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On the Dynamics of Advance Wetting Front in Furrow Irrigation in Nigeria

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Abstract: Two models, Davis and Fok and Bishop were explored to determine their furrow advance prediction accuracy in comparison with actual field observation in Nigeria. An expression that relates the intake rate with accumulated intake time using Kostiakov-lewis equation for field observation was found to be $Y = 0.71t^{0.76}$ Correlation coefficients between actual field observation and Davis model ranged from 0.99 to 0.81 and from 0.85 to 0.98 for Fok and Bishop model which indicated that the latter is more applicable as the stream size increases. Their generally high coefficient values indicated their usefulness in prediction. The field data analyzed and fitted by least square method of curve fitting to yield equation of the type $X = a(t)^b$ for a given irrigation condition. The equations relating the advance length and time at discharge (Q) 1.2 litres/sec and 0.6% slope are $X = 4.8t^{0.3}$ (Davis), $X = 2.6\,t^{0.57}$ (Fok and Bishop) and $X = 2.5t^{0.55}$ (field observation) while at discharge (Q) 2 litres / sec and the same slope, $X = 6.2t^{0.45}$ (Davis), $X = 3.2t^{0.59}$ (Fok and Bishop) and $X = 3.0t^{0.56}$ (field observation). Fok and Bishop model thus affords a more accurate prediction of the advance wetting front, having the least deviation within the context of this study.

Key words: Furrow, irrigation, dynamics, wetting front, Nigeria

INTRODUCTION

Efficiency in the application of irrigation water is of great economic importance to countries with limited water supplies. The criterion that determines the uniformity of water distribution is entirely economic and the emphasis on efficient use of water in irrigated Agriculture has created the need for steady improvement in irrigation design and operations[1]. Irrigation can then be regarded as any process, other than natural precipitation, which supplies water to crops, orchards, grass or any cultivated plants[2]. The increasing need for crop production for the growing population is causing rapid expansion of irrigation schemes throughout the world. Recent developments in sprinkler and trickle irrigation have done much to reduce labour while improving soil moisture regime for crop production. However, the same cannot be said of surface irrigation[3]. It was reported that the distribution of irrigation land is dominated by five countries namely. India, China, Pakistan, Old soviet Union (USSR) and the United States of America (USA)[2]. Over 60% of the world's total irrigated land is in Asia and over 70% of the global aggregate is in developing countries[4]. Africa has not developed irrigation to the same extent as other countries particularly Asia. Only a little more than 0.3% of 2817 million hectares covered by FAO's 51 member nations is currently irrigated. This is by contrast, India, which has only about one-tenth of the surface area of Africa irrigated nearly five times as much land[5]. Irrigation in Nigeria dated back to 1930 in the North with the use of shaduff, a simple device for lifting water using the principle of lever to irrigated fadamas. It was only of late that farmers in the south started to grow high valued crops during dry season using irrigation techniques. The catastrophes left behind by the devastating drought of early 70's, gave birth to the eleven river basins development authorities (RBDAs) in the mid 70s to undertake the responsibilities of developing and managing irrigation schemes in Nigeria amongst other functions[5]. Attempts to describe flow in surface irrigation began this century though elementary, greater understanding of the process of water movement in surface irrigation and modern computational analysis have made prediction of wetting front possible[6]. Some of the methods used for the prediction include Davis and modified Hall's (as cited by Fennimore and

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Jack) approach in the use of commercial integration method for calculating differential advance length in borders. The expression developed by Davis takes into account the variable infiltration rate, water surface profile, roughness and channel shape and field depressions. In an effort to get improved expression for water advance, Shull as cited by Strelkoff[2] used more complicated infiltration and storage functions without defining water surface profile. Wilke and Smerdon as cited by Katapodes[4] summed up the series of Phillips and Farell as solution for Kostiakov and Lewis for advance problem. Although, the field evaluation of an irrigation system is a valuable tool, a mathematical expression of rate of advance also has some definite advantages. It does not only allow the designers to estimate rate of advance before the system is constructed, but also permits a study of the factor upon which rate of advance is dependent and would serve to point out current deficient data[1]. Almost all the approaches made so far do not take into account the ever changing shape of water surface profile except Davis and Fok and Bishop approaches. These approaches applied inflow – out flow method in estimating the advance wetting front in the irrigation systems.

