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Assessment of Surge Irrigation Technique under Furrow Irrigation System in the Nile Delta

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Abstract: Field experiments were conducted to investigate the performance and limitations of surge irrigation technique in the Nile Delta of Egypt. The experiments consisted of different surge irrigation treatments compared with continuous discharge; all evaluated using two irrigation discharges-2.4 (Q1) and 3.2 (Q2) L s^{-1} per furrow. The irrigation treatments were: continuous discharge (I1), surge flow with a cycle ratio (CR) of 0.33 (I2), surge flow with a CR of 0.50 (I3), surge flow with a CR of 0.67 (I4) and surge flow with a CR of 0.75 (I5). The suitability of surge irrigation was assessed based on consumptive use of water, water advance rate, grain yield and several efficiencies. Results obtained on the average basis of two discharge treatments indicated that I5 could save 11% (75 mm) and 12.1% (84.4 mm) of the water applied in 2002 and 2003, respectively. For consumptive use of water, 14 treatment could save 2.7% (14.6 mm) and 2.9% (15.8 mm) under Q1 and Q2 irrigation discharge respectively, for the two studied seasons. Applying the surge irrigation technique increased maize grain yield by 9.8% (746.7 kg ha^{-1}) and 4.4% (344.4 kg ha^{-1}) under respective discharge treatments for the two studied seasons. Increased irrigation discharge led to increased water application efficiency and improved water distribution uniformity. The highest mean values (kg m^{-3}) of water utilization efficiency were 1.284 (2002) and 1.30 (2003) from the interaction between Q2 irrigation discharge and surge I3.

Key words: Surge irrigation, irrigation efficiencies, irrigation discharge, Nile delta, Egypt

Introduction

Surface irrigation methods account for more than 85% of the total volume of water used for irrigation in Egypt. They generally have a low level of performance. Research projects and studies provide ample evidence of the urgent need to improve farm water control in Egypt (Abu-Zeid and Rady, 1992). Thus, efficient on-farm irrigation methods are necessary for increasing crop production per unit of water applied. Although well designed and managed surge-irrigated systems have the potential to improve the performance, versatility and efficiency of surface irrigation systems (Humpherys, 1989), many furrow systems generally operate at significantly lower efficiency.

Surge flow irrigation has the potential to control both the time required for water to flow across the field (advance time) and infiltration rate, thereby reducing the amount of percolated water at furrow head and achieving better uniformity in soil moisture distribution. Podmore *et al*. (1983) and

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Coolidge *et al*. (1982) reported that surge flow can provide a significant improvement in the efficiencies and uniformity of surface irrigation. To complete the advanced phase of surge irrigation requires 30 to 50% less water application to furrows as opposed to continuous flow irrigation. Some studies compared between surge and continuous flow irrigations and proved significantly shorter advance time for surge flow than continuous flow. Surface irrigation efficiency is at a maximum when systems are managed to minimize deep percolation and runoff while meeting irrigation requirements. Several management techniques have been developed to reduce water losses during the irrigation event (Ismail and Depeweg, 2002; Ismail *et al*., 2004).

Surge flow provides the desired crop water requirement at almost 40% saving in water and time as well as improving the distribution uniformity and application efficiency of irrigation to about 90% (Melkamu *et al*., 1998; El Dine and Hosny, 2000; Saied, 1992).

From the earlier studies, it is inferred that the importance of increasing flow rate is well recognized. However, the knowledge and data available to support the development of surge technology in Egypt is still limited. The experiments conducted in previous studies provide little information on the effect of irrigation discharge, surge treatments and their interactions on irrigation efficiencies. Therefore, this study aims to determine: (1) the best period of irrigation pulses and the intervals between these pulses, (2) the best irrigation discharge when applying surge technique along the furrow length to achieve better water utilization efficiency under clay soils in the Nile Delta of Egypt.

