PERFORMANCE OF SURGE IRRIGATION UNDER BORDERS

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Field tests were conducted to compare continuous and surge irrigations in the plots of similar dimensions for assessing their potential in improving irrigation system performance and wheat production. Water applied during surge treatments advanced faster compared with continuous one. On the average, water saving of 8 to 34 percent was observed in surge-irrigated plots under different levels of discharge and tillage depth. Keeping in view different parameters like volume of water, distribution uniformity, application efficiency, deep percolation losses and yield of wheat, the surge mode of irrigation is convincingly better compared with conventional/continuous irrigation even under the border irrigation.

INTORUDUCTION

Export bills of Pakistan Government in food grains are threatening and this situation may worsen, if proper planning is not done within this decade. Amongst others, water management is one of the major factors that have always strained our agricultural production. Therefore, every effort should be made to introduce such irrigation methods that farmers can adopt to minimize the loss of water by improving system performance and maximize their benefits from the limited water resources. One way to improve this situation is the application of surge irrigation instead of conventional surface irrigation methods.

Surge irrigation is the intermittent application of water to furrows or borders in a series of on-off time intervals, which vary from few minutes to hours. Surging benefits reported may include faster water advance, increase in infiltration uniformity, a reduction in the total volume of water required for irrigation and less total irrigation time (Podmore and Duke, 1982; Izuno and Podmore, 1985; Latif, 1992). The primarily objective of the present study was to investigate the potential of surge irrigation in terms of irrigation system performance.

Past work

Surge irrigation gained popularity when Stringham and Keller (1979) found that even a smaller stream size in surged irrigation completed the irrigation advance phase faster than continuous one. This phenomenon was discovered while the authors were trying to automate cutback furrow irrigation by reducing the inflow during wetting phase to reduce tail water runoff.

Mahmood (1991) compared surge and continuous flow irrigation techniques in furrows. The furrow slope was 0.01 percent and the soil was sandy clay loam. Length of the furrows was 55 m with 76 cm spacing. The plot with continuous/conventional irrigation treatment took about 17% lesser time to complete the advance please than the surge treatment. This unexpected performance of surge advance rate was considered to be associated with soil, leveled field and a smaller discharge of 0.055 cu-m/min.

Results of the study conducted by Mahmood and Sial, 1992, revealed that larger off time in smaller cycle ratios resulted in more soil sealing and consequently a faster advance compared with other values of cycle ratios (less than one). Water advance was faster in shallow tilled plots than deep tilled plots because deep tillage provided greater depth of loose soil ready for water intake (Mahmood *et al.,* 1995). However, the surge irrigation was found to be better than its counterpart in respect of application, deep percolation and water requirement efficiencies and uniformity of water distribution in the soil profile over entire length of the field. This behavior of surge irrigation encourages additional work on various aspects of surge irrigation.

Khan (1993) took an initiative to test the concept of surge flow irrigation at the same site under border irrigation system. Results showed that surge flow irrigated borders had higher application efficiencies and less total water applied than the plots under continuous flow irrigation. This study establishes the advantage of surge technique over the conventional one in border irrigation. Results of the study were similar to those reported by Westesen and Biglen (1986) and Mahmood *et al.* (1997) using surge flow technique on large graded borders under different conditions.

MATERIALS AND METHODS

A field measuring 96 x 60 m was selected for experimentation at MAK Experimental Farms 20 kilometers west of Faisalabad city. The area was divided into two main blocks each 48 x 60 m. Each block consisted of 8 borders of equal size (6 x 60m). The first block was plowed with conventional narrow tine cultivator to a depth of 11 cm whereas the second block was chiseled up to 27 cm depth, followed by one pass of rotavator. Two levels of discharge, that is, 21 liter/s and 27 liter/s were used for assessing the performance potential of surge irrigation. Field was nearly flat and application of water was made using tube well water with the help of Hydro-Pulse Value designed in a way to create surges of water with constant or variable cycle times. Soil sampling was done 24 hours before as well as after the application of irrigation at three locations in the experimental main blocks in 30 cm increments up to 120 cm depth with the help of a sampling tube for estimating system performance parameters. Advance rates of the flowing water were measured in each plot. For this, stakes were placed at five meter intervals starting from the head up to tail end of the field and the flow time for arrival of water at each stake were recorded with the help of a stop watch. Water discharge was measured by flow meter. The soil texture was found to be sandy clay loam and the crop grown during experimentation was wheat. Grain samples were taken at head, middle and tail of the each border for yield estimation of wheat crop. The data collected for both surge and continuous irrigation were analyzed.

