Salt Removal Technology by Shallow Subsurface Drainage in Combination with a Cut-drain

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Summary

In Uzbekistan, secondary salinization of irrigated lands is caused by rising groundwater level due to excessive irrigation and drainage system malfunction. Countermeasures such as drainage system maintenance, drainage facility construction, and leaching opration have been adopted to control salinity. However, there are still fields where salinity levels remain high because of incomplete dredging operations, reduced deep subsurface drainage system discharge capacity, or ineffective approaches to vertical drainage operations. To achieve stable production and crop diversification, prompt salt removal is necessary. Thus, we proposed a shallow subsurface drainage technology to ensure effective salt removal from the surface soil layer. The technology was studied in combination with a new drain drilling technique (Cut-drain) developed in Japan. It was experimentally introduced in farmers' fields in the Syrdarya Region. A leaching test performed in the study field revealed that highly saline water was observed at the outlet of the drainage pipe. The results of our study showed an approximately 20% increase in cotton yield, along with a decreasing salinity trend in the surface soil layer. Our study demonstrated that this technology can be employed as an effective measure for controlling salinity in a field.

Key words

Salinization, Drainage, Subsurface drainage, Cut-drain

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1. Introduction

In Uzbekistan, secondary salinization of irrigated lands has been caused by rising groundwater table due to excessive irrigation and drainage system malfunction. The current drainage system has been deteriorating since the 1990s, after the dissolution of the Soviet Union. The system is mainly composed of open channel, subsurface, and vertical drainage. To improve irrigated land, the government of Uzbekistan started a special fund to repair and replace these aging systems, resulting in satisfactory conditions in some areas. However, there are areas where the drainage systems are in disrepair (Frenken, ed., 2013). Incomplete dredging operations and inadequate open drainage maintenance have caused an increase in the drainage water level. Under such drainage conditions, some deep subsurface drainage outlets have been blocked by soil or submerged in the drainage water, leading to poor groundwater discharge under the field. Currently, the performance of vertical drainage systems has been lower compared to their performance at the time of original construction. We revealed that vertical drainage could not sufficiently control the groundwater level because of a shortage and inappropriate timing of operations (Okuda et al., 2015a). In fields with a malfunctioned drainage system, to achieve stable agricultural production and well adapt the field to crop diversification, prompt and steady salt removal technology is required. Regarding prompt salt removal, a study indicated that shallow subsurface drainage (main drainage depth: 70 cm) was an effective method to discharge infiltrated water with salt (Chiba et al., 2012).

Thus, we proposed a shallow subsurface drainage technology to effectively remove salt from the field. In general, shallow subsurface drainage requires high drain pipe density (pipe length per unit area), which increases construction costs. Therefore, this technology was studied in combination with a "Cut-drain" as a low-cost alternative. A Cut-drain is constructed by a new drain drilling machine developed in Japan. This was the first trial to apply Cut-drains in a semi-arid area for the removal of salt using shallow subsurface drainage. The experimental study was conducted on farmers' fields in the Syrdarya Region, the Republic of Uzbekistan. In this paper, we report experimental field results using shallow subsurface drainage technology with Cut-drain.

2. Materials and methods

2.1 Study area

The study area is shown in **Fig. 1**. Desert and steppe regions occupy 60% of Uzbekistan and are located in the western area of the country. The eastern area connects to the Tian Shan mountains and Pamir plateau. The country is sandwiched between the Amu-Darya and Syr-Darya rivers, both of which flow to the Aral. The weather is a continental climate. It is characterized by drastic temperature changes, with hot and dry summers and cold and wet winters. Annual precipitation ranges from 100–250 mm in the desert region, 200–545 mm at the foot of mountains or plain areas, and 400 mm and over in mountain areas (Makhmudov, 2006). The Syrdarya Region is located to the east of the steppe region, which is a plain area. The aridity index is 0.32, and the average precipitation over the last five years is 335 mm.

It is classified as a semi-arid region. The temperature sometimes exceeds 40 °C in the summer and below −10 °C in the winter. Precipitation is mainly observed from October, end of autumn, to April, beginning of spring.

Fig. 1 Location map of research sites

According to the Farmers' Council of Uzbekistan data, the country had 4.3 million ha of irrigated land in 2014. Currently, 47% of this land is affected by salinization (the electric conductivity of the saturation extract of the soil, $EC_e > 2$ dS m^{-1}). In particular, salinization is spreading over 98% (280 thousand ha) of the irrigated land in Syrdarya Region.

