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Validation of Surge Model Using Furrow Gradient and Flow Retardance

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Authors' contributions

This work was carried out in collaboration among all authors. Author ES designed the stud, performed the analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AS and SS managed the analyses of the study. Author SS guided the research. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: Surface irrigation, our oldest method of applying water on to the cropped land, has withstood the test of time because of its many advantages. Over the years, minor changes have been made to improve the efficiency of surface irrigation system.
Aim: The present study was taken to validate the existing model with furrow gradient and flow retardance.
Principle: The experimental layout has been made to accommodate the variance such as the furrow gradients (0.3%, 0.6% and 0.1%), the modes of irrigation namely the continuous flow as control and the surge flow as the treatment. Surge irrigation is a relatively new technique whereby water to surface irrigated furrows is applied intermittently in a series of relatively short ON and OFF time periods of irrigation cycles.

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Results: It is claimed that the ON-OFF cycling of the flow for specific time periods produces surges during the ON period and influences the soil intake during the OFF period when water soaks into the soil. 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. The SURGEMODE model can only gives the net water front advance time that can be predicted for non-vegetated condition and a standard reference slope. However when the furrow is getting vegetated or when the slope gradients are changed, the water front advance predicted through the existing model cannot be predict accurately.
Conclusion: Hence, the study involved to validate the existing model with furrow gradient and flow retardance. The use of revalidated existing SURGEMODE model with the correction factor would be the exact suitable model for the local condition.

Keywords: SURGEMODE model; validation; furrow gradient; flow retardance.

1. INTRODUCTION

Over exploitation of surface water resources and unscrupulous pumping of groundwater have led the farming community to a precarious situation of counting every drop of water towards sustaining maximum possible crop production [1,2-4]. Even as micro irrigation systems are gaining popularity, surface irrigation systems such as border strips or furrows or check basins are still in vogue and are quite inevitable from the point of view of farm management. Surface irrigation, our oldest method of applying water on to the cropped land, has withstood the test of time because of its many advantages. Over the years, minor changes have been made to improve the efficiency of surface irrigation system. Surge irrigation is a relatively new technique whereby water to surface irrigated furrows is applied intermittently in a series of relatively short ON and OFF time periods of irrigation cycles [5-8]. It is claimed that the ON-OFF cycling of the flow for specific time periods produces surges during the ON period and influences the soil intake during the OFF period when water soaks into the soil [9-11,12]. 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 [12,13,14-16]. The SURGEMODE model [17] can only gives the net water front advance time that can be predicted for non-vegetated condition and a standard reference slope. However when the furrow is getting vegetated or when the slope gradients are changed, the water front advance predicted through the existing model cannot be predict accurately. Hence, the study involved to validate the existing model with furrow gradient and flow retardance.

2. METHODOLOGY

Physical characteristic of the experiment site has to be determined.

2.1 Experimental Layout

The experimental layout has been made to accommodate the variance such as the furrow gradients (0.3%, 0.6% and 0.1%), 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 both under non - vegetated 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.

2.2 Hydraulic Design Feature of Surge Flow Furrow Irrigation Layout (Surge Cycle Timing Parameters)

The patterns of water front advance are influenced by the following factors:

1. The furrow inflow rate Q normally ranging from 0.5 lps to 3 lps per furrow in the non-silting to non-erosive flow regime.
2. The width W or spacing between the furrows in cm ranging from 15 cm to 120 cm depending on the kind of crop and its canopy.
3. The length of the furrow L ranging from 50 m to 200 m for a surge flow layout.
4. The ON time of the surge cycle.
5. The number of surge cycle N ranging from 5 to 10.
6. The surge cycle ration Rc that determines the OFF time based on the ON time.
7. The flow retardants caused by the vegetative shoot and roots growth of the plants with reference to crop growth stages, as depicted by the factor Fr.
8. The furrow gradient that accelerate the gravitation of flow through the furrows as depicted by the factor Fg.