The objectives of this study therefore are to ascertain the efficacy of the two infiltrations and advance parameters estimation models (Davis and Fok and Bishop) in predicting the advance wetting front in furrow irrigation in comparison with field evaluation on a sandy loam soil in Nigeria. It is also to come up with guidelines and makes recommendations for selection of stream sizes for furrow irrigation under the specified soil condition.

MATERIALS AND METHODS

Field evaluation: Field evaluation of the advance wetting front was conducted in a furrow 25 m long at Mokoloki irrigation project site Ogun state Nigeria which has been in use for over twenty five years. The site has an area of about fifty hectares of land. A total of nine furrows (flat bottom type) were used with 0.8 m spacing between the furrows. Six inflow streams of 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 litres per second were applied on beds having 0.4, 0.5 and 0.6% slope. The cumulative advance time was recorded with a stop watch. Readings/measurements were taken each time the water advance by one metre starting from the upstream end of the stream. Soil survey was carried out to determine the properties of the soil under investigation. Properties such as particle size analysis, field capacity, dry bulk density, infiltration rate and moisture content. These were carried out using conventional methods.

Evaluation using mathematical models: Two models were used for evaluating the advance wetting front in this study. They are Fok and Bishop as well as Davis approaches. Davis employed finite difference method in computation of the advance length for a certain time interval. Fok and Bishop predicted the approximate advance curve by performing a double integration with respect to time on the pre-determined infiltration function of Kostiakov-Lewis type. The ratio of the result and time, giving the average depth of water infiltrated into the soil for a given time.

Fok and Bishop approach

Assumptions on fok and bishop approach: For a non steady, non-uniform, open-channel flow, it is impossible to obtain a mathematically exact solution that involves all the related factors, However, it is possible to obtain an approximate solution for fluid flow problem using the following assumptions:

- The field is homogenous i.e. slope, width, composite roughness and intake rate do not change with location
- The inflow q is constant at the upper and where the flow enters the field and the flow is sub critical on the soil surface.
- The normal depth of the inflow, D_0 which is constant at the upper end of the field can be determined from the given inflow q, width of the borders, W, slope and Manning's roughness coefficient.
- The slope of the field is limited within the range of the mild slope with normal depth greater than critical depth.
- The water surface profile constitutes a family of curves with a common intercept at the normal depth at the end of the field and the shape of the profile follows parabolas of different degrees.
- The length covered by the advancing water sheet. L is an empirical function of the form $L = at^b$, where t = advance time and a and b represent the empirical constants.

The inflow-outflow method is based on the continuity principle expressed as:

$$qt = \Delta D \quad (1)$$

$$D = Ds + Da \quad (2)$$

$$A = WL \quad (3)$$

The empirical expression for intake rate is;

$$Y = Kt^n \quad (4)$$

Integrating,

$$Y = \int dt = \frac{Kt^{n+1}}{n+1} \quad (5)$$

let $K = \frac{K^1}{n+1}$ and $\alpha = n+1$

Let T_1 total time, t_s advance time

Height of water level at any distance to the normal depth D_o is

$$h = D_o(1 - \frac{t_s}{T_1}) \quad (6)$$

At any given time t_1, the water covered length L_1 and at any point between D and L_1, the intake time, $t - t_s$, therefore the accumulated intake is;

$$y = K(t_1 - t_s)^\alpha \quad (7)$$

$$\frac{d_a}{d_s} = y \quad (8)$$

$$d_a = yds \quad (9)$$

$$A = \int yds \quad (10)$$

$$B = \int hds \quad (11)$$

$$S = ats^b \quad (12)$$

Differentiating (10)

$$\frac{ds}{dts} = abts^{b-1} \quad (13)$$

$$ds = abts^{b-1}dts \quad (14)$$

the volume balance equation at T_1 is;

$$qT = A + B \quad (15)$$

$$qT_1 = \int_0^b yds + \int_0^b hds \quad (16)$$

$$= \int_O^B K(t - t_{s1})^\alpha ds + \int_o^b D_o(1 - t_s/T_1)ds \quad (17)$$

Further differentiation with respect to the total time T_1.

