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INCREASING IRRIGATION EFFICIENCY BY MANAGEMENT STRATEGIES: CUTBACK AND SURGE IRRIGATION

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ABSTRACT

Increasing irrigation efficiency always has been one of the main concerns of experts and farmers. In previous researches, many methods have been proposed to achieve this purpose. But in surface irrigation farmers often received themselves required water in specified time (cutoff time) and the limited amount (input discharge). Thus, not all methods that increase irrigation efficiency are applicable. If the cutoff time to be constant only input discharge is a parameter that by reducing it using management practices farmers are able to increase irrigation efficiency. In this study, using different types of inflow regimes include continuous flow, cutback, fixed surge, and variable surge, increasing irrigation efficiency examined in border irrigation. Obtained results from performed simulation using SIRMOD software showed that cutback and surge irrigation methods were able to increasing irrigation efficiency to the amount of 11.66% and 28.37%, respectively. Farmers according to the limitation of inflow regime choice can identify the best amount of input discharge to achieve maximum of irrigation efficiency.

Keywords: border irrigation, irrigation management strategies, SIRMOD software, surge irrigation.

INTRODUCTION

Surge irrigation, also known as intermittent irrigation or surge flow (Stringham and Keller, 1979), has emerged over the last 30 years as one of the most efficient strategies for use of irrigation water. The advantages of surge flow surface irrigation fall into three broad categories (Evans and Leib, 2003):

a) Surged water advances to the end of the field at least as rapidly as continuous flow irrigation with the same inflow rates but with a smaller volume of water, thus greatly improving the uniformity of application during the advance phase.
b) Growers can reduce tail water and deep percolation losses and can improve application efficiencies under proper automated management.
c) Surge irrigation provides an inexpensive means of automating, managing, and accurately controlling the surface application of water to a field while reducing labor requirements.

Surge irrigation is one of the famous methods in irrigation management and has been studied in many articles, which some of them will be described in the following.

