Suitable inflow rate and furrow length for Simplified Surge Flow Irrigation

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Summary

In the arid lands covering Uzbekistan, furrow irrigation with low application efficiency is still widely used due to a lack of funds and shortage of labor. To save water and prevent secondary salinization caused by excessive irrigation, it is important to adopt low-cost and easy water-saving irrigation methods. Onishi et al. (2017) proposed simplified Surge Flow (SF) irrigation that does not require expensive equipment and merely divides the water supply into two phases at one-day intervals. This study conducted the suitable inflow rate and furrow length of simplified SF to improve water application efficiency in Uzbekistan. Five experimental plots (total area of 2,250 m^2, with 25 furrows) were set up and the inflow rates for two plots were 5 Ls^{-1} (F5.0) and that for the others were 1.7 Ls^{-1} (F1.7). The conventional irrigation method (F5.0C and F1.7C) and simplified SF (F5.0S and F1.7S) were applied to cases of furrow length of 100 m under each inflow rate. In addition, simplified SF was applied on a 50 m furrow at F1.7 (F1.7S-50). In the first irrigation using simplified SF, water was supplied from the start point of the furrow (0 m) for half of the furrow length (50 m, 25 m). In the second irrigation, water was supplied from the start point to the end of the furrow (100 m, 50 m). The application efficiency in F1.7S and F1.7S-50 was higher than that in F1.7C and F1.7C-50, and the highest was in F1.7S-50. The water supply duration was shorter in F5.0S, but the total volume of supplied water was larger than that of F1.7C. These results indicate that shortening furrow length might be an effective way to save water using simplified SF with a low inflow rate, and in contrast, that it is necessary to extend furrow length with a high inflow rate.

Keywords
Arid land, Salinization, Water-saving, Furrow irrigation, Surge Flow irrigation

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1. Introduction

1.1 Back ground

Irrigated agriculture has the potential to increase crop yields and make a significant contribution to food security. The FAO estimates that irrigated farmland produces 40% of the world's crops while occupying only 20% (300 million ha) of global cultivated area (1.6 billion ha) (FAO, 2011). On the contrary, soil salinity is a major abiotic stress, and reduces global agricultural productivity. Salinization of arable land has dramatically increased in the last few decades (Martin et al., 2012), and it has had a global impact; one forecast shows 30% of arable land will be lost by around 2028, and up to 50% by 2050 (Wang et al., 2003). In addition, 1-2% of global irrigated area is lost to salinization every year, with its effect in arid and semi-arid regions being particularly large (FAO, 2002). In arid and semi-arid regions, irrigation is indispensable for agricultural production, but inappropriate water management causes secondary salinization. There are two main causes of secondary salinization: the inflow of salts within irrigation water, and the rise in groundwater table due to poor drainage. If salts do not leach out of soil, they accumulate through evaporative water loss and root water uptake (Devkota et al., 2015). In general, water-saving and drainage improvement techniques are carried out to mitigate salinization. Salt leaching is, because of its low cost, also a popular salinity removal measure among farmers.

1.2 Salinization in Central Asia

In Central Asia, which is an arid and semi-arid region, there has been remarkable secondary salinization caused by inappropriate water management. Large-scale irrigation was conducted from the 1960s (during Soviet Union era) in the Amu-Darya and Syr-Darya river basins, which were previously steppe or desert areas. In the Republic of Uzbekistan (hereafter, “Uzbekistan”), cotton production with furrow irrigation was carried out on much of the irrigated farmland. Although irrigation greatly increased the agricultural production of the former Soviet Union, inappropriate water management caused severe salinization. As a result, Uzbekistan has the largest area of salt-affected farmlands among the Central Asian countries (**Table 1**) (Karen, 2013). Salt-affected farmland is defined as farmland where the electrical conductivity of the saturated extract of soil (EC_e) is 2 dS m^{-1} or more. Furthermore, soils from the plains of Central Asia are naturally rich in salt. In addition, the development of irrigation has increased the risk of secondary salinization (Shirokova and Morozov, 2006).