$$qT_1 = K\int_O^{T_1}(t_1 - t_s)^\alpha abts^{b-1}dts + D_o\int_O^{T_1}(1 - t_s/T_1)abts^{b-1}dts \quad (18)$$

Continuing the differentiation and incorporating $L = \alpha T^b{}_1$ where L is the distance at time T_1 and δz subsurface shape factor and δs surface shape factor.

$$qT_1 = KT_1\alpha L(1 - \frac{\alpha b}{b+1} + \frac{\alpha(\alpha-1)b}{2!(b+2)} + ...) + \frac{D_O}{1+b}L \quad (19)$$

$$qT_1 = KT_1\alpha\delta zL + D_o\delta sL \quad (20)$$

$$\text{But } \delta z = (1 - \frac{\alpha b}{b+1} + \frac{\alpha(\alpha-1)b}{2!(b+2)} + ...) \text{and} \delta s = \frac{1}{1+b}$$

Substituting in Eq. 18 and making L the subject,

$$L = \frac{qT_1}{KT_1\alpha\delta z + D_o\delta s} \quad (21)$$

Equation 20 above was developed for border irrigation systems neglecting the side wall effect of the channel. Applying correction factor, it can be modified for furrow irrigation system due to the cross sectional area of the furrow which can be expressed in terms of the normal depth, D_o and the wetted perimeter. It was shown by Rec (as cited by Renault[1]) that the relationship takes the form:

$$q = C^1D_oK \quad (22)$$

Where C^1 and K are constants that can be determined empirically.

For furrow irrigation, the equation applicable is:

$$L_i = \frac{qT_I}{\frac{uD_o^{mi}}{1+b} + w\delta zKT_I^\alpha} \quad (23)$$

Where uand m^i are the area coefficients for the cross sectional area in terms of normal depth, Do, W is either the wetted perimeter or width of flow of channel depending on the method of estimating. The intake rate which is the exponent m^i is equal to 2 except where the channel cross section is irregular.

Davis approach: The relationship between total filtration y = y (t) and Vsi are given by different curves with time t as a parameter. While the depth of water at each point could be computed, a simple and more general approach was to assume that the types of function represented by the water surface was the same at all instant of time. With this assumption, the ratio of actual volume of surface storage to the volume of the circumscribing parallel pipe is a constant B which should be greater than one-half but less than one. This value would not only depend on shape of water surface but shape of furrow.

This average volume correction, termed puddle factor and is denoted by the symbol P. The volume of water in storage above the soil surface (Vsi) at any time t_i is

$$Vsi = (Bx\ F\ (Do) + P)\ xi \qquad (24)$$

$$\Delta Vsi = \Delta\ (Bx + Do + P)\ xi2 \qquad (25)$$

The increment of volume of water applied Vsi to the soil in relation to the areas whose corner is $Y_3Y_4Y_5$ is given by

$$\Delta Vsi = Y_2\ \{(Y_1 - (Y_1 - 1) + (Y_1 - 1 - (Y_1 - 2)\}\ \Delta x1 + Y_2 \\ \{(Y_1 - 2 - (Y_1 - 3) + (Y_1 - 3 - (Y_1 - 4)\}\Delta X_2 ..... + FCY_1\Delta X_i \qquad (26)$$

Where F is a factor modifying the infiltration function to permit the use for all conditions of furrow shape, spacing and depth. C is a constant for subsurface storage factor.

$$\Delta Vai = FCY_1\Delta x_i + P_2\Delta x_i - 1 + P_3\Delta x_i - 2 + ... \qquad (27)$$

$$\text{Where}\ \ P_1 = \frac{1}{2}(Y_1 - (Y_1 - 2) \qquad (28)$$

P_1, P_2.... P_i are constants

By the law of conservation of matter, the quantity of water flowing into the furrow at any time of increment must be equal to the sum of the increments of storage produced. The mass balance for the furrow during any time increment is given as

$$q\Delta t = FCY_1 - FCY\Delta x_i + P_2\Delta x_i - 1 + \\ P_3\Delta x_i - 2 + ... + (BD_o^2 + P)\Delta x_i \qquad (29)$$

$$\Delta x_i = \frac{q\Delta t - (P\Delta x_i + P_i - 1 + \Delta x_2 + ...P_2\Delta x_i - 1)}{FCY_1 + BD_o^2 + P} \qquad (30)$$

Assumptions of davis:

- The shape of furrow is either parabolic or V-shape
- The volume of water in surface storage is expressed as a function of D_o^2
- The infiltration function must be modified by a factor F to permit the use of the equations for all conditions of furrow shape, spacing and depth of water.

