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Research Paper :

Hydraulic of broad bed furrow through volume balance approach in medium black soil

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ABSTRACT

The volume balance approach gives the reliable estimation of uniformity and efficiency by considering soil parameters. The present experiment was conducted at Junagadh Agricultural University on medium black soil in groundnut crop with six broad beds of 0.6 m wide each and five furrows of top width of 0.5 m each of 15 m long through volume balance approach with different discharge. The furrow geometry was measured by furrow profilometer and corresponding furrow parameters were calculated. The maximum average application efficiency *(Ea),* deep percolation ratio and tail water ratio were found to be 66.52 per cent, 1.12 and 32.41, respectively at 1.50 lps/m discharge. The study showed that the field irrigation system should be designed properly for getting the maximum efficiencies and to reduce deep percolation and tail water losses. The poorly designed system may lead to losses of water more than 50 per cent.

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Key words : Furrow irrigation system, Broad bed furrow, Volume balance

In Saurashtra region of Gujarat state, only 16 per cent area is under irrigation. Groundnut (*Arachis hypogaea* L.) is main cash crop, which is cultivated in *Kharif* season. However, due to vagaries of the south - west monsoon, its yield fluctuates year by year. If the rainfall occurs more than 600 mm and distributed timely during the season as per its various critical growth stages, its yield would be about 2500 kg/ha. However, this yield level is possible in favourable monsoon years, which generally occurs in 3 years out of every 10 year cycle. Groundnut crop is being preferred and cultivated during summer season for better yield and less damages with insects/pests. As water is scarce in the region, there is need of an efficient irrigation system for summer irrigated groundnut crop. In fact, furrow irrigation system is a common practice followed by farmers of this region.

However, there is need of a proper designed irrigation system for replenishing the root zone with enough moisture to avoid stress to crop. Historical design practice based primarily on volume balance concepts is now replaced with hydrodynamic, zero-inertia and kinematic wave models (Walker and Skogerboe, 1987).

Volume analysis by Hall (1956), Philips and Farrell (1964), Wilke and Smerdon (1965) and Hart *et al.* (1968) solved the Lewis Milne equation without resorting to an assumption regarding the advance rate functional form. Kiefur (1959) and Fok and Bishop (1965) considered alternative volume model with Kostiakov infiltration function to derive analytic volume expression. Strelkoff and Katapodes (1977) proposed the zero inertia model. Clemmens(1979), Elliott *et al.*(1982) and Oweis (1983) applied this model to surface irrigated conditions including furrows. Wilke (1968) studied the hydrodynamic flow in furrow irrigations. However, the volume balance methodology is still used though the state of art technology has superseded the volume balance concept. This concept provides the procedures without cumbersome detail of advanced theory. The influence of variables such as field slopes and length, roughness of the field and infiltration characteristics of the soil are ascertained easily. This method also requires cross section, tail water volume (Elliott and Walker, 1982 and Walker and Scogerboe, 1987) Here effort has been made to determine the hydraulic performance of furrow irrigation for the soil of this region by using a volume balance approach described by Walker and Scogerboe (1987).

METHODOLOGY

The present experiment was conducted for the summer groundnut crop in the Mechanized Cultivation Farm of Junagadh Agricultural University, Junagadh.

Infiltration characteristic:

The infiltration equation describing infiltration of water in soil given by Kostiakov Equation (1932) as below was used for fitting the observed data obtained through double ring infiltrometer test at experiment site.

$$I = at^b \qquad (1)$$

where, I = infiltration rate (cm/min), t = elapsed time (min), and a,b = fitting constants

The equation 1 indicates that the infiltration rate will approach zero after a long period of time, which is physically not correct. However, this equation is valid for limited period of irrigation.

The infiltration data were plotted on log-log paper and the best fitting straight line was drawn so that observed plotted points could closely match the straight line. The slope of the graph was taken as the coefficient b and the value of I read at unit time was taken as the coefficient a.

Furrow geometry:

The length and top width of furrow were considered as 15 m and 0.50 m, respectively. The slope of field along the furrow was 0.12 per cent and width of bed was 0.60 m (As per farmers' usual practice). The furrow profile was measured using locally made furrowprofilo meter. The schematic diagram of field plot is given in Fig. 1.

