

ASSESSMENT OF OPERATIONAL PERFORMANCE OF A FURROW IRRIGATION SYSTEM AT BACITA SUGAR COMPANY

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Abstract

This paper investigates the operational performance of a furrow irrigation system at the sugarcane plantation of the Nigerian Sugar Company Bacita, Kwara State. The volume balance method was adopted to determine infiltration of water into the furrows. The study indicated that the soil intake characteristic equation could be expressed as $I = 149.63 T^{0.545}$. The irrigation time and effective furrow length were estimated to be 12 hr and 170 m respectively. The application and potential efficiencies were determined to be 71% and 78% respectively. The two efficiencies indicate fairly good management of the furrow irrigation system. However, the relationship between the furrow length and the time taken by the irrigation water to advance along a furrow is best fitted by a polynomial function and represented by $L = -0.0029T^2 + 1.4289T + 4.9428$. Also, the relationship between the accumulated depth and the elapsed time is best fitted by a polynomial function ($D = -0.0009T^2 + 0.4695T + 37.88$). This shows that there is no linear relationship between furrow length and time, and accumulated depth and elapsed time.

1. Introduction

Furrow irrigation is a method of applying water to crops by means of small sloping channel (Benami and Ofen, 1993) and the method is used for row crops such as sugar cane. The crops are grown along raised beds and the channels (furrows) run along both sides of the beds. Furrows normally have small longitudinal slopes (0.5 – 3 %) and are open at the lower end for excess water to drain out. In furrow irrigation, water is applied at the high end of the channel and conveyed by gravity into small channels to the vicinity of crops (Mazumder, 1983). Water is applied in the furrow until the desired application rate and lateral penetration are obtained. While the water is advancing, it infiltrates down the soil profile and laterally to provide the desired wetting of the soil. The amount of infiltrated water at a point along the furrow depends on the time that water is in contact with the soil at that point. This time is known as the infiltration (intake) opportunity time.

Efficient water application in furrow irrigation depends on the knowledge of the hydraulic characteristics of flow in the soil. The flow phenomenon in furrow irrigation is that of unsteady open channel flow with decreasing discharge (Michael, 1978). The shape and spacing of furrows have a considerable effect on the irrigation time, and hence effects on efficiencies. The ability to change furrow shape, spacing, length, flow rate and the Management Allowed Deficiency (MAD) provide more management controllable functions than are available for other methods. Infiltration of water into the furrows is the most important variable affecting the characteristics of flow in furrows and may be determined by the gravimetric method, by specially designed furrow infiltrometers, or by the volume (inflow – outflow) method. Good results have been obtained using these methods, but their practical applications depend upon the accuracy desired, and upon the time and money available (Jensen, 1980). The volume method was used in this investigation because it gives the average infiltration value by compensating for various errors inherent in the furrow arising out of soil heterogeneity, furrow cross-sectional difference, cracks and puddling effect (Jensen, 1980).

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The purpose of investigating the operational performance of irrigation system includes (i) the determination of the potential efficiency of the system as designed and the actual efficiency that is obtained with present management, (ii) determination of how effectively the system can be operated and (iii) to obtain information that will assist engineers in designing other systems (Meriam and Keller, 1978). The parameters investigated in this study include; water advanced rates, furrow infiltration rate, infiltration capacity, effective irrigation time, optimum furrow length and field efficiencies.

2. Materials and methods

The investigation was conducted at the Nigerian Sugar Company, Bacita. The company is located in a small town of Bacita (9°N and 5°E) in Kwara State. The company has a sugarcane plantation that uses furrow irrigation to supply water to the crop. The spacing and the length of the existing furrows were 75 cm and 350 m respectively. The soil of the area is sandy-clay loam with land slope ranging between 0.2 to 0.5%.

The furrow under investigation was divided into 18 sections (20 m apart) and a V-notch weir was installed at the entrance to measure the flow rate. As water reached each marked section, the width and depth of flow and the time taken to advance through the section were determined. The procedure was repeated for the rest of the sections. The accumulated infiltration depths were also estimated.