The general equation is given as:

$$\Delta x_i = \frac{q\Delta t - \sum_{r=o}^{i=r} P_i - r\Delta x_i}{FCY_i + BD_o^2 + P} \qquad (31)$$

RESULTS AND DISCUSSION

The result of the particle size analysis of soil sample by using the hydrometer method and the physical properties of the soil is as presented below. Form the soil analysis using the textural triangle, the soil class is sandy loam .

The measured advance wetting front for various flow rates from 1.0 L/s to 2.0 L/s is as shown on Table 1. It was observed that as the stream size increases, the advance length also increases.

Result prediction using Fok and Bishop approach:

$$L_i = \frac{qT_I}{\frac{uD_o^{mi}}{1+b} + w\delta zKT_I^{\alpha}} \qquad (32)$$

All terms remain the same as defined under symbols and notations. b is given by the Eq as:

$b = e^{-0.6\alpha}\ 0.6338$ where $\alpha = 0.76$, K = 0.71

δs = 1/ 1 + 0.6338 = 0.6120

$$\delta z = (1 - \frac{\alpha b}{b+1} + \frac{\alpha(\alpha - 1)b}{2!(b+2)} + ...) \text{and} \delta s = \frac{1}{1+b}$$

Substituting using all the notations,

$\alpha = 0.76$, K = 0.71, u = 1.1, W = 1.8, $D_o = 0.068$, q = 1.645, Ti = 2, 4, 6, 8,.….

δz = 0.683, m = 2 and δs = 0.6120

Substituting in Eq. 32, we have,

$$L_1 = \frac{1.6 \text{ x } 2 \text{ x } 10^{-3} \text{ x } 60}{1.8 \text{ x } 0.71/100 \text{ x } 2^{0.8} \text{ x } 0.683 + 1.1 \text{ x } 0.6120 \text{ x } 0.068^2} = 12.60 \text{ m}$$

For L_2, we have,

$$\frac{1.6 \text{ x } 4 \text{ x } 10^{-3} \text{ x } 60}{1.8 \text{ x } 0.71/100 \text{ x } 4^{0.8} \text{ x } 0.683 + 1.1 \text{ x } 0.6120 \text{ x } 0.068^2} = 14.50 \text{ m}$$

Table 1: Results of the siol's physical properties

Physical Properties		Type and value
Soil texture	Sandy loam	(%sand = 62.65 %)
Field capacity	14.5%	(% clay = 17.3%)
Dry Bulk density	1.45 gm/cc	(% silt – 20.1 %)
Infiltration rate	27.00 cm/hr	

Table 2: Field evaluation of advance wetting front with different flow rates

Distance moved	Times in minutes with different flow rates					
Metres	1.0 L/s	1.2 L/s	1.4 L/s	1.6 L/s	1.8 L/s	2.0 L/s
1.0	0.2	0.1	0.08	0.06	0.05	0.02
2.0	0.5	0.3	0.12	0.1	0.08	0.08
3.0	0.6	0.4	0.30	0.25	0.12	0.1
4.0	0.8	0.7	0.5	0.40	0.35	0.25
5.0	1.8	1.5	1.2	0.8	0.50	0.30
6.0	2.8	2.2	1.4	1.0	0.70	0.80
7.0	3.2	2.8	1.6	1.2	0.90	1.0
8.0	4.0	3.4	1.8	1.6	1.2	1.6
9.0	4.4	3.8	2.1	1.8	1.3	1.8
10.0	5.6	4.2	2.3	2.0	1.4	2.0
11.0	6.0	5.4	2.5	3.0	1.5	2.5
12.0	7.4	6.0	3.0	3.2	2.0	2.8
13.0	8.0	6.4	3.5	4.2	2.6	3.0
14.0	12.2	6.8	4.0	4.8	2.8	3.6
15.0	13.8	7.2	5.0	5.2	3.0	5.8
16.0	18.0	9.8	6.4	6.2	3.2	6.2
17.0	22.0	11.4	7.6	7.0	4.4	6.5
18.0	25.0	12.8	8.6	9.0	6.0	7.0
19.0	30.0	14.0	10.2	11.2	7.0	7.4
20.0	35.0	16.0	12.4	12.0	7.8	7.6
21.0	42.0	20.0	15.6	14.6	8.2	8.0
22.0	50.0	27.0	18.1	17.0	12.8	10.0
23.0	60.0	35.0	25.0	19.6	16.8	12.0
24.0	80.0	42.0	30.0	20.5	17.4	14.0
25.0	90.0	50.0	35.0	25.5	22.5	16.0