Materials and Methods

Field experiments were carried out at Kafr El-Sheikh governorate, located in the northern Nile Delta, Egypt, during the summer (June 13~Sept. 30) of 2002 and 2003. The experiment site is located at the 31° 11′ N latitude and 30° 39′ E longitude. The main treatments of irrigation discharge were adjusted as: 3 L s^{-1} m^{-1} (i.e., 2.4 L s^{-1} per furrow) and 4 L s^{-1} m^{-1} (i.e., 3.2 L s^{-1} per furrow) denoted as Q1 and Q2, respectively. According to Saied (1992), the discharge rates were decided to reduce water losses through deep percolation and maximum non-erosive flow depending on the soil intake rate of the experimental field. Five cycle ratios of surge flow were used as sub treatments: irrigation with continuous discharge (control) (I1), irrigation with a cycle ratio (CR) of 0.33 (5 min on and 10 min off) (I2), irrigation with a CR of 0.50 (10 min on and 10 min off) (I3), irrigation with a CR of 0.67 (10 min on and 5 min off) (I4) and irrigation with a CR of 0.75 (15 min on and 5 min off) (I5).

The experimental fields were provided with furrow irrigation system with a furrow width of 0.8 m and furrow length of 80 m, with a gentle slope of 0.001 m m^{-1}. There were 5 furrows per plot. Water was applied at the furrow head using siphon tubes. The furrows had a blocked end. The first irrigation was done immediately after planting and the second irrigation was done 21 days after planting. Thereafter, the irrigation intervals were scheduled every 15 days. The water was applied 7 times during each season. Maize was planted in the experimental fields as a test crop. The experiment was arranged in split plot design with three replicates for each treatment. Each plot size was 4×80 m = 320 m^2.

The physical and chemical properties of the soil at the studied location during the growing season are presented in Table 1. The soil bulk density was determined according to Vomocil (1957). Soil samples were taken from soil layers of 0~20, 20~40, 40~60 and 60~80 cm and analyzed for soluble cations and anions, pH and electric conductivity. Soil samples were air-dried and screened to pass a 2-mm sieve. Soil texture was determined by the pipette method. Electrical Conductivity (EC) and pH of the soil moisture were measured in a 1:5 water extract using pH and EC meters. The analytical methods employed for chemical analyses were as follows: (1) determination of Na^+ and K^+ in a 1:5 soil-water solution by flame photometer (Jackson, 1967); (2) determination of Ca^{2+} and Mg^{2+} using

Table 1: Physico-chemical properties of the soil at Kafr El-Sheikh during the growing seasons

Depth (cm)	Physical properties: Particle size distribution (%) Clay	Silt	Sand	Texture class	Bulk density (g cm^{-3})	Wilting point (%)	Field capacity (%)	Saturation capacity (%)
0-20	57.0	16.6	26.4	Clayey	1.20	31.5	45.5	54.9
20-40	59.0	17.5	23.5	Clayey	1.21	32.4	46.5	54.4
40-60	66.0	15.0	19.0	Clayey	1.22	32.9	47.1	54.1
60-80	67.0	15.0	18.0	Clayey	1.24	33.0	47.4	53.3

Depth (cm)	$pH_{1:5}$	Chemical properties* $EC_{1:5}$ (dS m^{-1})	Cation (meq L^{-1}) Na^+	K^+	Ca^{2+}	Mg^{2+}	Anion (meq L^{-1}) HCO_3^-	Cl^-	SO_4^{2-}	$SAR_{1:5}$
0-20	8.0	2.1	9.7	0.3	6.0	5.5	3.8	11.0	5.7	4.05
20-40	8.2	2.2	11.2	0.4	5.2	5.0	6.5	12.8	2.5	4.96
40-60	8.3	2.5	14.5	0.3	5.5	6.5	5.5	14.0	7.3	6.42
60-80	8.2	2.65	17.0	0.3	5.0	4.0	6.7	11.0	8.61	8.02

* Extraction for ions was carried out in a soil-water ratio of 1:5

atomic absorption spectrophotometer; (3) determination of SO_4^{2-} using visible spectrophotometer and Cl^- using titration method (Jackson, 1967). Sodium adsorption ratio (SAR) is computed to get sodification in the soil solutions. All agricultural operations and conditions such as land preparation, fertilizer application, planting date and maize variety were the same for all treatments.

