Salt Pushing Effect to the Side of the Ridge by Fixed Skip Furrow Irrigation
- Case study in the Republic of Uzbekistan -

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Summary

In Central Asia, secondary salinization caused by incorrect irrigation has become a serious problem. Water-saving techniques, drainage improvements, and leaching have been adopted as general measures to mitigate salinization. However, the construction of water-saving and drainage facilities requires plenty of funds. A relatively easy and inexpensive water-saving method is skip furrow irrigation (SFI), by which every alternate furrow is irrigated. In regular SFI, furrows are irrigated alternately (ASFI) during each irrigation event. However, if the irrigation furrows are fixed (FSFI), the salts in the soil might be pushed towards the other side of the ridge. To analyze this salt distribution, a field study comparing every furrow irrigation (EFI), ASFI and FSFI was conducted at a farmland in Uzbekistan. In EFI, the salt content in the center of the ridge increased. Also, in ASFI, the salt content decreased at the wet side of the ridge but after second irrigation, increasing at the center of the ridge. Whereas in FSFI, the salt content on the left (dry) side of the ridge increased, indicating a salt pushing effect. The findings of this study suggest a possibility of more efficient removal of the salt in the surface soil by combining FSFI and the dehydration method.

Keywords
Salinization, Water-saving, Furrow irrigation, Skip furrow irrigation

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1. Introduction

1.1 Background

Soil salinity is one of the major abiotic stresses causing reduced agricultural productivity worldwide. Salinization of arable land has dramatically increased over the last few decades (Martin et al, 2012). The main cause of secondary salinization is the inflow of salt with irrigation water, followed by an increase in the groundwater table due to excessive irrigation and poor drainage. In the absence of leaching, salt accumulates in the soil, especially in the topsoil, because of water loss through evaporation and root uptake (Devkota et al, 2015). Therefore, to mitigate salinization in general, water-saving techniques and drainage improvements should be undertaken as precautionary measures, with leaching being popular among farmers as a salt removal measure because of its inexpensiveness.

1.2 Salinization in Central Asia

In Central Asia, where there are extensive arid and semi-arid areas, secondary salinization caused by inappropriate water management techniques has become a serious problem, with major influences on agricultural production. In Central Asia, large scale irrigation development was conducted during the 1960s (in the Soviet Union era) in the Amu Darya and Syr Darya river basins, which were previously steppe or desert areas. In particular, Republic of Uzbekistan (hereinafter Uzbekistan), cotton production occurred on developed farmland. Although it contributed greatly to the agricultural production of the former Soviet Union, incorrect water management techniques caused severe salinization. As a result, Uzbekistan has the largest salt affected farmlands among all the Central Asian countries (**Table 1**) (Karen, 2013). Salt affected farmland is defined as a farmland where the electrical conductivity of a saturated extract of the soil (EC_e) is higher than 2 dS m^{-1}.

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)

In Uzbekistan, although 27 years have passed since the country's independence from the Soviet Union, in 1991, government control of cotton and wheat production is still ongoing. Current cotton and wheat production are carried out by an agricultural corporation called "*Fermer*," which leases government farmland under a long-term agreement (Onishi, 2012). Cultivation on such *Fermer* farms usually involves furrow irrigation with low application efficiency. Under the current scenario, it is difficult for *Fermer* to install water-saving and drainage facilities because of their high costs. As a result, leaching is the only practical measure available to them because of low cost. However, there is concern about the influence of the hardpan layer, which is formed by the long-term treading pressure of agricultural machines, on the effectiveness of leaching.

A relatively easy and inexpensive water-saving method is skip furrow irrigation (SFI), which is often called alternate furrow irrigation. In this method, instead of irrigating all furrows, water is supplied to one of the two neighboring furrows (i.e., alternate furrows), viz., to one furrow for every two ridges (**Fig. 1**). In conventional SFI, the wet furrows are alternated during each irrigation event (ASFI) (Brouwer et al., 1985).