Table 1 Salinized area of the total area under irrigation in Central Asia

Country	Area equipped for irrigation		Area salinized by irrigation		
	Year	ha	Year	ha	(%)
Uzbekistan	2005	4,198,000	1994	2,141,000	51
Kyrgyz	2005	1,021,400	2005	49,503	5
Tajikistan	2009	742,051	2009	23,235	3
Kazakhstan	2010	2,065,900	2010	404,300	20
Turkmenistan	2006	1,990,800	2002	1,353,744	68
Total		10,018,151		3,971,782	40

Source: Irrigation in Central Asia in figures (Karen, 2013, FAO Water Reports 39, pp 68)

1.3 Irrigated agriculture in Uzbekistan

In Uzbekistan, even after 27 years of independence from the Soviet Union, the government continues to control cotton and wheat production. Current cotton and wheat production are carried out by the agricultural corporation "*Fermer*," which has long-term lease agreements to use government farmland (Onishi, 2017). Of the 3,700 thousand ha of total irrigated farmland harvested in Uzbekistan, cotton accounts for 1,406 thousand ha, and wheat accounts for 1,295 thousand ha (Karen, 2013). 73% of harvested farmland by irrigation is under government control. The area of farmland managed by *Fermer* is vast (around 50 ha or more), and the corporation widely practices furrow irrigation. In Uzbekistan, surface irrigation is conducted on 4,276 thousand ha (in 1994), which is 92% of the cultivated area (4,651 thousand ha, in 2009) (Karen, 2013). The advantages of surface irrigation are its simplicity of use by farmers, low capital investment requirement, and resistance to wind (Walker, 1989). Contrarily, its disadvantages are its low application efficiency and high labor requirement (Walker, 1989). 90% of global irrigated land is irrigated using relatively inefficient surface irrigation methods (Siyal et al., 2016). In the case of furrow irrigation, it is necessary to dig channels to introduce water, and salts tend to accumulate in the top of ridge where crop is planted (Brouwer, 1985). *Fermer* cannot make investments to improve the infrastructure for water management in most cases, owing to a lack of funds and labor force. Consequently, careless irrigation has been conducted, and excessive irrigation is often observed on *Fermer* farmlands. Excessive irrigation has caused large amounts of salts to be deposited onto farmlands, raising the groundwater table and causing secondary salinization. Therefore, water conservation at the time of irrigation is important to prevent salinization. However, it is still difficult for *Fermer* to install highly efficient irrigation systems, like drip or sprinkler systems, because of a lack of funds.

1.4 Water-saving based on furrow irrigation (simplified Surge Flow irrigation)

Surge Flow irrigation (SF) is a water conservation method based on furrow irrigation (**Fig. 1**). The SF method achieves water conservation by irrigating intermittently instead of continuously.

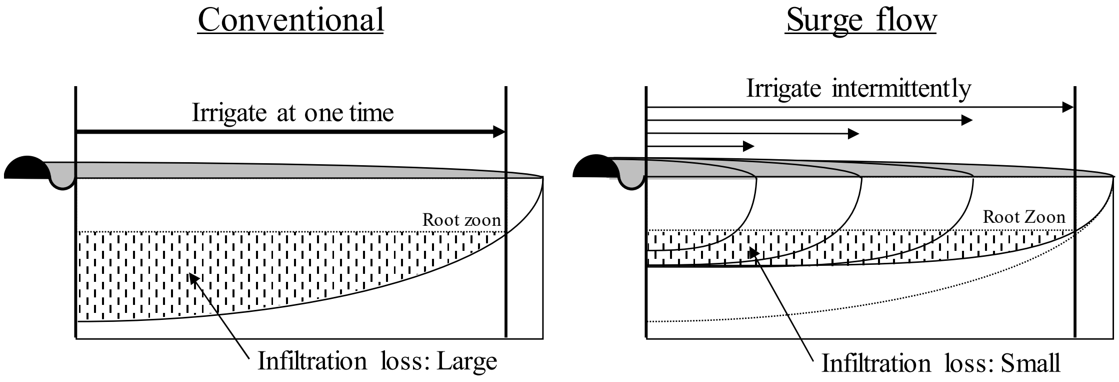

Fig. 1 Concept of Surge Flow irrigation

The advantage of SF is that it decreases infiltration loss by reducing soil permeability through cyclic irrigation. The first water supply reduces soil permeability, speeding up water flow during the second water supply. Four physical processes cause the reduction in infiltration: consolidation, owing to soil particle migration and reorientation; air entrapment; the redistribution of water; and channel smoothing (Alan and Karen, 1994). Alan and Karen (1994) reported that SF has resulted in an approximately 50% saving of irrigation water without significant reduction in peppermint yield, from the level consumed by conventional irrigation. In Uzbekistan, Horst et al. (2005) conducted an experiment at a cotton field in Central Fergana Valley and reported an irrigation water saving of 21% by using SF.

SF is a useful method to save water, but it requires irrigation equipment such as supply pipes and switching valves; therefore, introduction of the method might be difficult for *Fermer*. Considering the physical and economic state of *Fermer*, Onishi et al. (2017) proposed the 'simplified SF' method (**Fig. 2**), which does not require expensive equipment. The method simply divides water application into two phases at one-day intervals (SF-1 and SF-2). They found that the method saved around 10% of water. In this study, optimum inflow rates and furrow lengths of simplified SF were conducted to improve water application efficiency.