Fig. 1. Surge irrigation layout

Fig. 2. Long furrow layout

Fig. 3. The furrows 1, 3, 5...etc. were irrigating (ON time) and OFF time in the alternative furrows

Fig. 4. Surge irrigation during vegetation stage

2.3 Surge Cycle Timing Parameters

Step I: The depth equivalent of irrigation in cm of water was calculated based on the available water holding capacity of the effective root zone and the allowable soil moisture depletion at 50% as follows [18].

$$d = \frac{(FC - WP)\ x\ D\ x\ ASMD\%}{100} \qquad (1)$$

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
FC = Mean field capacity
WP = Mean wilting capacity
D = effective root zone depth

For the present field layout, FC = 33.45, WP = 16.45, D = 60 cm, ASMD = 50%,

Therefore d = 5 cm

Step II: Net duration of irrigation (T_n) per furrow

$$T_n = \frac{W\ \ x\ L\ x\ d}{600\ Q} \qquad (2)$$

Where

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

$$T_n = \frac{90 \ x \ 60 \ x \ 5}{600 \ X \ 1} \quad (3)$$

T_n = 45 min ≈50 min (according for unforeseen water losses and erosion cum sedimentation within the furrow length)

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 given by

$$T_{ON} = \frac{T_n}{N} = \frac{50}{10} = 5 \text{ min} \quad (4)$$

Step IV: OFF time

The OFF time of surge cycle (T_{OFF}) is given by, considering a surge cycle ratio Rc= ½ that is $T_{ON} = T_{OFF}$

Hence $T_{ON} = T_{OFF}$ = 5 min (5)

Step V: Total cycle time

Tc = $T_{ON} + T_{OFF}$ = 5 + 5 = 10 min (6)

Step VI: Gross duration of irrigation

Tg = N Tc- T_{OFF} = N T_{ON} + (N-1) T_{OFF} = (10 X 10) -5 = 95 min (7)

Step VII: Prediction of net water front advance time

The SURGEMODE [1] can only gives the net water front advance time that can be predicted for non-vegetated condition and a standard reference slope of 0.3% i.e Fr = 1 for non-vegetated furrow and Fg=1 for a furrow slope gradient of 0.3%. However when the furrow is getting vegetated or when the slope gradients are changed then Fr ≠ 1 & Fg≠ 1. With reference to the condition of vegetation right from the stage of sowing to harvest the flow reactance increases that is Fr becomes more than 1. But For slope gradient less than 0.3% the water front advance time increases and hence Fg more than 1. For slope gradient more than 0.3% the water front advance is quickened and hence Fg is less than 1.

The SURGEMODE model's waterfront advance component is given by [17]

$$T_n = 0.00975 \, x \frac{L^{1.189} \, x \, N^{1.206} \, x \, {T_{ON}}^{1.389}}{W^{0.489} \, x \, Q^{0.0205} \, x \, {R_c}^{0.206}} \quad (8)$$

Observation have been taken for the times taken by the advancing water front to reach every 10 m of the furrows as well as water front advance distance per cycle at the end of each ON time. Upto the end of the individual ON time water front advance due to the inflow diverted at the end of the ON time the inflow is cut off and the water front has to advance depending on its own head with simultaneous recession into the soil.

2.4 Correction Factor for Flow Retardance (Fr) and Furrow Slope Gradient (Fg)

Non vegetation condition in flow retardance and 0.3% slope in furrow gradient were considered as the reference and based on this condition correction factor was determined as the ratio of observed water front advance to predicted water front advance [19].