RESULTS AND DISCUSSION

Surge versus continuous flow irrigation advance

The cumulative advance time data for both surge and continuous irrigation systems averaged across the discharge and tillage levels are given in **Table 1**. A comparison of surge and continuous flows indicates that 13.92% less time is required to complete advance phase under surge flow compared with continuous flow. This behavior of surge is in accordance with the one reported by Bishop *et al.* (1981) on silt loam soil using variable cycle ratios and time. The results obtained by Bishop et al. (1981) indicate three to four times faster advance rate in surged flow compared with continuous one. Similarly the results reported by Manges and Hooker (1984), Phillip et al. (1982), Strongman and Keller (1979) and Evans et al. (1987) are also in line with the results obtained in the present study. The reasons for lesser time required for the surge flow to complete the advance phase stem from the fact that infiltration rate of soil is slowed in subsequent surges and this reduction in infiltration is primarily due to the consolidation of a thin layer of fine material at the bottom of the furrow or the border by the destruction of the soil aggregates. As the water drains down from the field between surges, a negative pressure develops that consolidates the surface layer by collapsing the larger pores, attracting small particles into the lattice between larger particles, and getting clay and silt into a layered structure. As a result the permeability of the soil surface is reduced and thereafter infiltration rates are lowered. The reduction in soil permeability seems to be more pronounced in sandy loam soils. Evidence of the consolidation of the fine layer between surges can usually be observed in the field 5-15 minutes 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 sealing the surface layer. This mechanism brings reduction in infiltration, increasing the advance rate, and thus reducing the application time for completing the irrigation during surge irrigation.

Table 1. Comparison of surge and continuous flow irrigation advance times

Distance from Stream (m)	Continuous Flow (min)	Surge Flow (min)
05	01.70	01.52
10	03.41	02.98
15	05.53	04.78
20	07.05	07.01
25	09.13	08.75
30	11.57	10.12
35	14.98	12.00
40	17.56	14.44
45	20.67	17.24
50	23.53	19.00
55	27.06	21.00
60	29.62	26.00

Effect of stream discharge on irrigation advance time

Cumulative water advance times for the two discharge levels are given in **Table 2-a** and **Table 2-b.** The discharge 27 *l*/s has better performance compared with 21 *l*/s both under surge and continuous irrigations in terms of time. Interaction of the discharge with type of flow is also interesting. The larger discharge is 44.5% faster than smaller one under surged mode of irrigation; whereas, the same is 20.1% under continuous flow. It further suggests that the larger discharge is more beneficial especially under the surge irrigation. However, other penalties of larger discharge like total water volume should be kept in view while comparing with its counterpart.

As the larger discharge advances faster, it results in a thinner water application with minimal deep percolation losses. The larger discharge may therefore, be more beneficial in case of light soil. In fact, for a larger discharge, the surface roughness and depression storage cannot inhibit movement of water front. In

Table 2-a. Effect of stream discharge on irrigation advance time under surged flow

Distance from stream (m)	Discharge (27 l/s) Advance time (min)	Distance from stream (m)	Discharge (21 l/s) Advance time (min)
13	03.17	11	03.50
24	07.37	20	08.00
37	12.51	37	13.50
60	18.68	49	20.00
-	-	60	27.00

Table 2-b. Effect of stream discharge on irrigation advance time under continuous flow

Distance (m)	Discharge (27 l/s) Advance time (min	Discharge (21 l/s) Advance time (min)
05	01.83	01.57
10	03.03	03.58
15	04.92	06.14
20	06.43	07.67
25	08.74	09.53
30	11.28	11.87
35	14.54	15.43
40	16.91	18.21
45	19.62	21.72
50	22.04	25.02
55	24.65	29.46
60	26.92	32.32

addition, for higher discharge value, the tail end of field starts receiving water before the head becomes waterlogged, whereas for smaller discharge (21 l/s), the value of discharge is slightly higher than the infiltration rate of the soil, secondly the roughness and depression storage become a great hurdle in the movement of water front for this reason the head of the field becomes water logged as the water reaches the tail end of the field.

Effect of tillage depth on advance rate

The data on cumulative advance times for two levels of tillage depth averaged across the discharges are given in **Tables 3-a** and **3-b**. The cumulative time required for the water front to reach the far end of the border was 21.40 minutes in the plots tilled to 11 cm depth and 31.05 minutes for those tilled to 27cm depth. The trend is clear, that is, the advance is faster by 40.4% in shallow tilled soil compared with deep tilled soil. Apparently considerable water saving results by selecting shallow tillage coupled with surge mode of irrigation. It may, however, be remembered that deep tilling is established practice in modern agriculture and the deep tillage brings with it manifold economic benefits in terms of breakage of hard layer, washing salts from the root zone and ultimately the yield of crops.

Table 3-a. Effect of tillage depth on advance time of water front in surged flow.