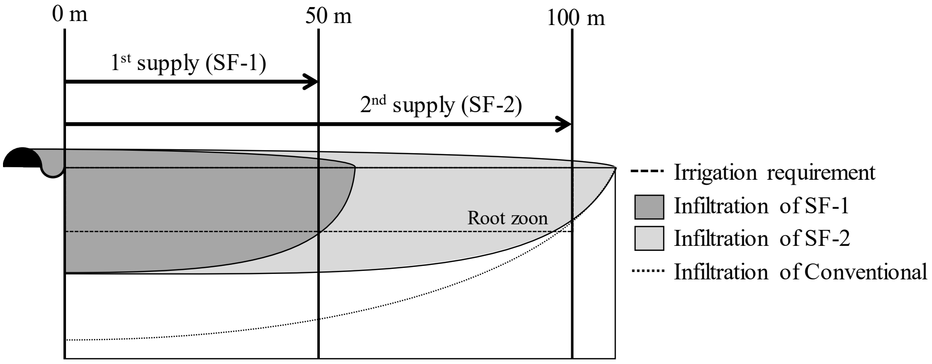

Fig. 2 Concept of simplified SF

2. Materials and Methods

2.1 Study Area

The field study was conducted at the Nozima Durdona Fayz farm (N farm), which belongs to the Axmedov Water Consumer's Association in the Mirzaabad district of the Syrdarya Region (**Fig. 3**). In the Syrdarya Region, 98% of the irrigated farmlands is salt-affected (Onishi et al., 2017), average daily temperature reaches 30°C in summer and drops to 0°C in winter. Total annual precipitation in the region is 320 mm, however, the cumulative precipitation from June to September is very low (20 mm).

The size of a typical field in Syrdarya Region is approximately 40-60 ha and that of the N farm is approximately 51 ha (820 m×620 m). In the N farm, irrigation canal is located on the east of the farmland, whereas the drainage is located on the north and west of the farmland. Usually, irrigation is conducted two or three during cotton cultivation. The irrigation water is supplied to plots divided by temporary channels. The typical size of a plot is about 5-10 ha and the furrow length are approximately 200 m. We measured the inflow rate to one furrow, and it ranged between 0.5 and 2.0 Ls^{-1}.

The properties of N farm soil were analyzed using soil samples from depths of 5, 15, 25, 35, 50, and 70 cm. Bulk density, saturated hydraulic conductivity, and soil texture are shown in **Table 2**.