Mostafazadeh-Fard *et al*. (2006) developed and evaluated an automatic surge irrigation system in furrow irrigation. The results showed that the system was able to accurately and automatically irrigate the furrows by surge method based on information were given to the system. For the same discharge and volume of water applied to the furrows the water advance along the furrows were faster for surge flow as compared to the continuous flow. Valipour (2012) determined number of required observation data for rainfall forecasting to agricultural water management. Rodríguez *et al*. (2004) compared surge irrigation and conventional furrow irrigation for covered black tobacco cultivation in a Ferralsol soil. The surge flow furrow irrigation with variable time cycles increased the application efficiency by more than six fold, and the water volume was reduced by more than 80% compared to continuous irrigation. The largest rises in distribution uniformity and reductions in percolation losses were obtained with a furrow length of 200 m and a discharge of 1 liter per second, respectively. Sial *et al*. (2006) studied performance of surge irrigation under borders. 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 was convincingly better compared with conventional/continuous irrigation even under the border irrigation. Jensen and Shock (2001) considered surge irrigation or at last a modified surge program on the first irrigation as a strategy for furrow irrigation. Rogers and Sothers (1995) discussed about application of surge irrigation. Izuno and Podmore (1986) developed a technique for managing surge irrigations on a particular filed to achieve uniform and efficient applications. Evans *et al*. (1995) studied about surge irrigation with residues to reduce soil erosion. This study showed that soil erosion in furrows can be effectively controlled by the use of crop residues at rates of about 0.66 Mg/ha in the furrow area. Coupal and Wilson (1990) adapted water-conserving irrigation technology the case of surge irrigation in Arizona. The analysis indicated that water costs, under conservative but realistic assumptions, would have to rise to US$ 0.08/m3 before surge irrigation would be economically viable as a substitute for open ditch furrow irrigation. Valipour (2012) determined Hydro-Module using CROPWAT and AGWAT softwares. Unger and Musick (1990) used ridge tillage for managing irrigation water on the U.S. Southern Great Plains. The results showed that furrow irrigation of ridge-tilled land was an effective and widely accepted method of crop production on much of the irrigated land in the Southern Great Plains. Rasoulzadeh and Sepaskhah (2003) studied scaled infiltration equations for furrow irrigation. In surge irrigation, the values of saturated hydraulic conductivity and final infiltration rate were considered as 80% of those in a continuous furrow. It is noteworthy that scaled infiltration equations cannot be applied to a heavily cracked clay soil where initial infiltration occurs in the cracks rather than through the matrix. Valipour *et al*. (2012) studied soil heat flux based on energy balance equation used to estimate evapotranspiration successfully. Szogi *et al*. (2007) used erosion control practices integrated with polyacrylamide for nutrient reduction in rill irrigation runoff. A 2-year field study was conducted that combined polyacrylamide with (1) check dams, (2) surge irrigation, (3) surface drains, and (4) grass filter strips successfully. Valipour (2012) determined critical areas of Iran for agriculture water management according to the annual rainfall. Kanber *et al*. (2001) compared surge and continuous furrow methods for cotton in the Harran plain. Surge flow reduced the water intake of a surface soil loosened by tillage by 13±23% as compared to continuous flow, thus manifesting an incomparable advantaged to the level furrow systems. Bautista (1991) validated the kinematic simulation of surge border irrigation. The results of the computer simulations agreed with measured results. Horst *et al*. (2007) assessed impacts of surge-flow irrigation on water saving and productivity of cotton. The best irrigation water productivity (0.61 kg/m^3) was achieved with surge-flow on alternate furrows, which reduced irrigation water use by 44% (390mm) and led to high application efficiency, near 85%. Results demonstrated the possibility for applying deficit irrigation in this region. Kay (1990) reviewed water management methods (such as surge irrigation) in surface and overhead irrigation. He resulted that greatest progress will undoubtedly be made by the application of simple, well established principles and practices. The role of training cannot be underestimated. Ali and Talukder (2008) using surge irrigation reviewed increasing water productivity in crop production. Popova and Periera (2008) scheduled surge irrigation for furrow-irrigated maize under climate uncertainties in the Thrace plain of Bulgaria. The results indicate that vulnerability to climate change is higher for non-irrigated crops and that coping with possible rainfall decreased requires adopting less sensitive crop varieties, including when deficit irrigation would be applied for water saving. One of the newest surface irrigation methods is surge flow irrigation in which water applies intermittently to the furrows (Yonts *et al*., 1996). Miller and Shock (1993) compared surge irrigation with conventional continuous flow on an onion field in Ontario, Oregon. They reported a decrease in runoff on surge flow from 50 percent on continuous to 29 percent on the surge flow, resulting in a slight yield loss of 90 cwt/ac, only 15 cwt/ac below the area's average. Available nitrogen was also monitored. Surge flow irrigation resulted in a loss of 186 lb N/ac less than continuous flow. Khan (1993) took an initiative to test the concept of surge flow irrigation 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. Evans *et al*. (1982) combined crop residue applications in the furrows with surge flow near Prosser, WA, using corn stalks for the residue. The surge flow rates were established at 15-30 Lpm for the first, and 7.5-15 Lpm for subsequent irrigations. They reported that the combination of surge flow and higher surface residue levels increased application efficiencies calculated based on inflows-outflows up to 88.3% for 7.6 Lpm inflow rate with surge flow, and substantially reduced sediment losses. They also observed that in some cases the surge flow wetting fronts advanced at a more rapid rate than those of continuous flow, with no appreciable increase in erosion with relatively small residue rates. In comparing the rate of advance and application uniformities in furrows containing different levels of straw residue for both continuous and surge flow applications near Prosser, WA, Valipour (2012) compared surface irrigation simulation models using SIRMOD software and assessed different irrigation conditions. Evans *et al*. (1987) found that continuous and surge furrow streams advanced at approximately the same rate for each residue level. They reported that surge irrigation reduced infiltrated depths along the length of the furrow compared to the continuous flow treatments at the same residue levels, and concluded that because of the increase in application uniformity under various levels of crop residues, surge flow was preferable to continuous flow furrow irrigation.

Previous studies have shown that surge flow irrigation helps to improve surface irrigation efficiencies and uniformities and have several advantages over conventional irrigation method (Bishop *et al*., 1981; Izadi *et al*., 1991; Yonts *et al*., 1996; Fekersillassie and Eisenhauer, 2000). However, in previous studies surge irrigation only compared with continuous inflow and performed often for furrow irrigation. In this paper by using SIRMOD software all inflow regimes include continuous flow, cutback, fixed surge, and variable surge was compared for border irrigation.