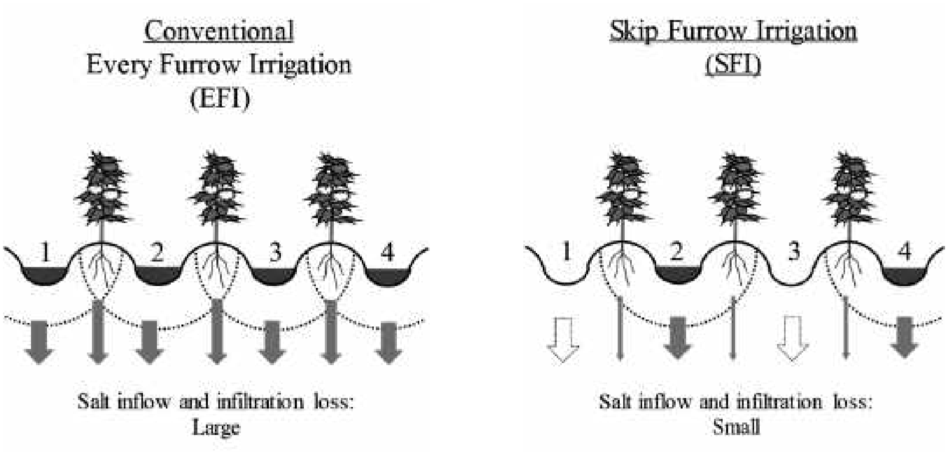

Fig. 1 Concept of skip furrow irrigation

The advantage of SFI is that it can reduce the amount of water supplied, and reduce infiltration and evaporation loss, as well as lateral flow, in the non-irrigated furrows. Alan and Karen (1994) reported that approximately 58% of irrigation water was saved without significant reduction in peppermint yield when SFI was applied, compared with when every furrow irrigation (EFI) was used. However, the disadvantages of SFI are that it takes a longer time to completely irrigate the whole field and a larger labor force to relocate the irrigation furrow during each irrigation event (Alan and Karen, 1994). Typically, crops are planted in the center of the ridges, however, in EFI, the salt in the soil tends to accumulate in the highest point of the ridge (Brouwer et al., 1985). To avoid this, if the irrigation furrows are fixed in SFI (FSFI), then the salts in the soil might be moved towards to dry side of ridge, rather than being accumulated in the center of the ridge. According to Devkota et al. (2015), more salt was accumulated at the dry side of ridge under FSFI. These authors also reported that the irrigation-induced movement of salts in the shallow soil layer, up to 15 cm depth, was larger than that in the deeper layers.

In the present study, to develop an efficient furrow irrigation technique that can reduce water usage and mitigate salinization, we researched the fixed skip furrow irrigation (FSFI) in which the wet furrow is fixed, unlike in ASFI where it is not fixed, and evaluated its effectiveness by comparing it with EFI and ASFI in a cotton field in Uzbekistan.

2. Materials and methods

2.1 Study area and site description

In the Syrdarya Region 98% of the irrigated farmlands is salt affected (Onishi et al, 2017). This area was selected as the study area in the present study (**Fig. 2**). Daily average temperature in the Syrdarya Region increases to 30 °C in summer and decreases to approximately 0 °C in winter. The annual precipitation is approximately 320 mm, however, the cumulative precipitation from June to September is very low (approximately 20 mm).

