DETERMINATION OF DESIGN INFLOW RATE IN FURROW IRRIGATION USING SIMULATED ADVANCE AND RECESSION CURVES

N.A.A.Okereke, J.O. Duru,
B.A. Nwachukwu and C.N. Madubuike,
School of Engineering and Engineering Technology, Federal University of Technology, Owerri, Nigeria.

ABSTRACT
Advance and recession curves were simulated for three stages of maize growth in furrow irrigation. The selected stages were: the emergence stage, two weeks after planting; the development stage, about two months after planting; and the maturing stage, about one month to harvest time. The advance and recession times were predicted for successive points along the furrow lines for various inflow rates at the development stage of the crop growth using three models. The simulated advance and recession data were used to compute the intake opportunity time distribution along the furrow line. The infiltrated depth distribution and hence the water application efficiency and distribution uniformity were computed for the inflow rate, which gave 87% *and* 89% *for the maize emergence stage:* 75% *and* 60% *for the maize development stage and 95% and* 89% *for the maize maturing stage. The design inflow rate for each furrow was taken as the minimum inflow rate which gave rise to a minimum water application efficiency of 60% and a minimum distribution uniformity of 75%. It is recommended that the procedure described in this work is useful for the modification of existing furrow irrigation systems and the establishment of new ones. Also, the design procedure presented can be used for any field that is suitable for furrow irrigation system by making use of the relevant parameter estimates that can be obtained from the field.*

INTRODUCTION
In the development of a furrow irrigation system, certain factors are considered. These factors could be political, social, economic or technical. The aspirations, however, are realized or lost at the farm level because, whether or not the goal is achieved at the end will ultimately translate into crop water requirements during each growing season. Therefore the farm level should be the logical focus of irrigation planning and design; Doorenbos, et al. (1980).

For an adequate inflow rate, the intake opportunity times at measurement points along the furrow length will be approximately the same, thus indicating that the advance and recession curves must be approximately parallel (Mudiare, 1987 and Okereke, 1999) Fok and Bishop (1965) advance model was used to simulate advance data and compared with field data while for the vertical and horizontal recessions, Shockley, et al (1964) and Sherman and Singh (1978) models were used respectively.

Hydraulics of Furrow Irrigation
The flow rate down the furrow equals the application rate (Elliott and Walker 1982), which is given as:

$$Q = \frac{(r)^{8/3} S^2}{n} \qquad (1)$$

$$and\ q = Q/r \qquad (2)$$

$$=\frac{(r)^{8/3}S^2}{n} \quad (3)$$

where
Q = application rate
q = inflow per unit width of furrow
r = flow depth of furrow
s = bed slope of furrow
n = Manning's roughness coefficient

Infiltration in furrows

The infiltration function r (t') is defined as the rate at which water enters into the soil per unit area which is taken as a power function of time. The total quantity of water that is absorbed by the soil after time t' from the beginning of ponding, is:

$$D(t') = \int^{t'} o^{r}(t')dt' \quad (4)$$

And

$$r(t') = kt'^{n'} \quad (5)$$

r = infiltrated depth of water
t' = elapsed opportunity time
k,n = empirical constants

Advance Rate in furrows:

The advance rate of the water front down the furrow is found to be a power function of time of advance (Sirjani and Wallender, 1989).

$$X = at_{\times}^{b} \text{ .... } (6)$$

Where
X = advance distance
t_x, = time to advance a distance X
a and b = empirical constants

Recession rate in furrows:

The Shockley, et al (1964) equation also known as SWP model is given by Ram and Singh (1982) as:

$$t_v = t_o - t_a \quad (7)$$

$$= r^2/2sq \quad (8)$$

for the vertical recession

Where
t_v = time of vertical recession
t_o = time at completion of vertical recession
t_a = time of application cut off
r = average flow depth
s = furrow slope
q = inflow rate per unit width

while Sherman and Singh (1978) derived an expression for the time of horizontal recession for a free-draining furrow as:

$$t_r = \frac{1}{60}\left(\frac{\times}{\alpha f^{\beta-1}}\right)^{1/\beta} \quad (9)$$

where
β = 5/3 for manning's expression
X = distance from the upstream end

$$\alpha = S^{1/2}/n \quad (10)$$

$$f = \frac{1}{120}\left(\frac{D_o}{t_o} + \frac{D_N}{t_N}\right) \quad (11)$$

Water application efficiency and distribution uniformity:

Irrigation system efficiency can be evaluated by two types of efficiency parameters which includes: water application efficiency and water distribution uniformity or efficiency.