Amount of water applied was measured using a sharp edge crested weir for each plot. It was estimated by multiplying the irrigation time by irrigation discharge. The discharge was calculated using the following equation (USBR, 2001):

$$Q = \mu L\, H^{1.5} \tag{1}$$

Where: Q is the discharge ($m^3\ s^{-1}$), L is the width of the crest (= 0.5 m), H is the measured head above the crest, excluding the velocity head (m) and μ is the discharge coefficient empirically estimated as 1.14. The on-time plus the off-time of a furrow is additively known as the cycle time. Cycle time and cycle ratio were calculated, according to Izuno (1984):

$$\text{Cycle time} = [(\text{on-time}) + (\text{off-time})] \tag{2}$$

$$\text{Cycle ratio} = [(\text{on-time})/(\text{cycle time})] \tag{3}$$

The on-off cycle time was controlled by means of a stopwatch. The irrigation time (min) and number of surge cycles were measured when the waterfront had reached to the end of furrow length for each treatment.

The soil moisture content was measured at three locations, namely at the beginning, middle and end of the furrow. In each location, four points in vertical direction were selected and samples were taken at 20 cm intervals depths up to 80 cm, to determine the soil moisture content on dry weight basis. The samples were taken just before and 2 days after each irrigation, as well as just before maize harvest. Consumptive use of water was calculated, according to the equation proposed by Israelsen and Hansen (1962) with a modification:

$$CU = c \times \left[\frac{(\theta_2 - \theta_1)}{100} \times D \times B_d\right] \tag{4}$$

Where: CU is the amount of water consumptively used (mm), D is the soil depth (mm), B_d is the bulk density (g cm^{-3}), θ_2 is the soil moisture (%) after 2 days of each irrigation event (I) on dry weight basis, θ_1 is the soil moisture (%) immediately before the next irrigation event (I+1) on dry weight basis and c is the correction factor estimated as 1.20 to account for the CU for the three days after each irrigation. The consumptive use of water was calculated for the 80 cm soil depth, which was assumed to be the depth of the root zone as reported by Saied (1992).

Water application efficiency (%) was obtained by dividing the consumptive use of water by the amount of irrigation applied to the field, according to Michael (1978). Crop grain yield (kg ha^{-1}) was estimated from a (2.4×12.5 = 30 m^2) test plot and taken from three selected locations, namely at head, middle and end of each plot without border effect. After harvesting, the plants were sun-dried and then the grains weight was recorded in kg ha^{-1}. The Water Utilization Efficiency (WU_tE) (kg m^{-3}) was estimated as the weight of marketable crops produced (kg) per unit volume of applied water (m^3) (Michael, 1978). Crop Water Use Efficiency (CWUE) (kg m^{-3}) was estimated as the weight of marketable crops produced (kg) per consumptive use of water (m^3) (Michael, 1978). Water distribution efficiency (%), which evaluates the extent to which water is uniformly distributed, was determined from the following equation:

$$DU = 100 \times \left[1 - \frac{(Y)}{d} \right] \tag{5}$$

Where: DU is the water distribution efficiency (%), Y is the average numerical deviation from d and d is the average depth of water stored along the run, according to Israelsen and Hansen (1962). The data were statistically analyzed using the StatView software (SAS, 2002) with the probability level of 5%.

Results and Discussion

Total Amounts of Water Applied

As shown in Table 2, the amounts of water applied to different treatments decreased with an increase in irrigation discharge. This is because increasing irrigation discharge led to an increase in the speed of advance of irrigation water. With respect to the effect of cycle ratio treatments (CRs), all tested CRs of surge treatments used less amount of water than those of the continuous flow treatment.

Table 2: Water applied (mm), number of surge cycles and Irrigation time per irrigation (min) among the studied treatments in both seasons

		Summer 2002			Summer 2003		
Treatments		Water applied (mm)	No. of surge cycles	Irrigation time (min)	Water applied (mm)	No. of surge cycles	Irrigation time (min)
Q1	I1	693.5	Cont. flow	39.6	703.4	Cont. flow	40.2
	I2	686.7	7.8	39.2	691	7.9	39.5
	I3	642.4	3.7	36.7	664.5	3.8	38.0
	I4	636.9	3.6	36.4	650.1	3.7	37.1
	I5	611.2	2.3	34.9	623.3	2.4	35.6
Q2	I1	673.2	Cont. flow	28.9	690.2	Cont. flow	29.6
	I2	658.3	5.6	28.2	677	5.8	29.0
	I3	636.2	2.7	27.3	638.7	2.7	27.4
	I4	630.4	2.7	27.0	626.7	2.7	26.9
	I5	605.7	1.7	26.0	601.5	1.7	25.8
$LSD_{(0.05)}$* (Q×I)		NS	NS	NS	NS	NS	NS
	Q	2.133	0.053	0.077	1.487	0.026	0.122
	I	3.373	0.085	0.121	2.352	0.041	0.193

