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AZEEMI - SURGE POWER EQUATION: A SIMPLE TOOL FOR SIMULATION AND GRAPHICAL COMPARISON OF CONTINUOUS / SURGE ADVANCE RATES

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Abstract

Intermittent water application merits has proven completion of the advanced phase in lesser time in furrows, compared with conventional water application. Power equation was applied to model advance rates during surge irrigation, using two-point technique. A simple procedure was developed by modifying the power equation for simulating later surges advance data from the first surge, by introducing time-reduction factors. The developed equation was further generalized to combine the surge advance rate data, for comparing graphically with the continuous advance rate during an irrigation event. This equation has been named 'Azeemi-surge Power Equation (ASPE). Extensive and reliable field datas were collected from different field experimental stations and applied to verify the equation and developed procedure. From the results of this experimental study, it was concluded that the surging phenomena substantially increased the water movement in the furrows by causing reduction in the advance time during different irrigation events. Further, the results revealed that the advance data collected during irrigation events and simulated by the modified power equation (MPE) matched closely. It was also noted that the 'ASPE' equation helps in developing single advance curve from the surges applied during surge irrigation to compare surges vs.continuous advance rates in irrigated furrows graphically.

Keywords: Surge irrigation, advance rate, power equation, furrow.

1. Introduction

Surge irrigation has the potential to bring drastic changes in gravity irrigation practices that are currently in use. It has the merits of increasing irrigation efficiency by both reducing deep percolation and surface runoff losses from the irrigated fields, and ensures more sub-surface water distribution. All of this is accomplished by the effective means of achieving faster advance down the furrows during surge irrigation, when compared to continuous application [1-9]. Actually, wetting and dewatering consecutives cycles cause reduction in infiltration, resulting in faster movement of the waterfront. Consequently, advance time required to reach the far end of the field is substantially reduced. Furthermore, the total volume of water necessary to complete advance phase is lesser, when surge irrigation is used instead of conventional water applications. All of this leads to improving the uniformity of water distributed thus, improve the application

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efficiency and other performance parameters. Suggested mechanisms responsible for this behavior include surface sealing due to soil particle rearrangement, surface layer consolidation, a more diffuse wetting front, and air entrapment in the soil [10-12].

The Advancement of waterfront during surge irrigation is an important factor in evaluating its performance, and generally power equation is used to describe it. Extensive field data collection is necessary for prediction of surge advance rate in furrows due to the involvement of on-off surge cycles at various time intervals. More importantly, the comparison of surge and continuous advance rates is not based on graphical presentation of advance curves, and only performance indicators are in used so far. Still, simplified procedures are needed on different ways to model furrow advance rates to broaden its use to rapidly simulate and evaluate different scenarios regarding surge irrigation system design, evaluation, and management [13].

This paper focuses on modifying the existing advance power equation for surge irrigation in simulating the advance rate data of later surges from first surge, and to graphically compare surge and continuous advance rates in furrows.

2. Material and Method

2.1. The Power Equation

The Advancement of water over the surface is generally described by empirical power equation of time using observed field data as:

$$t_x = pX^r \tag{1}$$

where X is the waterfront advance distance in meter corresponding to the total advance time t_x in minute along the furrow length, and the parameter p and exponent r are empirical parameters determined by two-point fitting technique [14] as:

$$r = \log\left[\frac{\left(\dfrac{t_L}{t_{0.5L}}\right)}{\left(\dfrac{L}{L_{0.5L}}\right)}\right] \tag{2}$$

$$p = \frac{t_L}{L^r} \tag{3}$$

where t_L and $t_{0.5L}$ are the times for the advancement of waterfront to cover furrow length, L and one-half of the furrow length, $L_{0.5L}$ in minutes. Coefficient of determination R^2 was used as a goodness of fit between the observed and predicted advance rate values.

2.2. Azeemi-Surge Power Equation 'ASPE'

The flow of water over the soil surface presents a complex phenomenon due to spatial variability and non-uniformity in water distribution during any surface irrigation event. The surge irrigation

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further complicates this due to the multiple advances of waterfronts for varying on-off surge cycles during an irrigation event. Several studies have revealed that the surge advance travel time reduces in subsequent surges due to wetting and consolidation of soil [1, 16-17]. This causes reduction in infiltration and thus provides more uniform distribution of water, and higher water application efficiency [18-19]. Past studies revealed that surging effects are more pronounced after initial watering, during first surge [20-26]. Furthermore, it is also found in literature that the first surge behaves like continuous water advance, and the reduction in advance time occurs in successive surges but more pronounced on the wetted section of the first surge [12]. Therefore, it was hypothesized that advance time decreases from first surge to the subsequent surges with certain ratios, assuming the advance rate remained constant over the duration of the on-surge time cycles. To account the advance time reductions, the 'time-reduction factors' were introduced in the power equation for the respective surge to simulate the surge advance rate data. Thus, the modified form of the power equation named as, 'modified power equation' *MPE* is:

$$t_x = f_{tr}\, \mathrm{p}_1\, \mathrm{X}^{\mathrm{r}_1} \tag{4}$$

where, f_{tr} is the time-reduction factor, its value is uniform for the first surge but for subsequent surges, it is the ratio of the water advance time of subsequent surge up to wetted section of the first surge, to the advance time of first surge; p_1 and r_1 are the parameters determined using equations 2 & 3 for the first surge. Equation 5, as mathematically as possible, can describe the time-reduction factor:

$$f_{tr} = \frac{\mathrm{t}_{\mathrm{wsn}}}{\mathrm{t}_{\mathrm{s1}}} \tag{5}$$

where t_{s1} is the time for the advancement of waterfront for the first surge, and t_{wsn} is the advance time for the later surges up to the wetted section of the first surge in minutes; *n* is 1, 2….. for the 1st, 2nd, 3rd surge and so on.
For more simplicity and understanding, the Equation 4 has been described by the following general equation and is named as modified surge power equation '*MSPE*'.