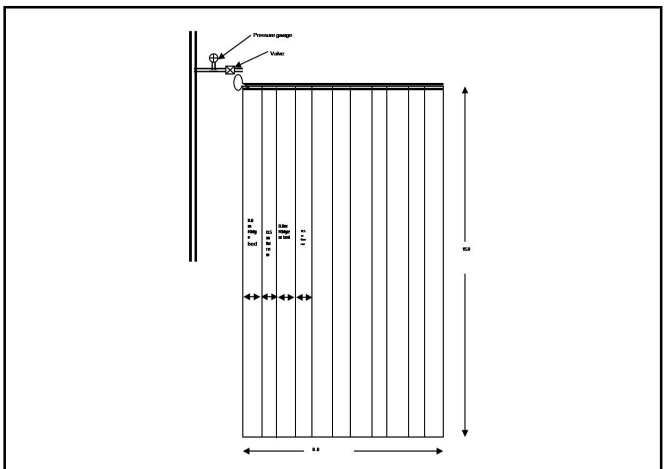

Fig. 1 : Field layout of the furrow irrigation system

Irrigation depth and infiltration:

Considering IW/CPE = 0.7, the depth of irrigation to be applied at the time of irrigation was considered as 3.50 cm. The advance of waterfront in furrow can be expressed as;

$$x = pt_a^r \qquad (2)$$

where,

x = distance that front has advanced in time t_a, and p, r = empirical parameters

The infiltration relationship can be described by Kostiakov- Lewis equation as given below:

$$Z = Kt^a + f_o t \qquad (3)$$

where, Z = infiltration depth per unit length after an infiltration opportunity time t, f_o = basic intake rate in units of volume per unit length per unit times, and K, a = empirical constants.

The empirical constants (K, a) and basic intake rate was determined by using formula as given below;

Determination of a:

The parameter a is given by

$$a = \frac{\ln (V_L/V_{0.5L})}{\ln (t_L/t_{0.5L} 0} \qquad (4)$$

where, t_L = advanced time to the end of the furrow (min), $T_{0.5L}$ = advance time to one half the furrow length (min)

$$V_L = \frac{Q_0 t_L}{L} - \sigma_y A_0 - \frac{f_0 t_L}{(1+r)} \qquad (5)$$

$$V_{0.5L} = \frac{2Q_0 t_{0.5L}}{L} - \sigma_y A_0 - \frac{f_0 t_{0.5L}}{(1+r)} \qquad (6)$$

where, t_L = advanced time to furrow end (min), Q_0= Inlet discharge m^3/min (0.012 m^3/min), r = empirical fitting parameter of advance equation 2, σ_y= surface storage shape factor which is taken as constant between 0.7 to 0.8 and L = length of furrow (m)

$$A_0 = C_1 \left(\frac{Q_0 n}{60\sqrt{S_0}} \right)^{C_2} \qquad (7)$$

$$C_2 = \frac{3\sigma_2}{5\sigma_2 - 2\gamma_2} \qquad (8)$$

$$C_1 = \left(\frac{\gamma_1^{0.67}}{\sigma_1^{1.67}} \right)^{C_2} \qquad (9)$$

where, n = manning's roughness coefficient taken as 0.04 for freshly tilled furrow, S_0 = longitudinal slope of furrow (0.0012 m/m), σ_1, σ_1 = shape coefficient and shape exponent for area calculation, Y_1, Y_2 = shape coefficient and shape exponent for wetted perimeter

Here, Area $A = \sigma_1 y^{\sigma_2}$ and Wetted perimeter,

$$\mathbf{WP} = \gamma_1 y^{\gamma_2}$$

Determination of K:

$$\sigma_z = \left(\frac{a + r(1-a) + 1}{(1+a)(1+r)}\right) \qquad (10)$$

where, $$K = \frac{V_L}{\sigma_z (t_L)^a}$$

Field observations:

The three furrows *viz.*, no.1, no.3 and no. 5 of 15 m long were divided into 15 equal parts of 1m long and stations were marked. The water was let into the furrow with the PVC pipes (with by pass and valve assembly). The advance time and recession time at every marked station were recorded.

Application efficiency (Ea):

In furrow irrigation system, application efficiency is the ratio of average depth added to root zone storage to average depth applied to the field.

$$E_a = \left(\frac{Z_{req} L}{Q_0 t_\infty}\right) 100 \qquad (11)$$

where, Z_{req}. = required depth of application in furrow (m^3/min) and t_{∞} = cut off time (min)

Deep percolation ratio (DPR):

Deep percolation ratio was determined by using following formula:

$$DPR = \left(\frac{V_{Z_{req}} L}{Q_0 t_\infty}\right) 100 \qquad (12)$$

where, $V_{z\ req}$ = total required infiltrated volume

Tail water ratio (TWR):

It is the ratio of average depth of field run off to average depth applied and would be given as;

$$TWR = 100\, E_a - DPR \qquad (13)$$

RESULTS AND DISCUSSION

The results of the present study as well as relevant discussion have been summarized under following heads:

Infiltration characteristics of soil:

The cumulative depth of infiltration is plotted against elapsed time on log-log paper and the infiltration curve obtained is presented in Fig. 2 and Fig. 3, respectively. The mathematical relationship for the soil found to be

$$d = 0.853\ (t_o)^{0.4415} \qquad (14)$$

From the Kostiakov's equation 14 the low value of a and high value of k indicates the higher infiltration rate of soil and the most of the infiltration take place during the first few minutes, mainly into cracks present in the dry soil. The value of exponent *a* varies from one irrigation to other and corresponding soil moisture present in the soil. However, in irrigation practices this equation is valid for limited period of irrigation.