MATERIALS AND METHODS

All inflow regimes include continuous flow, cutback, fixed surge, and variable surge in this study were run using full hydrodynamic simulation model. The full hydrodynamic model is based on governing equations in the form of the Saint-Venant equations:

$$\frac{\partial y}{\partial t} + \frac{\partial q}{\partial x} + \frac{\partial z}{\partial t} = 0 \quad (1)$$

$$\frac{\partial q}{\partial t} + \frac{2q\partial q}{y\partial x} + gy\frac{\partial y}{\partial x} = gy(S_0 - S_f) \quad (2)$$

Where, y (m) is depth of flow, q (m^3/s.m) is discharge in width unit, z (m^3/m) is volume of infiltrated in length unit, g (m/s^2) is gravity accelerate, S0 (m/m) is field slop, Sf (m/m) is energy gradient.

To characterize the infiltration process in surface irrigation, a modified version of the Kostiakov infiltration equation was used (Lewis, 1937). This is the one used in the surface irrigation simulation model SIRMOD (USU, 2001). This mathematical model was used in this work to conduct numerical experiments to determine optimum irrigation management strategies. The modified Kostiakov infiltration equation is:

$$z = K.T^a + f0.T \quad (3)$$

Where T is opportunity time (min), f0 is the basic infiltration rate (m^3/m.min), while K and a are empirical coefficients. SIRMOD characterizes infiltration in surge irrigation which requires estimation of the modified Kostiakov parameters for the first and third advance cycle.

Table-1 shows input data for evaluating of different inflow regimes using SIRMOD software in border irrigation.

Table-1. Input data for evaluating of different inflow regimes using SIRMOD software.

Q_{in} (l/s)	T_c (min)	L (m)	**n** ($s/m^{1/3}$)	S_0 (m/m)	**IF**	**Soil texture**	Z_{req} (mm)	**Crop**	**Simulation model**
3.0	480	250	0.15	0.001	0.5	Silty loam	100	Alfalfa	Full hydrodynamic

RESULTS AND DISCUSSIONS

Table-2 shows obtained results from running of SIRMOD software for input data in border irrigation.

Table-2. Obtained results from running of SIRMOD software for input data.

Inflow regime	**Application efficiency** (%)	**Requirement efficiency** (%)	**Distribution uniformity** (%)	**Deep percolation** (%)	**Tailwater** (%)	**Irrigation efficiency** (%)	**Inflow** (m^3)
Continuous flow	28.84	100.00	96.13	2.99	68.17	31.59	86.4

According to the Table-2 for 86.4 cubic meter of inflow volume, irrigation efficiency was 31.59% in continuous regime. For determining the best inflow discharge in continuous regime, amount of inflow discharge reduced and simulated by SIRMOD (Table-3).

In Table-3 for reducing input discharge amount of irrigation efficiency increased. If only achieving to the maximum irrigation efficiency be considered, Qin = 0.7 liter per second is the best choice but farmers tend that their yield does not reduce. In this condition Qin = 1.7 l/s is preferred over Qin = 0.7 l/s. However, Qin = 1.0 l/s due to increasing irrigation sufficiency in the amount of 30.14% and saving 20.2 m^3 of water and reducing only 4.87% requirement efficiency into the Qin = 1.7 l/s, can be considered as an alternative. Figure-1 shows a comparison between runoff hydrograph for Qin = 1.7 l/s and Qin = 1.0 l/s.

According to the Figure-1 and Table-3 for reducing 0.7 l/s of input discharge amount of tailwater reduced 30.14% and irrigation efficiency increased to the same amount. Table-4 shows cutback conditions.

According to the Table-4 for cutback ratio=0.3 maximum of application efficiency, distribution uniformity, irrigation efficiency and minimum of tailwater and inflow are accessible. Figures 2 and 3 shows process of simulation using SIRMOD software for cutback ratio=0.3.

In Figure-3 while water inflow attain to the end of border amount of discharge is changed to 0.9 l/s that this is 0.3 times of input discharge in Figure-2. Figure-4 shows runoff hydrograph in this cutback condition.

In Figure-4 while cutback ratio = 0.3 amount of tailwater is fall with a steep slope and follows with a trifle amount until all of water go away from border. Table-5 shows obtained results for fixed surge regime.