$$\mathrm{t}_{\mathrm{x}} = \mathrm{p}_{\mathrm{s}} \mathrm{X}^{\mathrm{r}_1} \tag{6}$$

in which p_s equals the product of f_{tr} and p_1.

In surge irrigation, multiple surges are needed for completing the advance phase and for complete irrigation. So, extensive field data is required in predicting the advancement of waterfront during surges, and in determining efficiency parameters. Moreover, on comparing surges vs. continuous advance graphically, it looks tedious and impractical as the number of surge curves appeared contrast to the continuous advance curve. To overcome this difficulty, the parameter f_{tr} of equation 4 was re-defined, taking into account the reduction in the advance time from all the surges applied i.e., from final surge to the first surge and further introducing advance-adjustment factor f_{aa} to minimize variation in the advance rate that occurred due to variation in infiltration along the length of furrow. Mathematically, the advance-adjustment factor f_{aa} can be described as:

$$f_{aa} = \frac{\sum t_{sa}}{\sum t_{sco}} \tag{7}$$

where t_{sa} is the total advance time for traveling the waterfronts during surges, and t_{sco} is the total

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cut-off time for all the surges applied during a surge irrigation, in minutes.
Thus, Equation 4 to determine the average surge advance rate from all the surges applied during irrigation has been named 'Azeemi-surge Power Equation' *ASPE* and written as:

$$t_x = n_s \, \mathrm{f}_{\mathrm{str}} \, f_{aa} \, p_1 X^{r_1} \tag{8}$$

where n_s is the number of surges applied during surge irrigation; f_{str} is the surges time-reduction factors and are the ratios of the water advance times of final surge up to the wetted section of surge, to the first surge advance time in minutes, and f_{aa} is the advance- adjustment factor, as already described by Equation 7.
Thus, for simplicity the 'Azeemi-surge Power Equation' *ASPE* can be written as:

$$t_x = p_{as} X^{r_1} \tag{9}$$

where p_{as} is given as:

$$\mathrm{p}_{\mathrm{as}} = f_{str} \text{ x } f_{aa} \text{ x } n_s \tag{10}$$

2.3. Evaluation of the Azeemi-Surge Power Equation

Testing an equation/model for its predictability is vital for establishing its suitability for the intended purpose. Plotting the observed and simulated values can ensure the accuracy of the proposed equation. Quantitatively, the observed values of advance rate measured during surge irrigation and those simulated by the Azeemi-surge power equation, could be compared, and analyzed in several ways. In this study, the prediction error based on absolute values was calculated by comparing the simulated values of the advance times to those measured in the field. The absolute percent error E_p is defined as:

$$E_p = \frac{100}{N} \sum_{i=1}^{N} \left(\frac{t_{obsi} - t_{simi}}{t_{simi}} \right) \tag{11}$$

where t_{obsi} is the observed and t_{simi} is the simulated/predicted advance time data in min at the i^{th} point and N is the number of observations.

2.4. Field Procedure

Field tests were conducted at three different field experimental stations varying in soil and other conditions within the vicinity of the province of Punjab, Pakistan. Each experimental field station consisted of three experimental sites. Each site having a field layout size of 120 m x 8 m was sub-divided into three plots. Each plot consisted of three furrows: continuous irrigation was applied to one furrow, while water was applied by surging to the other two furrows using pre-calibrated siphon tubes. The furrow layout was the same for all the experimental plots, which was systematic rather than random (Figure 1). Furrows were manually prepared and were parabolic in shape having a furrow spacing of 60 cm. Water was applied from a watercourse using siphon tubes, which were 1.52 m long and 5 cm in diameter. A constant head in the supply channel was maintained during irrigation. In each furrow, one siphon tube was installed, keeping one end of it dipped into the reservoir, while the other end was at the inlet of furrow for releasing water. A rubber plug was used at the discharging end of the siphon to stop the water flow, when

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desired. That is how on-off mechanism was provided during surging. Each furrow was operated separately during the experiment, and the observations were made by placing wooden stacks at equal intervals of 12 m along the length of furrows. The total volume of water applied to each furrow was calculated from

the flow rate and application time. Extensive advance rates data were collected from the experimental sites for both surge and continuous irrigations. Field data was used to apply the 'ASPE' (Equation 10) in simulating the advance rate from surges applied during surge irrigation, as a single advance curve, to compare it graphically with the continuous advance.

Table 1. Averaged advance rates observed at three selected furrows during 1st, 2nd and 3rd irrigations from experimental plots 'A', 'C' and 'B' respectively at BPF-Kasur experimental site.