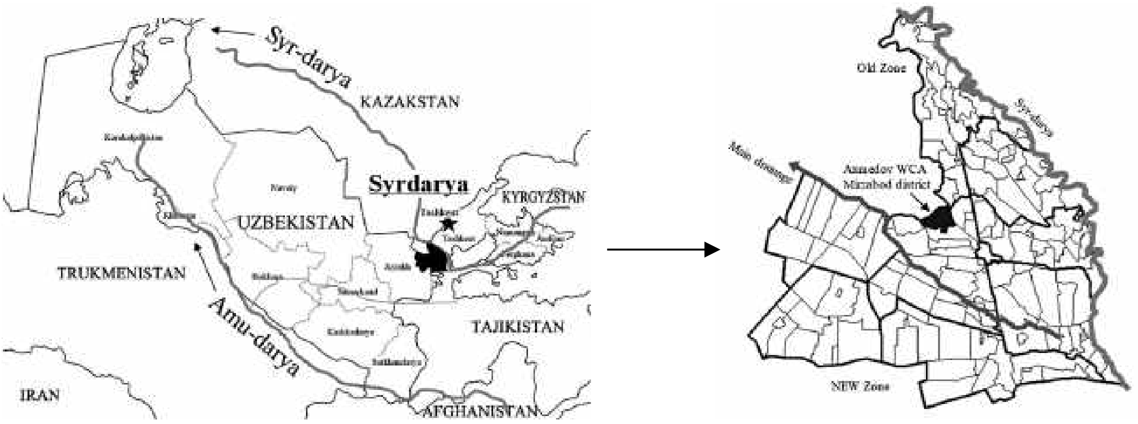

Fig. 2 Location of Syrdarya Region and Axmedov Water Consumer's Association (WCA)

The field study was conducted at the Nozima Durdona Fayz farm (hereinafter N farm), which belongs to the Axmedov Water Consumer's Association, and is located in the Mirzaabad district. According to the Hydro-Geological Melioration Expedition (HGME) of Uzbekistan, 99% of the irrigated farmland is salt affected in the Mirzaabad district. The N farm is approximately 50 ha in area, with a length of approximately 820 m from the East to the West, and 620 m from the North to the South. The irrigation channel is located along the eastern end of the farm, and drainage channels have been dug in the northern and western sides of the farm. The bulk density of the surface soil layer is 1.4 g cm^{-3}, whereas in depths of 20 cm to 40 cm the bulk density is higher, at 1.6 g cm^{-3}, indicating that the N farm had a hardpan layer that might have been compacted by the pressure of agricultural machinery operated for long.

2.2 Experimental set up and treatment

The experiment was conducted during the cotton cultivation period on the northeastern side of the N farm from 11th of July to 6th of September in 2017. Three treatments (EFI, ASFI, and FSFI, **Fig. 3**) with three repetitions, i.e., nine plots in total, were set up.

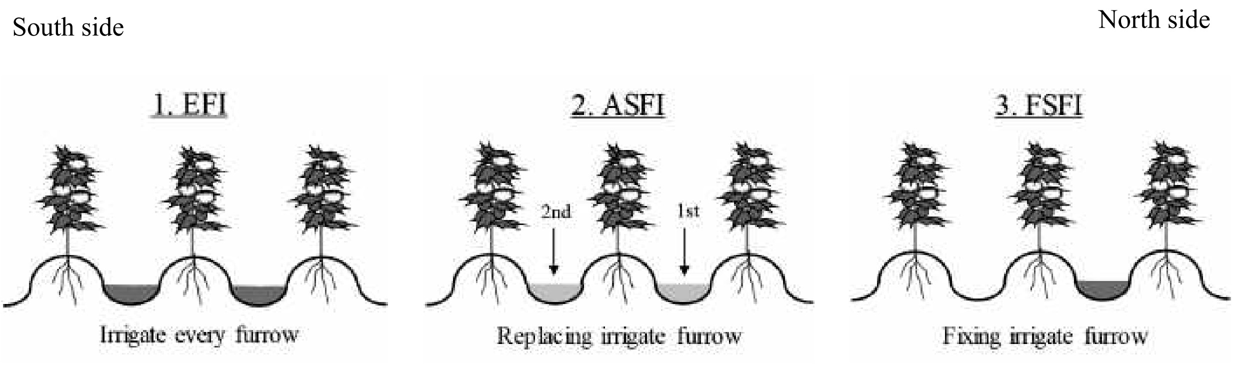

Fig. 3 Treatment of field experiment

In the experiment, the ridge and furrow size were 50 cm and 40 cm, respectively, based on the size widely used throughout Uzbekistan. Plot width and length were 1.3 (one ridge and two furrows) and 4.0 m, respectively. The direction of the furrows was from the East to the West. (**Fig. 4**)