The rate at which water infiltrated along the furrows was measured by installing two v-notch weirs at a distance of 30 m apart. The 30 m spacing served as the testing portion of the furrows. The V-notch at the inlet of each furrow was used to measure the quantity of water (Q_A) flowing into the testing portion of the furrow, while the second V-notch measured the quantity of water (Q_B) flowing out of the portion. The loss of water by infiltration is the difference between the water inflow and outflow through the v-notches ($Q_A - Q_B$) and substituted in equation (1) to obtain the infiltration rates (Jensen, 1980). Hence the intake rates determined from furrow tests were based on a series of inflow minus outflow rates over a specific length of furrow at different times.

$$I = \frac{3600(Q_A - Q_B)}{WL} \quad (1)$$

Where, I = infiltration rate, mmhr^{-1}

W = furrow spacing, m

L = length of the testing portion of a furrow, m

The infiltration data were fitted into the Kostiakov equation (Equation 2) and the parameters n and k of the soil were determined.

$$I = kT^n \quad (2)$$

Where, I = intake rate, mmhr^{-1}

k and n = dimensionless infiltration coefficients of the soil.

T = time, hr.

Equation 2 was integrated to obtain the intake depth (D) as given in Equation 3.

$$D = \frac{K}{n+1} T^{n+1} + CT \quad (3)$$

Where, k = initial intake characteristic of the soil and

C = constant (may be approximated to unsaturated hydraulic conductivity).

3. Results and discussion

The water advance data, accumulated infiltration depth and infiltration rates are presented in Tables 1, 2, and 3 respectively. From the analysis of the data obtained from Table 1, the relationship between the furrow length and the time taken by the irrigation water to advance along furrow is a polynomial function (Figure 1). The optimum furrow length was obtained to be 170m by adopting the quarter time rule in Figure 1. Quarter time refers to 25% of the total irrigation time and states that the irrigation water must advance to the end of the irrigating furrow at most by quarter of the total irrigation time for effective water utilization. (Jensen, 1980). The effective irrigation time estimated with Equation (3) was approximately 12hrs, hence the irrigation water must reach the end of irrigating furrow within 3 hrs for effectiveness. The application efficiency (the ratio of accumulated infiltration depth to the average depth of water applied) was obtained to be 71% while the potential efficiency (the ratio of the design depth of water to be applied to the evaluated depth of water applied) was computed to be 78%. The antecedent soil moisture content by weight was estimated to be 19.5%, while the bulk density was 1.42 during the period of field experimentation.

Table 1: Mean furrow water advanced data

Advanced Distance (m)	Time Elapse (Min.)	Width of Flowing Water b (cm)	Depth of Flowing Water y (cm)	Wetted Perimeter P (cm)
0	0			
20	12	71.5	2.8	77.8
40	22	72.5	2.8	78.8
60	38	72.5	2.9	79.0
80	60	73.0	2.9	79.5
100	80	73.5	2.9	80.0
120	100	73.0	3.0	79.7
140	130	73.5	3.2	80.7
160	165	74.0	3.0	80.7
180	203	74.0	3.2	81.2

Table 2: Estimation of mean accumulated infiltration depth

Furrow Wetted Area (10^3 cm^2)	Accumulated Storage (10^3 cm^3)	Accumulated Inflow (10^3 cm^3)	Accumulated Infiltration Volume (10^3 cm^3)	Accumulated Infiltration Depth (cm)
(1)	(2)	(3)	(3-2)	(3-2) / (1)
155.60	400.40	1080.00	679.60	4.37
315.20	812.00	1980.00	1168.00	3.71
474.00	1261.80	3420.00	2158.20	4.56
636.00	1693.60	5400.00	3706.40	5.83
800.00	2132.00	7200.00	5068.00	6.34
956.40	2628.00	9000.00	6372.00	6.66
1129.80	3292.80	11700.00	8407.20	7.44
1291.20	3552.00	14850.00	11298.00	8.75
1461.60	4262.40	18270.0	14007.60	9.59

Table 3: Estimation of mean furrow infiltration rate

(1) Elapse Time (Min.)	(2) Station A Flow (l/s) Q_A	(3) Station B Flow (l/s) Q_B	(2)-(3) Losses (l/s) ($Q_A - Q_B$)	Infiltration Rate I (mm/hr) Equation (1)
2	1.49	1.02	0.47	75.20
5	1.66	1.38	0.28	44.80
7	1.54	1.30	0.24	38.40
10	1.32	0.81	0.51	81.60
12	1.22	0.73	0.48	76.80
16	1.07	0.70	0.37	59.20
20	0.77	0.59	0.18	28.80
25	0.63	0.51	0.12	19.20
30	0.77	0.59	0.18	28.80
35	0.66	0.56	0.10	16.00
40	0.56	0.49	0.07	11.20

