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Research Article

Impact of Furrow Gradient and Flow Retardance on Waterfront Advance and Irrigation Usage Efficiency under Surge Irrigation

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Abstract

Surge irrigation is a promising improvisation over the traditional check furrow irrigation layouts. In case of the continuous flow mode, water front advance take a relatively longer time to reach the furrow tail end. The surge mode of water application involves alternate ON-OFF cycling of intermittent flows. The partial or complete saturation of subsoil creates an apparent reduction in the instantaneous infiltration rates of the soil. Water front advance pattern have been evaluated with 0.3 % furrow gradients under non-vegetated and vegetated conditions. Invariably in all the continuous flow long furrows 25 Per cent to 40 Per cent additional times were required to reach the furrow tail end. In case of the surge irrigated furrows out of 10 surge cycles 5 to 9 surge cycles were taken to reach the furrow tail end. A mathematical model (SURGEMODE) was validated and correction factors incorporated for varying slope gradients and vegetative flow retardance. The irrigation usage efficiency with continuous flow long furrow layout was reckoned in the range of 9.11 kg $ha^{-1}mm^{-1}$ to 10.94 kg $ha^{-1}mm^{-1}$ of water were as the surge irrigation layout could come out in a relative higher range of 11.55 kg $ha^{-1}mm^{-1}$ to 14.45 kg $ha^{-1}mm^{-1}$. Hence, surge irrigation shows reducing deep percolation losses in order to achieve high order of water distribution and irrigation usage efficiency.

Keywords: Continuous Irrigation, Surge Irrigation, Water front advance, correction factor, Irrigation use efficiency

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Introduction

Modern concept of irrigation such as drip, sprinkler or surge aim at minimizing the application and the storage losses of water by way of runoff and deep percolation so that water storage and distribution efficiency can be achieved in the range of 85-97 percentage with barest minimum losses of 15-8 percentage [1]. However, surface irrigation, our oldest method of applying water on to the cropped land, has withstood the test of time because of its many advantages. However, the short strips furrow layout leads to high time and labor to complete irrigation, conveyance losses and more than 20 per cent of the area lost for cultivation. A long furrow layout though limited by the availability of sufficient field length seems to be a feasible solution in order to minimize the land loss and to minimize irrigation efficiencies particularly when coupled with surge irrigation. In Surge irrigation applied water intermittently in a series of relatively short ON and OFF time periods of irrigation cycles [15]. The net result is a reduction in soil infiltration rates during subsequent surge ON periods and an increase in the rate of water front advance. So it is necessary to design surge cycle timing parameters and evaluate the impact of surge irrigation on the ultimate irrigation usage efficiency.

Materials and Methods

Experiment was conducted in Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. The experimental layout has been made to accommodate the variance as the furrow gradients 0.3 Per cent, the modes of irrigation namely the continuous flow as control and the surge flow as the treatment. The same experimental layout was subjected to field observation on water front advance, yield and irrigation usage efficiency, both under non - vegetated condition and the vegetated condition. For the reference crop chosen (bhendi), a paired row long furrow layout (60 m length and 90 cm furrow size with double row planting for 45 cm plant to plant spacing) has been made. The infiltration rate has been assessed by means of the standard formatting of double ring. The equation is as $I = 221.26\ t^{-0.948}$.

Hydraulic design feature of surge flow furrow irrigation layout

Surge cycle timing parameters

Step I

$$d = \frac{(FC - WP)XDXASMD\%}{100}$$

Where, d = depth equivalent of irrigation in cm of water, AWHC = available water holding capacity of the effective root zone, ASMD = available soil moisture depletion as 50%, FC = mean field capacity, WP = mean wilting point, D = effective root zone depth, For the present field layout, FC =33.45, WP =16.45, D =60 cm, ASMD =50 %, Substituting this d = 5.1 cm ≈ 5 cm

Step II Net duration of irrigation per furrow

$$T_n = \frac{W\ X\ L\ X\ d}{600\ Q}$$

Where T_n= net duration of irrigation, minutes, W = width of the furrow or the furrow spacing, cm, L = length of the furrow, m, Q = rate of inflow or discharge in l/s per furrow, For the present field layout, T_n = 45 min ≈ 50 min

Step III ON time of the surge cycle

Considering the irrigation to be completed in 10 surge cycles (N = 10). The ON time of a surge cycle is

$$T_{ON} = \frac{\mathrm{Tn}}{N} = \frac{50}{10} = 5\ min$$

Step IV OFF time

Considering a surge cycle ratio R_c= ½ that is $T_{ON} = T_{OFF}$, Hence $T_{ON} = T_{OFF} =$ 5 min