Case I: This condition is the reference condition based on which the SURGEMODE Model was developed to predict the net water front advance times. For this condition Fr = 1 and Fg = 1.
Case II: When the slope gradient increases from the reference level the water front advance rate are accelerated resulting in reduced water front advance times making Fg < 1 and Fr = 1.
Case III: When the slope gradient decrease from the reference level the water front advance rate are resulting in increasing water front advance times. For this condition Fg > 1 and Fr = 1.
Case IV: With reference condition, know that Fg=1 but when the vegetation starts to appear the correction factor for Fr>1.
Case V: When the slope gradient and vegetation increases from the reference level the correction factors Fg<1 and Fr>1.
Case VI: When the slope gradient decreases and vegetation increases from the reference level the correction factors Fg>1 and Fr>1.

3. RESULTS AND DISCUSSION

In the present era of acute water scarcity, consistent efforts are made towards judicious utilization of every drop of water towards sustaining agricultural production [20-22]. One of the promising design and layout substitution towards the end of minimizing deep percolation losses would be long furrows with SURGEMODE of irrigation involving alternate ON - OFF cycling of flows into individual furrows. The study concentrated to archive the proper hydraulic design features using determination of furrow gradient and flow retardance and the results are discussed and interpreted as follows:

Three treatments (R_1 = 0.3%, R_2 = 0.6% & R_3= 0.1% slope) and three replications (R_1, R_2 and R_3) were involved in the study with Q=1lps, N= 10, Rc = ½, L=60m, W=90 cm

3.1 Water Front Advance

With reference to the condition of vegetation write from the stage of sowing to harvest the flow retardance increases that is Fr becomes more than 1. But for slope gradient less than 0.3% the water front advance time increases and Fg more than 1. For slope gradient more than 0.3% the water front advance is quickened and Fg is less than 1. Hence, the original developed SURGEMODE model requires revalidation before it is used for a different experimental site condition. Observation 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 (since the advancing water front would never reach the furrow tail end with in the stipulated duration of irrigation 50 min). 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 [23-25]. Table 1 furnishes the hydraulic condition of the furrow with varying furrow gradient, the corresponding prediction equation and the additional duration of irrigation to make the advancing water front reach the furrow tail end.

3.2 Validation of SURGEMODE Model – Correction Factor

In case of vegetated furrows even though the slope changes may results either in a reduced value of water front advance or increasing the water front advance time in general and in particular causing more retardance of flow depending on the crop growth stages. Hence, for conditions other than 0.3% slope gradient under non-vegetated furrows the effect on the water front advance time is an integrated effect of both gradient and vegetation. For slope less than 0.3% both the slope gradient and the condition of vegetation in combination will try to increase the water front advance time. For slope gradient more than 0.3% the condition of vegetation will try to retard the flow that is accelerated by the slope gradient. The combination effect of slope gradient condition of vegetation is represent by Fr,g. in general the correction factor $F = T_a(o)/T_a(M)$

Where

Ta (o) = Observed water front advance time, min. Ta (M) = Model water front advance time, min

F is the correction factor that is taken as Fr for flow retardance alone, Fg for slope gradient alone, Fr,g for the combination effect of slope gradient & flow retardance were predicted and listed in Table 2.

3.3 Revalidation of SURGMODE Model for the Standard Operating Condition of 0.3%

Accordance with the SURGEMODE model a net water front advance time can be predicted taking Fr=Fg=F=1 for non-vegetated furrows with a standard furrow gradient of 0.3% [26]. However, for the experimental field the length of the furrow is limited to 60 metres only and for different combination of size of the furrow, furrow inflow rates, surge cycle ratio and number of surge cycles, to accomplish the design depth of irrigation, the value of Fg will not be exactly equal to 1 even for a furrow gradient of 0.3% .The present study the correction factor for the standard operating condition of 0.3% has been arrived at 0.88 (originally observed water front advance time is 24.36 min and the same when using the model as the base with Fg =1 was found to be 27.68 min. Hence, the correction factor Fg = 24.36 / 27.68 = 0.88).