Result prediction using davis approach: Parameters necessary to compute the advance wetting front using Davis approach such as the infiltration equation using Kostiakov-Lewis equation and normal depth were determined. The equation, given as $Y - Kt^{\alpha}$ and the values of K and α were estimated from the intake rate. The accumulated infiltration was plotted against time as shown in Fig. 1. The logarithmic expression of the above equation is log Y = log K + αlog t which when k and α values were substituted yield the following nine Eq.

$$0.342 = \log k + 0.699\alpha$$
$$0.602 = \log k + 1.00\alpha$$
$$0.748 = \log k + 1.176\alpha$$
$$0.854 = \log k + 1.301\alpha$$
$$0.929 = \log k + 1.378\alpha$$
$$1.017 = \log k = 1.544\alpha$$
$$1.077 = \log k + 1.602\alpha$$
$$1.138 = \log k + 1.699\alpha$$
$$1.193 = \log k + 1.778\alpha$$

Adding the first five and the last equations,

$$3.476 = 5 \log k + 5.574\alpha \quad (33)$$
$$4.426 = 4 \log k + 6.624\alpha \quad (34)$$

Solving simultaneously

$8.223 = 10.821\alpha$

$\alpha = 0.78$

Therefore

Substituting, α in Eq. 31

$3.476 = 5\log + 4.236$

$K = 0.71$

From the previous Eq. $Y = Kt^{\alpha}$

$$y = 0.71t^{0.78} \quad (35)$$

Evaluating the normal depth Do at the upstream and of the furrow using the convectional mathematical formulae for determining

Area = ZD^2_o, wetted perimeter = $D_o\sqrt{Z^2+1}$ and Hydraulic Radius A/P is $R = \frac{ZD_O^2}{2D_O\sqrt{Z^2+1}}$ Z is the slope ratio taken as 1:1

$2D_o\sqrt{Z^2+1}$

And $R = P^i D_o$ where $P^i = \frac{Z}{2\sqrt{Z^2+1}}$ = constant

From Manning's Eq.

$V = \frac{R^{2/3}S^{1/2}}{n}$ Where V = Velocity of flow

n = Manning's roughness coefficient

$$V = \frac{(P^1D_O)^{2/3}S^{1/2}}{n}$$

$$\text{Flow rate is } Q = AV = \frac{ZD_O^2(P^1D_0)^{\frac{2}{3}}S^{1/2}}{n} \quad (36)$$

$$\text{Therefore, } D_O = (\frac{qn}{S^{1/2}(P^1)^{2/3}Z})^{3/8} \quad (37)$$

Substituting all the values, q = 1.6 L/s, n = 0.03, Z = 1, S = 0.6%

$$D_0 = (\frac{1.6x10^{-3}x0.03}{0.006^{1/2}x0.5x1})^{3/8} = 0.068\text{m normal depth}$$

Determining the values of y in every 2 min interval from $y = 0.71t^{0.76}$ Eq. 35 at Δt = 2min

Y_1 = 0.71 x 20.76 = 1.2024
Y_2 = 0.7 x 40.76 = 2.0362
Y_3 = 0.71 x 60.76 = 2.7711
Y_4 = 0.71 x 80.76 = 3.4483