Step V Total cycle time

$$T_c = T_{ON} + T_{OFF} = 5 + 5 = 10 \text{ min}$$

Step VI Gross duration of irrigation

$$T_g = N\ T_c - T_{OFF} = 95 \text{ min}$$

Step VII Prediction of net water front advance time

The SURGEMODE model's waterfront advance component is given by [14]

$$T_a = 0.00975\ \frac{(L^{1.189})(N^{1.206})({T_{ON}}^{1.389})}{(W^{0.489})(Q^{0.0205})({R_C}^{0.206})}$$

Water front advance pattern

In case of continuous flow through long furrows, when the water front advance from the head end to the tail end continuous infiltration takes place simultaneously. Hence the advancing water front I likely to take a relatively longer time to reach the furrow tail end there by resulting in a non-uniform soil moisture distribution with more deep percolation at the head end and significant soil moisture deficit at the tail end. This non-uniformity of the soil moisture distribution increases with increasing in the length of furrow particularly when it exists 30 m or so [14]

Correction factor for flow retardance (F_r) and furrow slope gradient (F_g)

Non-Vegetated furrow with a slope gradient of 0.3%

Based on the SURGEMODE Model was developed to predict the net water front advance times. For this condition $F_r = 1$ and $F_g = 1$.

Vegetated furrow with the slope gradient of 0.3%

Here F_g=1 but $F_r \neq 1$ therefore $F_r = \frac{observedwaterfrontadvance}{predictedwaterfrontadvancewithFg\ =1\ \&\ Fr\neq 1}$

Irrigation Usage Efficiency

Irrigation Usage Efficiency is obtained as the ratio of the yield realized in kilogram per hectare of land per mm of irrigation water input, including the losses.

Results and Discussion

Design and layout of surge irrigation for the reference crop bhendi

As a control of comparison long furrows of same size and length used for the surge layout also been used for continuous flow layout. For design purposes the inflow rate per furrow has been fixed as 1 lit/ sec so that 5 lit/ sec from the storage source has been diverted into feeder channel for simultaneously ON & OFF 5 furrows each.

Continuous flow water front advance pattern

When the furrow inflows is continuous the flow depth gradually decreases along the water front advance due to simultaneous absorption by infiltration process governed by the soil moisture content at that time. Observations were made for the time of water front advance for every 5 metres length of the furrow and finally the length of water front advance at the end of design depth of irrigation. For the set of data obtained on water front advance distance L, metres Vs the corresponding water front advance time t, minutes, by regression a power form of equation of the type $t = KL^m$ was fitted. Where K & m are the characteristic constants for the water front advance pattern. Using this empirical equation the time taken by water front advance to reach tail end of the furrow was predicted. The actual additional time required to make the advancing water front to reach the furrow tail end beyond the design duration of irrigation was also observed compared with predicted values.

Continuous flow along 0.3 Per cent slope gradient in non vegetated furrow and vegetated furrow

This vegetative phase marks no difference with the non-vegetative furrows. In accordance with the water front advance prediction equation for non vegetated furrow and vegetated furrows (vegetative phase, flowering phase, fruiting Phase, maturity phase) the additional time required to reaches the end of furrow is determined. If time of irrigation is slightly greater than the predicted one indicates it may possibly due to variation in the soil infiltration characteristic [14].

Table 1 The additional time required to reaches the end of furrow

S.No	0.3% slope gradient -Phases	Actual water front advance distance, m	Additional time observed to reach tail end, min	Prediction equation	Time to reach tail end	Additional time predicted
1	Non - vegetation	43	28.52	$t = 0.317\ L^{1.37}$	77.45	27.45
2	Vegetative phase	44	22.31	$t = 0.27\ L^{1.397}$	74.43	24.43
3	Flowering phase	43	27.54	$t = 0.41\ L^{1.3}$	78.53	28.53
4	Fruiting phase	42	32.41	$t = 0.77\ L^{1.1}$	80.43	30.43
5	Maturity phase	42	30.32	$t = 0.63\ L^{1.16}$	81.47	31.47

Surge flow water front advance pattern

In case of the surge flow the advancing water front patterns indicate the effect of reduced infiltration rates indirectly such a depiction of the changes in the water front advance with reference to a sequence of ON times followed by OFF times is shown in the **Figure 2**. For instances, for the given conditions L= 60 m, R_c = 1/2, N = 5, G = 0.3% for the given inflow rate of 1 liter/sec the water front advance length and time observed for the I surge cycle have been remains the same as under continuous flow. However, the II surge cycle starts after time lag of 5 min as the OFF time. During the second surge cycle the partially saturated furrow portion during the first cycle will be fastly crossed due to reduction in infiltration rate over this portion during the II surge cycle ON time. After the I surge cycle distance again the furrow soil is relatively longer time to the I cycle. In this fashion alternates saturated furrow length and dry furrow length are to be covered by the subsequent surge cycle ON time. It is also observed that during the v cycle the advancing water front able to reach the furrow tail end in 5.01 minutes out of the 5 minutes ON time. Hence, the net water front advance time to reach the furrow length reckoned as (4 X 5) + 5.01 = 25.01 minutes [19].