The best choice according to the Table-5 is number of 9 surges with surge time equal to 20 minutes. Table-6 shows obtained results for fixed surge combined with cutback inflow regime.

According to the Table-6 for number of 2 surges with surge time = 80 min and cutback ratio = 0.2 maximum of irrigation efficiency is attained. Because minimum of surge time that is performable by SIRMOD software in this condition is 80 min, this amount set to achieve maximum of irrigation efficiency. Figure-5 shows runoff hydrograph in this condition.

According to the Figure-5 the first surge with surge time = 80 min go away from border. But in second surge due to the reducing soil infiltration amount of tailwater is more than first surge and while the second surge attain to the end of border is faced with cutback ratio=0.2 and input discharge is changed to 0.6 l/s. Table-7 shows obtained results in variable surge inflow regime.

The best choice according to the obtained results in Table-7 is number of 7 surges with surge time = 40 min and surge ratio = 0.9. In this condition maximum of irrigation efficiency is accessible. Figure-6 shows runoff hydrograph in this condition.

In Figure-6 first surge has not runoff but other surges are produced runoff that decline with the rate of 0.9.

Farmers according to the limitation of inflow regime choice can identify the best amount of input discharge to achieve maximum of irrigation efficiency as follows:

If farmers are able to use the cutback inflow regime, a cutback ratio = 0.3 (Table-4) due to the 11.66% incrassating irrigation efficiency and 6.7 m^3 water saving is better than Qin = 1.7 l/s in continuous regime (Table-3).

Table-3. SIRMOD solutions for continuous inflow regime.

Inflow regime	Q_{in} (l/s)	**Application efficiency** (%)	**Requirement efficiency** (%)	**Distribution uniformity** (%)	**Deep percolation** (%)	**Tailwater** (%)	**Irrigation efficiency** (%)	**Inflow** (m^3)
Continuous flow	0.7	98.82	79.69	79.91	1.12	0.06	99.94	20.2
Continuous flow	1.0	82.58	95.13	90.16	1.49	15.93	84.07	28.8
Continuous flow	1.2	70.93	98.05	93.63	2.16	26.92	73.08	34.6
Continuous flow	1.5	57.57	99.49	96.40	2.49	39.93	60.07	43.2
Continuous flow	1.7	50.89	100.00	97.16	3.04	46.07	53.93	49.0
Continuous flow	2.0	43.26	100.00	97.59	3.12	53.62	46.38	57.6
Continuous flow	2.2	39.33	100.00	97.58	3.29	57.38	42.62	63.4
Continuous flow	2.5	34.61	100.00	97.13	3.14	62.25	37.75	72.0
Continuous flow	2.7	32.04	100.00	96.79	3.17	64.78	35.17	77.8
Continuous flow	3.0	28.84	100.00	96.13	2.99	68.17	31.59	86.4

Table-4. Obtained Results for cutback inflow regime.

Inflow regime	**Cutback ratio**	**Application efficiency** (%)	**Requirement efficiency** (%)	**Distribution uniformity** (%)	**Deep percolation** (%)	**Tailwater** (%)	**Irrigation efficiency** (%)	**Inflow** (m^3)
Continuous flow cutback	0.3	60.90	100.00	97.23	4.69	34.41	65.59	42.3
Continuous flow cutback	0.4	52.55	100.00	96.96	4.44	43.01	56.99	48.6
Continuous flow cutback	0.5	46.22	100.00	96.71	4.11	49.67	50.33	54.9
Continuous flow cutback	0.6	41.25	100.00	96.60	3.79	54.96	45.04	61.2
Continuous flow cutback	0.7	37.24	100.00	96.51	3.50	59.26	40.74	67.5
Continuous flow cutback	0.8	33.94	100.00	96.47	3.25	62.81	37.13	73.8
Continuous flow cutback	0.9	31.18	100.00	96.41	3.02	65.79	34.10	80.1
Continuous flow cutback	1.0	28.84	100.00	96.13	2.99	68.17	31.59	86.4

Table-5. Obtained results for fixed surge regime.