Merriam (1980) and Adamu (1990) defined water application efficiency as the ratio of the average low quarter depth of irrigation water infiltrated and stored in the root zone to the total depth of water delivered to the field thus:

$$E_a = \frac{D_Z}{D_g} * 100 \quad (12)$$

where
E_a, = water application efficiency (%)

D_z, = average low-quarter depth infiltrated and stored
D_g, = gross irrigation depth.

Hart, et al (1979) specified that the water application efficiency, E_a, must not be less than 60% for satisfactory furrow irrigation performance.

Water distribution uniformity is defined as the ratio of the average, low- quarter depth of irrigation water infiltrated and stored to the average depth infiltrated, expressed in percent, thus (Merriam, 1980 and Adamu, 1990):

$$U_d = \frac{D_z}{D_{av}} * 100 \qquad (13)$$

Where

U_d, = water distribution uniformity (%)

D_{av} = average infiltrated depth

Water distribution uniformity, U_d must not be less than 70% for satisfactory furrow irrigation performance (Hart, et al 1979).

MATERIALS AND METHODS

The field work was carried out at the Lake Geriyo Irrigation Project located in Yola, Adamawa State of Nigeria, on the Upper Benue River Basin Development Authority Irrigation Project. The periods of the experiments were from January to June, 1996 and the early part of 1997. The experimental plot was planted to a maize crop of variety PAN 6195 of 120 days duration.

Lake Geriyo Irrigation Project (Lat 9.30^{0}N, Long 12.25°E), is located in the North-East of Yola town. The area records a mean annual rainfall of 910mm, the average maximum temperature is 35°C while the average minimum temperature is 23°C. The vegetation of the area is savannah type (Sudan savannah).

The experimental field measured about 6m by 110m producing six ridges and five furrows. The field was graded to a furrow slope of 0.10%. A drainage channel was provided at a distance of 100m from the upper end of each furrow, thus giving a total advance distance of 100m. The experimental field was found to have a soil type of predominantly sandy loam soil.

The field experiments were necessary in order to generate relevant data to verify the advance and recession models.

Determination of design inflow rate

The procedure adopted is to assume a value for the inflow rate, q, in the range 0.01≤q ≤ 0.36 m^3/min/m and simulate the advance and recession times for successive points along the furrow length (Michael, 1978). The intake opportunity times and infiltrated depths along the furrow length are then obtained using the advance and recession data. The water application efficiency and distribution uniformity are calculated and compared with recommended values for efficient furrow irrigation available in the literature. The procedure is repeated until the calculated water application efficiency and distribution uniformity indicate an efficient furrow irrigation system.

RESULTS AND DISCUSSION.

Results:

The summary of the design parameters are presented below:

Average slope of furrow strip, s = 0.001

Average infiltration depth, D = 0.5 $t'^{0.78}$

Manning's roughness coefficient, n = 0.025

Length of furrow strip, X = 100m

Water application depth = 20mm

Infiltration opportunity time, t' =$(20/0.5)^{1/0.78}$ = 113min

Water application efficiency, E_a. = 60% (assumed)

Corresponding design inflow rate, q

q = (0.020* 100)/(0.60* 113) = 0.03m^3/min/m

The calculated corresponding inflow rate of q = 0,03m^3/min/m based on maize crop water requirement, evaluated average infiltration depth and soil moisture capacity were tested for water application efficiency and water distribution uniformity.

Determination of water application efficiency and distribution uniformity

The maize development stage (stage II) is normally the stage at which water stress can most significantly affect the crop yield. Thus, the furrow irrigation system design is based on the parameters obtained for this stage. The evaluated water application efficiency and water distribution uniformity for $q=0.03m^3/min/m$ of the three growth stages of maize are presented in Tables 1, 2 and 3.

Table 1: Evaluation of Water Application Efficiency and Distribution Uniformity for $q=0.03m^3/min/m$ for stage I.