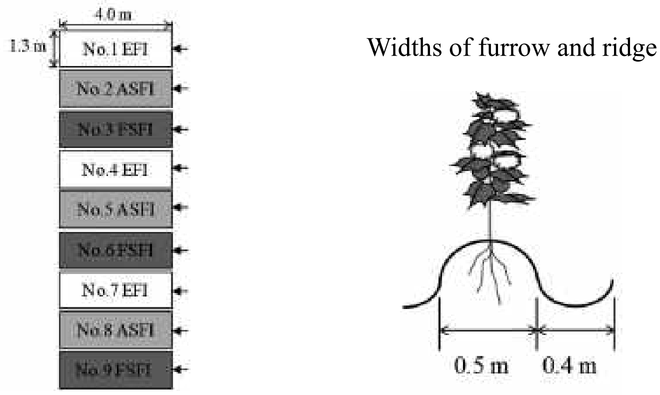

Fig. 4 Plot design of field experiment and ridge and furrow size

In EFI 0.52 m^3 (5.2 m^2 × 0.1 m) of water was applied with reference to 100 mm, on the basis of the standard amount applied in Uzbekistan, and half of this value (i.e., 0.26 m^3) was applied in the ASFI and FSFI treatments. Water was supplied using a gasoline pump (LGP 20-A, Leo Group Co, Ltd, Binhai town, Wenling city, China, discharge rate 5 Ls^{-1}). During the first irrigation in ASFI, the northern side furrow was watered, and then South side furrow was watered during the second irrigation (**Fig. 3**). In FSFI, the wet furrow was fixed at northern side. The first and second irrigations were conducted on July 12 and 25, 2017, respectively, and the electrical conductivity of the irrigation water during these events was 1.08 and 1.06 dS m^{-1}, respectively.

2.3 Soil salinity measurement

Soil salt distribution before and after irrigation in each treatment was measured by soil sampling. The soil was sampled from 0, 1, 5 and 10 cm depths at the center, left, and right side of the ridge in a center of each plot (**Fig. 5**).

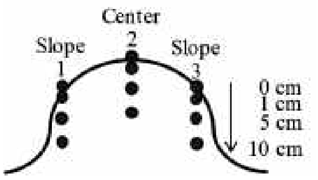

Fig. 5 Soil Sampling point of field experiment

The electrical conductivity of the 1:1 suspension of the soil samples ($EC_{1:1}$) was measured. The salt concentrations of the suspensions were estimated using the $EC_{1:1}$. Assuming that the major ions were calcium and chloride, total dissolved solids were calculated using the following formula obtained from a laboratory calibration:

$$c_{1:1} = 0.50\sigma^{1.10} \quad (1)$$

where, c is the concentration of the suspension (mg g^{-1}) and σ is the electrical conductivity of the suspension (dS m^{-1}).

The weight of salts per volume, θc (mg cm^{-3}) was calculated using the following formula (2).

$$\theta c = c_{1:1}\, Madd/V \quad (2)$$

where, θc is the $CaCl_2$ weight per unit volume (mg cm^{-3}), c is the $CaCl_2$ concentration of suspension, M_{add} is the weight of added distilled water (g), and V is the soil volume (cm^3).

3. Results and Discussion

3.1 Salt distribution

Soil sampling was conducted 1 day before and 2 days after each irrigation (July 11, 14, 24, and 27, 2017). July is a dry season. A rainfall of 0.4 mm was observed on July 13. The distribution of salt content before and after irrigation under each treatment is shown in **Fig. 6**. Contour map was drawn under assumption of linear distribution between two points.