LSD = Least significant difference, *Significant at 5% level

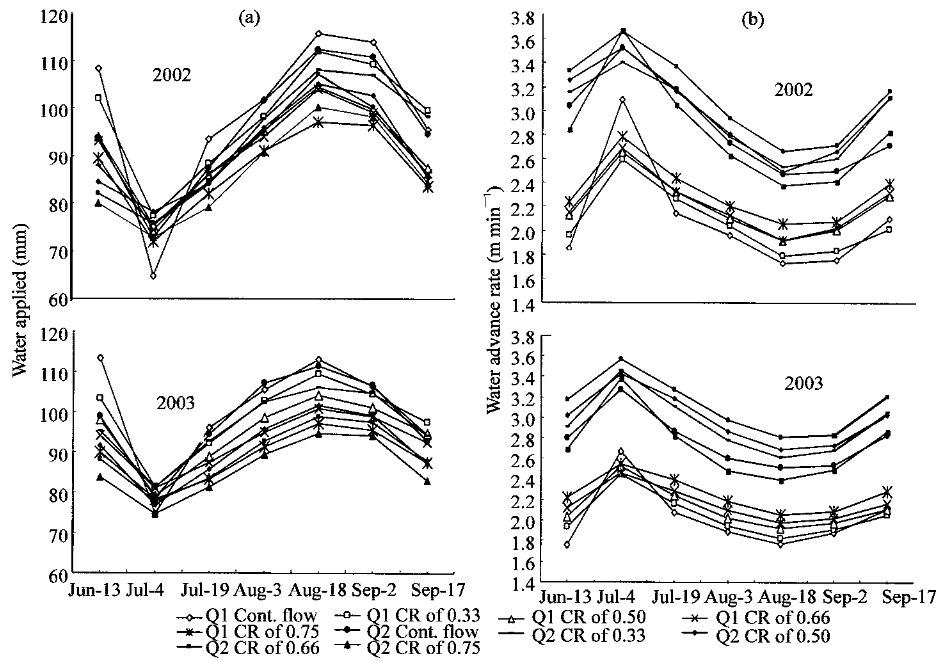

Fig. 1: Total amounts of water applied (mm) and rate of water advance (m min^{-1}) per irrigation among treatments

The overall average corresponding values for surge flow irrigation for the two growing seasons varied from 611.2~686.7 mm under Q1; from 605.7~658.3 mm under Q2 (2002); from 623.3~691 mm under Q1 and from 601.5~677 mm under Q2 (2003). Surge flow could significantly save water on average for all treatments by up to 7.1% (49.2 mm) and 6% (40.6 mm) in 2002 and up to 6.6% (46.2 mm) and 7.9% (54.2 mm) in 2003 of the continuous flow irrigation under Q1 and Q2 irrigation discharge treatments, respectively. For both seasons, the best treatment (I5) could make average water saving of 11.9% (82.3 mm) under Q1 (2002); 10% (67.5 mm) under Q2 (2002); 11.4% (80.1 mm) under Q1 (2003) and 12.9% (88.7 mm) under Q2 (2003) irrigation discharge treatments, respectively. These results indicated that surge flow irrigation used less amounts of water than continuous one. The trends observed above resemble to the results reported by Melkamu *et al.* (1998) and Ismail *et al.* (2004).

As shown in Fig. 1 a, the first irrigation consumed a large amount of water because of the dry pre-planting soil moisture conditions. Less amount of water was applied to plots in the second irrigation. In summer 2002, the amount of water application was recorded as low as 64.7 mm under a combination of Q1 and I1 treatments in the second irrigation. The reduced water application could be attributed to less amount of plant transpiration at an early stage of vegetative growth in maize. The reduction of water application in the initial stage of 2002 was relatively higher than that of 2003 because of higher potential evapotranspiration. The effect of soil moisture content on evapotranspiration varies with water holding characteristics, crop rooting characteristics and meteorological factors, which determine the level of transpiration (Doorenbos and Pruitt, 1977).