This study was conducted on actual farmlands in a Water Consumers' Association (WCA) of Axmedov at Mirzaabad District where the salinity level is the most serious in the Region (**Fig. 2**). The name of the farm studied is "Nozima Durdona Fayz," which covers around 30 ha.

Regarding the drainage condition, the farm adjoins open drainages. According to the topographical survey near the field, the difference of elevation between the drainage bottom and the lower field is approximately 2.0–2.5 m. During the winter season, the drainage water level rises by 0.5–1.0 m, resulting in an elevation difference of 1.0–2.0 m. The resulting hydraulic gradient from the field to open drainage becomes quite small (Kitamura et al., 2006).

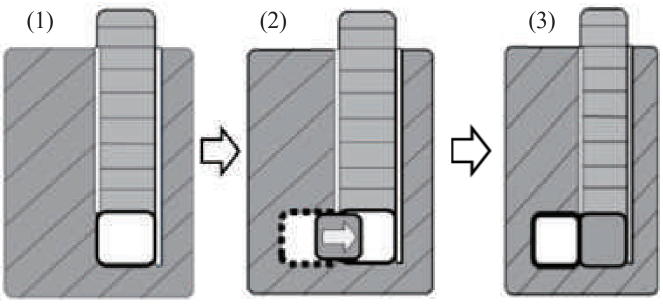
Fig. 2 Educed salt in wheat field (January 2, 2016 in Axmedov WCA)

2.2 Experimental field

A new shallow subsurface drainage system should be low-cost to disseminate widely among farmers. Therefore, this study used such a system in combination with a Cut-drain in actual farmers' fields.

Cut-drain construction has a unique drilling method. The drilling machine has two long blades and a side-cutter in the lower part. The blades are inserted into the soil, cutting a soil column of 10 cm width and raising it by 10 cm. The side-cutter simultaneously cuts a square-shaped section of soil from the side of the newly created space and slides this soil into the space formed by the risen soil block (Okuda et al., 2015b). The new cavity acts as a relatively stable mole drain (**Fig. 3**). The drilling machine is towed by a tractor (130–140 HP) to make a conduit under a certain depth (60–90 cm). A farmer can manage the drilling machine easily as a typical farming activity.

Drilling machine attached to tractor



(1) Cut soil column and push it up, forming a space
(2) Cut section of side soil and slide it into the space created in step 1
(3) A water conduction cavity complete (Cut-drain)
Mole-drain formation process

Fig. 3 Drilling machine and Cut-drain

The Cut-drain can act as a supplemental drain when used as a connection to the main drain. It can also lead water connecting to a field ditch (**Fig. 4**). A Cut-drain is constructed without any material. The soil texture most appropriate for Cut-drain construction is one with high clay and low sand content. In case of loam, Cut-drain durability is short.

As a Cut-drain is formed only by soil, there is a possibility of collapse caused by excessive preferential flow. According to soil profile surveys in the trial Cut-drain fields, some cavities of Cut-drains collapsed after irrigation or leaching operation because of a large amount of preferential flow. This preferential flow could be mitigated by irrigating the furrows where the blades would be inserted before construction (Okuda et al., 2017). However, it is advisable to construct Cut-drains before every leaching operation to ensure the cross-sectional area of water flow.