S/No	Dist. X (m)	t_x (min)	t_i (min)	t' (min)	T (min)
1	0	0	28.0	28.0	-
2	10	4.0	35.0	31.0	29.5
3	20	8.0	38.9	30.9	31.0
4	30	12.0	45.2	33.2	32.1
5	40	16.0	47.8	31.8	32.5
6	50	20.0	50.2	30.2	31.0
7	60	24.0	52.4	28.4	29.3
8	70	28.0	54.5	26.5	27.5
9	80	32.0	56.5	24.5	25.5
10	90	36.0	58.3	22.3	23.4
11	100	40.0	60.1	20.1	21.2

$t_x = (X/0.03)(0.005 + 0.00054t^{0.8})$

$t_x = 40$; $t_i = t_o + 1.83x^{0.6}$

$t' = t_i - t_x$

$t_N = 807$

$R_x = 0.052$; $t'_{av} = 30.12min$

$D_{av} = 9.2$; $D_g = 9mm$

$t'_{min} = 30min$; $D_{min} = 8mm$

$U_d = (D_{min}/D_{av}) * 100 = 87\%$ (satisfactory)

$E_a = (D_{min}/D_g) * 100 = 89\%$ (satisfactory)

Table 2: Evaluation of Water Application Efficiency and Distribution Uniformity for $q = 0.03m^3/min/m$ for stage II.

S/No	Dist. X (m)	t_x (min)	t_i (min)	t' (min)	T (min)
1	0	0	18.9	18.9	-
2	10	2.3	35.1	32.8	25.9
3	20	4.7	43.4	38.7	35.8
4	30	7.0	50.1	43.1	40.9
5	40	9.3	56.0	46.7	44.9
6	50	11.7	61.4	49.7	48.2
7	60	14.0	66.3	52.3	51.0
8	70	16.0	70.8	54.8	53.6
9	80	18.7	75.2	56.5	55.7
10	90	21.0	79.3	58.3	57.4
11	100	23.3	83.2	59.9	59.1

$t_x = (X/0.03)(0.005+0.0002t^{0.7})^8$

$t_x = 23.3$; $t_a = 17.5$; $t_o = 18.9$

$t_i = 18.9 + 4.06\,x^{0.6}$

$t_N = 796$

$R_x = 23.3/(796-23.3) = 0.030$

$t'_{av} = 47.2$

$D_{av} = 0.2\,(47.2)^{0.78} = 4mm$

$D_g = (0.03 * 17.5/100) * 1000 = 5mm$

$t'_{min} = (26+36)/2 = 31mm$

$D_{min} = 0.2\,(31)^{0.78} = 3mm$

$U_d = (3/4) * 100 = 75\%$ (satisfactory)

$E_a = (3/5) * 100 = 60\%$ (satisfactory)

Table 3: Evaluation of Water Application and Distribution Uniformity for q = 0.03m³/min/m for stage III.

S/No	Dist. X (m)	T_X(min)	t_i (min)	t' (min)	T (min)
1	0	0	31.7	31.7	-
2	10	4.0	41.8	37.8	34.8
3	20	8.0	47.0	39.0	38.4
4	30	12.0	51.2	39.2	39.1
5	40	16.0	54.8	38.8	39.0
6	50	20.0	58.2	38.2	38.5
7	60	24.0	61.2	37.2	37.7
8	70	28.0	64.1	36.1	36.7
9	80	32.0	66.8	34.8	35.5
10	90	36.0	69.3	33.3	34.1
11	100	40.0	71.8	31.8	32.6

t_r = $(X/0.03)(0.006+0.0007^{to.o})$
t_x = 40; = t_a = 30min
t_i = $31.7+2.53X^{0.6}$
t_N = 619.5; t'_{av} = 36.84
D_{av} = $0.7(36.84)^{0.\theta}$ = 8.43mm
D_g = (0.03*30/100)*1000 = 9mm
t'_{min} = 36.6
D_{min} = $0.7(36.6)^{0\theta}$ =8mm
U_d = (8/8.43)*100 = 95% (satisfactory)
E_a = (8/9)*100 = 89% (satisfactory)