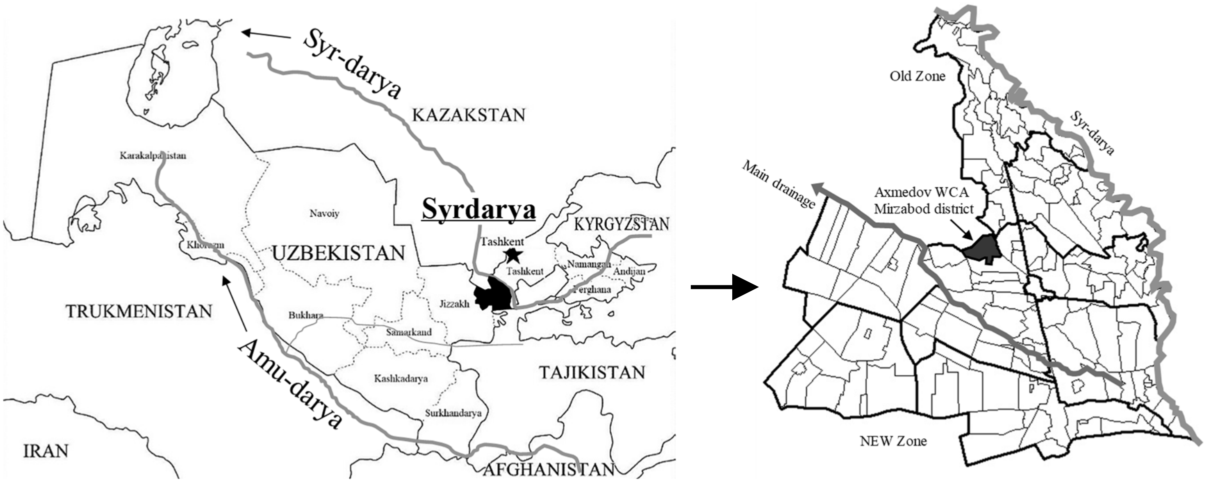

Fig. 3 Locations of Syrdarya Region and Axmedov Water Consumer's Association

Table 2 Physical properties of N farm soil

Depth (cm)	Bulk density (g cm^{-3})	Saturated hydraulic conductivity (cm s^{-1})	Texture Clay (%)	Silt (%)	Sand (%)	Soil type
5	1.37	3.07×10^{-4}	12.8	32.8	54.4	Loam
15	1.40	6.03×10^{-4}	13.2	31.2	55.6	Loam
25	1.56	4.06×10^{-5}	16.8	29.0	54.2	Clay Loam
35	1.62	4.62×10^{-5}	14.1	31.8	54.2	Loam
50	1.49	2.26×10^{-4}	15.6	29.0	55.3	Clay Loam
70	1.46	4.03×10^{-4}	9.3	35.2	55.5	Loam

Bulk density of surface soil (to a depth of 15 cm) is 1.4 g cm^{-3} but at depths of 25 cm to 35 cm it is 1.6 g cm^{-3}; here is it assumed that a hard soil layer has formed. Saturated hydraulic conductivity is lower in the hard soil layer (25-35 cm depth) than it is in the other layers. All depths were classed as either loam or clay loam according to the standards of the International Society of Soil Science. Readily Available Water (RAW: pF 1.8-3.0) was obtained from the soil moisture characteristic, which was analyzed using the pressure plate method (DIK-3483, Daiki Rika Kogyo Co. Ltd, Kounosu city, Saitama prefecture, Japan). Soil moisture characteristics are shown in **Table 3**.

Table 3 Soil moisture characteristics (cm^3 cm^{-3})

Depth (cm)	Field capacity (pF 1.8)	Depletion of moisture content for normal growth (pF 3.0)	Primary wilting point (pF 3.8)	Readily available water (RAW) (pF 1.8-3.0)
5	0.353	0.202	0.180	0.151
15	0.349	0.206	0.187	0.143
25	0.352	0.245	0.220	0.106
35	0.340	0.246	0.221	0.094
50	0.365	0.198	0.174	0.167
70	0.388	0.174	0.144	0.214

Field capacity (pF 1.8) was between 0.340 and 0.388 cm^3 cm^{-3}, Depletion of moisture content for normal growth (pF 3.0) was between 0.174 and 0.246 cm^3 cm^{-3}. The RAW of the hard soil layer (25-35 cm depth) was lower than it was in other layers.

2.2 Experimental setup and treatment

The experiment was conducted during the cotton cultivation period on the northeastern side of the N farm in July 2017. The average field slope is 1/1000. Furrows and ridges were made using a tractor and their widths were 0.4 m and 0.5 m respectively. Irrigation water was supplied using a gasoline pump (LGP 20-A, Leo Group Co., Ltd., Wenling city, China, discharge rate: 5 Ls^{-1}). The electrical conductivity of irrigation water was 1.42 dS m^{-1}. Five plots (total area of 2,250 m^2, with 25 furrows) were set up for the experiment (**Fig. 4**). Although normal inflow rate is 0.5 to 2.0 Ls^{-1}, advance of the water was often stopped due to unevenness of furrow. Therefore, in this study, a high flow rate more than twice the normal rate was applied to avoid the effects of the unevenness of the furrows. Further, it can be expected that infiltration loss decreases with the shortening in the irrigation time under high flow rate. In two plots, irrigation water was supplied to each furrow at an inflow rate of 5 Ls^{-1} per furrow (F5.0). In the other three plots, irrigation water was supplied to each furrow at an inflow rate of 1.7 Ls^{-1} per furrow (F1.7).