Water application depth increased with increasing crop growth started from the third irrigation to fifth irrigation and thereafter decreased again. The number of surge cycles required showed the same trend with the amount of water applied (Table 2).

Table 3: Water distribution%, consumptive use of water (mm), application efficiency, grain yield (kg ha^{-1}) and utilization efficiency as affected by the studied treatments in 2002 and 2003 seasons

	Water distribution efficiency (%)		Consumptive use of water (mm)		Water application efficiency (%)		Grain yield (kg ha^{-1})		Water utilization efficiency (kg m^{-3})	
Treatments	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Irrigation discharge										
Q1	80.68	80.46	534.8	541.8	81.92	81.42	7389.2	7608.4	1.134	1.145
Q2	82.87	83.55	530.2	529.2	82.85	82.00	7577.3	7774.6	1.186	1.207
LSD (0.05)	0.63**	0.65**	3.27**	2.76**	0.63**	0.43*	96.81**	98.5**	0.013**	0.013**
Surge cycles										
11	76.53	76.15	539.2	542.7	78.91	77.88	6885.9	7416.0	1.008	1.064
12	80.97	81.82	533.4	538.7	79.35	78.76	7026.4	7123.4	1.046	1.042
13	83.60	84.05	529.8	533.2	82.88	81.83	8027.6	8197.3	1.256	1.259
14	85.75	85.98	524.6	526.9	82.79	82.57	7957.3	8006.1	1.256	1.255
15	82.03	82.03	535.4	536.0	88.00	87.53	7519.2	7714.8	1.236	1.260
LSD (0.05)	0.99**	1.03**	5.17**	4.36**	0.99**	0.69**	153.1**	155.7**	0.021**	0.021**
Q×I	NS	NS	NS	NS	*	**	NS	NS	*	*

(LSD=Least significant difference; Q= Irrigation discharge; I = Surge treatments; Q× I = interaction; **$p<0.01$, *$p<0.05$ and ns = not significant)

Rate of Advance

The water advance rate increased with increasing cycle ratio and was higher under Q2 than under Q1 treatment. Surge flow treatments had lower irrigation time and higher water advance rate, for each of the irrigation discharge, as given in Fig. 1 b and Table 2. The mean water advance rate through all irrigations under Q1 treatment varied from 2.07~2.31 m min^{-1} for 2002 and from 2.04~2.26 m min^{-1} for 2003. The water advance rate under Q2 treatment varied from 2.88~3.12 m min^{-1} for 2002 and from 2.78~3.12 m min^{-1} for 2003. The irrigation was completed faster when surge flow irrigation technique was applied. Such a saving in time under surge flow irrigation was mainly because of a faster water advance, due to lower infiltration rate. The fastest advance occurred in I5 (CR of 0.75). Decreasing the off time in surge flow led to a reduced infiltration rate and resulted in a greater advance rate on wetted area. These results agree with Melkamu *et al*. (1998).

Water Distribution Efficiency

Data presented and Table 3 shows that the treatments with higher irrigation discharge (Q2) had higher values of distribution efficiency (82.87 and 83.55%). The lowest mean values of distribution efficiency were 80.68 and 80.46% recorded for Q1 irrigation discharge in 2002 and 2003 seasons, respectively. This means increasing irrigation discharge enhanced the uniformity of water distribution and is expected to provide good conditions for distributing irrigation water along and within the irrigation run. The surge flow treatments were more effective in improving the uniformity of soil moisture distribution along the field than continuous flow treatment. The highest mean values of water distribution efficiency were 85.75 and 85.98% obtained for the I4 surge irrigation treatment in the summer of 2002 and 2003, respectively. Among the surge flow treatments, the efficiency of water distribution increased as the surge CR increased up to CR of 0.66, then decreased with CR of 0.75 treatments. The explanation for these results is that surge flow irrigation leads to higher water distribution efficiency, due to less water losses by deep percolation and less amount of applied water during irrigation (El-Dine and Hosny, 2000).

