Water-saving Effect of Simplified Surge Flow Irrigation on Irrigated Farmlands in Arid Areas - A Case Study in the Republic of Uzbekistan -

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Summary

In some parts of irrigated farmlands in arid areas, decreasing crop productivity caused by secondary salinization due to excessive irrigation and poor drainage has become a serious problem. Water saving is required in such areas, but it is not easy to shift to a more efficient irrigation method due to lack of funds and difficulty in procuring equipment. For these reasons, furrow irrigation, although causing large infiltration losses, is still being widely practiced.

In order to save water in furrow irrigation through the use of a method which can be easily adopted by farmers, a simplified Surge Flow irrigation method (hereinafter referred to as ‘simplified SF’), which is a simple version of the regular Surge Flow method (hereinafter referred to as ‘SF’), was contrived. In SF, water is applied intermittently, about 4 times by using pipelines and valves, to obtain water-saving effect. On the other hand, in the simplified SF, a single furrow irrigation (conventional furrow irrigation) is just divided into two. In this research, the water-saving effect of the simplified SF was verified on irrigated farmlands exhibiting remarkable secondary salinization in Uzbekistan. In the furrow infiltration test, the cumulative infiltration at 60 minutes after the start of flooding, in the soil that has been supplied with water before one day, decreased by 9.5 mm compared with that of the dry soil; and the basic intake rate also decreased to less than 50%. In the comparative irrigation test between the conventional furrow irrigation method and the simplified SF on 100 m furrow (slope: 1/800), the speed of water advance during the second water supply by the simplified SF increased, and the total duration it took for the irrigation water to reach the end of the furrow (irrigation time) was 6,026 seconds (about 100 minutes); this was 742 seconds (about 13 minutes) shorter than that of the conventional method, which had an irrigation time of 6,768 seconds (about 113 minutes). These results therefore showed that the simplified SF could reduce the amount of water supplied to the furrow and the amount of oversupplied water by 11% and 15%, respectively.

This present study demonstrates the potential of the simplified SF as an effective water-saving method in the developing countries facing water management problems. It should be noted, however, that the water-saving effect of the simplified SF was lower than the 21% obtained with the use of regular SF in Fergana, Uzbekistan. In addition, stagnation of irrigation water due to the unevenness of furrows may have affected the water-saving effect of the simplified SF. Therefore, to deal with the future challenges concerning the application of the simplified SF in the field, it is necessary to consider optimal furrow length, as well as measures to suppress the influence of uneven furrows.

Keywords Salt accumulation, Furrow irrigation, Water-saving irrigation, Simplified Surge Flow irrigation method, Republic of Uzbekistan

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1. Introduction

1.1. Background

Irrigated agriculture in arid land, especially in developing areas where appropriate water management has not been conducted due to inadequate facilities and workforce, the negative effect by salt accumulation has become a serious problem. The United Nations Food and Agriculture Organization (FAO) estimates that approximately 1.5 million ha of irrigated farmland is abandoned every year due to waterlogging and salinization (Tony, 1995). If the abandonment of cultivation continues at this speed, in 50 years approximately 50% of the current irrigated farmland will be abandoned and the food supply capacity is expected to be halved (Kitamura, 2016).

This type of salt accumulation (secondary salinization) is remarkable in Central Asia where the development of large-scale irrigation occurred during the Soviet Union era, greatly contributing to agricultural production. Plain soils in Central Asia were originally rich in salts and there is a high risk of secondary salinization associated with irrigated agriculture (Shirokova and Morozov, 2006). The Republic of Uzbekistan, which played a role in cotton production during the Soviet Union era, has the largest salt affected farmland area (**Table 1**) (Karen, 2013). In this study, salt-affected farmland is defined as farmland where the electrical conductivity of the saturated extract of soil (EC_e) is 2.0 dSm^{-1} or more.

Agricultural production in Uzbekistan is conducted by a management entity with a legal persona called "*Fermer*", which are provides farmland owned by the country by way of long-term loan contracts (Onishi, 2012). The area of farmland is several dozen ha, and crop cultivation is conducted with furrow irrigation.

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)

As one of the water-saving methods based on furrow irrigation that reduces downward infiltration, there is Surge Flow irrigation (SF) (Walker, 1989). SF is a method used to reduce the permeability of furrows by stepwise water supply reducing the downward infiltration loss (**Fig. 1**). Four physical processes cause the reduction in infiltration: 1) consolidation, owing to soil particle migration and reorientation, 2) air entrapment, 3) redistribution of water, and 4) channel smoothing (Mitchell and Karen, 1994). In addition, the reduction of furrow permeability by first irrigation makes the water advance speed of irrigation after the second irrigation increase and can be expected to shorten the irrigation time.