By differentiating equation 14 with respect to time, the equation for infiltration rate I is obtained as:

$$I = 0.377\ (t_o)^{-0.5585} \qquad (15)$$

where, I = infiltration rate, cm/min and t = elapsed time, min

The relationship between infiltration rate I and time t is presented in Fig. 2.

$$Q = 115.02\ (P)^{0.4173} \qquad (16)$$

The infiltration characteristics of a soil vary spatially and temporally and due to this the available methods for

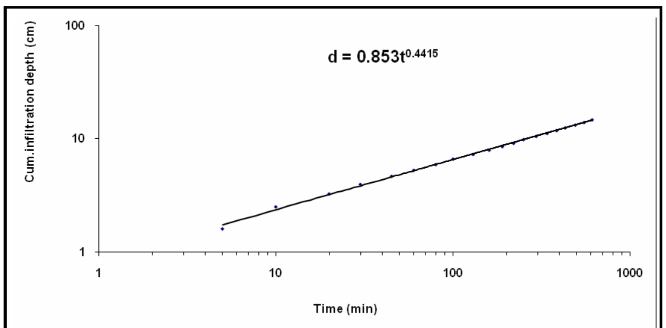

Fig. 2 : Plot between cumulative depth of infiltration and elapsed time on log-log paper

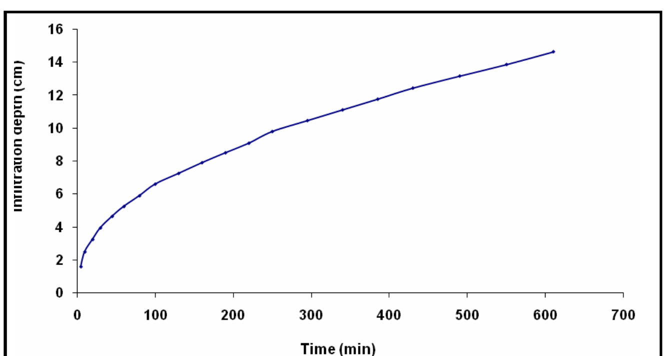

Fig. 3 : Relationship between infiltration depth and elapsed time

estimating the characteristics are either not suitable or have restrictions for their field use for irrigation. So, present furrow irrigation system was evaluated by volume balance approach. Infiltration characteristics determine advance and recession times, the depth of infiltration and the uniformity of water application during the irrigation and the infiltration parameters can change spatially and temporally within a field. In present study, infiltration characteristics was determined by double cylinder infiltrometer as a representative of the overall field conditions.

The furrow geometry data of furrow no.1, 2 and 3 were collected to derive the relationship between the depth of water in furrow and the corresponding top width of water surface. Different shape parameters, coefficients and exponents were calculated using the corresponding equations. The calculated values of parameters, coefficients and exponents are presented in Table 1 for different furrows used in this study.

Advance time, cut off time, depletion time and recession time:

Water was let in to furrows with the PVC pipe. The by-pass and valve assembly were fitted to maintain the constant discharge. The travel time of water advancing through each furrow was recorded at each marked station. The cut off time for each furrow was recorded along with depletion and recession times for each furrow. By using these observations, necessary parameters, coefficients and exponents were calculated (Table 2).

Fig. 4 illustrates the infiltration rate Vs elapsed time. The parameter f_o was estimated as 0.00025 m^3/min/m. Therefore, for different furrows the infiltration function was expressed as follows :