Number of surges	**Surge time** (min)	**Application efficiency** (%)	**Requirement efficiency** (%)	**Distribution uniformity** (%)	**Deep percolation** (%)	**Tailwater** (%)	**Irrigation efficiency** (%)	**Inflow** (m^3)
1	480	28.84	100.00	96.13	2.99	68.17	31.59	86.4
2	240	28.76	99.38	92.59	3.98	67.26	31.62	86.4
3	160	28.83	99.65	89.45	6.55	64.61	31.85	86.4
4	93	36.96	99.00	85.53	7.48	55.56	40.51	67.0
5	54	50.43	98.43	82.10	9.66	39.91	50.43	48.6
6	45	60.00	97.20	82.24	7.55	32.45	64.98	47.5
7	30	65.16	98.53	79.81	17.91	16.92	71.62	37.8
8	25	68.42	98.53	78.57	21.35	10.23	74.88	34.6
9	20	72.79	94.33	71.00	23.08	4.13	79.27	32.4
10	15	73.22	79.07	72.15	22.71	4.08	79.74	25.2

Table-6. Obtained results for fixed surge combined with cutback inflow regime.

Inflow regime	**Number of surges**	**Surge time** (min)	**Cutback ratio**	**Application efficiency** (%)	**Requirement efficiency** (%)	**Distribution Uniformity** (%)	**Deep percolation** (%)	**Tailwater** (%)	**Irrigation Efficiency** (%)	**Inflow** (m^3)
Fixed surge cutback	2	240	0.2	37.19	100.00	94.04	8.44	54.37	41.28	67.0
Fixed surge cutback	2	220	0.2	38.67	100.00	94.07	8.81	52.52	42.84	64.4
Fixed surge cutback	2	200	0.2	40.26	100.00	94.09	9.20	50.53	44.71	61.9
Fixed surge cutback	2	190	0.2	41.20	100.00	92.97	9.55	49.26	45.78	60.5
Fixed surge cutback	2	180	0.2	41.95	100.00	93.48	9.92	48.13	46.61	59.4
Fixed surge cutback	2	170	0.2	42.99	100.00	93.16	9.99	47.02	47.77	58.0
Fixed surge cutback	2	160	0.2	43.86	100.00	94.21	10.11	46.03	48.59	56.9
Fixed surge cutback	2	100	0.2	50.45	100.00	94.49	11.92	37.63	55.90	49.3
Fixed surge cutback	2	90	0.2	51.63	100.00	94.58	12.31	36.00	57.27	48.2
Fixed surge cutback	2	80	0.2	52.96	100.00	94.67	12.74	34.30	58.73	46.8

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Table-7. Obtained results in variable surge inflow regime.

Inflow regime	**Number of surges**	**Surge time** (min)	**Surge ratio**	**Application efficiency** (%)	**Requirement efficiency** (%)	**Distribution uniformity** (%)	**Deep percolation** (%)	**Tailwater** (%)	**Irrigation efficiency** (%)	**Inflow** (m^3)
Variable surge	2	240	0.9	30.65	99.29	92.00	3.31	66.05	33.27	81.0
Variable surge	3	160	0.9	32.83	99.28	87.91	5.47	61.70	35.89	75.6
Variable surge	4	93	0.9	45.64	98.58	89.14	6.83	47.53	49.46	54.0
Variable surge	5	54	0.9	70.63	96.62	80.64	7.33	22.04	75.57	34.2
Variable surge	6	45	0.9	70.69	96.70	80.67	7.28	22.03	75.63	37.4
Variable surge	7	40	0.9	75.78	100.00	81.81	18.39	5.83	82.30	32.4
Variable surge	8	25	0.9	70.57	70.62	78.46	16.22	13.21	76.94	22.5
Variable surge	9	20	0.9	67.28	57.65	76.84	16.99	15.73	73.28	18.0
Variable surge	10	15	0.9	63.68	42.18	73.28	14.81	21.51	69.40	16.6
Variable surge	11	10	0.9	64.70	29.81	72.83	10.83	24.48	69.89	11.5