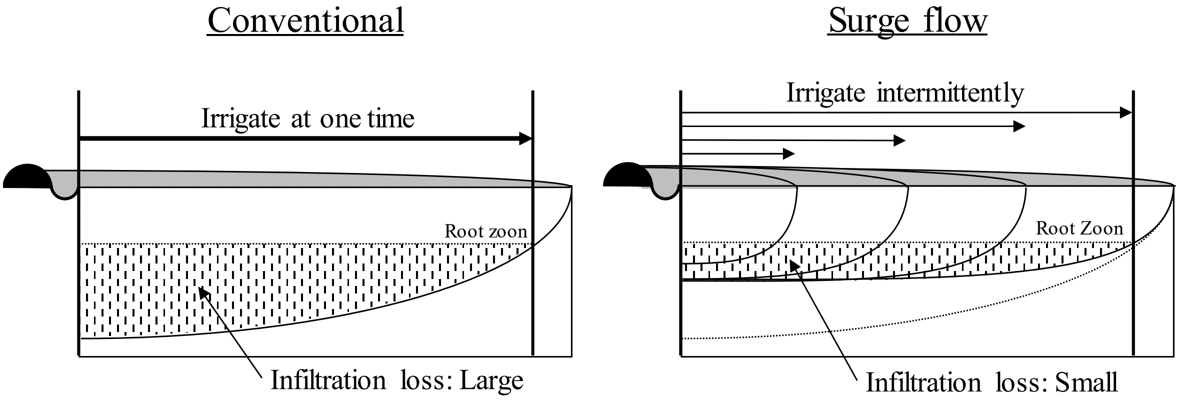


Fig. 1 Concept of Surge Flow irrigation

SF was developed and introduced in Bulgaria in the 1970s, and its introduction was attempted in Kyrgyzstan during the Soviet era. However, it did not reach widespread use. After that, it became widely used in the United States from around the 1980s, and became a worldwide technology (Horst et al., 2005). Horst et al. (2005) conducted an experiment at a cotton field in the Central Fergana Valley and reported an irrigation water saving of 21% by using SF. It is easy and low-cost, but in the rural area of Uzbekistan, it is difficult to purchase supply pipe and switching valves that are used in SF. Even if it could be procured, there would be a cost burden for *Fermer*.

For this study, in order to enable the adoption of water-saving technology by *Fermer*, we focused on the improvement of furrow irrigation without requiring new facilities and a large increase in labor. To facilitate its smooth introduction, we have simplified the SF by devising a method to reduce the SF from four water supply times to two, with one day interval (simplified SF). Simplified SF was applied to the *Fermer* field in Uzbekistan, and the water-saving effect by simplified SF was analyzed from the measured infiltration on furrows and water advance and recession times.

1.2. Irrigation agriculture and salt accumulation in Uzbekistan

Uzbekistan was forcibly assigned the role of cotton cultivation on farmland from the 1960's during the Soviet Union era where large-scale irrigation development has developed. Consequently, cotton is widely cultivated on irrigated farmland in Uzbekistan. After independence from the Soviet Union in 1991, the intensive cultivation of cotton continued and wheat cultivation for food self-sufficiency expanded. Currently, 100% of cotton and 50% of wheat is purchased by the government under strict production quotas. In general, in *Fermer* farmland, a two-year cultivation cycle is practiced. Cotton is grown from April to September, and wheat is grown from October to June in the same section after cotton cultivation. After wheat cultivation, leaching occurs in December then cotton is cultivated again in the next April. In cotton cultivation, irrigation is necessary due to low precipitation. However, irrigation water cannot reach the lower areas that are far from the main canal, and therefore some farmlands are not cultivated.

In Uzbekistan, 4,281 thousand ha of farmland are equipped with irrigation facilities, and in most of them (4,276 thousand ha), surface irrigation is used. Furthermore, of the 3,700 thousand ha of cultivated irrigated farmland, 1,406 thousand ha of cotton and 1,295 thousand ha of wheat are cultivated under government control (approximately 73%) (Karen, 2013). In cotton and wheat cultivation, furrow irrigation is widely used. However, its downward infiltration loss is large, and the percentage of water stored in the soil layer (effective soil layer) that is consumed by crops from the water reaching the field (application efficiency) is small (approximately 70% compared to 80 - 90% of the sprinkler irrigation) (Maruyama et al., 1998). In addition, the irrigation water that infiltrates downward recharges the groundwater and causes the groundwater level to rise.

Many *Fermer*s lack funds and labor, so that cannot invest in irrigation facilities and irrigation management. They have therefore developed inefficient irrigation management, often resulting in over-irrigation under furrow irrigation which lowers application efficiency. As a result, the groundwater level in the irrigated farmland rises, waterlogging becomes normal, and salt accumulation progresses.

Salt accumulation (the percentage of salinized area (EC_e> 2.0 dSm^{-1})) is large in the six regions of Karakalpakistan, Bukhara, Jizzakh, Navoiy, Syrdarya, and Khorazm, where irrigation is practiced using the Amu Darya and Syr Darya Rivers (hereinafter "Amu River, Syr River") as the water sources. It is thought that excessive irrigation under furrow irrigation is one factor. In particular, the damage to crop production in the Karakalpakistan which is located in the lower basin of the Amu River and faced the Aral Sea, is serious. Salinization is also progressing in the Syrdarya Region located in the middle portion of the Syr River, and salinization occurs in about 98% of the irrigated farmland (**Fig. 2**).

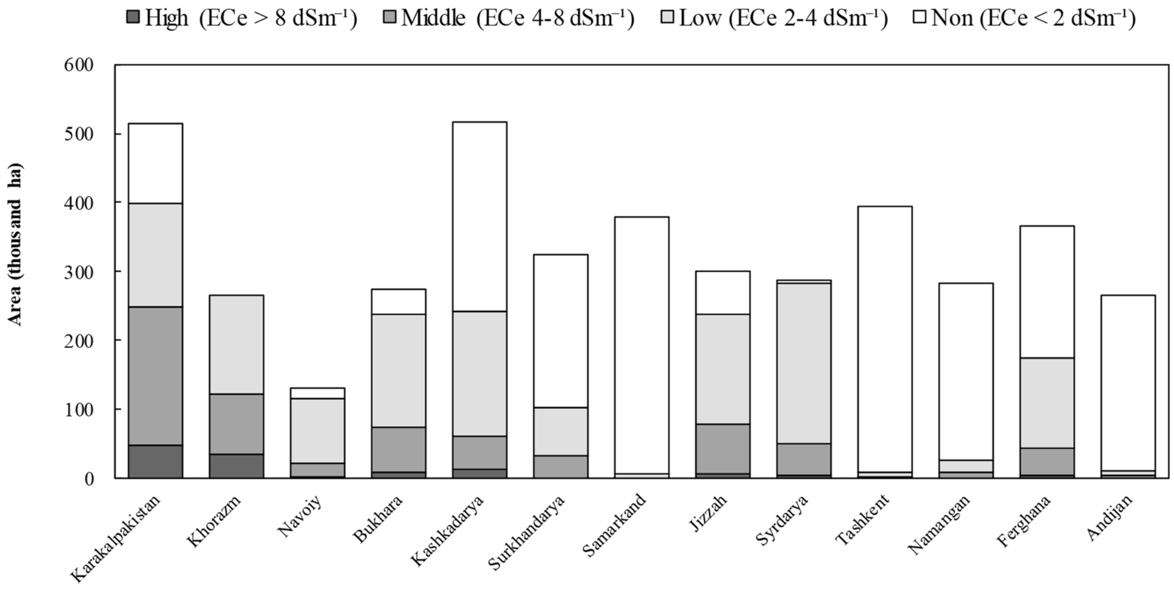


Fig. 2 Salt affected area of each region (2011)