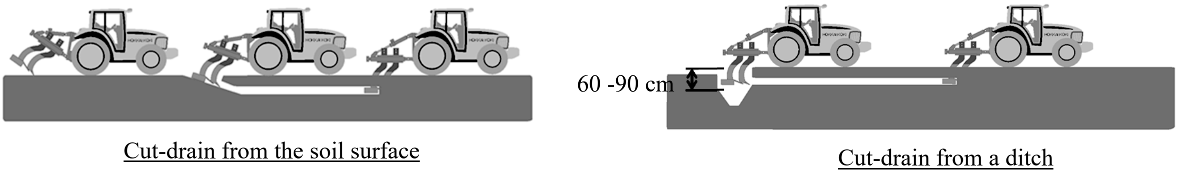


Fig. 4 Examples of execution in construction work

The design of the experimental field is illustrated in **Fig. 5**. According to the soil analyses of the field, the saturated hydraulic conductivity obtained by the falling head permeability test was shown between 7.7×10^{-5} cm s^{-1} and 5.0×10^{-6} cm s^{-1}, and the soil textures were classified as Clay, Clay Loam and Sandy Loam from the International Society of Soil Science standards. Two tile drains, which comprise perforated pipe and rice husk as hydrophobic material, were installed at a depth of around 0.8–1.0 m. The pipe length was 200 m. Cut-drains were constructed at a depth of 0.6–0.8 m. The spacing between Cut-drains was 5 m. Cut-drains cross the main drains to connect the part of rice husk towed by a tractor. In this study field, a 200 m Cut-drain was constructed in a single pass across the field. The Cut-drain direction was the same as the field gradient.

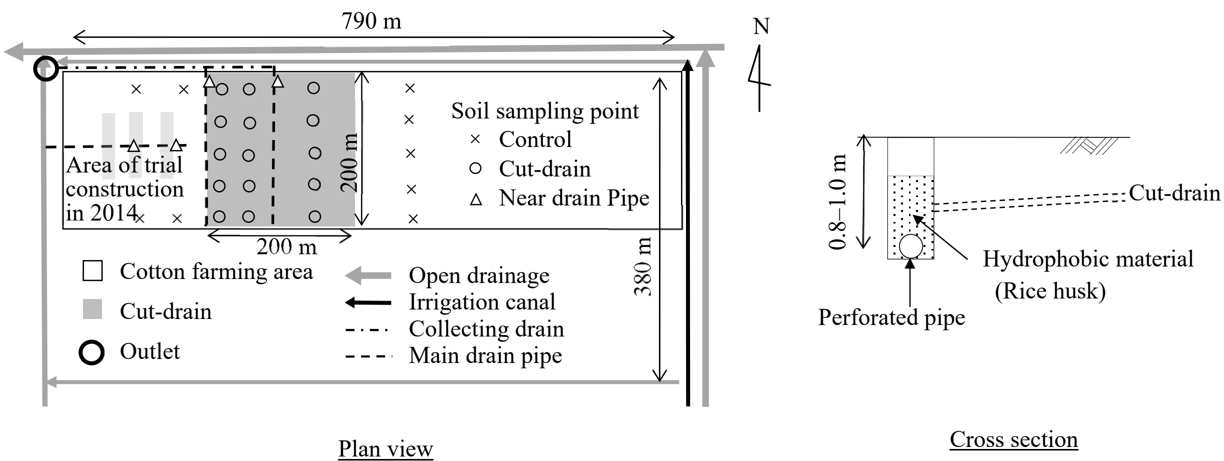


Fig. 5 Layout of experimental field

2.3 Evaluation methods

Shallow subsurface drainage evaluation was carried out in terms of water and soil salinity and crop yield.

2.3.1 Water salinity

The irrigation and discharged waters were taken from the irrigation canal and subsurface drainage outlet, respectively, to measure the electrical conductivity of water (EC_w).

2.3.2 Soil salinity

The soil samples were taken before (December 2016) and after leaching (February 2017) at five distinct layers (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm), using manual auger boring. The number of samples taken from the control field, Cut-drain field, and near tile drain pipe were 45, 75, and 20 (9, 15, and 4 sets), respectively. The sampling points are also shown in **Fig. 5**.

EC of 1:1 suspension was converted to EC_e using an empirical formula developed by the Research Institute of Irrigation and Water Problem (RIIWP), Uzbekistan (Shirokova et al., 2000).

2.3.3 Cotton yield

Cotton yield in terms of weight of cotton was measured to evaluate the effect of the shallow subsurface drainage. The sampling method was to pick cotton in a 1.1 m length by 0.9 m width of ridge and furrow so that the sampling area was equivalent to 1.0 m^2. Four samples were taken near each soil sampling point.

3. Results and Discussion

3.1. Water salinity

After leaching, high EC_w was observed at the subsurface drainage outlet. The EC_w of irrigation water and discharged water were around 1.16±0.02 (n=3) and 10.5±1.3 (n=20) dS m^{-1}, respectively, on average. This indicates that the discharged water contained more salt in the soil. The discharged water was observed after a rain event in April when the groundwater level became less than 1.5 m from the ground surface. Therefore, the surface water (leaching water and precipitation) may have had a predominant role in the discharged water salinity.