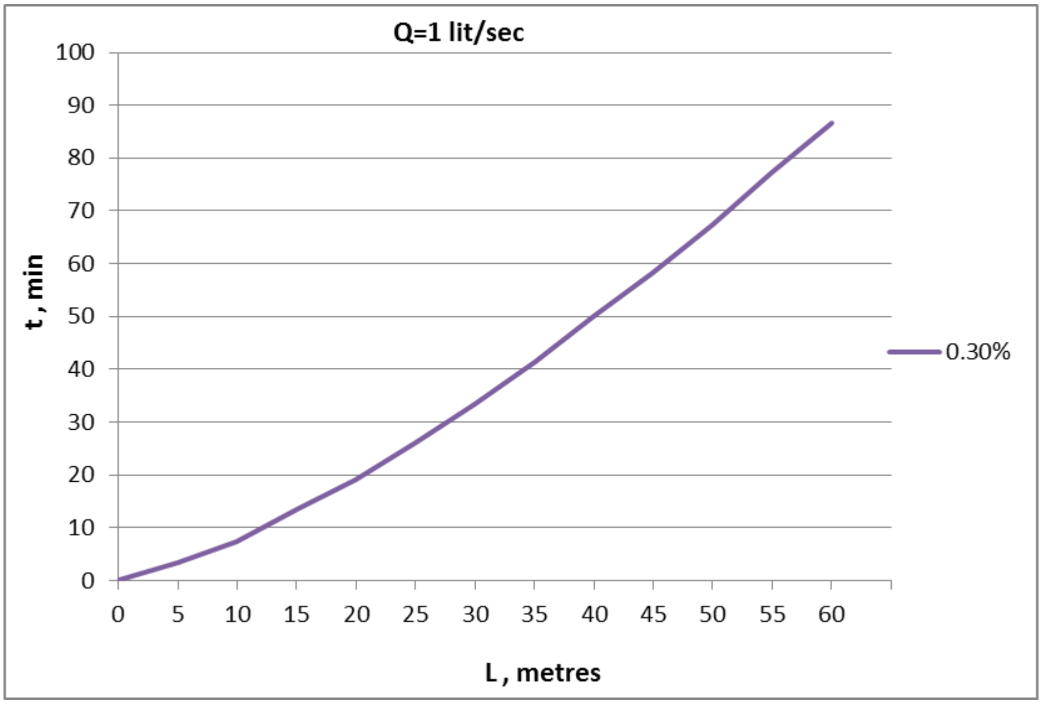

Figure 1 Continuous flow in non vegetated phase

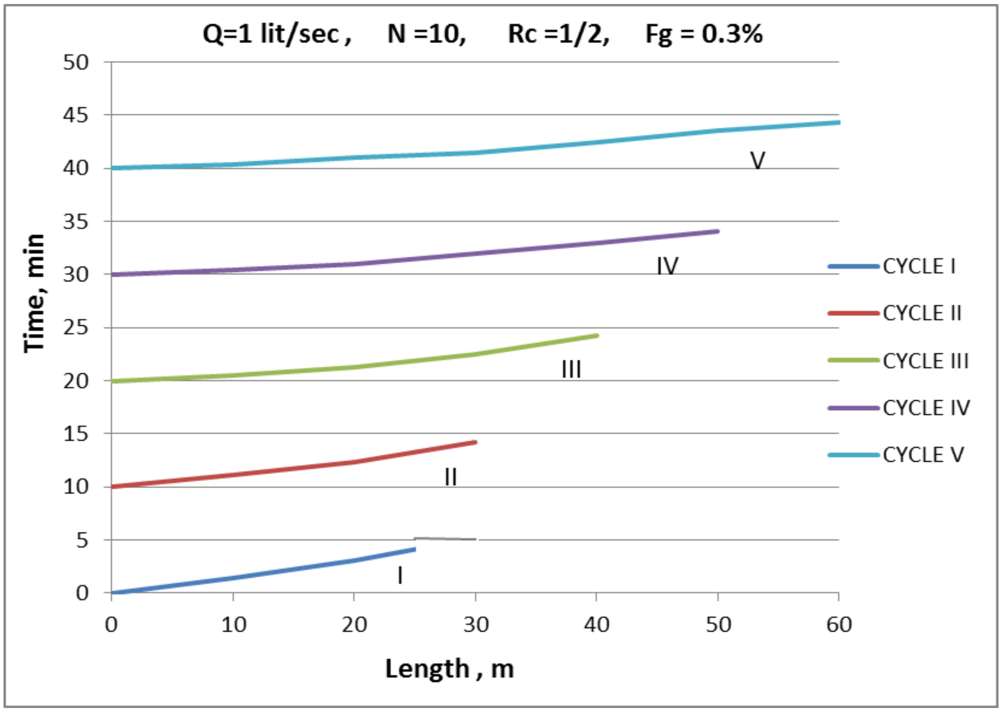

Figure 2 Surge flow in non vegetated phase

Surge flow water front advance along Non-vegetated and vegetated furrows

Same procedure of surge flow in non vegetated followed to determine the water front advance in vegetated furrows (vegetation phase, flowering phase, fruiting phase and maturity phase). Time taken for water front to reach the furrow tail end is tabulated in the **Table 2.**

Table 2 Time taken for water front to reach the furrow tail end in surge flow

Growth phases	Non-vegetative phase	Vegetative Phase			
		Vegetation	**Flowering**	**Fruiting**	**Harvesting**
Cycles	C5	C6	C7	C8	C9
Time, min	24.36	24.14	25	21.32	23.27

Prediction of water front advance under surge flow (Model correction factors development)

In case of the SURGEMODE of water application the water front advance does not happen continuously. Hence, the net water front advance time $(T_a)_{net}$ for would mean surge flow only a overall time taken by the advancing water front during the ON times only till the furrow end is reached. For furrow lengths 50 metres to 100 metres the prediction of net water front advance time can be done by using the available model SURGEMODE [14]. The combination effect of slope gradient condition of vegetation is represent by $F_{r,g.}$ in general the correction factor $F = \frac{T_{a(o)}}{T_{a\,(M)}}$ Where $T_{a(o)}$ is observed water front advance time, min. $T_{a(M)}$ is model water front advance time, min. Hence, the model has been revalidated to fit in the local condition of layout as