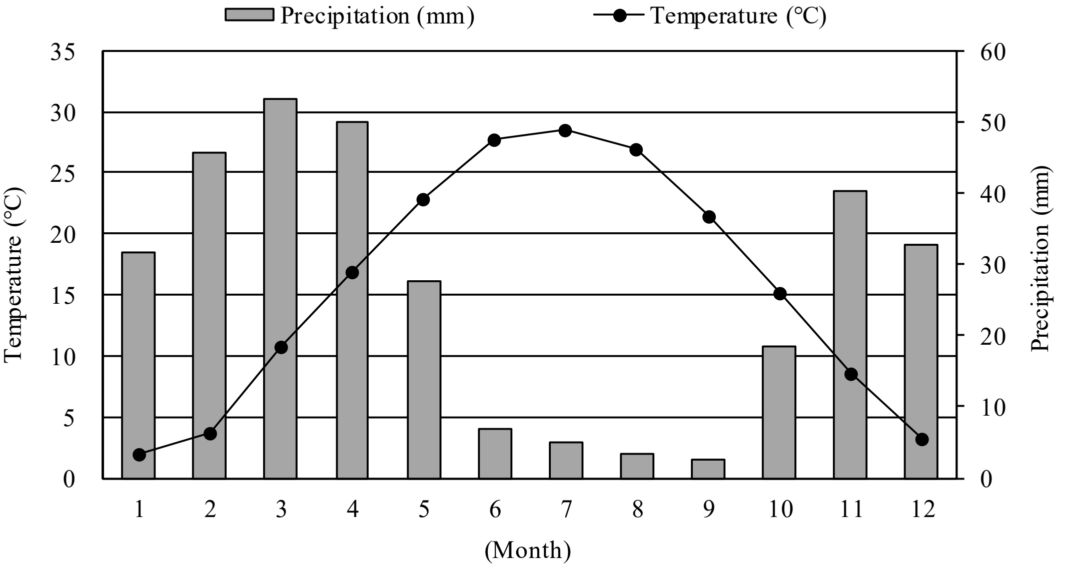
Adapted from data provided by the Farmers' Council of Uzbekistan

As measures against secondary salinization, the introduction of water saving methods such as sprinkler and drip irrigation with less lower infiltration loss is effective, but it requires expensive water supply facilities and maintenance costs, so is difficult for *Fermer*s to introduce.

2. Experimental area

In this research, the Syrdarya Region (**Fig. 3**) was selected as the study area. Approximately 98% of the irrigated farmland in the region is salt affected, and the need for counter measures is considered to be high. The field experiment was conducted at the Pakhtakor field (hereinafter "P field") of *Fermer*, which belongs to the Bobur Water Consumers Association, Oqoltin District. It is located in the southwestern area of the region and operates irrigated agriculture, with the Syr River as its water source. The daily mean temperature of the Syrdarya Region rises to 30 °C in summer and falls to approximately 0 °C in winter. The annual precipitation is approximately 320 mm, but the accumulated precipitation from June to September is very low, being approximately 20 mm (**Fig. 4**).

Fig. 3 Location of Syrdarya Region and Bobur Water Consumer's Association



Source: Yangiyer weather station in Syrdarya region

Fig. 4 Average precipitation and temperature in Syrdarya Region (2004-2015)

In the Oqoltin area, 99% of irrigated farmland is salt affected, but the degree is low. Approximately 74% of irrigated farmland is classified as low level (**Table 2**). The area of the P farm is as large as 136 ha, with a vertically long partition shape of approximately 620 m east-west and 2,200 m north-south. The irrigation canal is located on the eastern side of the farmland, and drainage is located on the western side. In cotton and wheat cultivation, a ridge was constructed from south to north, and a temporary channel was constructed from west to east with a 100–200 m interval. Furrow irrigation was conducted via a temporary channel from south to north.

Table 2 Salt affected area in the Oqoltin district (2008)

Irrigated area	Non (ECe < 2 dSm^{-1})		Low (ECe 2 - 4 dSm^{-1})		Middle (ECe 4 - 8 dSm^{-1})		High (ECe > 8 dSm^{-1})	
ha	ha	%	ha	%	ha	%	ha	%
43,692	551	1.3	32,495	74.4	9,412	21.5	1,234	3.8

A particle size analysis of soil in P field (**Table 3**) was conducted at the Glistan University located in the Syrdarya Region. The particle size ratio of 0.05-0.01 mm was the highest, accounting for 38.6%, 0.05 mm or more accounted for 23.3% and 38.1% accounted for 0.01 mm or less. **Fig. 5** indicates the average value of bulk density ρ_d (100 cm depth) measured at three points in the P field. The bulk density of the surface soil layer was approximately 1.4 g cm^{-3}, however it was high, being from 10 cm to 50 cm deep, and the bulk density was approximately 1.6 g cm^{-3}. It is consequently considered that a hard soil layer was formulated by the long-term compaction of agricultural machinery.

