. The field experiment and Volume Balance results are very close to each other. Experimental results are different from USDA-SCS equation results, but there is a relationship between both. There is a coefficient between field results and USDA-SCS equation result for furrow length. The coefficient (0.41) can multiply by UDSA-SCS result is 73 m which is very close to the field experimental result of 71 m.

Key words: Furrow length, empirical equations, field data

INTRODUCTION

Surface irrigation is the most extensively used way of applying irrigation water in the world and furrow irrigation one of its main variants (Elliot and Walker, 1982).

There are a number of methods of applying water to croplands. As the oldest and most common method of watering croplands, surface irrigation has evolved into an extensive array of configurations. The distinction between types of surface irrigation systems is based on physical features of the irrigated fields. An alternative to flooding the entire field surface is to construct small channels along the primary direction of water movement. Water introduced in these furrows, creases, or corrugations infiltrates through the wetted perimeter and moves vertically and laterally thereafter to refill the soil (Walker and Skogerboe, 1987).

Generally, however, furrow irrigation is favored for less then 2-3% slope and by moderate to slow intake soils. Furrow length depends on water inflow rate and field slope. Usually long furrow length is preferred by the user because of short furrows need more time and labor, but long furrows need high inflow rate.

The inflow rate, which is affected by the slope, the length of the furrow and the intake rate, can be adjusted by the designer to achieve good uniformity and to irrigate to the required depth in reasonable time. The effectiveness of an irrigation water supply can be increased by improving the efficiency of water application. In surface irrigation, water application efficiency is influenced principally by the amount of water applied, the intake characteristics of the soil and the rate of advance of water over the soil surface. Optimal furrow length and irrigation cut-off can be determined according to soil infiltration characteristics and by the time ratio, to achieve maximum application efficiency.

Uniform flow in furrows depends on soil infiltration properties. For this reason, A quarter time rule is very often used in furrow irrigation application. The quarter time rule is the time that water reaches to end of furrow has to be equal ¼ of time the water would give to furrow for depletion. If the time over than ¼ of applying depletion time, it imposes serious problems on fields that allow water high deep percolation from soil surface to deeper soil profiles and this is meaning of low application efficiency.

Generally, field experiments need a high level of labor, considerable installation time and management also needs high attention levels to get good results. Scientists investigate relationships between surface irrigation flow length and water application time. Results of the research produce new theories and methods (Elliot and Walker, 1982; Walker and Busman, 1990; Katopodes and Strelkoff, 1977; Strelkoff and Katopodes, 1977; Walker and Humpherys, 1983; Jaynes and Clemmens, 1986; Childs *et al*., 1993; Oyonarte *et al*., 2002).

The evaluation of surface irrigation at the field level an important aspect of both management and design

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Field measurements are necessary to characterize the irrigation system in terms of its most important parameters, to identify problems in its function and to develop alternative means for improving systems (Walker, 1989).

Estimation of soil infiltration is a major problem in irrigation studies due to proper selection of the technique used to determine the parameters of the infiltration models, the use of empirical models and its dependence on soil moisture, soil characteristics and surface roughness. The techniques used to determine soil infiltration characteristics (Holzapfel *et al*., 1988; Walker and Busman, 1990).

For furrow irrigation, the shape and size of the furrow affect the volume of water infiltrated because of the size increases the water perimeter and the area of contact between soil and water in the furrow (Trout, 1992). The objectives of this research were to measure from field and also determine infiltration characteristics in furrows and classify soils into intake families by USDA-SCS and Volume Balance Equations. Compare results of Empirical and field furrow characteristics and results. Determine optimum furrow length by using equations for experimental area.

MATERIALS AND METHODS

This experiment was conducted at Altinova village at the Bafra Plain in Samsun Province, Turkey. Some physical properties of the experimental soils are given in Table 1. The soil is a clay soil, approximately 0-90 cm depth.

Furrows were installed with 1.20 m centres and 100 m in length. The slope of furrows was 0.0036 mm^{-1}. Irrigation water was diverted from an irrigation canal on the south side of the experiment area. Inlet and outlet flow measurement equipment was installed in furrows.