And from Eq. 27 where

$$P_1 = \frac{1}{2}(Y_1 - (Y_1 - 2)$$

P2 = ½ ($Y_2 - Y_0$) = ½ (2.0362) = 1.0181
P3 = ½ ($Y_3 - Y_1$) = ½ (2.77111 – 1.2024) = 0. 7844
P4 = ½ (1/2 – Y_2) = ½ (3.4483 – 2.0362) = 0.7061
F = 1.8

$$\Delta x_i = \frac{q\Delta t}{FCY + BD_O^2 + e_1} \quad (38)$$

Know (= 0.70 Yi = 1.2024, e = 0.005, q = 1.61L / s = 1.61x 10^{-3} m^3/s and substituting we, have

$$\Delta x_1 = \frac{1.6x10^{-3}x60x2}{1.8x0.70x1.2024 + 375x0.068^2 + 0.005} = 6.0\text{m}$$

$$\Delta x_2 = \frac{q\Delta t - P_2\Delta x_i}{FCY_1BD_o^2 + e}$$

$$= \frac{1.6 \times 10^{-3} \times 60 \times 2 - (1.0181 \times 6/100)}{1.8 \times 0.70 \times 1.2024 + 3.75 \times 0.068^2 \times 0.005}$$

= 40.23 m

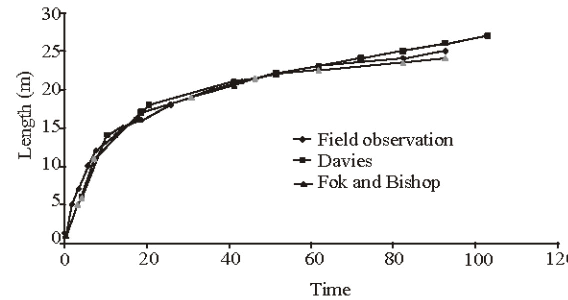

Fig. 1: Graphs of observed and computed rates of water in furrows of sandy loam soil at Q = 1.0l/s and slope 0.6%

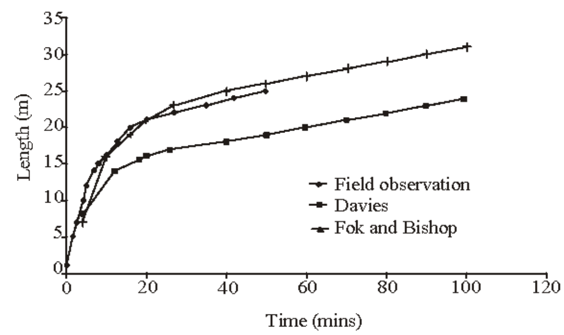

Fig. 2: Graphs of observed and computed of rates of advance ofloam soil at Q =1.2l/s and slope 0.6% water in furrows of sandy

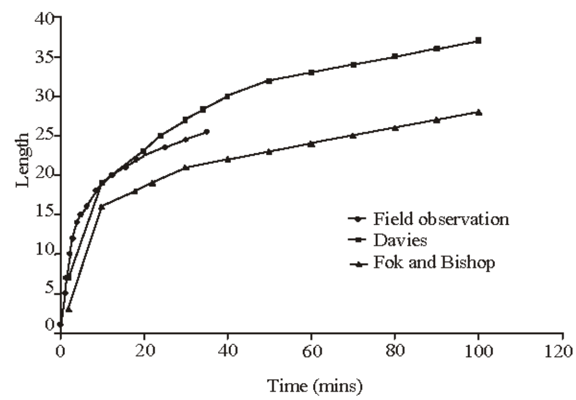

Fig. 3: Graphs of observed and computed rates of advance of water in furrows of sandy loam soil at Q=1.4l/s & slope 0.6%

$$\text{Similarly for } \Delta x_3 = \frac{q\Delta t - (P_3\Delta x_2 + P_2\Delta x_1}{FCY_1BD_o^2 + e}$$

= 0.192 - (0.0314 to 0.0407)

= 1.20 m

Comparison of the observed and computed rates of advance: The comparisons of computed and observed rates of advance for the field studies are as shown in