Table 3 Particle size composition (weight fraction)

Weight Fraction (%)						
> 0,25 (mm)	0,25 - 0,1 (mm)	0,1 - 0,05 (mm)	0,05 - 0,01 (mm)	0,01 - 0,005 (mm)	0,005 - 0,001 (mm)	< 0,001 (mm)
2.2	0.4	20.7	38.6	13.6	13.5	11.2

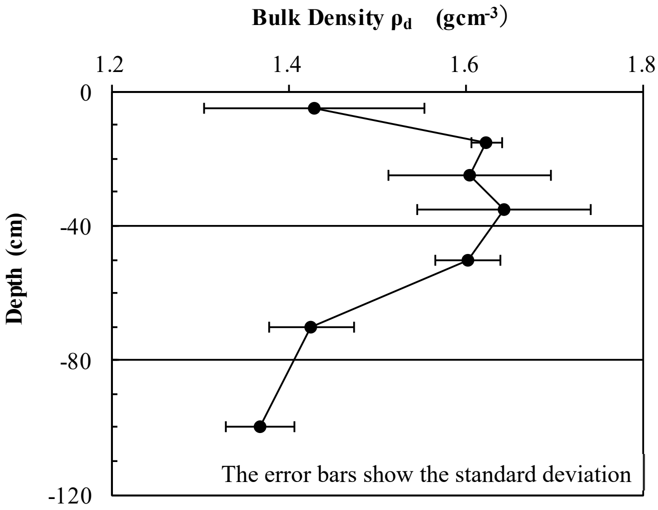


Fig. 5 Bulk density of each depth

3. Materials and Methods

3.1 Condition of experimental field

In the P field, laser leveling was conducted in 2009, cotton was cultivated in April–September 2010, and wheat was cultivated in October 2010–June 2011. The test was conducted during the non-cultivation period after the wheat harvest. The test area was plowed after wheat harvest in July 2011, and then test furrows were created by a tractor in a north-south direction. The interval between ridge and furrow was 0.5 m and 0.4 m which is the most common size for cotton cultivation in Uzbekistan. The average slope of the furrows was approximately 1/800.

3.2 Water flow test

Water was supplied by normal furrow irrigation (conventional) and simplified SF to the test furrow, and then the speed of water advance and water recession time were measured.

In the ordinary SF method, water supply pipe was installed to the water inlet side and water supply was controlled by a start or stop switching valve. Generally, water was supplied intermittently four times following the SF method (**Fig. 6**) (Guy, 2013). If switching work was conducted manually by *Fermer*, it was assumed that the amount of work would increase. However, in simplified SF, water supply pipe is not required nor a lot of additional work by *Fermer*. It simply divides the water application into two phases at one day intervals.

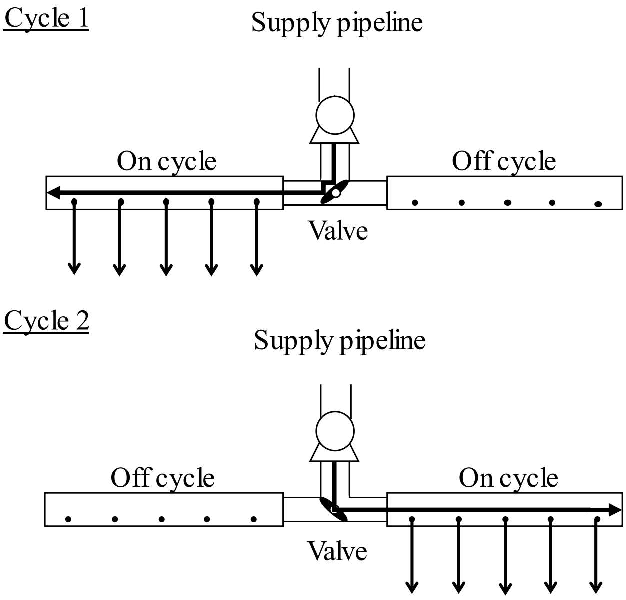


Fig. 6 Typical Surge Flow system

Illustration adapted from Guy F (2013) "Growers Guide to Surge Flow Irrigation", **Fig. 2**.

In the simplified SF trial for 100 m furrows, water was supplied from the start of the furrow (0 m) for half of the furrow length (0 to 50 m) at first irrigation (SF-1) and when irrigation water reached 50 m of the furrow, the water supply was stopped. When the water supplied by SF-1 disappeared from the surface of furrow (next day of SF-1), the start to the end of the furrow (0 to 100 m) was watered by a second irrigation (SF-2) (**Fig. 7**).

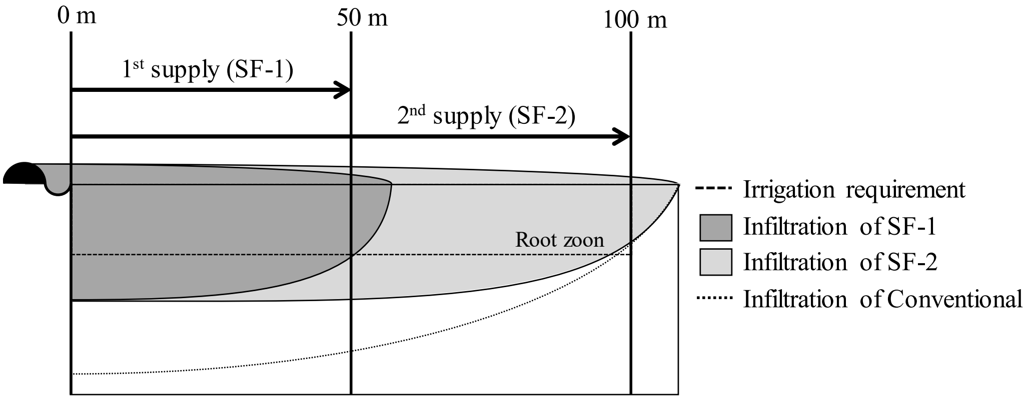


Fig. 7 Method of simplified Surge Flow irrigation

In the water flow test, water was supplied to five furrows with lengths of 100 m by conventional and simplified SF. Water was supplied from a temporary channel, as in *Fermer's* method and inflow rate was controlled at approximately 0.00045 $m^3 sec^{-1}$.

In simplified SF, the SF-2 was conducted for approximately 20 hours after the SF-1, and when irrigation water reached within 100 m of the furrow, the water supply was stopped. Conventionally, water was supplied until the irrigation water reached 100 m at the end of furrow once, and at that time water supply was stopped. The water was supplied without blocking the 50 m and 100 m points of furrow, and even after stopping the water supply, the water allowed to flow down to over 50 m or 100 m.