Distance (m)	Tillage Depth (11 cm) Advance time (min)	Distance (m)	Tillage Depth (27 cm) Advance time (min)
12	02.67	10	04.00
18	06.34	21	09.00
27	10.01	33	15.00
45	15.68	49	22.00
60	21.68	60	30.00

Table 3-b. Effect of tillage depth on advance time of waterfront in continuous flow.

Distance (m)	For Tillage Depth (11 cm) Advance Time (min)	For Tillage Depth (27 cm) Advance Time (min)
05	01.55	01.85
10	03.42	03.39
15	05.09	05.98
20	06.50	07.55
25	08.37	09.89
30	10.03	13.12
35	12.50	17.46
40	14.85	20.27
45	17.18	24.16
50	19.31	27.75
55	21.26	32.85
60	23.14	36.10

Water volume ratio of surge and continuous irrigation

One measure of the effectiveness of surge irrigation expressed as volume ratio (It is the ratio of water volume applied in surge method to the volume of water applied in conventional method). For all possible combinations of tilling depth and discharge levels, the volume ratio remained less than one **(Table 4).** This clearly indicates less total water is required to complete the advance phase in surged irrigation compared with continuous one.

Table 4 further reveals that a larger discharge coupled with deeper tillage resulted in the maximum water saving of 34 % among all the other combinations. This also suggests the surge mode of irrigation can even offset ill-effects of deeper tillage in water saving.

Christiansen's uniformity coefficient for surge versus continuous irrigation

Christiansen's uniformity coefficient is another measure of the effectiveness of water application. Christiansen's uniformity coefficient is used to describe the water distribution pattern throughout the plot. The UCC for surge irrigation is 10-15 % higher than continuously irrigated plots for both discharge and tillage levels **(Table 5).**

Table 4. Effectiveness of irrigation advance using volume ratio

Tilling Depth (cm)	Irrigation Method	Q (l/s)	Time (min)	No. of Surges	Water Volume (m^3)	Volume Ratio (V_s/V_c)	Water Saving (%)
11	Surge	27	15.33	4	24.83	0.76	24
		21	24.00	5	30.24	0.92	8
	Continuous	27	20.25	1	32.81	-	-
		21	26.02	1	32.78	-	-
27	Surge	27	22.00	4	35.64	0.66	34
		21	30.00	5	37.80	0.78	22
	Continuous	27	33.58	1	54.40	-	-
		21	38.62	1	48.66	-	-

Q = discharge
V_s = water volume in surges
V_c = water volume in continuous irrigation
Water saving (%) = $(V_c-V_s) / V_c \times 100$ (for same tilling depth)

Table 5. Christiansen's uniformity coefficient for different levels of various factors

Method	Discharge (1/s)	Tillage Depth (cm)	No. of Surges	UCC (%)
Surge	27	11	4	93
	27	27	4	95
	21	11	5	96
	21	27	5	86
Continuous	27	11	1	90
	27	27	1	84
	21	11	1	87
	21	27	1	82

Better performance of the surge irrigation in respect of UCC is associated with the fact that surges cause breakage of soil aggregates resulting in sealing of soil microspores. This process reduces the water infiltration during the subsequent surges especially near the stream end of the field. On the contrary, the continuous flow irrigation results in flooding near the stream end and therefore, disturbing the distribution of water through length of the field.

Application efficiency and deep percolation ratio for surge and continuous flows

In addition to several other parameters, an irrigation system is also evaluated in terms of irrigation application efficiency and deep percolation ratio (DPR). These performance parameters were determined to bring out the relative benefits of surge and continuous irrigation flows (**Table 6**).

Table 6. Application efficiency and DPR as affected by surge and continuous flows

Method of Irrigation	Discharge (1/s)	Tillage Depth (cm)	E_a (%)	DPR (%)
Surge	27	11	67.03	09.68
	27	27	56.79	25.56
	21	11	57.81	21.95
	21	27	48.48	38.39
Continuous	27	11	57.13	23.20
	27	27	32.47	55.91
	21	11	35.53	30.41
	21	27	39.20	48.86

Where, Ea = Water application efficiency
DPR = Deep percolation ratio

On the average, application efficiency of surged irrigation was 57.5% compared with 41.1% for the continuous one. Once again, it establishes the superiority of the surge flow over its counterpart. The highest application efficiency of 67.03% is associated again with the surge mode of irrigation having larger stream discharge and shallower tilling depth. The lowest value of application efficiency of 32.47% was registered in the plots with continuous flow, higher discharge and deeper tillage. These responses were expected in the light of discussions presented earlier. The highest deep percolation losses (DPR) of 55.91% were recorded in the plots under continuous irrigation, higher discharge and deeper tillage, whereas the least DPR of 9.68% was recorded in the plots under surge irrigation, with larger discharge and shallower tillage. This has established the benefit of surge flow over the continuous once.