$$T_{a(net)} = 0.011088\, X \frac{L^{1.189}\ X\ N^{1.206}\ X\ {T_{ON}}^{13189}}{W^{0.489}\ X\ Q^{0.0205}\ X\ {R_C}^{0.206}}\ X\ \mathrm{Fg\ xFr}$$

$$T_{a(net)} = 0.011088\, X \frac{L^{1.189}\ X\ N^{1.206}\ X\ {T_{ON}}^{13189}}{W^{0.489}\ X\ Q^{0.0205}\ X\ {R_C}^{0.206}}\ X\ 0.88 X\ 1$$

$$T_{a(net)} = 0.00975\, X \frac{L^{1.189}\ X\ N^{1.206}\ X\ {T_{ON}}^{13189}}{W^{0.489}\ X\ Q^{0.0205}\ X\ {R_C}^{0.206}}$$

Table 3 Correction factor (F) for water front advance time under surge

Growth phases	Non-vegetative phase	Vegetative Phase			
		Vegetation	**Flowering**	**Fruiting**	**Harvesting**
F	1.00	1.18	1.46	1.68	1.76

Irrigation Usage Efficiency (IUE)

The apparent reduction in the yields pertaining to continuous flow plots may be due to excessive deep percolation losses out of the depth of irrigation with highly non-uniform soil moisture distribution pattern head to tail end of the yield. Hence, surge treatment yields 18.8 kg $ha^{-1}mm^{-1}$ of irrigation water usage efficiency [18]. Now the continuous flow treatment registers 15 kg $ha^{-1}mm^{-1}$ yield due to relatively high deep percolation losses & non-uniform distribution efficiency.

Conclusion

In continuous flow 25-45 Per cent of additional duration required to reach the tail, in Surge flow within designed 10 surge cycle 5 to 9 cycle was taken to reach the tail end. In surge flow water distribution efficiency in the range of 73-83 Per cent while in the continuous flow register 60 Per cent. The water usage efficiency under surge irrigation was 11.55 to 14.15 kg ha^{-1} mm^{-1} and in continuous flow mode 9.11 to 10.94 kg ha^{-1} mm^{-1}

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