3.2 Soil salinity

The average values of soil salinity (EC_e) in the upper surface layer (0–60 cm) and lower layer (60–100 cm) before and after leaching are shown in **Fig. 6**. Percentage reductions of soil salinity after leaching are also shown in **Fig. 6**. After leaching, the relative soil salinity of the upper layer of the control field, Cut-drain field, and near the drain pipe were 67%, 62%, and 50%, respectively. The soil salinity of the upper layer with a shallow subsurface drain was slightly lower than the control. However, there was no significant difference (p<0.05) based on the analysis of variance (ANOVA) among the fields with a large dispersion of soil salinity.

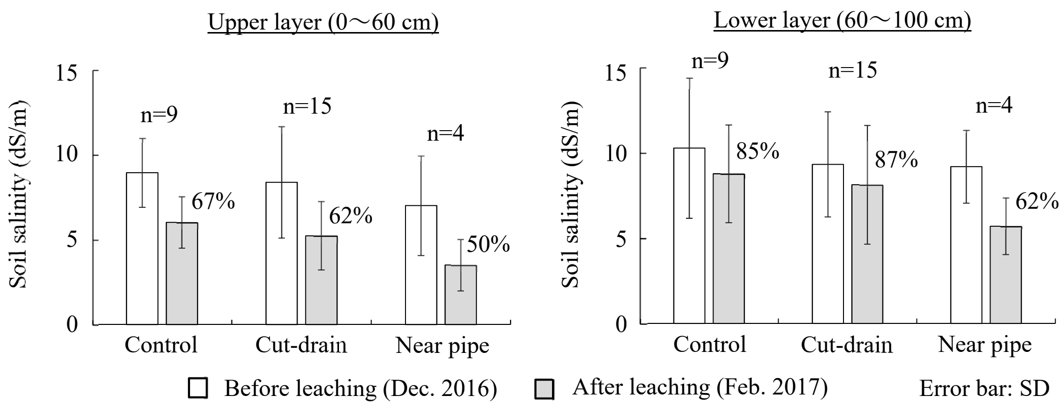


Fig. 6 Rate of soil salinity change

3.3 Cotton yield

The yield survey results are shown in **Fig. 7**. During the cultivation period from May to August 2017, irrigation was conducted between July and August. The total irrigation depth was approximately 400 mm based on a farmer's interview. The precipitation was 9 mm during the cultivation period. The groundwater level kept decreasing from around 1.2 m to 3.0 m in the whole field except during the irrigation period. The cotton yields in the control field, Cut-drain field, and near the pipe drain were 3.3, 3.9, and 4.0 t ha^{-1}, respectively. There is a significant difference in yield based on ANOVA. The Cut-drain field produced approximately 18% higher yield compared with the control (t-test, $p<0.01$). This result indicates that shallow subsurface drainage could be an effective measure in a high salinization field to improve crop yield.

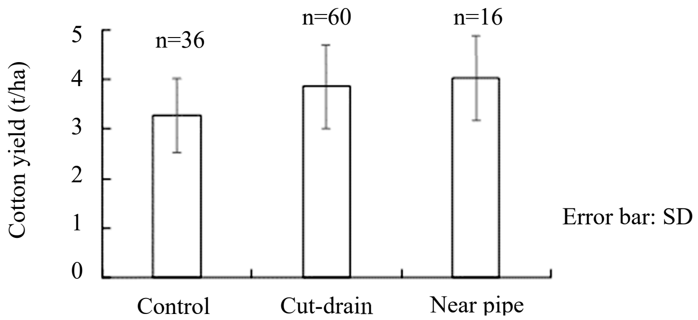


Fig. 7 Cotton yield in 2017

4. Conclusion

Shallow subsurface drainage used in combination with a Cut-drain can help discharge excess water from a field to the open drainage area even during a period of high drainage water level. High EC_w value at outflow was observed during a leaching period and then again in the spring after a rain. Shallow subsurface drainage could remove a significant amount of salt from the field by leaching in addition to that removed by rain. In this study, the influence on soil salinity was not clear. Further studies are therefore necessary to clarify this point. According to the yield survey, an approximately 20% increase in cotton yield was observed in the subsurface drainage field compared with the control field. This technology may be employed as an effective measure to improve agricultural productivity.

One point of discussion is that shallow subsurface drainage technology cannot control deep groundwater. Therefore, further research is needed to clarify the long-term effect or negative effect caused by groundwater levels.

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