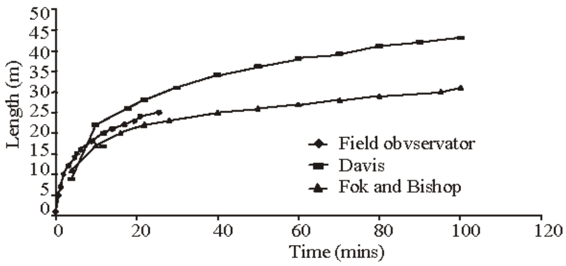

Fig. 4: Graphs of observed and computed rates of advance of water in furrows of sandy loam at Q = 1.6l/s and slope 0.6%

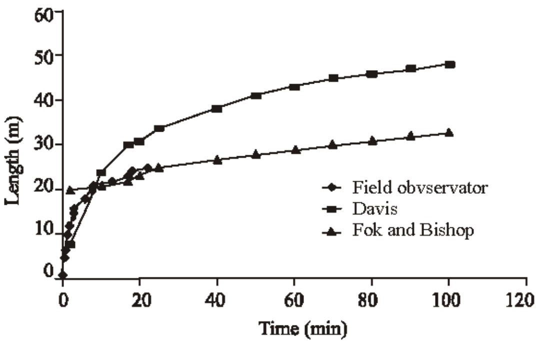

Fig. 5: Graphs of observed and computed rates of advance of water in furrows of sandy loam at Q = 1.8l/s and slope 0.6%

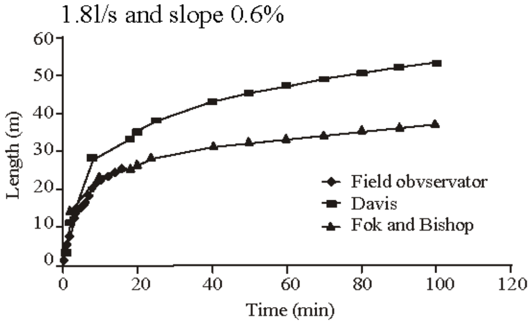

Fig. 6: Graphs of observed and computed rates of advance of water in furrows of sandy loam at Q =2.0L/S and slope 0.6%

Fig. 1-6 which show tremendous similarity in comparison. In all study, the models predicted the rate of advance water front fairly accurately. The models performed well with the computed data and were applied quite satisfactorily to fields of non-uniform slopes or slightly irregular slopes. Statistical analyses using correlation coefficients and regression analyses between the observed values from the field. Davis approach as well as Fok and Bishop approach are as shown on Table 3-5. There was very high correlation between the predicted values of Davis approach and the field evaluation, although this began to decrease as the flow rate increases in Table 4 however, the correlation of field evaluation to Fok and Bishop approach was lower but increased as the flow rate increases. This suggests that the Fok and Bishop approach will be better applied to project design Table 3. Also, the correlation between the two approaches (Davis and Fok and Bishop) was low at low discharge but increases as flow rate increases. This infers that there was a good basis for comparison between the two models. Plots of the advance length versus accumulated advance time were plotted which gave series of curves and were expressed by the equation,

Table 3: Regression equations and correlation coefficients of advance lengths from field evaluation and Fok and Bishop approach

Flow rate, litre/sec.	Regression equation	R	No of points
1.0	$X= 1.2t^{0.60}$	0.82	12
1.2	$X= 1.4t^{0.63}$	0.85	12
1.4	$X= 1.5t^{0.64}$	0.95	12
1.6	$X= 1.7t^{0.65}$	0.96	12
1.8	$X= 2.0t^{0.67}$	0.96	12
2.0	$X= 2.3t^{0.70}$	0.97	12

Table 4: Regression Equations and Correlation Coefficients of Advance Lengths from Field Evaluation and Davis Approach

Flow rate, litre/sec.	Regression equation	R	No of points
1.0	$X = 1.5t^{0.51}$	0.99	12
1.2	$X = 1.8t^{0.55}$	0.98	12
1.4	$X = 2.0t^{0.57}$	0.92	12
1.6	$X = 2.2t^{0.54}$	0.90	12
1.8	$X = 2.6t^{0.60}$	0.87	12
2.0	$X = 2.8t^{0.63}$	0.83	12

Table 5: Regression Equations and Correlation Coefficients of Advance Lengths from Davis and Fok and Bishop Approaches