Irrigation event	Irrigation technique	On-off time (min)	Cycle ratio	Surge No	Advance distances times (min) Mid-point $X_{0.5L}$	Mid-point $t_{0.5L}$	Wet-point X_{wL}^*	Wet-point t_{ws}^*	End-point X_L	End-point t_L
1st Irrigation	Continuous	24-0	1		60	09	-	-	120	24
Plot A	Surge	10-5	0.66	1	36	5.33	-	-	72	12.17
		10-5	0.66	2	60	4.33	72	5.38	60	4.33
2nd Irrigation	Continuous	16	1		60	6.45	-	-	120	16
Plot C	Surge	4-4	0.5	1	36	2.75	-	-	60	7.47
		4-4	0.5	2	48	2	60	2.67	96	7.73
		4-4	0.5	3	60	2.4	60	2.4	120	7.89
3rd Irrigation	Continuous	21	1		60	10	-	-	120	21
Plot B	Surge	6-4	0.66	1	24	4	-	-	36	8.95
		6-4	0.66	2	36	3.11	36	3.11	60	7.75
		6-4	0.66	3	60	6.5	36	2.12	120	16

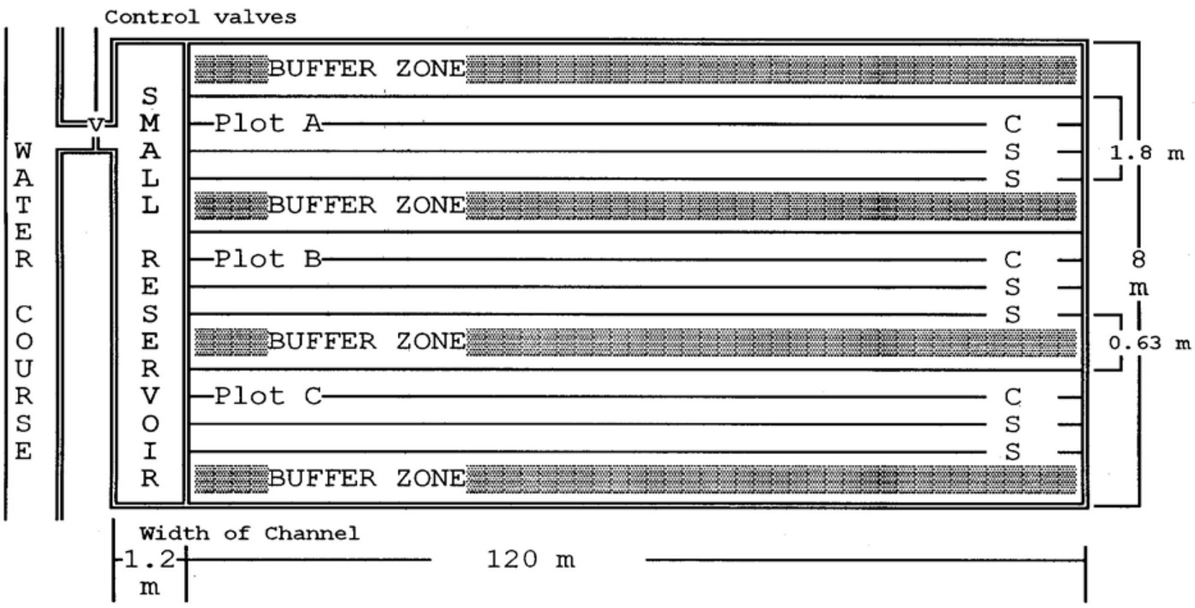

Figure 1. Experimental field layout for continuous and. surge irrigation furrows at 'Kasur' site.

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* X_{wL} is the distance traveled on the wet furrow section and t_{ws} is the corresponding advance time for latter surges.

To demonstrate the application of 'ASPE', the data collected for 1st, 2nd and 3rd irrigations from plots 'A', 'C' and 'B' at one of the experimental site in Kasur is presented in this paper as an example. A summary of the field observed input advance distance-time data at mid-point, up to the wet-point of the first surge, and at the end of the surge on-time for each surge of water during different irrigations from different furrows are given in Table 1. For more detail, interested readers should refer to Latif and Ittfaq [23, 27].

3. Results and Discussion

The advance phase in surface irrigation is very important for efficient irrigation. A longer advance time normally increases the water losses due to slow advance rates. Therefore, a high inflow is recommended to obtain rapid advance, thereby reducing the advance time, and maximizing uniformity of water infiltration. Innovation in surface irrigation, like surge irrigation, has brought drastic increase in the advance rates, especially in furrow irrigation method. Most importantly, it causes decrease in the infiltration and provides faster advance rate, causing more uniform distribution of water [28].

The Field data collected for different irrigations from one of the selected sites at Kasur experimental field station is used to describe the application of *ASPE* in this paper. Power equation was applied to describe the behavior of advance rates, during both the continuous and surge irrigations. The advance data at mid-point and end of the on-time for each surge of water are used to find the parameters 'p' and 'r' of the power equation using two-point technique (Equations 2 & 3). However, the wet-point, i.e., up to the first surge wetted furrow section, and end-point advance times for latter surges, are used to determine the time reduction factors in simulating the surges advance rates. The resulting parameters 'p' and 'r' during different irrigations obtained by using the two-point technique, are given in Table 2, for both continuous and surge applications.