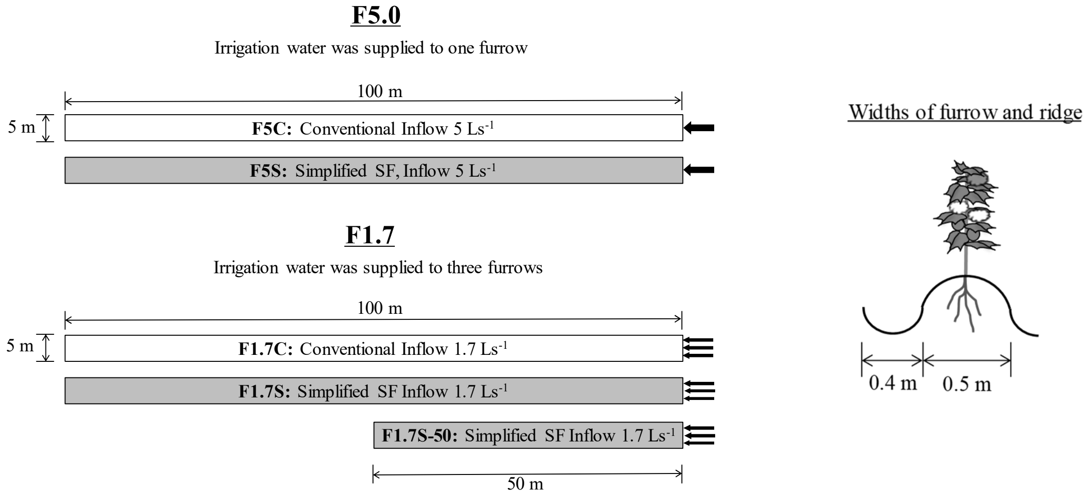

Fig. 4 Design of experimental plots

In each plot, a conventional and simplified SF method was applied to 100 m (F5.0C, F5.0S, F1.7C and F1.7S); and in addition, simplified SF was applied on a 50 m furrow in plot F1.7 (F1.7S-50). The ends of all the furrows were blocked and when irrigation water reached the end of the furrow, the water supply was stopped. In the simplified SF trial, water was supplied from the start of the furrow (0 m) for half of the furrow length (50 m, 25 m) at first irrigation (SF-1), and from the start to the end of the furrow (100 m, 50 m) at second irrigation (SF-2). The SF-2 was conducted about 20 hours after the SF-1. This water flow test had three replicates comprising the central three furrows of each plot (the two furrows at both ends of the five furrows in the plots were not used).

2.3 Estimation of furrow infiltration

In order to estimate the amount of infiltration water during the irrigation periods, furrow infiltration tests were conducted before the water flow tests. The furrow infiltration test was carried out on dry soil and wet soil (one day after water supply) conditions, a Maliot tank supplied the flooding water and the amount of infiltration water was measured 60 minutes after flooding. The results from the infiltration test in dry soil are assumed to be the values of all dry soil, i.e. all the furrow area of conventional and SF-1, and the furrow area of 25-50 m or 50-100 m under SF-2. The results from wet soil are assumed to be the values of all wet soil i.e. the furrow area of 0-25 or 0-50 m under SF-2. Kostiakov's Infiltration Model was used to estimate infiltration.

$$D = ct_i^n \tag{1}$$

where, D is the cumulative infiltration depth at time t_i, t_i is elapsed time (min), c and n are intake constants. The Basic Intake rate Ib of each condition was calculated using formula (2).

$$I_b = 60cn\{600(1-n)\}^{n-1} \tag{2}$$

During the water flow test, 'time' was measured at every 10 m advance in water flow; this was used to estimate water flooding time in the furrow. The furrow flooding time was calculated at each furrow point (1 m interval) during irrigation; time was estimated using the formula (3) proposed by Ikeura et al. (1998).

$$t_a = al^3 + bl \tag{3}$$

where, t_a is the water advance time until it flows down at the distance l, l is the distance from water inlet (m), and a and b are constants. In this study, cumulative infiltration depth at 1 m interval was calculated using formula (4).

$$D = c\left\{\frac{t_f - t_a}{60}\right\}^n \tag{4}$$

where, t_f is the finishing time of water supply.

The estimation of infiltration water focused on the irrigation period

2.4 Water requirement

Water requirement (mm) was determined from the soil moisture consumption and RAW. Soil moisture consumption was determined by using the volumetric water content of sampling soil which was sampled twice: 24 hours and 12 days after irrigation. Soil sampling was conducted on the 14th and 25th of July 2017, and during this term there was no rain. According to groundwater monitoring data from the experimental field in July 2015, the groundwater table fell to approximately -2.5 m by the time of irrigation, and then it was raised to approximately -1.5 m after irrigation. After the irrigation term, the groundwater table fell gradually, and then stabilized at approximately -3.0 m until the leaching term in December.

Soil moisture was reduced to a depth of 30 cm from 24 hours to 12 days after irrigation, about 58% of which was reduced at the surface soil layer (up to 10 cm depth). Therefore, the effective soil layer is up to 30 cm deep and the critical soil layer for water content for normal growth was concluded to be the surface layer (10 cm). From the *RAW* of the surface soil layer (0.151 $m^3\ m^{-3}$) and thickness of critical soil layer (10 cm), Total Readily Available Moisture (*TRAM*, 26.1 mm) was obtained using formula (5).

$$TRAM = (f_c - M_L) \times D_{ls} \times \frac{1}{C_p} \tag{5}$$

where, f_c is field capacity ($m^3\ m^{-3}$), M_L is depletion of moisture content for normal growth ($m^3\ m^{-3}$), D_{ls} is thickness of critical soil layer (mm), C_p is soil water consumption ratio of critical soil layer. In salt-affected farmland, it is necessary to add Leaching Requirement (*LR*) to control soil salinity. The *LR* (0.038 mm) was calculated formula (6) (Ayers and Westcot, 1994).