3.3 Estimation of furrow infiltration

In order to estimate the infiltration water volume on furrows during the irrigation period, furrow infiltration tests were conducted before the water flow tests. The furrow infiltration test was conducted on dry and wet soil conditions (one day after water supply). The results from the infiltration test in dry soil are assumed to be the values of all dry soil, meaning all the furrow area of conventional and SF-1, and the furrow area of 50-100 m under SF-2. The results from wet soil are assumed to be the values of all wet soil, meaning the furrow area of 0-50 m under SF-2. A Maliot tank supplied the flooding water and the amount of infiltration water was measured 60 minutes after flooding. The 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.

During the water flow test, 'time' was measured at every 10 m of 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 and time was estimated using the formula (2) proposed by Ikeura et al. (1998):

$$t_a = al^3 + bl \tag{2}$$

where, t_a is the water advance time until it flows down at the distance l, l is the distance from water inlet (m), a and b are constants.

The recession time of the irrigation water varies, but in this study, it is assumed that it decreases linearly from upstream to downstream, and formula (3) is used:

$$t_r = el + f \tag{3}$$

where, t_r: is the water recession time from water supply at the distance l, l is the distance from water inlet (m) e and f are constants.

From the start and end time of flooding at each point (1 m interval) estimated by the equations (2) and (3), the flood time of irrigation water is calculated. From this time, the infiltration depth (mm) per 1 m was calculated using formula (1). Cumulative infiltration depth at 1 m interval was calculated using formula (4).

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

The amount of water supplied to the furrows was measured by a triangular weir installed at the inlet.

3.4 Water requirement

In calculating the irrigation water amount, the water supplied beyond the design irrigation requirement is regarded as the loss water, and of the infiltration water at each point, the exceeding infiltration from the Water requirement is regarded as the infiltration loss. Water requirement was determined from the root distribution of cotton and the available moisture (the amount of water effective for crop growth). In root surveys, root samples collected 49 days after sowing in P field were used. The root samples were divided into 5 cm depths, dried at 60°C for 24 hours, and the weight of each layer was measured (**Fig. 8**). The roots were extended to 25 cm depth, but 90.4% of the roots were concentrated at a depth of 10 cm. From this result, the soil layer up to a depth of 10 cm was defined as the critical soil layer on water content for normal growth, which is the soil layer that plays the most dominant role in the water consumption of the effective soil layer.

Available moisture was determined from the results of measurement (pF 1.6-3.2) of the soil of P field imported to Japan by the pressure plate method (DIK-3483, Daiki Rika Kogyo Co. Ltd, Kounosu city, Saitama prefecture, Japan). The soil that was collected at a depth of 0-20 cm was used and was air dried and passed through a 2 mm sieve. The air-dried soil was filled uniformly with 10 cm depth bulk density (ρ_d = 1.47 g cm^{-3}) of P field in a sample cylinder (400 ml, φ= 113 mm, h = 40 mm). After being capillary saturated for 24 hours, it was then used for the test. **Fig. 9** illustrates the relationship between the obtained suction and the soil water content (hereinafter, “pF-water characteristics”).

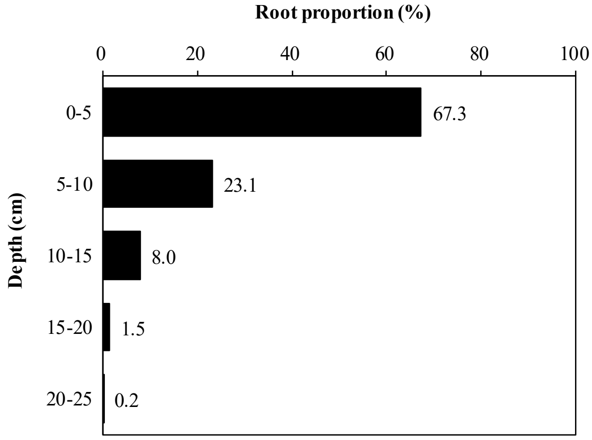


Fig. 8 Root proportion of cotton

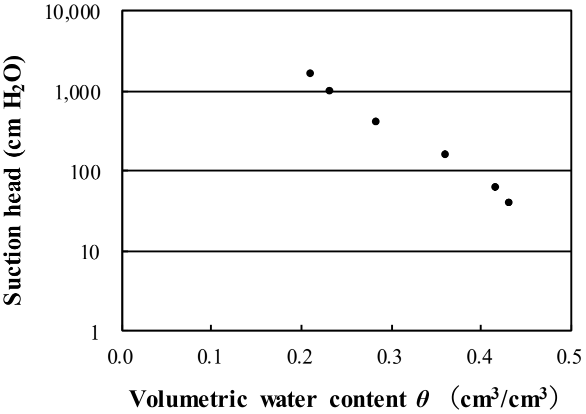


Fig. 9 pF-soil moisture

The available moisture (pF 1.8-3.0) was then set to 0.185 ($cm^3\ cm^{-3}$) (= 0.418-0.233). From the critical soil layer of 0-10 cm and the available moisture of 0.185 ($cm^3\ cm^{-3}$), the total readily available moisture (TRAM) of 20.5 mm was calculated by the equation (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 this study, C_p was substituted by root weight ratio.

In salt-affected farmland, the addition of Leaching Requirement (*LR*) is necessary to control soil salinity. The *LR* (0.032 mm) was calculated using formula (6) (Ayers and Westcot 1994):

$$LR = \frac{ECw}{5ECe - ECw} \tag{6}$$

where, *LR* is the leaching requirement (mm), EC_w is the electrical conductivity of the applied irrigation water in dS m^{-1} (1.2 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*, 21.2 mm) was calculated by the formula (7) (Ayers and Westcot 1994):

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

4. Results and discussion

4.1 Soil texture and saturated hydraulic conductivity of P field

The results of classification into sand, silt and clay by the USDA method based on the particle size analysis of Gulistan University, and the saturated hydraulic conductivity obtained by the falling head permeability test are shown in **Table 4**. From the USDA soil classification, the soil in the P field was classified as Silt Loam. The wide ratio of silt and clay is due to the difference in particle size classification between the Gulistan University and the USDA method.