Flow rate, litre/sec.	Regression equation	R	No of points
1.0	$X =1.3t^{0.55}$	0.73	20
1.2	$X =1.5t^{0.56}$	0.73	20
1.4	$X =1.8t^{0.50}$	0.74	20
2.0	$X =2.3t^{0.57}$	0.75	20

X = Advance length (m,) t = Advance time (min)

$$X = at^{b}$$

Further expressed logarithmically as,

$$\text{Log } X = \log a + b \log t$$

This gives a straight line in which the slope gives the values of b and the intercepts give the values of log a. from these values, the equation relating advance length and time at Q = 1.2 litres/sec and slope 0.6% are given as follows,

Davis, $X = 4.8t^{0.3}$

Fok and Bishop, $X = 2.6t^{0.57}$

Field data, $X = 2.5t^{0.55}$

Going by the above analyses, the two models have proved useful but Fok and Bishop affords a more accurate prediction of the advance wetting front, having the least deviation within the context of this study.

CONCLUSION

Mathematical models are useful tools in predicting the responses of irrigation systems to design and operation parameters. The merits of prediction equations will be judged by their applicability to systems design and Analysis. Fok and Bishop as well as Davis appear to have several advantages over some other equations in that infiltration rates and hydraulic parameters that change with time have been considered. In the study of indication of erosion hazards, these equations will provide a sound basis for evaluation of potential irrigation efficiency. Fok and Bishop expresses the advance length as a function of inflow discharge, irrigation time, normal depth of flow at the upper end of the field, width of the channel and the intake rate constant. The correlation between field data and data from the model gave high values especially as the stream size increases. It ranged from 0.85 to 0.98 and therefore gave good result as evident in comparison with filed data Fig. 1 to 6. Davis model relates advance length as a function of inflow discharge irrigations time, normal depth of flow at the upper end of the field surface, shape factor, channel width and intake constant. The correlation coefficients between field data and the model ranged from 0.99 to 0.81. The correlation coefficients are high especially at higher discharge rates and at low stream sizes. An important observation from the computed advance length using Davis and Fok and Bishop Equations show that irrigation cycle can be completed faster with larger stream sizes. A stream size of 1 litre/sec will advance to a length of 28 metres in one hour, 55.5 metres with 2 litres/sec, 166 metres with 6litres/ sec and 222 metres with 8 litres/sec for the same period under the same soil condition. However, the major factor limiting the use of very large stream size is that smaller stream size will limit the amount of soil erosion (soil loss). One of the most important applications of these prediction equations is in preliminary project planning and distribution sstem design stages. The rate of discharges needed to irrigate furrow systems efficiently and economically should be designed into any irrigation project to avoid serious discrepancies between the quality needed for effective irrigation and the quantity delivered.

The recommendations are as follows:

- A wider range of stream sizes should be tried out on different soil conditions to know the stream size that will be most appropriate for the specified soil condition with minimal soil loss.
- Greater furrow lengths should be used for further studies to determine the appropriate length of furrow that a chosen stream size can successfully irrigate.
- Other forms of intake functions like $Li = ato^m$ $y = B + Ee^{-rt}$ should be explored in further studies of Fok and Bishop Equation.

SYMBOLS AND NOTATIONS

The following symbols have been adopted for use in the study

A	=	Area covered by irrigation water
A_i	=	Area of the water distribution profile in the soil at time t_i
a	=	Empirical constant of the advance time function
	=	Constant for the ratio of actual storage to the volume of circumscribing parallel pipe
B_i	=	Area of the water distribution profile on the surface storage at time t_i
	=	Constant of the actual infiltration to the volume of circumscribing parallel pipe
	=	Empirical; constant of the inflow discharge as a function of the inflow normal depth
	=	K/nt_i = empirical constant of the accumulated intake equation, co-empirical constant of the intake equation
D	=	Average depth of water absorbed by Area A
Da	=	Average depth of water absorbed by the soil at a given time.
Do	=	Normal depth of the inflow
Ds	=	Average depth of water on soil surface at a given time
da	=	Differential length covered by water during irrigation
dt	=	Differential time of the application time
E	=	Empirical constant of the intake equation
e	=	2.71 of the base of natural logarithms
W	=	Width of the flow channel in a border furrow
L	=	Length of border or furrow

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