To determine the infiltration characteristics five furrows had installed, two side furrows were conducted for blind furrow, middle three furrows were conducted for measure data. Three orifices were installed 100 m from furrow head. Water depth in the furrow was adjusted to not exceed 75% of furrow depth. Furrow width was measured at three points. Furrow cross-section is shown in Fig. 1.

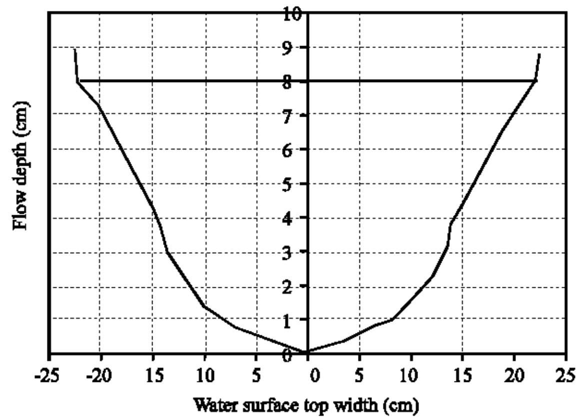

Fig. 1: Measured furrow cross-sectional area and irrigation water in furrow

Determination of furrow length under field conditions: Furrow length and application time are the most important factors affecting efficiency in furrow irrigation. Under given soil conditions, when the furrow length is short, surface runoff increase; if furrows are long, then deep percolation losses increase. The objective of an optimum design is to maximise water application efficiency by minimizing the losses. The ratio between the times required for infiltration of the net amount of water needed for root zone and the time when the water front reaches the end of the run (time ratio) plays an important role in determining optimum furrow length and providing maximum irrigation efficiency. The ratio has given most of the literatures and is called Quarter time rule (Hart *et al*., 1980). Optimal furrow length and irrigation cutoff are related to soil infiltration characteristics (Walker, 1989). As above, furrow length and inflow rate can be determined by the quarter time rule.

For the field experiment, the flow rate has to be as much as the maximum point of soil erosion for particular soil. One of the equations to calculate the maximum rate was given by Hamad and Stringham (1978) below,

$$Q = \alpha . S^{\beta} \quad (1)$$

Where:

Q = Maximum flow rate (L sec^{-1})

S = Furrow slope

α and β = Coefficient parameters depends of soil properties (Table 2)

Table 1: Some physical properties and soil textures of experiment field

Soil depth (cm)	Field capacity Pw (%)	Permanent wilting point Pw (%)	Bulk density (g cm^{-3})	Texture			
				Sand (%)	Clay (%)	Loam (%)	Class
0-30	40.26	23.11	1.32	15.40	45.34	39.18	SiC
30-60	38.38	24.32	1.35	14.48	51.34	34.18	C
60-90	39.47	23.89	1.41	17.48	50.34	32.18	C

Table 2: Coefficient parameters used for maximum flow rate for furrow

Soil	a (L sec^{-1})	b
Heavy texture	0.892	-0.937
Mid. heavy texture	0.988	-0.550
Mid texture	0.613	-0.733
Light texture	1.111	-0.615
Very light texture	0.665	-0.548

Table 3: Furrow intake family and advance coefficients (Hard *et al*., 1980)

Intake family	Empirical coefficients a	b	c	F	g
0.05	0.5334	0.618	7.0	7.16	1.088×10^{-4}
0.10	0.6198	0.661	7.0	7.25	1.251×10^{-4}
0.15	0.7110	0.683	7.0	7.34	1.414×10^{-4}
0.20	0.7772	0.699	7.0	7.43	1.578×10^{-4}
0.25	0.8534	0.711	7.0	7.52	1.741×10^{-4}
0.30	0.9246	0.720	7.0	7.61	1.904×10^{-4}
0.35	0.9957	0.729	7.0	7.70	2.067×10^{-4}
0.40	1.0640	0.736	7.0	7.79	2.230×10^{-4}
0.50	1.1960	0.748	7.0	7.97	2.556×10^{-4}
0.60	1.3210	0.757	7.0	8.15	2.883×10^{-4}
0.70	1.4430	0.766	7.0	8.33	3.209×10^{-4}
0.80	1.5600	0.773	7.0	8.50	3.535×10^{-4}
0.90	1.6740	0.779	7.0	8.68	3.862×10^{-4}
1.00	1.7860	0.785	7.0	8.86	4.188×10^{-4}
1.50	2.2840	0.799	7.0	9.76	5.819×10^{-4}
2.00	2.7530	0.808	7.0	10.65	7.451×10^{-4}