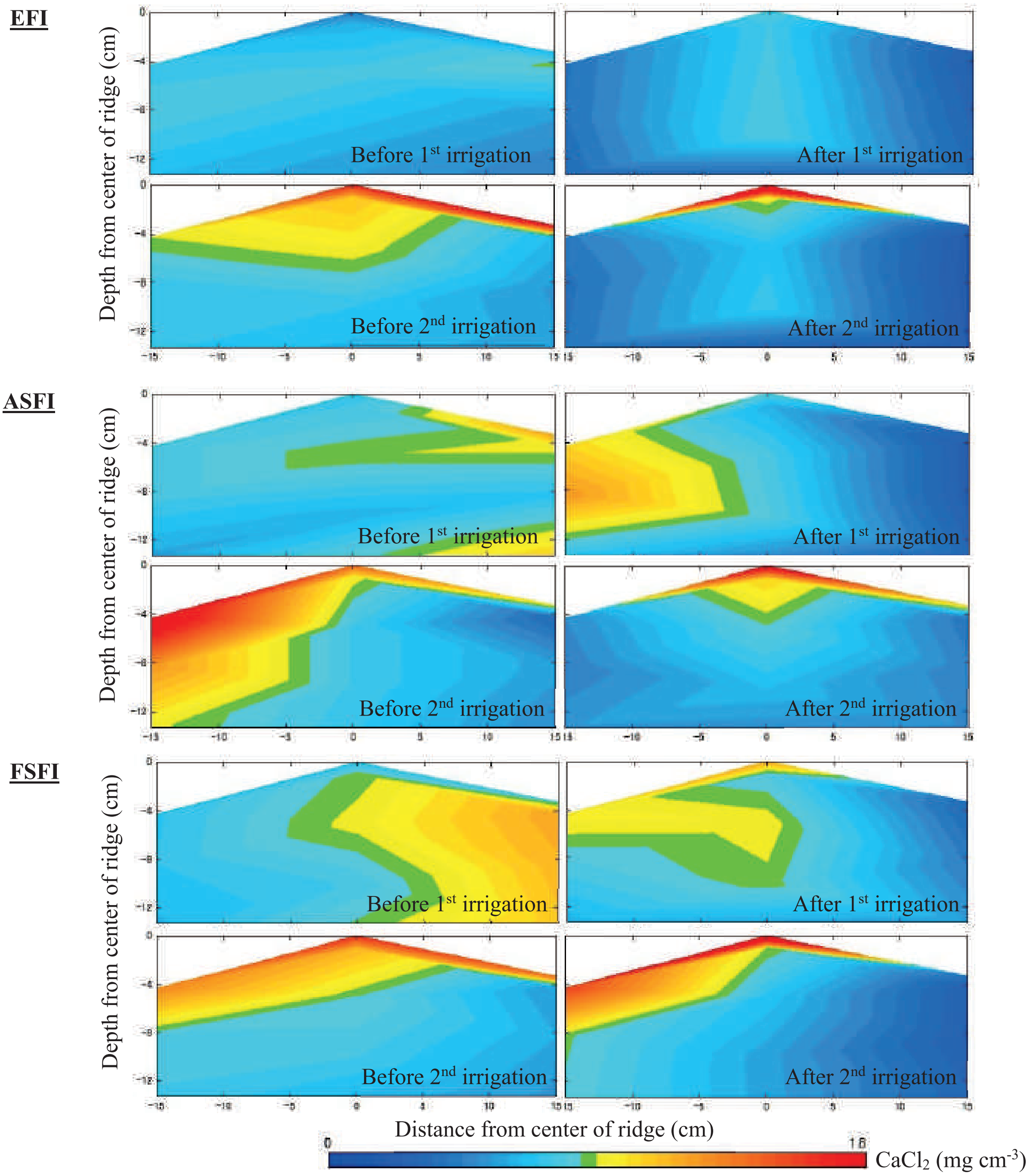

Fig. 6 Salt distribution before and after irrigation

Salt was found to be accumulated at the soil surface in all the treatments; however, the pattern of accumulation was different. In EFI, the salt content on the left and right side of the ridge decreased but increased at the center of the ridge. In ASFI, the salt content decreased at the wetting side of the ridge (first irrigation right side, second irrigation left side), whereas after the second irrigation, the salt content increased at the center of the ridge. In contrast, in FSFI, the salt content in the right (wetting) side decreased, whereas it increased on the left (dry) side of ridge. This indicates the salt pushing effect of the FSFI.