$$LR = \frac{EC_w}{5EC_e - EC_w} \tag{6}$$

where *LR* is the leaching requirement (mm), EC_w is the electrical conductivity of the applied irrigation water in dSm^{-1} (1.42 $dS\ m^{-1}$) and EC_e is maximum electrical conductivity to obtain 100% of the cotton yield (7.7 $dS\ m^{-1}$). From *TRAM* and *LR*, Required Water (*RW*, 27.2 mm) was calculated by the formula (7) (Ayers and Westcot, 1994).

$$\mathrm{RW} = \frac{TRAM}{1 - LR} \tag{7}$$

3. Results and Discussion

3.1 Furrow infiltration

The cumulative infiltration data as functions of time under dry (SF-1) and wet (SF-2) condition are shown in **Fig. 5**. Dots are the average of three trials in the field. Basic intake rate (I_b) and intake constants obtained by regression analysis are listed in **Table 4**. The amount of cumulative infiltration after 60 minutes of SF-1 and SF-2 were 83 mm and 28 mm, respectively. Variation of data for SF-2 was smaller than that of SF-1. The basic intake rate of SF-2 was 63% lower than that of SF-1. A large reduction in I_b was also reported by Onishi et al. (2017) for a different land area managed by the Water Consumer's Association.

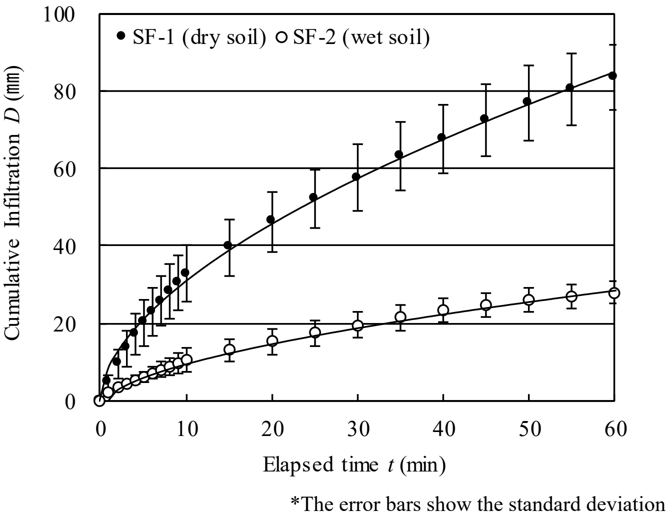

Fig. 5 Cumulative infiltration curve

Table 4 Basic intake rate I_b and

Treatment	I_b (mm hr^{-1})	c	n
SF-1	25.4	8.36	0.57
SF-2	9.5	2.60	0.59

3.2 Duration of application and amount of supplied water

The water flow test was conducted from July 25th to 27th, 2017. The duration of application for each furrow, and time taken for the water to advance every 10 m was measured at three furrows.

Table 5 Duration of application

Inflow rate	Plot	SF-1		SF-2		Total (s)
		Length (m)	time (s)	Length (m)	time (s)	
$5Ls^{-1}$	F5.0C	100	1,148	0	0	1,148
	F5.0S	50	462	100	930	1,392
$1.7Ls^{-1}$	F1.7C	100	3,289	0	0	3,289
	F1.7S	50	1,236	100	1,431	2,667
	F1.7C-50	50	1,299	0	0	1,299
	F1.7S-50	25	374	50	640	1,014

The irrigation times of each treatment are listed in **Table 5**. The irrigation times are the averages of the values measured at three furrows. The irrigation time of F1.7C-50 was obtained using the data of F1.7C up to 50 m. In the case of inflow rate of 5 Ls^{-1}, the total duration of F5.0S was 21% longer than that of F5.0C. In contrast, the total duration of F1.7S was 19% shorter than that of F1.7C. And in the case of 50 m of furrow length, total duration of F1.7S-50 was 22% shorter than F1.7C-50.

The amount of supplied water and application efficiency for each plot are shown in **Table 6**. In this study, the volume of Required Water (*vRW*) was calculated assuming that the width was 0.9 m (ridge and furrow), the depth was 0.0272 m (*RW*), and the length was 100 or 50 m. The application efficiency is defined as the ratio of *vRW* to supplied water amount and we assumed that all supplied water infiltrated into the ridge and furrow. Regarding the inflow rate of 1.7 Ls^{-1}, the applied water amount for 50 m by conventional (F1.7C-50) was used as the data for F1.7C up to 50 m.