Consumptive Use of Water (CU)

Table 3 shows the CU for each irrigation treatment. With an increase in surge cycle ratios, the CU decreased up to a CR of 0.66 and then increased with a CR of 0.75 during the growing seasons. The values of CU were higher for continuous flow irrigation than those for surge flow irrigation treatments. The most probable explanation for these finding that more available soil moisture provide a chance for

Table 4: Water application and utilization efficiencies as affected by the interaction between irrigation discharge and surge cycles treatments in 2002 and 2003 seasons

		Water application efficiency (%)			Water utilization efficiency (kg m^{-3})		
Year	Treatments	Q1	Q2	Mean	Q1	Q2	Mean
2002	I1	77.94	79.88	78.91	0.990	1.026	1.008
	I2	78.22	80.47	79.35	1.008	1.084	1.046
	I3	82.92	82.83	82.88	1.228	1.284	1.256
	I4	83.11	82.47	82.79	1.234	1.278	1.256
	I5	87.40	88.61	88.01	1.213	1.258	1.236
	Mean	81.92	82.85	82.39	1.135	1.186	1.160
	F-value		3.519*			1.247*	
2003	I1	78.26	77.49	77.88	1.051	1.078	1.065
	I2	78.95	78.56	78.76	1.024	1.059	1.042
	I3	81.47	82.19	81.83	1.218	1.300	1.259
	I4	81.24	83.89	82.57	1.210	1.299	1.255
	I5	87.19	87.86	87.53	1.222	1.299	1.261
	Mean	81.42	82.00	81.71	1.145	1.207	1.176
	F-value		8.163**			4.164*	

*p significant a 0.05; **p significant at 0.01

more luxury water use, which ultimately resulted in increasing transpiration. Also, the I5 decreased CU by an average of 3.8 mm during 2002 and by an average of 6.7 mm during 2003.

In general, increasing irrigation discharge decreased CU for the surge and/or continuous flow irrigation. The mean values of CU in the two seasons were 538.3 and 529.7 mm for Q1 and Q2 irrigation discharge treatments, respectively.

Water Application Efficiency

The water application efficiency of the different irrigation treatments are presented in Table 3 and 4. All the surge flow irrigation treatments showed higher application efficiency than continuous flow irrigation treatment. The average (2002 and 2003) application efficiencies for surge irrigation treatments under Q1 were 78.1 for I1, 78.6 for I2, 82.2 for I3, 82.2 for 14 and 87.3% for I5. For Q2 discharge treatment, the average application efficiencies for surge irrigation treatments were 78.7, 79.5, 82.5, 83.2 and 88.2%, respectively. The higher efficiency observed under surge flow irrigation treatments with larger CRs (I5) can be attributed to the surface seal caused by intermittent wetting and decrease in surface hydraulic roughness of wet advance.

It was also noted that the Q2 irrigation discharge treatment significantly increased the water application efficiency more than the treatment of Q1 irrigation discharge for both seasons. This might be attributed to better uniformity of water distribution. The highest mean values of water application efficiency with highly significant difference were 88.61 and 87.86% obtained for the interaction between Q2 and I5 treatment in the summer season of 2002 and 2003, respectively.

Grain Yield

Table 3 shows the mean maize grain yield from each treatment based on irrigation discharge and surge irrigation method. An increase in irrigation discharge led to significant increase in mean grain yield for both seasons. This may be due to better uniformity of water distribution along the furrow. Among the surge irrigation methods, the highest mean grain yields were 7577.3 and 7774.6 kg ha^{-1} for Q2 treatment, in 2002 and 2003, respectively.

Further increases in the cycle ratio larger than the surge CR of 0.5 (I3) led to a decrease in grain yield. The highest mean values of grain yield were 8027.6 and 8197.3 kg ha^{-1} obtained for the I3 surge irrigation treatment in the summer of 2002 and 2003, respectively. From the results, applying surge flow irrigation increased maize grain yield compared to continuous flow irrigation, possibly because the surge flow treatments were more effective in improving the uniformity of soil moisture distribution along the field than continuous flow treatment.