Determining furrow infiltration parameters in field by inflow-outflow methods: Water moves horizontally and vertically in soil. The ring infiltration test measures vertical water movement in soil. In general, a relatively large number of field measurements of infiltration are required to represent the average field condition. Methods that employ a static water condition (such as ring infiltration) often fail to indicate the typically dynamic field condition. There are other approaches for obtaining field representative infiltration function, based on the response of the field to an actual watering (Walker and Skogerboe, 1987).

USDA-SCS Method: Hart *et al*. (1980) gave the definition of the USDA-SCS method. The basis of the SCS design is to classify soils into intake families. According to the SCS equation, families are as determined follows. Cumulative intake (mm), the time water is in contact with soil (min) and a, b and c are constants unique to each intake family. Values of constants are given in Table 3.

The opportunity time required for intake of selected net application depth, d_n, the net opportunity time can be estimated by using Eq. 2.

$$T_n = \left[\left(d_n \frac{w}{p} - c\right)/a\right]^{1/b} \tag{2}$$

The time for water to advance to successive points along the furrow calculated by regression analysis of trial measurements, is a semi-logarithmic relation of length, inflow rate and slope (Hart *et al*., 1980). The advance time can be estimated by using Eq. 3.

$$T_i = \frac{L}{f} \exp^{\frac{g.L}{Q.S^{0.5}}} \tag{3}$$

Where:

Tn	=	The net opportunity time (min)
dn	=	The desired net application depth (mm)
W	=	Furrow width (m)
P	=	(m)
Q	=	Inflow rate (L sec^{-1})
S	=	Furrow slope (m m^{-1})
Ti	=	Advance time (min)
a,b,c,f,g	=	Empirical coefficients

Volume balance method: The volume balance model has been the basis for most design and field evaluation procedures and has been proven with field and laboratory data (Fok and Bishop, 1965; Walker and Skogerboe, 1987). It allows quick and reliable definition of infiltration rates over the length of the field and it is easily extended to indications of uniformity and efficiency parameters (Fok and Bishop, 1965; Levien and Souza, 1987; Walker and Skogerboe, 1987).

The volume balance model is applied primarily to the advance phase and can be written for the furrow condition. At a time (t) water entering the field will progress a distance (x) toward the lower end as illustrated in Fig. 2.

It is implicit that the discharge at the field inlet (Q_0) is steady, so that at time (t) the product of Q_0 and t equals the volume of water on the soil surface ($V_y(t)$) plus the volume infiltrated ($V_z(t)$) which are both time dependent. This can be presented as equation (4) (Fok and Bishop, 1965; Levien and Souza, 1987; Walker and Skogerboe, 1987).

$$Q_0.t = Vy(t) + Vz(t) \tag{4}$$

The length (x) covered by water at the time (t) can be estimated by Eq. 5.

$$x = At^b \tag{5}$$

Where:

x	=	The distance covered by the water in time (t) in meters
t	=	Total water application time in minutes and A and b empirical constants of advance function (De Tar, 1989)

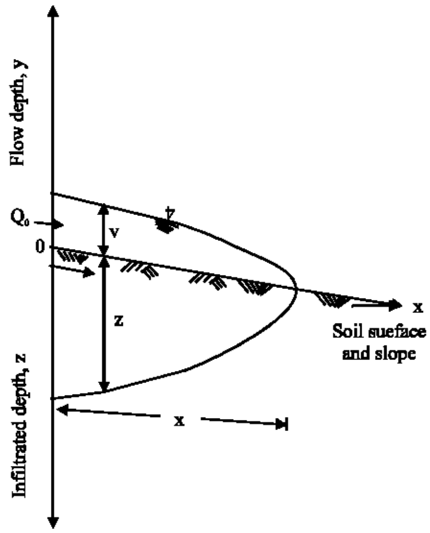

Fig. 2: Definition sketch of an advancing flow down a furrow (Walker and Skogerboe, 1987)

A commonly used expression for the infiltration function (z) which is dependent on infiltration opportunity time (t) is given Eq. 6.

$$z = k.t^a \tag{6}$$

Where:

z = The cumulative infiltration depth;
t = The infiltration opportunity time and k and a are constants for a given soil at a particular moisture level (Christiansen *et al*., 1966).