Table 6 Amount of supplied water and application efficiency

Inflow rate	Plot	Supplied water (m^3)	vRW (m^3)	Application efficiency (%)
5 Ls^{-1}	F5.0C	5.74	2.45	43
	F5.0S	6.96	2.45	35
1.7 Ls^{-1}	F1.7C	5.59	2.45	44
	F1.7S	4.53	2.45	54
	F1.7C-50	2.21	1.22	55
	F1.7S-50	1.72	1.22	71

Application efficiency of F5.0S was 8% lower than that of F5.0C. Contrarily, application efficiency of F1.7S was 10% higher than that of F1.7C, and that of F1.7S-50 was 16 % higher than that of F1.7C-50. These results suggest that the high inflow rate (5 Ls^{-1}) did not have a water-saving effect on 100 m furrow length.

3.3 Water advance curve

The water advance curves for SF-1 and SF-2 in each inflow rate are shown in **Fig. 6**. The water advance constants obtained by regression analysis are listed in **Table 7**.

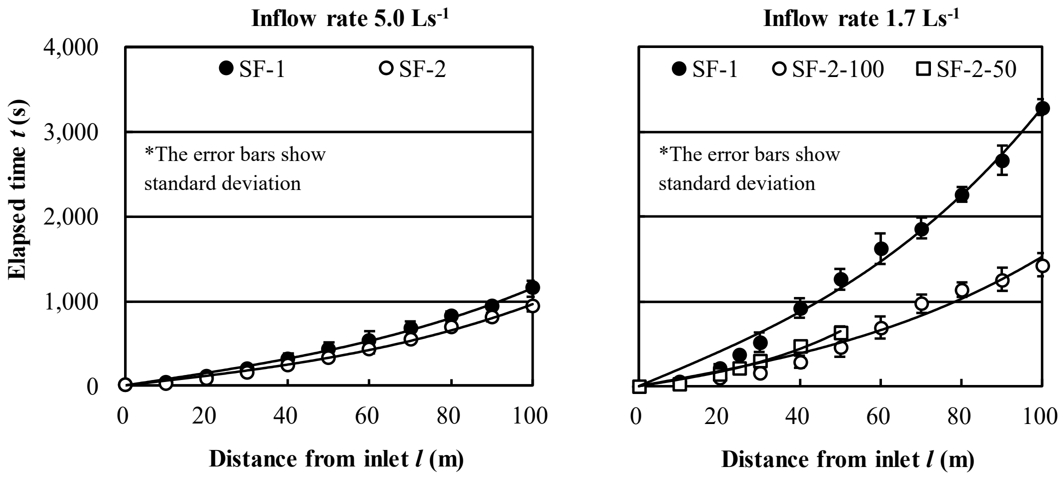

Fig. 6 Water advanced time in SF-1 and SF-2 at every 10 m

Table 7 Water advance constants *a*, *b*

Inflow rate	Length (m)	Treatment	a	b
5.0 Ls^{-1}	100	SF-1	0.0004	7.23
	100	SF-2	0.0004	5.51
1.7 Ls^{-1}	100	SF-1	0.0013	19.88
	100 (wet 50)	SF-2	0.0007	8.63
	50 (wet 25)	SF-2	0.0022	7.67

At an inflow rate of 5.0 Ls^{-1}, the effect of SF-1 on SF-2 advance time was not large, and arrival time at 100 m of SF-2 was just 218 seconds (19%) shorter than that of SF-1. On the contrary, in 1.7 Ls^{-1}, the arrival time at 100 m and 50 m of SF-2 was shorter by 1,858 (56%) and 659 (51%) seconds, respectively. These results indicate that a 100 m furrow length is not suitable for shortening the water advance time under high inflow rate.

3.4 Estimation of furrow infiltration

The amount of cumulative infiltration water in furrows was estimated using the Kostiakov formula (Eq.1) and water advance formula (Eq.3), which was obtained from inflow and furrow infiltration test results and formula (Eq.4). The target for estimation was the time for the irrigation water to reach the end of the furrow. Therefore, in this study, recession time after water supply was not considered. For this reason, there was no infiltration at the end of the furrow. The distribution of cumulative infiltration for each treatment is shown in **Fig. 7**. Cumulative infiltration and amount of infiltration loss are shown in **Table 8**. We define infiltration loss as the amount of water that infiltrated more than *RW* (27.2 mm). Loss ratio is defined as the ratio of infiltration loss to *vRW*.