Table 4 Classification of soil texture and saturated hydraulic conductivity

Location	Classification of soil texture (%)			Saturated hydraulic conductivity
	Sand	Silt	Clay	
	> 0.02 mm	0.02 mm - 0.002 mm	0.002 mm >	(cm s^{-1})
Pakhtakor	23.3	52.1 - 65.6	11.1 - 24.6	1.36×10^{-5}

4.2 Furrow infiltration

Cumulated furrow infiltration before and after water supply obtained from the results of the furrow infiltration test are shown in **Fig. 10** and **Fig. 11**. The value is the average of the results obtained in three tests. **Table 5** indicates the Intake constant and Basic Intake rate (I_b) of the infiltration formula obtained by regression analysis based on the measurement results. The cumulative infiltration of SF-1 and SF-2 showed the same change until about 10 minutes, but after that, the infiltration of SF-2 gradually decreased after 60 minutes. SF-2 decreased by 9.5 mm compared to SF-1. In addition, I_b of SF-2 decreased to less than 50% before water supply (SF-1). The variation in the measurement results was large in SF-1 and small in SF-2. It is considered that the permeability of the furrow can be uniformly reduced by supplying water in advance, even in the furrow with uneven permeability.

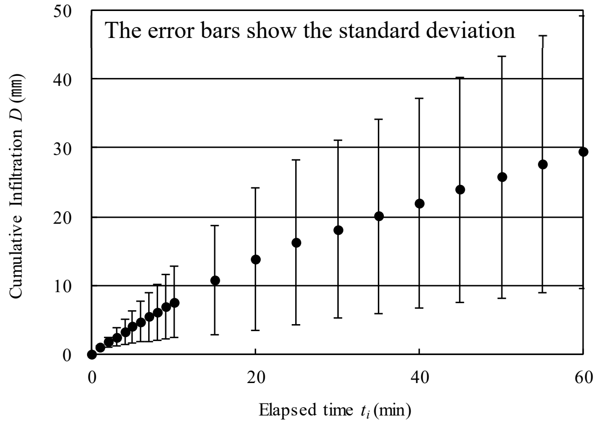


Fig. 10 Cumulative infiltration curve (before water supply)

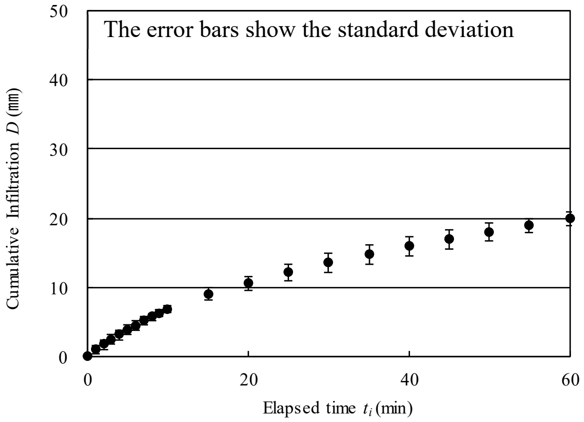


Fig. 11 Cumulative infiltration curve (after water supply)

Table 5 Intake constants c, n, and basic intake rate I_b

Treatment	*c*	*n*	I_b *(mm* hr^{-1}*)*
SF-1	1.059	0.83	24.0
SF-2	1.202	0.71	11.5

4.3. Water advance speed

In each treatment, water was supplied to five furrows with lengths of 100 m. The test plot was conducted using laser leveling with a 1/800 slope in 2009, and flow test was conducted on neighboring furrows to make same condition. The slope of furrow was made by the same tractor, but there was some unevenness. The cessation of water flow occurred in three furrows under the conventional method. Conversely, the simple SF method did not cause water stagnation, and water flow of up to 100 m was completed in all furrows. Therefore, in simplified SF, it could be considered that reduction of permeability and smoothing of furrows by SF-1 made it possible for SF-2 to reach the end of furrows without stop of water. However, even in the simplified SF, there is a possibility that water stoppage due to the unevenness of furrows may occur in SF-1 and the non-flowing section (50-100 m) of SF-2. Although it is difficult to eliminate the unevenness of the furrows completely, measures such as making uniform furrows and increasing inflow (m^3 sec^{-1}) rate are considered necessary.

The distance of water movement and elapsed time under the conventional and the simplified SF are shown in **Fig. 12** and **Fig. 13**. **Table 6** shows the constants of the water advance formula obtained by regression analysis based on the measurements. The three furrows in which the stagnation occurred under the conventional method were excluded from the comparison. The average value of two furrows under conventional and five furrows under Simple SF was used.

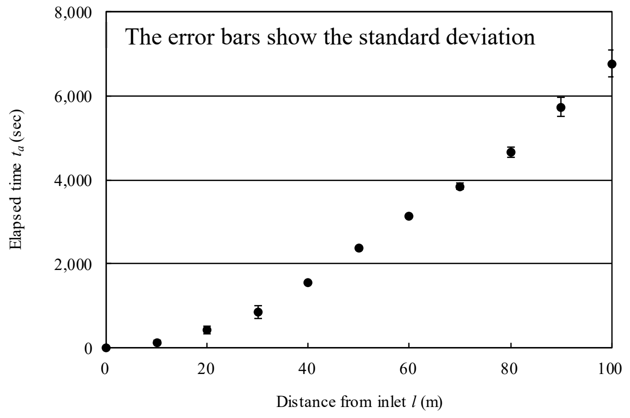


Fig. 12 Water advanced curve (Conventional)