The result of the simulated advance and recession curves, the water application efficiency and water distribution uniformity are given in Tables 1, 2 and 3 respectively for the three stages of growth of maize, namely emergence (stage 1), development (stage 11) and maturing (stage 111) while the curves are shown in Figures 1, 2, and 3 for the design inflow rate of 0.03m³/min/m. The application rate, q = 0.03m³/min/m is found to be adequate for the furrow irrigation system based on the computed water application efficiency and distribution uniformity

DISCUSSION

Rate of Advance in Furrows

Fok and Bishop (1965) equation which is a form of the volume balance equation, was modified further and simplified on the assumption that both advance and infiltration functions can be represented by power functions of time. On verification (see Tables 1,2 and 3) the equation is found to be suitable for the maize emergence, development and maturing stages with mean error not exceeding-15. 1 %.

Rate of Recession in Furrows

It is an experimental fact that when the water application at the upstream end of the furrow is cut off, water recedes first vertically and then horizontally due to the combined effects of infiltration and surface runoff. On verification (see Tables 1,2, and .3), the Shockley, Woodward and Phelan (SWP) 1964 vertical recession model was found to be better in terms of error margin between observed and calculated vertical recession times when compared to the time of irrigation, the error margin not exceeding -4%.

The Sherman and Singh (1978) and Ram and Singh (1982) in the horizontal recession model assumed constant average infiltration rate and used kinematics wave theory to derive explicit expressions for the time of horizontal recession for a free draining furrow. The error margin was within allowable limit and thus found suitable for the field test.

Evaluation of Inflow Rate:

Various inflow rates were evaluated at different stages of maize growth. They yielded satisfactory advance ratio and satisfactory distribution efficiency/ uniformity but very low application efficiency. But an evaluated inflow rate of 0.03m^3/min/m yielded satisfactory advance ratio; satisfactory water distribution efficiencies/ uniformities and water application efficiencies of 87% and 89% for the maize emergence stage; 75% and 60% for the maize development stage; and 95% and 89% for the maize maturing stage respectively.

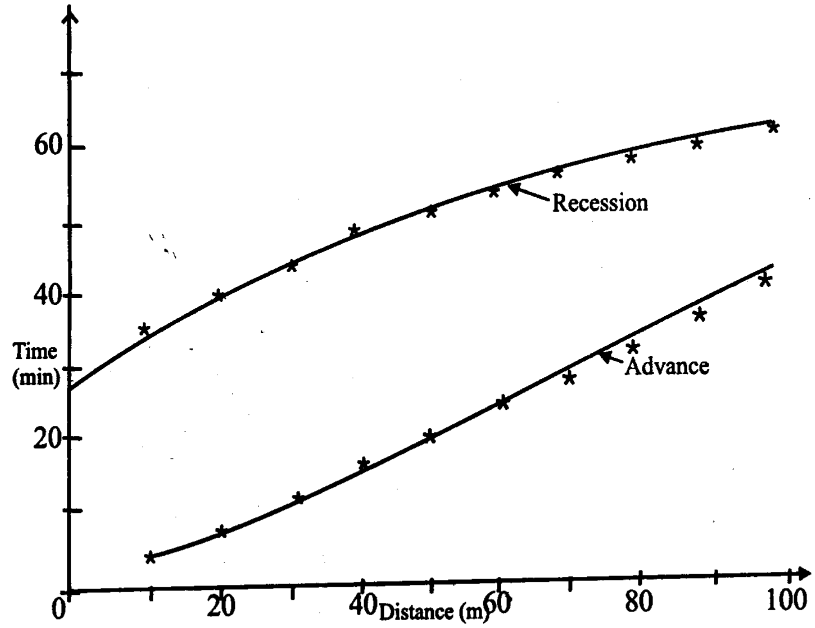

Fig. 1 Simulated Advance and Recession Curves for q_o = 0.03m^3/min/m of maize stage I