Yield of crop

One of the important parameters in the evaluation of any soil-water-plant system is the yield of crop. Wheat yields obtained from the plots are given in **Table 7-2a and 7-b.** As revealed from these tables, yields are invariably higher for deep tilled plots compared with shallow ones.

The differences in the deep tilled plot were up to 35% in surge irrigation plots as against 21% in the continuous plots. However, there is a penalty of larger volume of water being used by the deep tilled plots. Therefore, the decision as to the adoption of deep tillage needs to be made carefully by examining its additional water requirements and economic returns in terms of yield. It may be remembered here that surged plots with higher discharge (27 *l*/s) and greater tilling depth (27 cm) **(Table 4)** rendered maximum water saving compared with continuously irrigated plots. Thus the adoption of surge mode of irrigation can comfortably offset the ill-effects of deep tillage on water saving. It may be further noted the maximum average yield of wheat was 5411 kg/ha and it was observed in the surge irrigated plots with higher discharge and tilled to deeper depth **(Table7-b).** This establishes the worth of surge irrigation in terms of yield, deeper tillage and water saving.

CONCLUSIONS

In view of the inherited losses and other inefficiencies of continuous/conventional irrigation system, surge irrigation has proved to be a better alternative in the present study. Surge irrigation was tested with special emphasis on advance rate under different levels of tillage depth and discharge. The literature in general advocates a beneficial application of surge technique

Table 7-a. Grain yield for tillage treatment (11 cm)

Method	Discharge (1/s)	Head of Plot (Stream end)	Middle of Plot	Tail of Plot	Average
		Yield per hectare (kg)			
Surge	27	4166	4083	4083	4111
	27	4166	4791	5500	4819
	21	5083	3750	4125	4319
	21	3750	5833	5500	5028
Continuous	27	4500	4166	5000	4555
	27	3333	4500	4375	4069
	21	4833	4500	4166	4500
	21	5666	5000	3625	4764

Table 7-b. Grain yield for tillage treatment (27 cm)

Method	Discharge (1/s)	Head of Plot (Stream end)	Middle of Plot	Tail of Plot	Average
		Yield per hectare (kg)			
Surge	27	5700	4900	5633	5411
	27	6166	4083	4733	4994
	21	5916	6250	5366	5844
	21	4566	5166	5900	5211
Continuous	27	4916	5166	4566	4883
	27	4666	4833	5250	4916
	21	4900	4783	5416	5033
	21	5033	5083	5117	5078

under furrow irrigation whereas present study has proved usefulness of surge method under border irrigation as well. Salient findings of the present study are summarized as under.

1. Surge irrigation is proved to be a water saving technique as it, on the average, saves 13.92% time in terms of the advancement of the water front on previously irrigated wet sections make the advance rate more efficient compared with continuous flow. The reasons for time saving were largely associated with development of a compacted layer due to collapsing soil aggregates.
2. Generally, the advance rates of surge and continuous flows were indifferent up to 30 meters from the stream end and the differences became apparent with increase in the distance, therefore, maximum benefits of surged flow can be realized in longer fields.
3. The larger discharge was 44.5% faster than smaller one under surged mode of irrigation; whereas, the same is 20.1% under continuous flow. It further suggests that the larger discharge is more beneficial especially under the surge irrigation. However, other penalties of larger discharge like total water volume should be kept in view while comparing with its counterpart.
4. Water front advancement was faster by 40.42% in shallow than deep tilled plots for surged flow. Apparently considerable water saving results by selecting shallow tillage coupled with surge mode of irrigation. It may, however, be remembered that deep tilling is established practice in modern agriculture and the deep tillage brings with it manifold economic benefits in terms of breakage of hard layer, washing salts from the root zone and ultimately the yield of crops.
5. The water volumes saved by surge irrigation over continuous one were up to 34%. This saving however, was affected by depth of tillage and level of discharge.
6. The UCC was 10-15 % higher for surge method than continuous under similar levels of tillage depth and stream discharge. It is encouraging that water distribution over the entire field can be uniform through employment of surge method.
7. The application efficiency of surged irrigation was 57.5% compared with 41.1% for the continuous one. Similarly, the highest deep percolation losses (DPR) of 55.91% were recorded in the plots under continuous irrigation, whereas the least DPR of 9.68% was observed in surge irrigation. All these observations establish the benefits of surge flow over the continuous one.

8. Wheat yields were invariably higher in deep tilled plot. Interestingly, the maximum average yield of wheat was 5411 kg/ha and it was observed in the surge irrigated plots with higher discharge and tilled to deeper depth.
9. Keeping in view different parameters like volume of water, distribution uniformity, application efficiency, deep percolation losses and yield of wheat, the surge mode of irrigation is convincingly better compared with conventional/continuous irrigation even under the border irrigation.

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