The volume of water above the soil surface can be found by integrating the flow area over the advance distance Eq. 7.

$$Vy(t) = \int_0^x A\,(s,t)\,dS \tag{7}$$

in which s is the integrand of x and A is the cross-sectional area. In the absence of a momentum or energy relationship to describe the temporal and spatial distribution of A, the volume balance model assumes that the average area, $\bar{A}$, is constant. The usual practice to define Â is shown in Eq. 8.

$$\bar{A} = \sigma y.\ Ao \tag{8}$$

Where, σ_y = The surface water profile shape factor (i.e., the ratio of the average area to the inlet area, A_0). σ_y values can be between 0.6-0.8 (Delibas, 1994). The inlet area (A_0) is assumed to be a function of the normal depth associated with the discharge, slope, roughness and hydraulic radius at the field inlet (Alazba, 1999). Eq. 7 reduces to Eq. 9.

$$Vy(t) = \sigma y.\ Ao.\ X = \bar{A}X \tag{9}$$

The volume of infiltrated water is found by integrating the infiltrated volume per unit length, Z(s, t), over the advance length:

$$Vz(t) = \int_0^x Z(S,t)\quad dS \tag{10}$$

For practical uses Eq. 10 can be written as Eq. 11.

$$Vz(t) = \sigma_z.Z_0.X \tag{11}$$

Where:

Z_0 = The infiltrated depth at the field inlet.
σ_z = A subsurface shape factor can be calculated by 1/(1+a), where, a is an infiltration parameter. (Alazba, 1999).

The Lewis-Milne equation can be written in terms of both shape factors as:

$$Q_0.t = \sigma_y.A_0.X + \sigma_z.Z_0.X \tag{12}$$

Lewis and Milne (1938) described a recursive method of solving the border advance problem.

The change in surface inflow, $Q_0\Delta_t$, equals the change in surface storage, A Δx_4, plus the change in subsurface storage. Thus, using the trapezoidal rule, the subsurface volume can be estimated by;

$$\begin{aligned} Q_0.\Delta t = {} & \sigma_y.A_0.\Delta X_4 + \sigma_z.Z_1\Delta X_4 \\ & + \frac{\left[(Z_4 - Z_3) + (Z_3 - Z_2)\right].\Delta X_1}{2} \\ & + \frac{\left[(Z_3 - Z_2) + (Z_2 - Z_1)\right].\Delta X_2}{2} \\ & + \frac{\left[(Z_2 - Z_1) + (Z_1 - 0)\right].\Delta X_3}{2} \end{aligned} \tag{13}$$

In which the $\frac{Z_i - Z_{i-2}}{2}$ equation can be written as;

$$\Delta X_4 = \frac{Q_0.\Delta t - a_4.\Delta X_1 - a_3.\Delta X_2 - a_2.\Delta X_3}{A + \sigma_z.Z_1} \tag{14}$$

These results can be written in general form as Eq. 15

$$\Delta X_i = \frac{Q_0.\Delta t}{A+\sigma_z.Z_1} - \sum_{k=1}^{i-1}\left[\frac{Z_{i-k+1}-Z_{i-k-1}}{2.(A+\sigma_z.Z_1}\Delta X_k\right] \quad (15)$$

RESULTS AND DISCUSSION

Equation 2 was used to determine maximum inflow that would not cause erosion in furrow. The result was 2.32 L sec^{-1}, with the chosen constant being 2.00 L sec^{-1} inflow for furrow experiments.

The derived infiltration equation was based on inflow and outflow measurements. Measured inflow and outflow data was plotted with cumulative depth to get the infiltration equation for the research field soil with the result given in Eq. 16

$$D = 0.9446\ T^{\ 0.4624} \quad (16)$$

According to the experimental area soil physical properties, the calculated irrigation water amount was 96 mm. After using Eq. 16, D was 9.6 cm and Tn was 151 min.