Table 2. Coefficients 'p' and 'r' of simple power equation for continuous and surge irrigations during 1st, 2nd and 3rd irrigations at field plot 'A', 'C' and 'B'

Irrigation event	Irrigation technique	Surge number	On-off time periods (min)	Simple power-equation parameters		Coefficient of determination
				R	p	R^2
1st Irrigation	Continuous		24-0	1.415	0.027	0.99
Plot A	Surge	1	10-5	1.191	0.075	0.99
		2	10-5	1.637	0.005	0.99
2nd Irrigation	Continuous		16-0	1.311	0.030	0.99
Plot C	Surge	1	4-4	1.956	0.002	0.99
		2	4-4	1.95	0.001	0.99
		3	4-4	1.717	0.002	0.99
3rd Irrigation	Continuous		21-0	1.070	0.125	0.99
Plot B	Surge	1	6-4	1.986	0.007	0.99
		2	6-4	1.787	0.005	0.99
		3	6-4	1.300	0.032	0.99

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All the mathematical models for the advancement of waterfront in furrows by employing surge and continuous irrigations were found to be exponential functions of the advance time (Table 2). The exponential nature of these models can be determined with high degree of coefficient of determination i.e., 0.99. The use of empirical formulation sometimes simplify the physical process and provide better understanding of the phenomena.

During surge irrigation, consecutive wetting and dewatering cycles first surge cause reduction in infiltration and then the water moves faster. Thus, the advance time required to reach the end of the field is consequently reduced. With regards to the reduction in advance times between latter surges from the wetted furrow section of the first surge, it was hypothesized that the advance time decreases uniformly in the entire on-time of a surge cycle for latter surges from the first surge and it further increases, but slowly and continuously, with the subsequent surges of an irrigation event.

Therefore, the power equation (Equation 1) was modified by defining the time-reduction factors for the respective surge using the parameter 'p_1' of 1st surge, keeping parameter 'r_1' constant for the entire surge irrigation. This was done by multiplying parameter 'p_1' with the respective time-reduction factor. Thus, modified surge power equation (Equation 6) was used to simulate advance time data for the subsequent surge. The time-reduction factors, determined by applying Equation 5 and their resulted adjusted parameters 'p_s' of the modified surge power equation for different irrigations, are given in Table 3.

Table 3. Estimated time reduction factors 'f_{tr}' and modified coefficients 'p_s' of modified power equation for different surges during 1st, 2nd and 3rd irrigations.

Irrigation event	Surge No	Surge on-off time (min)	Advance time to the dry-section of 1st surge (min)	Modified surge power equations parameters			Equation performance indicators	
			t_{wsi}	p_1	f_{tr}	p_s	Ep (%)	STD
1st irrigation	1	10-5	12.17	0.075	1	0.075	2.137	4.385
Plot A	2	10-5	5.38	0.075	0.442	0.033	1.165	3.737
2nd irrigation	1	4-4	7.47	0.002	1	0.002	12.18	2.712
Plot B	2	4-4	2.67	0.002	0.357	0.0001	3.568	2.415
	3	4-4	2.4	0.002	0.321	0.0001	2.356	2.779
3rd irrigation	1	6-4	8.95	0.007	1	0.007	0.464	3.657
Plot C	2	6-4	3.11	0.007	0.347	0.0002	0.536	3.012
	3	6-4	2.12	0.007	0.237	0.0001	2.574	6.808

The surge advance rate curves developed by applying power equation (Equation 1) using two-point technique and simulated by the modified power surge equation (Equation 6) for the latter surges during different irrigation events, are plotted in Figures 2 to 4 for more clarity.

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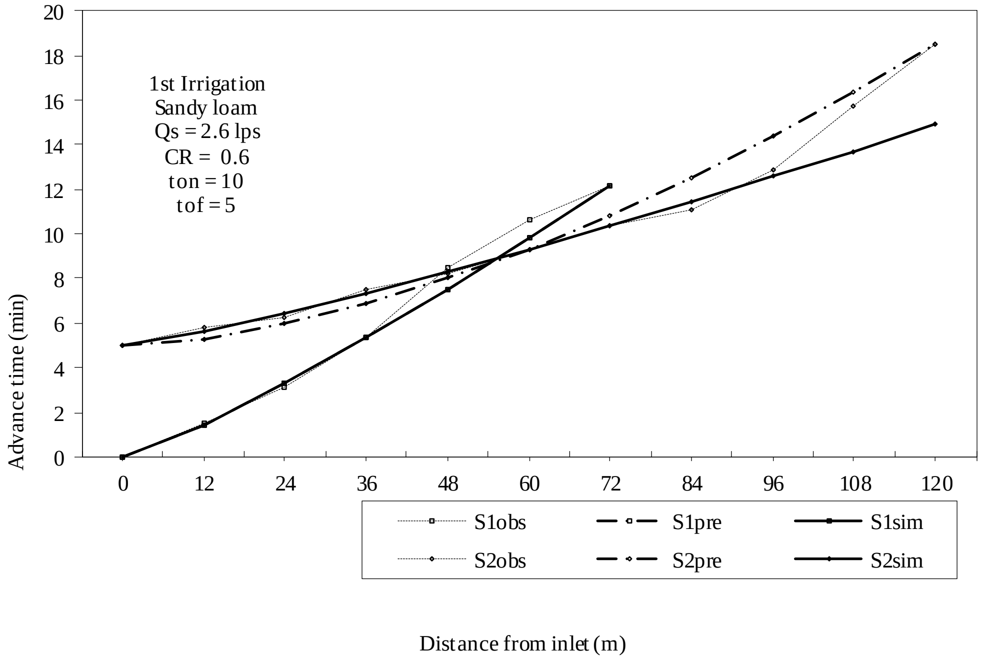

Figure 2. Comparison of observed (obs), predicted (pre) by two-point technique, and simulated (sim) by modified surge power equation, surge advance rates for irrigated furrow in plot 'A.