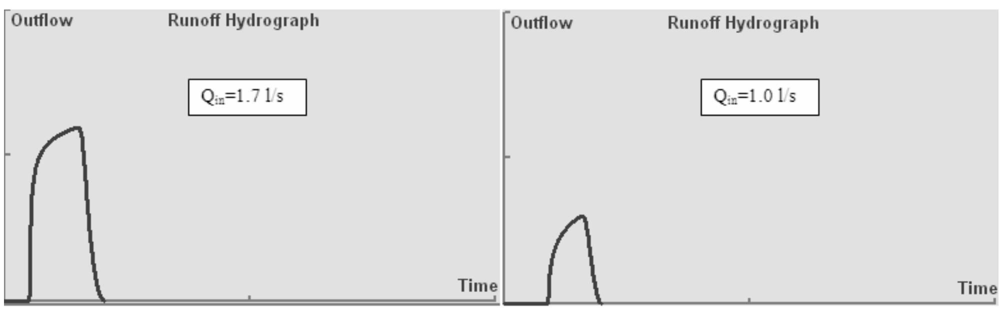

Figure-1. Comparison between runoff hydrograph for Qin = 1.7 l/s and Qin = 1.0 l/s.

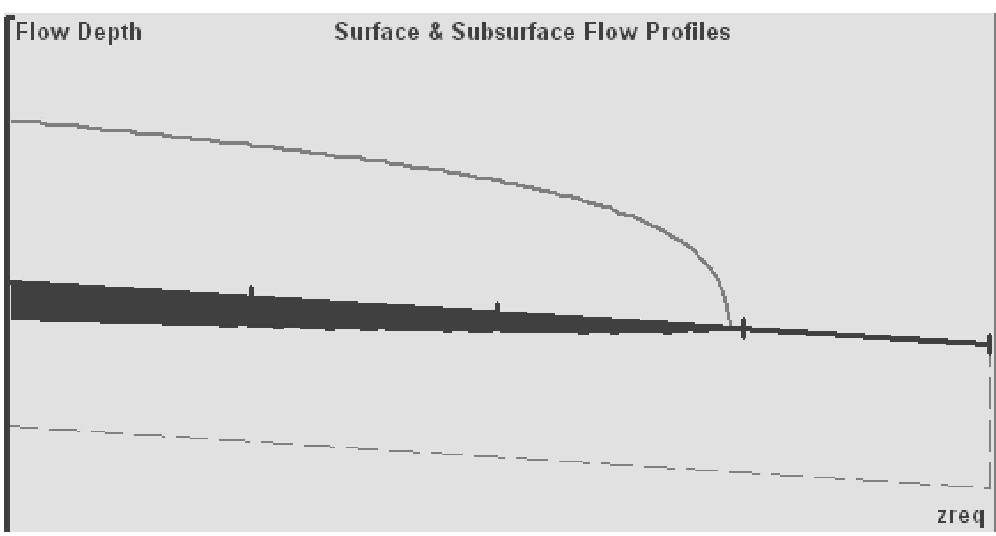

Figure-2. Water inflow before attain to end of border

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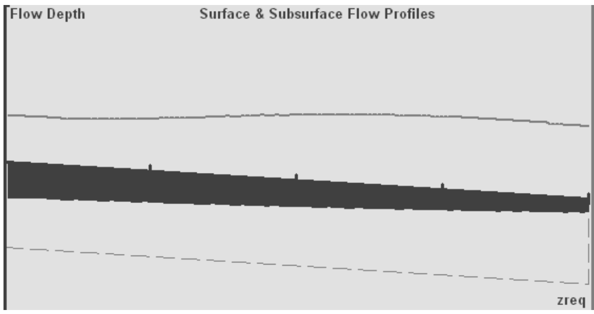

Figure-3. Water inflow after attain to end of border.

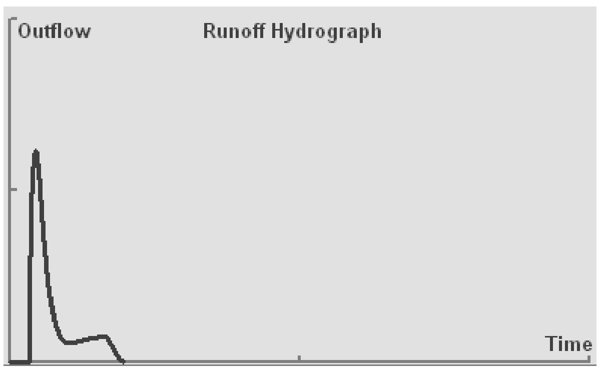

Figure-4. Runoff hydrograph for amount of cutback ratio equal to 0.3.