The results from the experiment and the USDA-SCS and Volume Balance Methods are plotted on the same graph in Fig. 3.

Experimental results were compared with the empirical methods the USDA-SCS and Volume Balance individually. Statistical analysis found that the relationships between the experiment result and USDA-SCS were y=0.4143x+1.6792 and R^2 is 0.998. The statistical result shows that relationships between field experiment and USDA-SCS are significant at the 1% probability level. As the result shows, the USDA-SCS method can be used to determine furrow length but there is a coefficient between methods (Fig. 4).

The Results of statistical comparison found that the relationships between the experimental result and Volume Balance Method were y = 0.7313x+12.307 and R^2 is 1.0. Results show that the Volume Balance method can be used to determine furrow length directly (Fig. 5).

According to the results, USDA-SCS and Volume Balance Equations can be used to determine furrow length on the Bafra Plain. Results of maximum furrow length are 71 m from the field experiment, 79 m from Volume Balance Equation and 172 m from USDA-SCS equation.

The field experiment and Volume Balance results are very close to each other, can be use to predict furrow length by using this empirical equation. Experiment results are different from USDA-SCS equation results, but there is a relationship between them. As it was mentioned earlier, there is a coefficient between both the values of USDA-SCS furrow length multiplied by the coefficient of 0.41, can be get close value. The result is 73 m, which is very close to the field experimental results of 71 m.

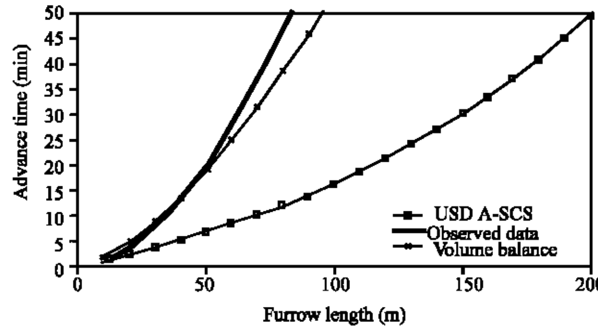

Fig. 3: Observed and predicted advance for furrow

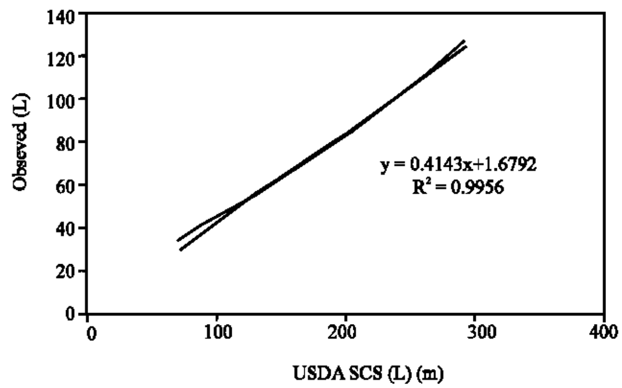

Fig. 4: Relationships between predicted USDA-SCS and observed furrow length

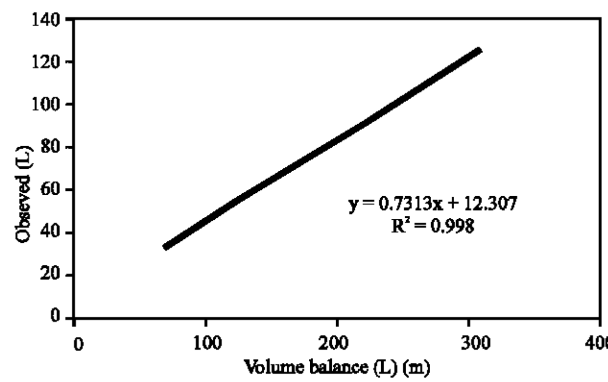

Fig. 5: Relationships between predicted volume balance and observed furrow length

CONCLUSIONS

The furrow irrigation data used in this study was collected from the field measurements. In general, the furrow length for furrows does not differ significantly for each method. However, a calculated USDA-SCS furrow length value slightly different than field measurements. The study has shown the Volume Balance method predicts significant furrow length. However USDA-SCS method can be used to predict but need a calibration with a constant value.

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