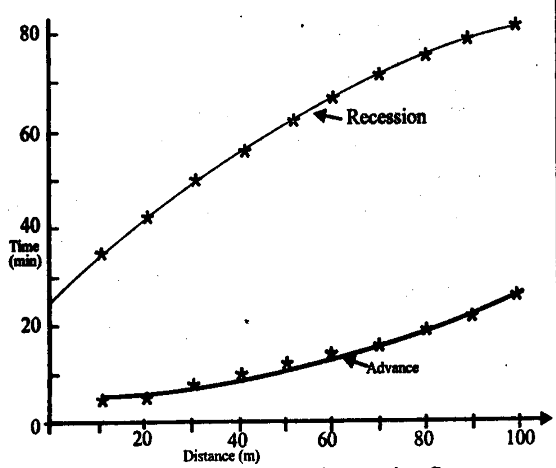

Fig. 2 Simulated Advance and Recession Curves for q_o = 0.03m^3/min/m of maize stage II

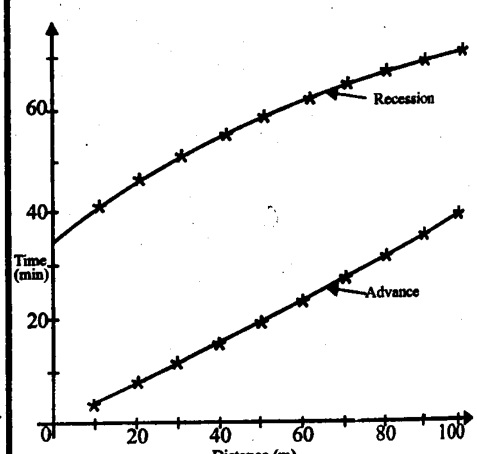

Fig. 3 Simulated Advance and Recession Curves for q_o = 0.03m^3/min/m of maize stage III

CONCLUSION

In conclusion, the following points are made:

a. The optimum application rate, q, of *0.03m^3/min/m* for the three phenological stages of growth of maize was obtained and it gave satisfactory water distribution uniformities and application efficiencies of 87% and 89% for the emergence stage; 75% and 60% for the development stage; and 95% and 89% for the maturing stage respectively.

b. The procedure in this work is useful both for the modification of existing furrow irrigation systems and the establishment of new ones.

REFERENCES

Adamu, J.Y. (1990). Prediction of Advance and Recession Curves and Design of Border Irrigation System. M.Sc. thesis A.B.U. Zaria Nigeria.

Doorenbos, J; A.H. Kassam and G. Uittenbogaarch, (1980). Yield Response to Water. Irrigation and Agricultural Development. *U.N.. Pub. Johl,* s.s. (ed) Pergamon Press, N.Y. USA.

Elliott, R.L and W.R. walker (1982). Field Evaluation of Furrow infiltration advance functions. *Trans. Of the ASAE* 25 (2): 396-400

Fok, Y.S. and A.A. Bishop (1965). Analysis of Water Advance During Surface Irrigation. *Journal of Irrigation and Drainage Engineering Div. ASCE.* 91 (IRI):99-116

Hart, W.E; P. Gideon and G V. Skogerboe (1979). Irrigation Performance: An Evaluation. *Journal of the Irrigation and Drainage Div. ASCE.* 105 (IR3): 275 286.

Merriam, J.L. (1980). Evaluating Irrigation Systems and practices, Design and Operation of Farm Irrigation Systems. Jensen, M.E. (ed), *ASAE Publ.* St Joseph Michigan, USA. pp 720-760

Michael, A. M. (1978). *Irrigation Theory and Practice.* Vikas Publishing house, New Delhi, India.

Mudiare, O, J. (1987). Estimation of Design inflow into irrigation Borders using Advance and Recession curves. *Nigerian Journal of Engineering* 4 (2): 1- 9

Okereke, N.A.A. (1999). *Evaluation of Suitable Advance and Recession Models for Design of furrow irrigation system* Ph.D thesis F.U.T. Owerri, Nigeria.

Ram, R. S. and V. P. Singh (1982). Evaluation of Models of Border Irrigation Recession. *Journal of Agric. Eng. Research.* 27 (3): 235-252.

Sherman, B. and V. P. Singh (1978). A Kinematic Model of Surface Irrigation. *Water Resources Res.* 14 (2): 357- 364.

Shockley, D.C; H. C. Woodard and J. J. Phelan (1964). Quasi - Rational Method of Border Irrigation Design. *Trans. of the ASAE.* 7(4) :420-423.

Sirjani, F. and W. W. Wallender. (1989). Stochastic Infiltration from Advance in Furrows. *Trans. of the ASAE.32(2):* 649-654.