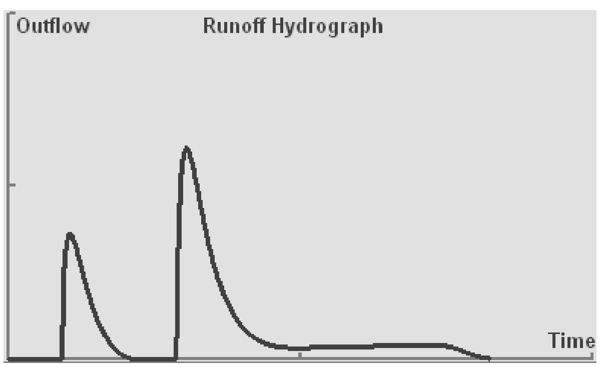

Figure-5. Runoff hydrograph in fixed surge/cutback inflow regime.

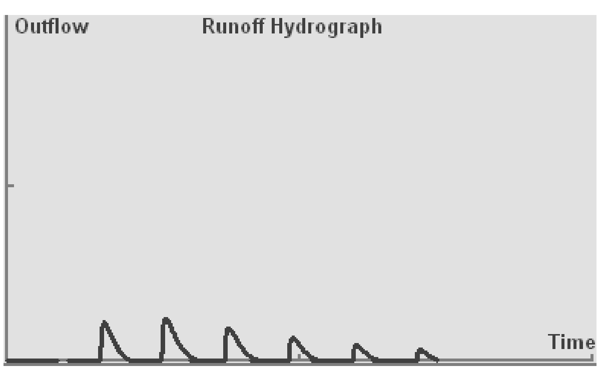

Figure-6. Runoff hydrograph in variable surge regime.

If farmers are able to use the fixed surge combined cutback regime, number of 2 surges with surge time = 80 min and cutback ratio = 0.2 (Table-6) due to the 4.80% increasing irrigation efficiency and 2.2 m^3 water saving is better than Qin = 1.7 l/s in continuous regime (Table-3).

If farmers are able to use the variable surge regime, number of 7 surges with surge time = 40 min and surge ratio = 0.9 (Table-7) due to the 28.37% increasing irrigation efficiency and 16.6 m^3 water saving is better than Qin = 1.7 l/s in continuous regime (Table-3).

If do not need to establishing requirement efficiency = 100%, Qin = 1.0 l/s (Table-3) in continuous regime due to the 30.14% increasing irrigation efficiency and 20.2 m^3 water saving and number of 9 surges with surge time = 20 min in fixed surge regime due to the 25.34% increasing irrigation efficiency and 16.6 m^3 water saving is better than Qin = 1.7 l/s in continuous regime (Table-3).

Irrigation efficiency in SIRMOD software is an average of other efficiencies. To more accurate and better choice can be used from hierarchical analysis (Valipour and Montazar, 2012) or sensitive analysis (Valipour and Montazar, 2012) or genetic algorithm (Valipour and Montazar, 2012) methods.

CONCLUSIONS

In this study, using different types of inflow regimes include continuous flow, cutback, fixed surge, and variable surge, increasing irrigation efficiency examined in border irrigation. Obtained results from performed simulation using SIRMOD software showed that cutback and surge irrigation methods were able to increasing irrigation efficiency to the amount of 11.66% and 28.37% and reducing inflow to the amount of 6.7 m^3 and 16.6 m^3 water saving, respectively. Farmers according to the limitation of inflow regime choice can identify the best amount of input discharge to achieve maximum of irrigation efficiency. If do not need to establishing requirement efficiency = 100%, can be used from alternative options with more water saving.

Abbreviations

T = Opportunity time (min)
K, a = Empirical coefficients
f_0 = Basic infiltration rate (m^3/m.min)
z = Volume of infiltrated in length unit (m^3/m)
x = Distance (m)
Q_{in} = Input discharge (m^3/s)
S_f = Energy gradient (m/m)
y = Depth of flow (m)
q = Discharge in width unit (m)
g = Gravity accelerate (m/s^2)
n = Manning roughness coefficient (s/m1/3)
S_0 = Field slope (m/m)
T_c = Cutoff time (min)
t = Time (s)
L = Length of border (m)

IF = Intake Family
Z_{req} = Required depth (m)

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