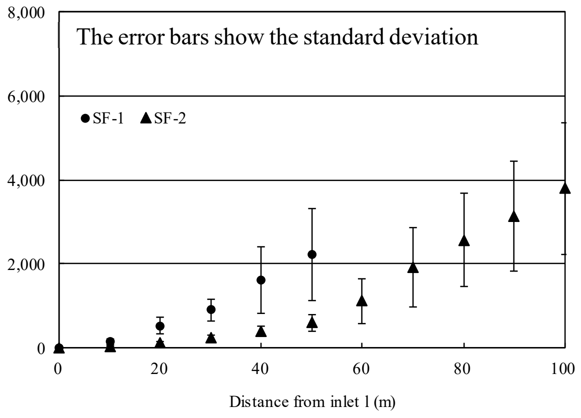


Fig. 13 Water advanced curve (SF-1, SF-2)

Table 6 Water advance constants *a*, *b*

Treatment	***a***	***b***
Conventional, SF-1	0.00326	36.72
SF-2	0.00321	8.21

In conventional, the time required for the irrigation water to reach 50 m and 100 m points of furrows was 2,367 seconds (~39 minutes) and 6,768 seconds (~112 minutes), respectively. In the SF-1 of the simplified SF, the arrival time to the 50 m point was 2,220 seconds (37 minutes), which was close to the conventional. In SF-2, it reached the point of 50 m in 613 seconds (~10 minutes), and the time was shortened by more than 70% compared with the conventional method and SF-1. The arrival time of SF-2 to the 100 m point was 3,806 seconds (~63 minutes), which was approximately 56% shorter than the conventional method. From these results, the time required for the simplified SF method (the sum of SF-1 and SF-2) is 6,026 seconds (~100 minutes), which was shortened by 742 seconds (~12 minutes) compared to the conventional time of 6,768 seconds (~112 minutes). By shortening the water flow time by applying simplified SF, the amount of water supplied to the furrows was reduced by approximately 11%, and the amount of water loss was reduced by approximately 15%. Therefore, in simplified SF, water flow of up to 50 m of furrow by SF-1 causes a uniform decrease in permeability and smoothing of furrows, and as a result, the water advance speed in SF-2 was greatly improved.

However, in the application example of the SF method in Fergana, the water saving effect obtained was approximately 21%, but in this simplified SF, it was approximately 11%. This is considered because the amount of water supply was as low as two (Ferugana case: 4 times), the water supply interval was long (approximately 20 hours), and the water supply ratio was low, at 0.00045 $m^3 sec^{-1}$ (Fergana case: 0.0012-0.0030 m^3 sec^{-1}).

4.4 Water recession time

Water recession time of conventional and simplified SF is shown in **Fig. 14** and **Fig. 15**. **Table 7** shows the constants of the water recession formula obtained by regression analysis based on the measurement results. The water recession time is the time from the arrival of irrigation water at each point to the disappearance of the water from the surface of the furrow. The construction level of furrows was similar, but due to local unevenness in the furrows, the irrigation water recession time varied in both conventional and simplified SF.

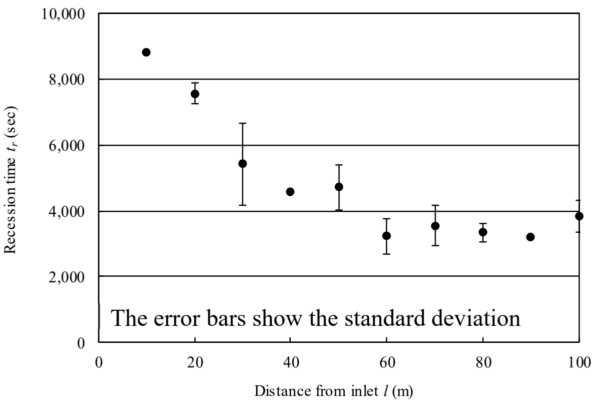


Fig. 14 Water recession time (Conventional)

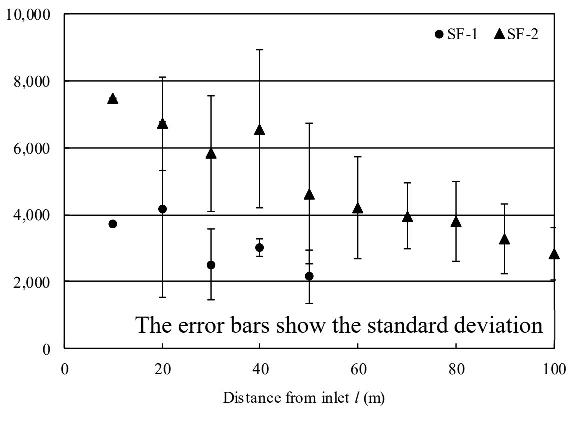


Fig. 15 Water recession time (SF-1, SF-2)

Table 7 Water recession constants e, f

Treatment	*e*	*f*
Conventional	-54.7	7,834
SF-1	-42.9	4,399
SF-2	-50.9	7,729

In both the conventional, SF-1 and SF-2, the water recession time tended to decrease from the water inlet side to the lower side. Compared with the conventional, water advance speed of SF-2 improved, but there was no large difference in the water recession time.

4.5 Estimation of infiltration water

The estimated amount of infiltration water is shown in the reference level because there is a possibility of underestimating the infiltration loss of the conventional due to there being a large variation in the results of the furrow infiltration test in dry soil. The distribution of infiltration water which was calculated by the formula of infiltration, water advance and water recession is shown in **Fig. 16**. In both the conventional and the simplified SF, the amount of infiltration water decreased from the inlet to the lower section.

The infiltration water of SF-2 decreased by up to 50 m due to the reduction effect of SF-1. Its reduction was 50.9 mm at the inlet, and 32.5 mm at the 50 m point of the furrow compare with conventional. However, the amount of infiltration increased after entering the unirrigated section after 50 m of furrow. **Fig. 17** shows the total amount of infiltration water in the simplified SF that combines SF-1 and SF-2. Conventional and simplified SF, 21.2 mm, which required water volume, was supplied to the entire section of the 100 m furrow.