These results indicate that the salts in the soil might have moved with flow of irrigation water in the soil. Therefore, in EFI, salts were accumulated in the center of the ridge where irrigation water from both sides merged. In ASFI, salts were transported to the dry side of the ridge; however, the place of the flow changed at each irrigation, resulting in salt accumulation in the center of the ridge. In FSFI, since the place of water flow during irrigation was kept constant, salts were accumulated on the side of the ridge. In addition, the effect of irrigation on the change of salt accumulation was higher in the surface soil (0 cm depth) than in the deeper soil.

3.2 Cotton yield

Cotton yield survey was conducted on September 11, 2017. The fresh cotton weights of each plot (3.6 m^2) were measured (**Fig. 7**).

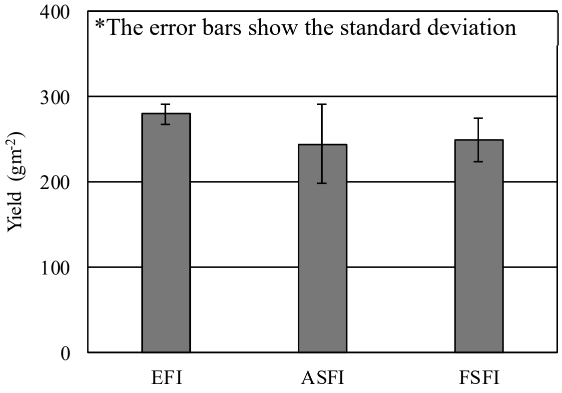

Fig. 7 Cotton yield in each treatment

Cotton yield was lower in the ASFI and FSFI treatments by 13 and 11%, respectively, than that in the EFI treatment, although there was no significant difference and the standard deviation of EFI was smallest. However, since the amount of water applied was halved in the ASFI and FSFI treatments only during the test period, both ASFI and FSFI had the same amount of water applied as EFI during the other periods; this might be why the decrease in cotton yield was not as large. *Fermer* may accept such slight reduction in yield if they can increase cultivated area with saved water or volumetric water pricing is introduced.

4. Conclusion

In the present study, we evaluated the distribution of salt in the soils under EFI, ASFI and FSFI, focusing on surface soil (down to 10 cm depth) in which water consumption and salt changes were high before and after irrigation. We found that the salts in the soil were transported with water flow onto the ridge of the furrows, and if the irrigated furrows remained constant during each irrigation, it was possible to push the salts in the soil to the side of the ridge. Large amounts of salt pushed by FSFI were accumulated along the ridge side, especially in the surface layer (0 cm depth), which was greatly affected by evaporation demand. Therefore, FSFI could be an effective measure for mitigating salinization.

However, even if the salt in the soil is successfully accumulated on the surface layer with FSFI, there is the possibility of it returning to the deeper layers again if it is not removed. An effective method of removing salt from the surface soil is the dehydration method. In the dehydration method, the powerful evaporation demand in arid areas is utilized to collect salt from the soil onto a cloth or a sheet that has been laid on the surface (Abe et al, 2000). There is a possibility that salt in the surface soil can be removed more efficiently by combining the FSFI and dehydration methods.

Further research is required to evaluate the desalination effect of the combined FSFI and dehydration methods, and verification of the efficacy of this technique on cotton yield. If proven effective, this combined technique might be useful as a salt removal method to compensate for leaching during winter in the arid areas. In addition, to evaluate water-saving effect of FSFI, it is necessary to monitor supplied water for cotton in whole cultivation period.

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