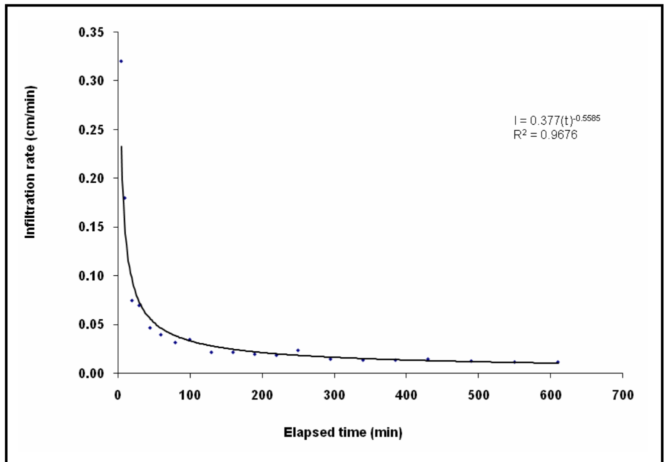

Fig. 4 : Relationship between infiltration rate and elapsed time

$$\mathbf{Z = Kt^a + f_o\, t} \quad (17)$$

or $$\mathbf{Z_i = K\,(t_r - (t_a)_I)^a + f_o\,(t_a)_I} \quad (18)$$

The infiltration function is very important as the basic infiltration rate is used to determine the advance time of flow through the furrow length and calculated parameters K and a in the infiltration function depend on the infiltration. The depth of water infiltrated at each marked stations were computed with the help of advance time and recession times. The infiltration volume by using data of advance time and recession time is presented in Table 2.

Irrigation efficiency and system performance:

A single parameter is insufficient for performance evaluation of furrow irrigation system. Conceptually, the adequacy of irrigation is dependent on the water stored

Table 1 : Calculated values of furrow shape parameters, coefficients and exponents for different furrows

Furrow nos.	Parameters, coefficients and exponents												
	σ_1	σ_2	y_1	y_2	C_2	C_1	σ_z	σ_y	p	r	K	a	A_0
1	3.452	9.887	1.112	6.025	0.793	0.707	3.326	0.750	4.304	0.991	0.004	0.192	0.016
2	3.524	9.997	1.122	5.986	0.789	0.712	3.810	0.750	3.932	1.045	0.004	0.095	0.017
3	3.474	9.998	1.122	5.991	0.789	0.715	4.464	0.750	3.416	1.193	0.004	0.071	0.017
Average	3.483	9.961	1.119	6.001	0.791	0.712	3.867	0.750	3.884	1.076	0.004	0.120	0.017

Table 2 : Calculated values of application efficiencies (Ea), deep percolation ratio (DPR), and tail water ratio (TWR) for different furrows at 2.00 lps/m discharge

Sr. No.	Furrow nos	V_z	Ea	DPR	TWR
1.	1	0.070	44.64	3.89	51.47
2.	3	0.068	43.52	3.51	52.97
3.	5	0.0729	45.03	4.24	50.74
4.	Average	0.0703	44.40	3.88	51.72

within the crop root zone, tail water, the uniformity of applied water and the unused storage capacity of the soil profile following irrigation. The calculated values of application efficiency, deep percolation ratio and tail water ratio are presented in Table 2 for each furrow. The average values of application efficiency, deep percolation ratio and tail water ratio were found to be 44.40 per cent, 3.88 and 51.72, respectively. The volume of water stored in root zone is determined using trapezoidal rules.

It is observed that the application efficiencies are very low. The possible reasons for low efficiencies may be due to insufficient refill in the root zone (deep percolation of water through fissures and crakes due to stone flakes in hard pan) and the excess tail water. However, efficiencies can be improved by preparing precise furrow after medium to deep ploughing(just below soil depth to disturb natural hard pan), reducing discharge and by reducing the longitudinal slope of field. However, reducing longitudinal slope is not immediate possible solution. Therefore, only way to improve efficiencies is to customize the discharge and furrow shape parameters. Generally farmers are using furrow formulator is of fixed tyne type implement. Therefore, reducing discharge is only way to improve efficiencies. The efficiencies were computed for reduced discharge of 1.75, 1.50 and 1.25 lps/m in hard pan disturbed soil. The efficiencies were found to be more for discharge of 1.50 lps/m and are given below:

Ea = 66.52 per cent, DPR = 1.12 and TWR = 32.41

Conclusion:

Field experiments were conducted on summer groundnut crop at the Mechanized Cultivation Farm, Junagadh Agricultural University, Junagadh. Six broad beds of width 0.6 m and five furrows of top width 0.5 were constructed having size of 6 m x15 m. The time of water front advancement and recession were recorded for each marked stations. The irrigation system was evaluated by volume balance approach. By using various field parameters and observations, application efficiency, deep percolation ratio and tail water ratio were determined at different discharge. The Maximum average application efficiency (Ea), deep percolation ratio and tail water ratio were found to be 66.52 per cent, 1.12 and 32.41, respectively at 1.50 lps/m discharge. The study shows that the field irrigation system should be designed properly for getting the maximum efficiencies and to reduce deep percolation and tail water losses. The poorly designed system may lead to losses of water more than 50 per cent.

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