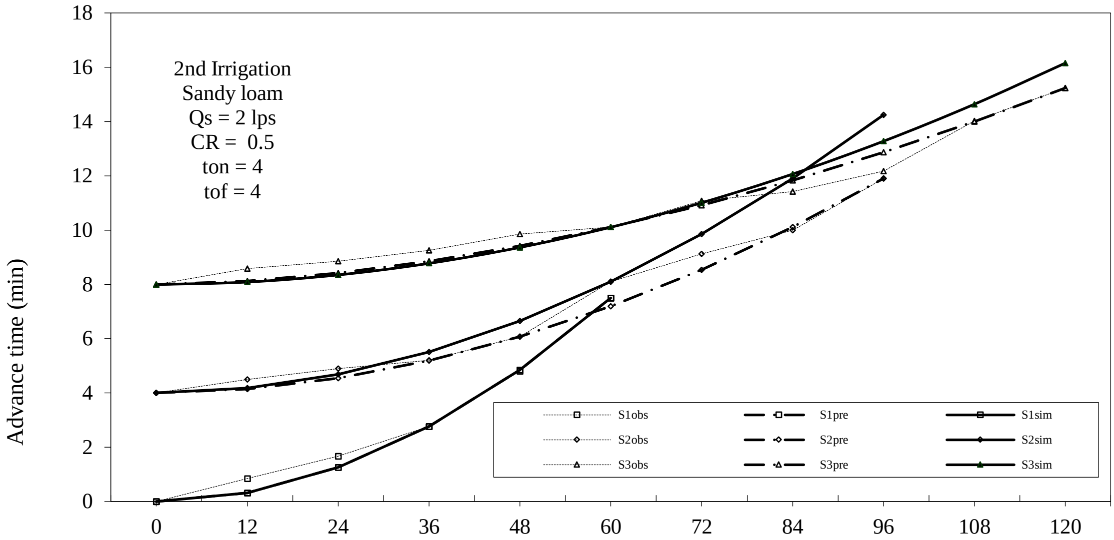

Figure 3. Comparison of observed (obs), predicted (pre) by two-point technique and simulated (sim) by modified surge power equation, surge advance rates for irrigated furrow irrigated in plot 'C'.

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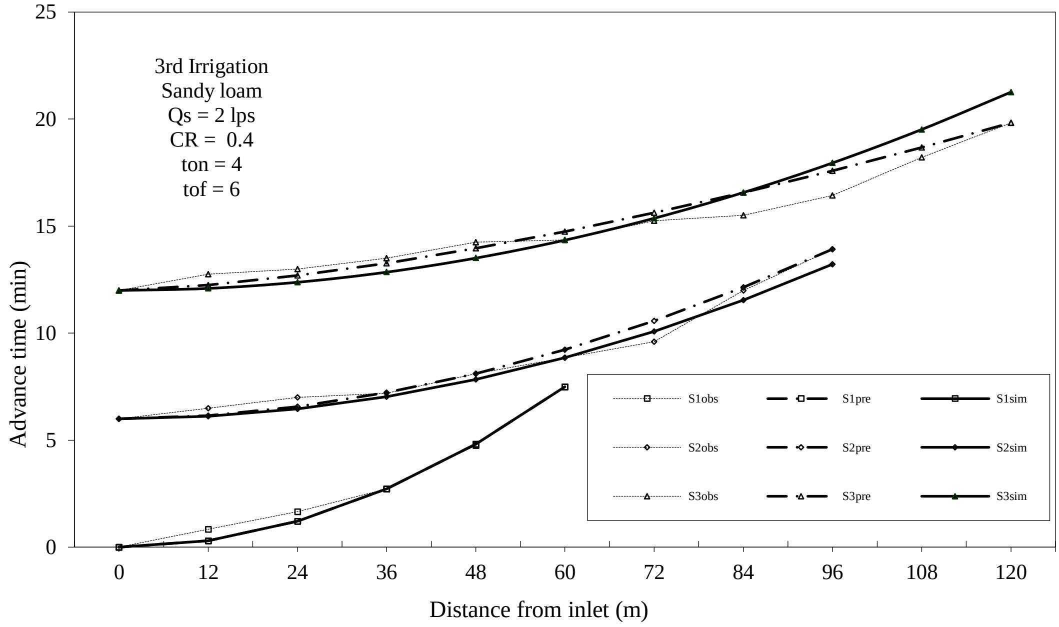

Figure 4. Comparison of observed (obs), predicted (pre) by two-point technique and simulated (sim) by modified surge power equation, surge advance rates for irrigated furrow in plot 'B'.