The infiltration characteristic equation of the soil, ($I = 149.63T^{-0.5453}$) as shown in Figure 2 revealed the intake characteristic constants k and n to be 149.63 & -0.5453 respectively. Also from Figure 2, the infiltration capacity (I_c) of soil was obtained to be 20 mmhr^{-1} . The curve of accumulated depth versus elapsed time is presented in Figure 3. The relationships between the accumulated depth versus elapsed time and that of furrow length (L) versus elapsed time depict a polynomial function and hence were fitted to polynomial functions.

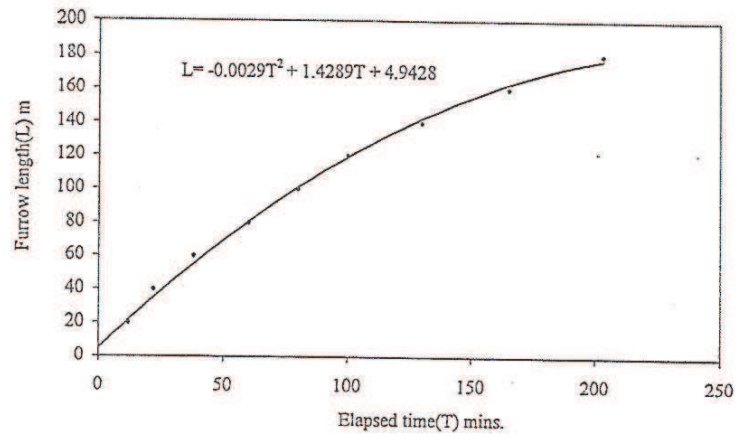


Figure 1: Advanced furrow length and time curve

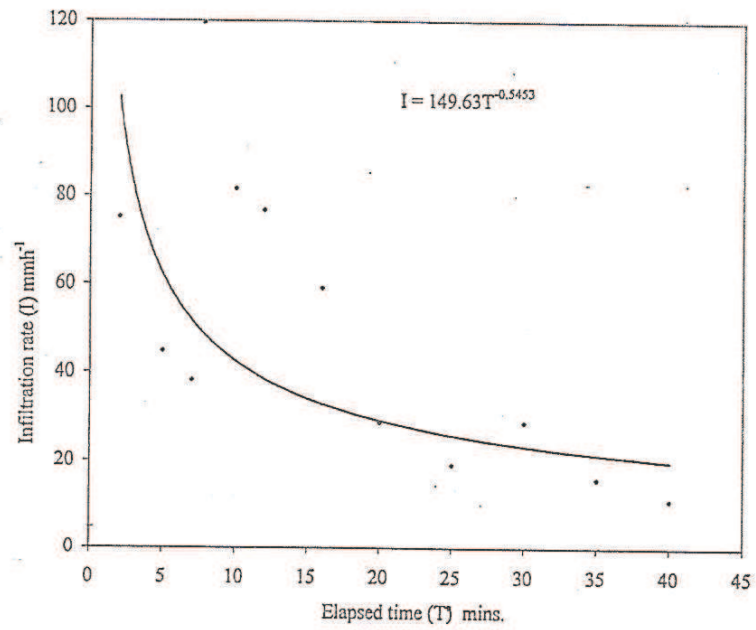


Figure 2: Infiltration characteristics curve

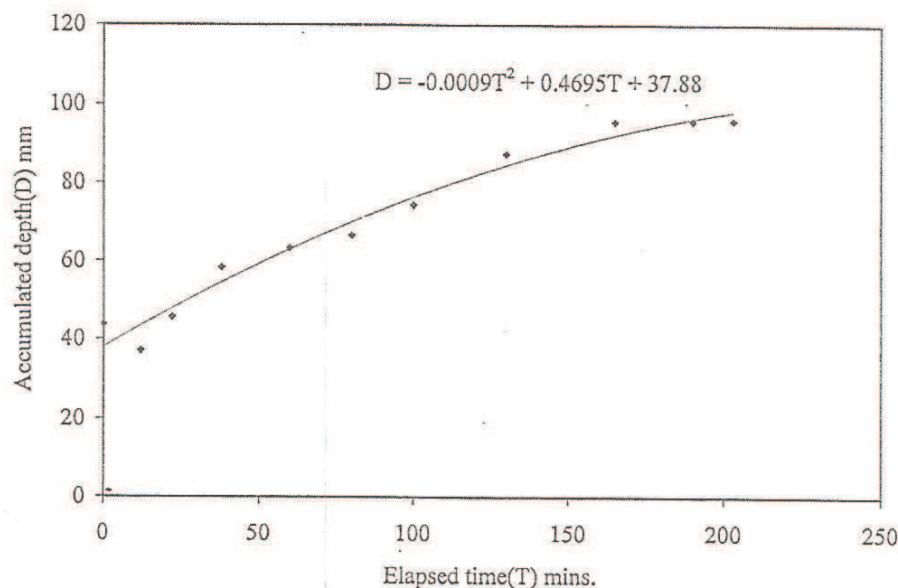


Figure 3: Accumulated depth and time curve

The infiltration capacity I_c of the soil estimated (20 mmhr^{-1}), is slightly higher than the general value for sandy-clay loam, which is the representative soil at the study area. The reason for the higher value may be due to variation in soil constituent along the furrow length. The effective irrigation time (12hr), is in contrast to that practiced presently. Preliminary observation showed that irrigation water was often left inside the furrow for a whole day before it was allowed to flow out to drain. This practice encourages too much water loss to deep percolation, which consequently results to high water table problems if unchecked. The optimum furrow length of 170m obtained was almost half of the existing furrow length of 350m. The inference from this is that the management adopts twice the value of the optimum furrow length and the irrigation time.

The management adopts the furrow length of 350 m hoping to reduce labour requirements for irrigation. This practice however, does not favour efficient management of irrigation water. The present practice of leaving irrigation water inside the furrow for more than a day instead of 12 hr is since this could affect the operational performance of the system.

The maximum spacing between furrows must be such that the lateral movement of water will wet the entire cross-sectional area in less than the irrigation time needed to replace the soil moisture deficiency at the lower end. Soil texture is also an important parameter to be considered in determination of furrow spacing. The furrow should not be spaced more than 50 to 60 cm apart in sandy soil while it should be 100 cm or more in clay soil (Michael, 1978). At Bacita Sugar Company, the furrow spacing in the experimental field was measured to be 75 cm, which falls within the allowable limit. The application efficiency (AP), which is a measure of how effectively the irrigation system is being operated, was computed to be