Hence, the model has been revalidated to fit in the local condition of layout as

$$T_{a(net)} = 0.011088x\frac{L^{1.189}xN^{1.206}xT_{ON}{}^{1.318}}{W^{0.489}xQ^{0.0205}xR_C{}^{0.206}}xFg\ x\ Fr \tag{9}$$

$$T_{a(net)} = 0.011088x\frac{L^{1.189}xN^{1.206}xT_{ON}{}^{1.318}}{W^{0.489}xQ^{0.0205}xR_C{}^{0.206}}x0.88\ x\ 1 \tag{10}$$

$$T_{a(net)} = 0.00975x\frac{L^{1.189}xN^{1.206}xT_{ON}{}^{1.318}}{W^{0.489}xQ^{0.0205}xR_C{}^{0.206}} \tag{11}$$

Table 1. Water front advance prediction equation. The design duration of irrigation: 50 min

S. No.	Condition	Slope gradient	Actual Water front advance distance, m	Additional time observed to reach tail end, min	Predicted equation	Time to reach tail end	Additional time predicted
1	Non - Vegetation	0.3%	43	28.52	$t=0.32L^{1.37}$	77.45	27.45
		0.1%	38	40.43	$t=0.47L^{1.37}$	88.54	38.56
		0.6%	52	12.37	$t=0.25L^{1.37}$	61.51	11.51
2	Vegetation Phase	0.3%	44	22.31	$t=0.27L^{1.37}$	74.43	24.43
		0.1%	38	43.34	$t=0.37L^{1.37}$	91.54	41.54
		0.6%	50	11.01	$t=0.21L^{1.37}$	59.43	09.43
3	Flowering Phase	0.3%	43	27.54	$t=0.41L^{1.37}$	78.53	28.53
		0.1%	38	48.43	$t=0.39L^{1.37}$	94.46	44.46
		0.6%	53	10.22	$t=0.25L^{1.37}$	61.45	11.45
4	Fruiting Phase	0.3%	42	32.41	$t=0.77L^{1.37}$	80.43	30.43
		0.1%	38	49.54	$t=0.79L^{1.37}$	97.32	47.32
		0.6%	50	15.01	$t=0.42L^{1.37}$	63.35	13.35
5	Maturity Phase	0.3%	42	30.32	$t=0.63L^{1.37}$	81.47	31.47
		0.1%	37	46.37	$t=0.76L^{1.37}$	98.54	48.54
		0.6%	55	15.03	$t=0.44L^{1.37}$	64.53	14.53

Table 2. Correction factor (F) for water front advance time under surge irrigation (L=60m, W = 90 cm, Q = 1 lps, N = 10, T_{ON} = 5 min, Rc = ½)

Crop growth phases	0.3%	0.1%	0.6%
i) Non-Vegetated	1.00	1.16	0.95
ii) Vegetative			
1) Vegetation	1.18	1.26	1.05
2) Flowering	1.46	1.53	1.31
3) Fruiting	1.68	1.71	1.40
4) Harvesting	1.76	1.86	1.63

4. CONCLUSION

Replacement of the conventional short strip furrow layouts with a long furrow layout results in significant saving of land and manpower [27]. In other words if the entire root zone is to be saturation with a continuous flow 25-40% additional time of irrigation above the net duration of irrigation is inevitable [28]. These also address zero more deep percolation losses nearer to the head reaches. In case of the intermittent flows into the furrow by way of alternate surge ON-OFF timing the overlapping of flow during ON time and recession of flow during OFF times would create a situation of reduced infiltration rates due to partial or complete saturation of the sub soil [10]. This intern accelerates the water front advance and with 5 or 6 surges with in the design duration of irrigation the water front would easily reach the furrow tail end. The conventional check furrow system of irrigation is not favored for mechanized farming due to the hindrances offered against the movement of man and machinery for irrigation operation as well as the package of cultivation practices. But surge flow furrow irrigation system is ideal to facilitate mechanized farming. The use of revalidated existing SURGEMODE model with the correction factor would be the exact suitable model for the local condition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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