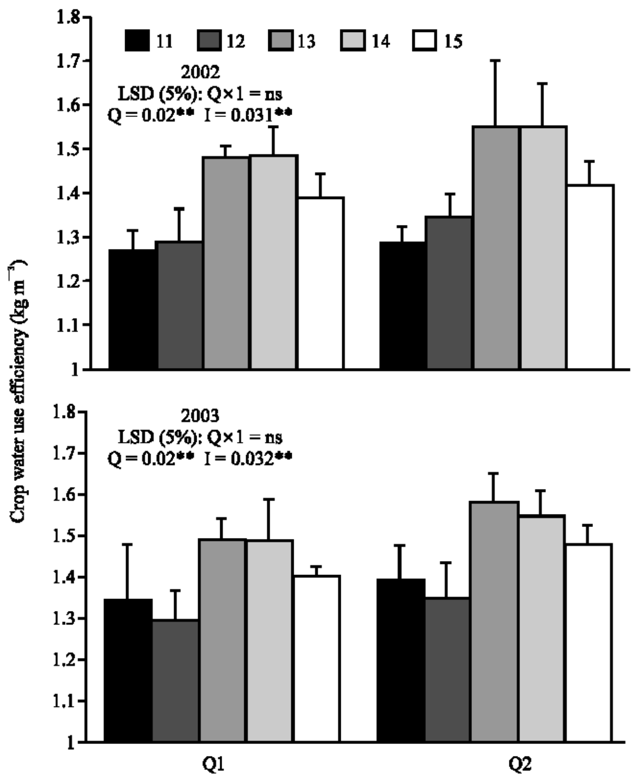

Fig. 2: Crop water use efficiency (kg m^{-3}) as affected by irrigation discharge and surge treatments. (LSD = Least significant difference; Q = Irrigation discharge; I = Surge treatments; Q× I = interaction; **p<0.01, *p<0.05 and ns = not significant)

Water Utilization Efficiency (WUtE)

Table 3 and 4 show the surge irrigation treatments had higher Wu_tE than continuous flow treatment. The highest mean values of WU_tE with highly significant difference were 1.236 and 1.260 kg m^{-3} obtained for the I5 treatment in the summer season of 2002 and 2003, respectively. The highest WU_tE was about 1.284 and 1.3 kg m^{-3} for Q2 irrigation discharge and at the surge I3 in the 2002 and 2003, respectively. The mean values under all the irrigation discharge treatments including continuous flow treatment indicated that Q2 treatment had WU_tE of 1.186 and 1.207 kg m^{-3} which were considered better than Q1, during the two growing seasons. This implies that surge flow and increasing irrigation discharge enhanced the uniformity of soil moisture distribution and minimized percolation losses, as well as leaching of nutrients from the root zone.

Crop Water Use Efficiency (CWUE)

As plotted in Fig. 2, the interaction between Q2 irrigation discharge and I3 gave CWUE of 1.550 and 1.582 kg m^{-3}, which were the highest for the two seasons. The lowest value was about 1.27 kg m^{-3} from the combination of I1 and Q1 irrigation discharge for 2002 and was about 1.298 from combination of I2 and Q1 irrigation discharge in 2003. In general, the highest CWUE was observed under the treatment of I3. Also, an increase in irrigation discharge led to an increase in the mean values of CWUE.

Conclusions

Continuous flow is an easier way to apply surface irrigation than surge flow, but to increase grain yield, save water and improve water application efficiency, surge flow should be applied especially in clayey soils. Surge flow irrigation used less amounts of water than continuous flow. It could save water on the average up to 6.6% (44.9 mm) and 7.2% (50.2 mm) of the continuous flow irrigation in each season. Based on series of results from the viewpoint of water economy, it is recommended to apply the treatment that showed the highest performance in WU_tE, namely, the treatment under 4 L s^{-1} m^{-1} (i.e., 3.2 L s^{-1} per furrow) irrigation discharge and irrigation with a CR of 0.50 (10 min on and 10 min off) treatment (WU_tE were 1.284 and 1.3 kg m^{-3} in each season). The highest mean grain yields were 8027.6 and 8197.3 kg ha^{-1} obtained from applying irrigation with a CR of 0.50 (10 min on and 10 min off) treatment in both seasons. High irrigation discharge led to an increase in the water application efficiency, water distribution efficiency, water utilization efficiency, crop water use efficiency and grain yield for both seasons.

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