The absolute percent error as calculated using Equation 10 varies from 0.464 to 12.18% (Table 3) for different surge irrigations. These values are below 15% and thus, fall within the acceptable limit. The observed data curves, indicate that, as expected, the advance phase during the first surge behaves like continuous irrigation for equal instantaneous inflow rates in all the field tests (Figures 2 to 4). It is interesting to note from these figures that the distance traveled by the advancing front is less on newly cultivated field during first irrigation, and the water advances slowly. When the next surge is applied, the distance traveled by the advancing front towards the lower end of furrow field is more for higher instantaneous inflows and less number of surges are needed in order to reach the waterfront as it advances to the lower end of the field. It can also be observed from the figures that the advance curves predicted by the two-point technique nicely matched with the observed data. The surge curves are nearly parallel to each other up to the point where the furrows were wetted by the previous surges, and then water movement slowed down due to inflow cutoff. The advance sharply decreased during recession due to off-time of the surge, but it moved faster during the next wetting phase.

The reasons for this response are the mechanisms mainly involved in explaining the effects of surge irrigation. These includes: (i) filling of cracks that develop during flow interruption with bed load during the following surge [17]; (ii) greater sediment detachment and movement caused by more rapid advance of the surge stream front [17,29]; (iii) forced deposition (and consolidation) of suspended sediment on the furrow perimeter when the water supply is interrupted [11]; and (iv) air entrapment [30] and its expansion upon rewetting [31].

The simulated advancement of waterfront for latter surges by applying modified power equation, has shown that the simulated advance curves initially matched closely and follow the same pattern as observed in the field, but afterward, it slightly over or underestimates the advance time

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compared with the observed advance time. This variation may be due to assuming a constant value of the parameter 'r1' of the first surge for the latter surges, as simulation is made based on the first surge advance data in which the water movement is slowed along the furrow but actually in the field, it moves faster during latter surges. This parameter was considered constant to simplify the simulation procedure from limited measured data. Low absolute error values (Table 3), support the application and adoptability of the modified surge power equation to simulate the advance data for latter surges during surge irrigation.

3.1. Advance Rates Surge vs Continuous

The application of the modified surge power equation was further extended to simulate the advance rates from the surges applied during surge irrigation, to broaden its applicability and to compare with continuous advance rates graphically. This would certainly help in estimating irrigation performance of surge irrigation by simply using available software for continuous irrigation. This was accomplished by re-defining the time-reduction factor 'f_{tr}' based on surges applied during surge irrigation event. The time reduction factor for surge irrigation was calculated by taking the ratio of the final surge advance time to the 1st surge advance time and is denoted as, 'f_{str}'. Another factor called advance-adjustment factor 'f_{aa}' was also calculated by taking the ratio of the total advance times to the total on-time for the application of surges during surge irrigation (Equation 7). These factors were multiplied with parameter 'p_1' of the 1st surge and the number of surges 'n_s' applied during surge irrigation to find the adjusted parameter 'p_{as}' of the *ASPE* equation. These are presented in Table 4.

Table 4. Estimated advance adjustment factors 'f_{aa}' and adjusted modified coefficients 'p_{as}' of Azeemi-surge power equation during 1st, 2nd and 3rd; irrigations plots for different plots.

Field site	Irrigation event	Number of surges	Surge times (min)				Parameters of Azeemi-surge power equations			
		n_s	t_{sco}	t_{sa}	t_{sa1}	t_{san}	p_1	f_{str}	f_{aa}	p_{as}
A	1st irrigation	2	20	25.6	12.2	5.38	0.075	0.442	1.282	0.085
C	2nd irrigation	3	12	24.0	7.47	2.40	0.002	0.321	1.924	0.501
B	3rd irrigation	3	18	32.7	8.95	2.12	0.007	0.391	1.816	0.005

By applying equation 9, the average single advance curve was simulated from surges applied during surge irrigation and was compared with the continuous advance curve in Figures 5 to 7 for different irrigations in plots 'A', 'C' and 'B' respectively. The figures 5 to 7 indicate that the advance phase of waterfront simulated by 'ASPE', is faster during surge irrigation, compared with continuous irrigation advance except for 3rd irrigation at experimental site 'B'. This unexpected behavior for the 3rd irrigation may be associated with the slow movement of the advancing front during 1st surge and larger variation in empirical parameters, which are used in simulating the advance rates by applying 'ASPE'.