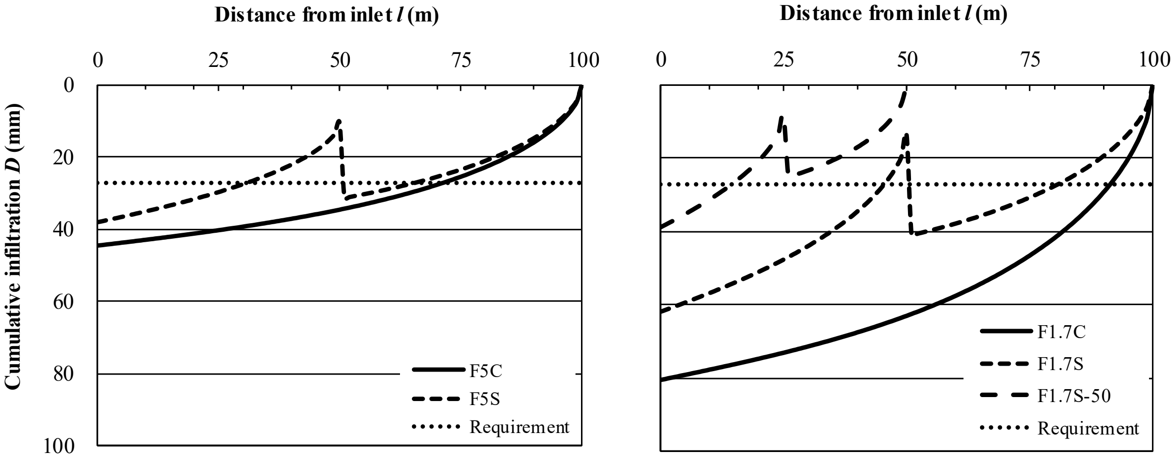

Fig. 7 Distribution of cumulative infiltration water during irrigation time

Table 8 Amount of cumulative infiltration water and infiltration loss during irrigation time

Inflow rate	Plot	vRW (m^3)	Infiltration (m^3)	Loss (m^3)	Loss ratio (%)
5 Ls^{-1}	F5.0C	2.45	2.86	0.64	26
	F5.0S	2.45	2.26	0.20	8
1.7 Ls^{-1}	F1.7C	2.45	5.22	2.85	116
	F1.7S	2.45	3.32	1.05	43
	F1.7C-50	1.22	1.34	0.27	22
	F1.7S-50	1.22	1.01	0.09	7

As mentioned above, at an inflow rate of 5 Ls^{-1}, the volume of supplied water was large. However, if infiltration time was limited during the irrigation period, the infiltration loss was small, and furthermore, simplified SF could reduce infiltration loss. An inflow rate of 1.7 Ls^{-1} resulted in simplified SF showing a clear water saving effect. The effect of F1.7S-50 was larger than that of F1.7S. However, the infiltration loss of 1.7 Ls^{-1} was larger than that of 5 Ls^{-1}. This result indicates that shortening furrow length might be an effective way to save water using simplified SF with a low inflow rate; in contrast, it is necessary to extend furrow length with a high inflow rate.

4. Conclusion

In the study, we studied inflow rate and furrow length of simplified SF. First, from the infiltration tests, we confirmed that preliminary water supply to the furrow effectively lowers the permeability of the furrow. Furthermore, we found that a high inflow rate (5 Ls^{-1}) did not save water when applied to a furrow length of 100 m. We presumed that irrigation water could rapidly reach the ends of the furrows, but the total volume of water applied might increase. In contrast, a low inflow rate (1.7 Ls^{-1}) applied to furrow lengths of 100 m did save water with simplified SF. Water conservation was even greater with short furrow length (50 m). However, if infiltration time was limited during the irrigation period, infiltration loss was reduced at both inflow rates. This result shows that the simplified SF (which divides a single irrigation cycle into two phases with a one-day interval) can reduce infiltration.

Simplified SF would also be useful when inflow rate is insufficient for furrow length. In practice, it is difficult to control inflow rates in the field in Uzbekistan owing to a lack of equipment and labor force. Therefore, to practically apply simplified SF, if the irrigation water in flow rate can be calculated, furrow length can be adjusted. If it is difficult to adjust the furrow length, so as an alternative, it would also be effective to adjust the timing of stopping of the water supply. For example, in the case of a high inflow rate, water supply could be stopped before the water front reaches the end of the furrow to reduce excessive water supply. On the contrary, according to the estimation of furrow infiltration, the *RW* was not fulfilled in the downstream area, and this may cause water stress in cotton. As a control measure, it would be effective to adjust the time of stopping the water supply.

Further studies involving an intermediate flow rate (3.0 Ls^{-1}) and on the timing of stopping water supply are necessary to identify suitable conditions for enhancing water conservation effects of simplified SF. In addition, although simplified SF is expected to save water, it is necessary to understand soil salinity distribution when it is applied.

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