71%, while the potential efficiency (PE), which is a measure of how effectively the system was designed to be operated, was computed to be 78%. The values of the efficiencies are fairly good, but could still be improved upon. For example, the improvement in the operational efficiency could be achieved if the management can adopt irrigation time and furrow length of 12 hrs and 170 m respectively.

4. Conclusion and recommendations

The operation performance investigation carried out at the Nigerian Sugar Company, Bacita involved the use of inflow – outflow method to determine infiltration characteristics of the soil at the Sugar cane plantation. The method adopted gives the average infiltration characteristics by compensating for various errors inherent in the furrow arising out of soil heterogeneity, furrow cross-sectional difference, cracks and puddling effects. From the investigations made, the following conclusions can be drawn:

- (i) An infiltration characteristic equation for the soil at the study area was derived based on Kotstiaikov model and is given by $I = 149.63T^{-0.5453}$ thus the infiltration characteristics coefficient of the soil, n & k were -0.545 and 149.63 respectively.
- (ii) The intake depth equation established was $D_i = 330T^{-0.455}$.
- (iii) The application efficiency (AP) of the furrow irrigation system obtained was 71%. In order to eliminate high water table hazards, AP should be greater than or equal to 80%.
- (iv) The potential efficiency, for which the system was design, was evaluated to be 78% instead of 100%. This value can be improved upon.
- (v) The furrow length and the irrigation time were obtained as 170 m and 12 hrs respectively.

To improve application and potential efficiencies at the Bacita Sugar Company, the following recommendations are made :-

- (i) The should discourage the practice of leaving irrigation water inside the furrow more than the effective irrigation time to avoid deep percolation and eventual rise in water table. The estimated irrigation time, in accordance to the infiltration characteristic coefficient of the representative soil at the studied area, is approximately 12 hrs.
- (ii) The management should also endeavour to adopt the optimum furrow length obtained based on the quarter time rule for effective management of irrigation water. The optimum furrow length obtained was 170 m.

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