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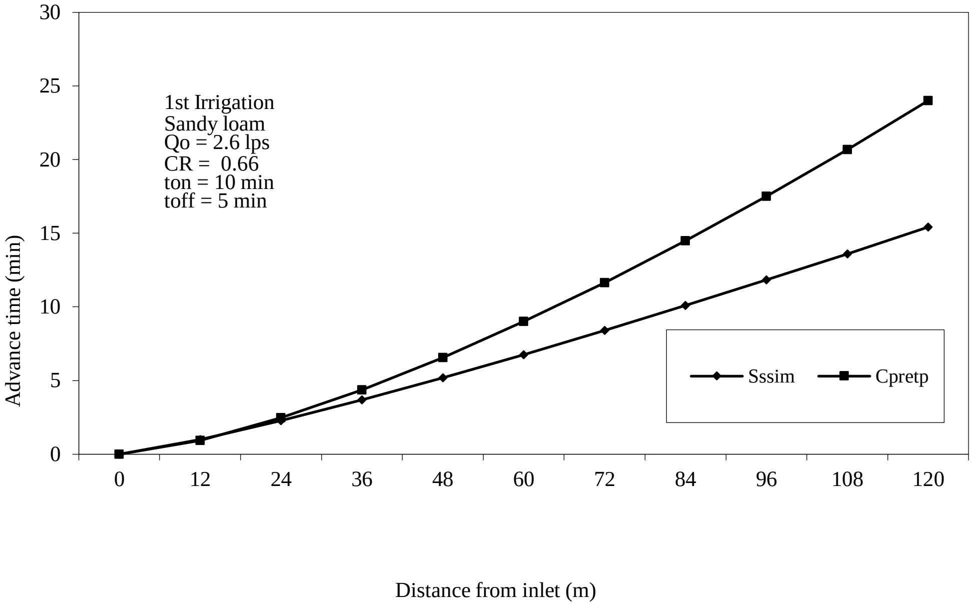

Figure 5. Comparison of advance rates between predicted continuous advance (Cpretp) with the simulated (ssim) by Azeemi-surge power equation for the surges applied during 1st irrigation at furrow irrigated experimental plot 'A'

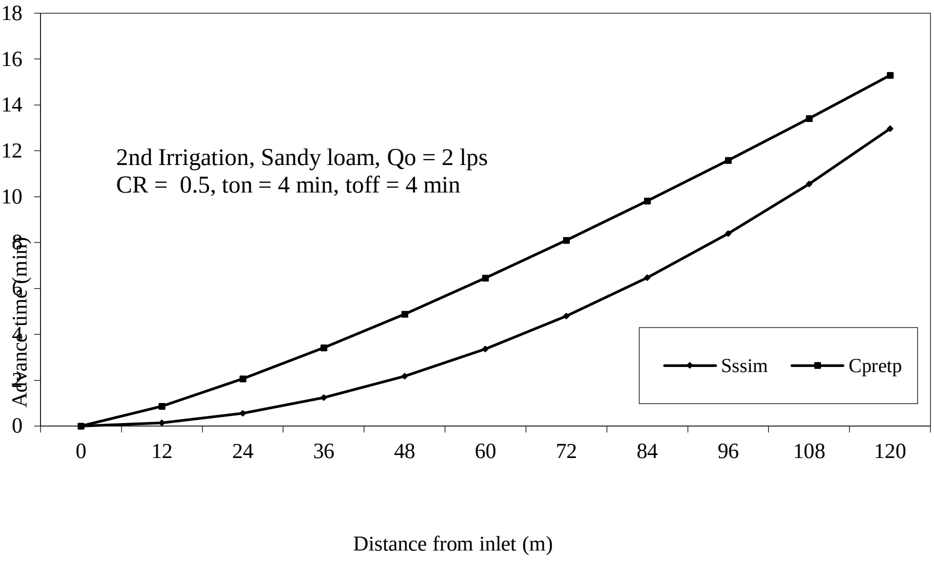

Figure 6. Comparison of advance rates between predicted continuous advance (Cpretp) with the simulated (ssim) by Azeemi-surge power equation for the surges applied during 2nd irrigation at furrow irrigated experimental plot 'C'

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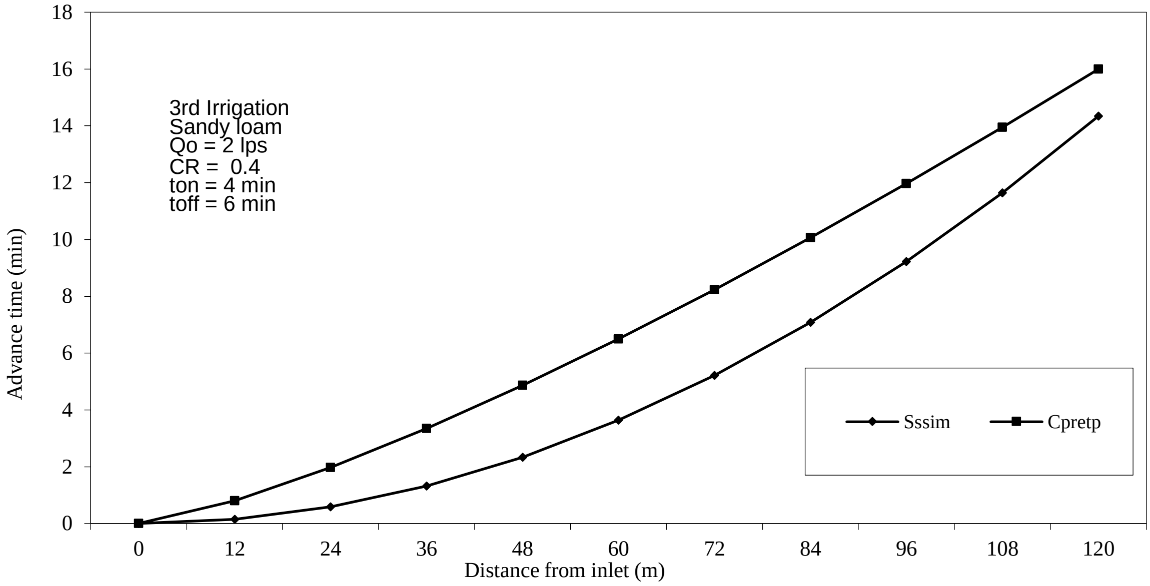