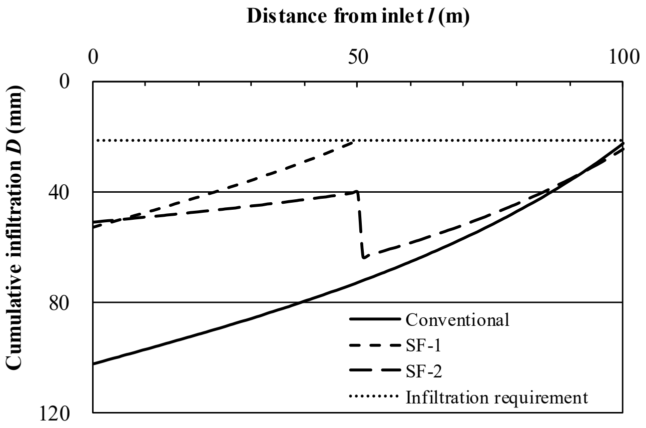


Fig. 16 Distribution of infiltration water of each method

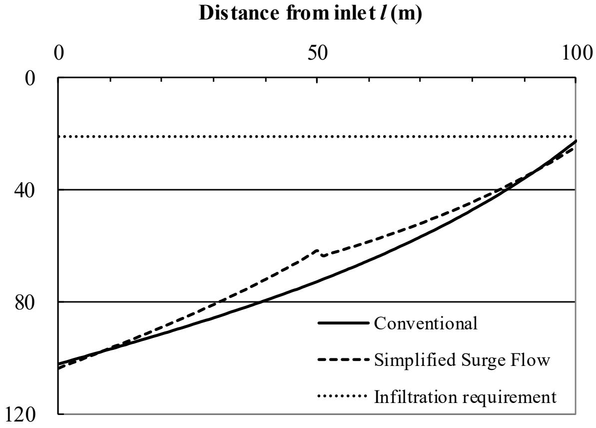


Fig. 17 Distribution of infiltration water of each method

In both conventional and the simplified SF, the amount of infiltration water at end of the furrow (outlet) section is around required water. At the water inlet, the simplified SF supplies water twice with SF-1 and SF-2, so the conventional and the simplified SF have the same amount of infiltration water. However, the amount of infiltrated water at the 50 m point in the center of the furrow decreased by 11.0 mm in the simplified SF compared to the conventional and the amount of infiltrated water in the simplified SF decreased in the 8-92 m section, with the maximum at the 50 m point. Therefore, in the simplified SF, the water-saving effect is considered the highest at the 50 m point, which is the end of the section that passes through SF-1. As the water-saving effect was small compared to the normal SF, it is, however, necessary to study for a larger water-saving effect, such as shortening the furrow length. In the normal SF, water supply and stop were repeated at short intervals, but in the simplified SF of this test, the water supply interval between SF-1 and SF-2 was long (approximately 20 hours). For this reason, the reduction effect of infiltration by the simplified SF as lowered. As an improvement measure, it is considered effective to shorten the water supply interval by implementing SF-1 in the evening and performing SF-2 in the early morning of the following day.

The amount of supplied water to the furrow measured by the triangular weir at the water inlet was 3.03 m^3 by the conventional and 2.70 m^3 by the simplified SF. The reduction of irrigation water was approximately 11% and the reduction of infiltration loss was approximately 15%. Conversely, the infiltration water volume was 2.77 m^3 by the conventional and 2.62 m^3 by the simplified SF. Infiltration water volume was reduced by approximately 5% and the infiltration loss was reduced by approximately 8%. The reason why the reduction of infiltration water was smaller than the supplied water may be that flooding time in the 100 m furrow was decreased due to runoff caused by the unblocked end of the furrow (outlet). Therefore, we conclude that the amount of infiltration water can be further reduced by closing the end of the furrow and stopping the water supply earlier.

5. Conclusion

In this study, we examined the water-saving effect using the simplified SF with improved furrow irrigation, with the consideration that it is easy to be adopted by *Fermer*. In the normal SF, water supply pipe is installed on the upstream side of the field, and the water saving effect is obtained by intermittent water supply with a switching valve (Walker, 1989). However, even with the simplified SF, which does not have a water supply pipe or valve and just divide regular furrow irrigation to twice with one day interval, it can reduce the amount of supplied water by approximately 11% and infiltration loss by approximately 15%. This is achieved by decreasing permeability and smoothing the furrow surfaces by SF-1. This suggests that the simplified SF can be an effective first step in water conservation because it can be easily applied to the current furrow irrigation even in developing regions that have water management issues. Furthermore, the combination of simplified SF and other water saving technology such as land leveling (Ikeura et al., 2011) and alternate furrow irrigation (AFI) which irrigates every other furrow, is considered possible to further reduce the amount of irrigation water and infiltration loss. In this water flow test, however, irrigation water stagnated due to local unevenness, so in order to obtain a sufficient water-saving effect by the simplified SF, the creation of uniform furrows and increase of inflow rate (m^3 sec^{-1}) is necessary to suppress the effects of uneven furrows.

In this test, priority was given to workability in the vast field of Uzbekistan, and the distance of irrigation furrows at SF-1 was set to 50 m, but the water-saving effect was lower than the normal SF. Ikeura et al. (1998) proposed short furrow lengths for the purpose of optimizing the application efficiency under border irrigation in sandy fields, so that the lengths of irrigated furrow such as shortening SF-1 lengths would maximize water-saving effects. Furthermore, in Uzbekistan, the crushing of the hard soil layer is being conducted for the purpose of improving poor drainage and leaching effects. However, it is possible that the large pore generated by crushing promotes the preferential flow of irrigation water. There is a risk that infiltration loss during irrigation will increase. As a future issue for the field application of the simplified SF, it will be necessary to verify the synergistic effect of the combined use of the simplified SF and AFI, the measures to suppress the influence of unevenness in the furrows, optimal water flow distance, and water-saving effects at drainage improvement fields.

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