Figure 7. Comparison of advance rate between predicted continuous advance (Cpretp) with the simulated (ssim) by Azeemi-surge power equation for the surges applied during 3rd irrigation at furrow irrigated experimental plot ‘B

It is also noted from these figures that in some cases, the advance curve simulated for surge irrigation initially overlaps with the continuous advance, and afterward, it diverts showing faster movement in completing the advance phase compared with continuous irrigation. This behavior of surge is in accordance with the one reported by [1], who indicated three to four times faster advance rate in surge flow compared with continuous one in furrows. Similarly, the results reported by Mahmood, 1993 [32], are also in line with the results obtained in the present study. One common conclusion of these scientists is that the surge flow technique requires lesser time compared with its conventional counterpart. The reason for this response is now well understood and associated with the infiltration phenomenon that occurred in subsequent surges in the previously wetted furrow section(s) due to consolidation of a thin layer of fine material at the bottom of the furrow, by destruction of the soil aggregates and other reasons as discussed earlier. As a result, the permeability of the soil surface is reduced, and thereafter infiltration rates are reduced in the previously wetted section(s) of furrow during subsequent surges. Evidence of the consolidation of the fine layer between surges can usually be observed after the water has completely drained from the field. Tension cracks are formed between the layer of fine material, and those less disturbed by the flow. When water is again introduced into the field, sediments are deposited in these cracks and they begin to swell, thereby further compacting the surface layer. This mechanism causes increase in the advance rate and thus reduces the application time in completing the irrigation event during surge irrigation.

Testing the application of ‘ASPE’ in simulating the average advance rate from surges, is a complicated phenomenon. This is because of the reason that the advance rate during early surges never reached the lower end of the furrow, and therefore estimating the average trends from surges is not possible. It needs some logical procedure to verify it for the advance simulated by ‘ASPE’. To accomplish this, the advance rate data simulated both by the modified surge power equation and predicted by the two-point technique for surges were,

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extended to the entire length of furrow and then averaged. These data were then compared with the advance data simulated with the 'ASPE', and absolute percent error is used as an indicator to test its accuracy. The resulting average advance data simulated for different irrigations presented in Table 5 shows that the absolute percent error varies from 1.88 to 8.81%, which further supports the accuracy of using 'ASPE' in simulating the advance rate for surge irrigation. This would certainly help in graphically comparing continuous and surge advance rates in furrows.

Table 5. Comparison of average advance times predicted (Sa_{pre}) by two-point technique, simulated by modified power equation (Sa_{sim}) with the simulated (Sa_{ssim}) by Azeemi-surge power equation from surges

Distance from furrow inlet (m)	Average advance times (min)								
	Plot A			Plot C			Plot B		
	Sa_{pre}	Sa_{sim}	Sssim	Sa_{pre}	Sa_{sim}	Sssim	Sa_{pre}	Sa_{sim}	Sssim
0	0	0	0	0	0	0	0	0	0
12	0.875	1.038	0.99	0.20	0.179	0.161	0.23	0.175	0.151
24	2.127	2.371	2.27	0.75	0.696	0.623	0.82	0.691	0.594
36	3.603	3.843	3.67	1.63	1.539	1.378	1.74	1.541	1.324
48	5.257	5.414	5.18	2.82	2.701	2.418	2.97	2.722	2.34
60	7.062	7.062	6.75	4.32	4.18	3.742	4.49	4.233	3.639
72	9.003	8.775	8.39	6.12	5.971	5.345	6.32	6.072	5.219
84	11.07	10.54	10.1	8.22	8.073	7.227	8.43	8.237	7.08
96	13.25	12.36	11.8	10.6	10.48	9.384	10.8	10.73	9.221
108	15.53	14.22	13.6	13.3	13.2	11.82	13.5	13.54	11.64
120	17.92	16.12	15.4	16.3	16.22	14.52	16.5	16.68	14.34
Ep (%)	-	-	1.88	-	-	8.81	-	-	3.09

4. Conclusion

Several studies revealed that surge irrigation has proven its worth in terms of the reduction in infiltration thereby improving advance rate and reducing the irrigation application time, consequently leading to more uniform distribution of water along the furrow length. Field observed data indicated that surge irrigation causes reduction in the advance time, thereby increasing the advance rates in furrows. Several reasons have been presented for this reduction. It was also observed that the surging affects are more pronounced during first surge. A new and straightforward technique is presented for simulating the latter surge advance rates using 1st surge data, and respective later surge advance time at the end of surge cycle. Comparison of the observed results with the one simulated, has shown a fairly good agreement except for one case. The concept of the application of modified surge power equation was further generalized to simulate the single advance rate data from all surges applied during surge irrigation. The equation so developed is named 'Azeemi-surge Power Equation' *ASPE*. The application of 'ASPE' during surge irrigation is found to be good addition in comparing surge vs continuous advance rates graphically in furrows. It also presents a mean to overcome the laborious data collection during surges.

Conflict of Interest: The authors declare that they have no conflict of interest

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