Problems and Measures for the Adoption of Cut-drain and Its Applicability to Soil Conditions in Uzbekistan

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Summary

Secondary salinization of irrigated lands in Uzbekistan has been caused by excessive irrigation and rising groundwater levels due to the malfunction of drainage systems. Measures such as drainage system maintenance or leaching has been conducted, but there are fields where salinity levels remain high. The use of a shallow subsurface drainage system has been proposed to ensure the complete removal of percolation water after leaching, but it is considered to be an expensive option. Therefore, the possibility of introducing a drain drilling machine (Cut-drain) which has been developed recently in Japan, was studied. Employing Cut-drain has presented some problems because it rises up to the soil surface and causes the occurrence of preferential flow under dry soil conditions. In this study, we examined the soil moisture conditions suitable for the construction of Cut-drain and the effectiveness of a method for mitigating preferential flow. The results showed that there was a borderline soil moisture condition needed in the construction of Cut-drain. More than 9–11% moisture was required in the first soil layer (from the surface to 20 cm below it) and 12–15%, in the second layer (from 20 to 40 cm). Furthermore, it was found that the preferential flow could be mitigated by irrigating the furrows before construction.

Key words

Salinization, Subsurface drainage, Cut-drain, Soil moisture, Preferential flow

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1. Introduction

1.1 Background

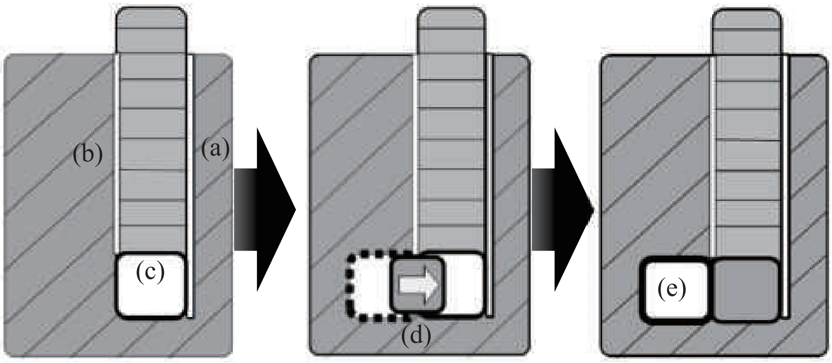
A stable food supply is required to address the world's growing population, and highly productive irrigation agriculture plays an essential role in world food production. Irrigated agriculture represents approximately 20% of total cultivated land but contributes 40% of the total food produced worldwide (FAO, 2015). In arid areas, especially where irrigation is required, the soil salinization of agricultural land is progressing due to excessive irrigation with saline water, water leakage, and rising groundwater tables caused by inadequate management of drainage systems. Salinized farmland accounts for approximately 25% of irrigated areas, including slightly salinized land (Kitamura, 2016).

Irrigated farmlands have expanded in the arid and semi-arid areas of Central Asia since large-scale irrigation development projects were conducted utilizing the Amu Darya and Syr Darya Rivers as water sources (Tsutsui, 1996). The Syrdarya Region of the Republic of Uzbekistan, an arid and semi-arid area, has experienced secondary salinization of irrigated farmland, where facilities such as open channel drainage, deep subsurface drainage and vertical drainage were installed with governmental support. Leaching operation is periodically conducted by mid-sized agricultural enterprises (known as "*Fermer* (farmer)") as a counter measure to directly remove salts.

On-site observations at open channel drainage surrounding irrigated farmland before and after the leaching operation were conducted in winter and have shown that leaching has removed salts from the soil, as demonstrated by increases in the amount of discharge water as well as the saline density in the water after leaching (Okuda et al., 2015a). However, the groundwater level remains high in farmland with malfunctioning drainage systems and in areas far from open channel drainages such as the center of farmland surrounded by open channel drainages and around irrigation canals. Here, the density of salts remains high in soil because leaching water only infiltrates downwards and is not sufficiently drained away from the field.

Shallow subsurface drainage systems are thought to be an effective counter measure in such farmlands to lower the groundwater level, which can reach 50 cm below the soil surface and ensure removal of percolation water with contained salts following leaching (Chiba et al., 2012). The shallow subsurface drainage system requires less labor in construction per unit length compared to deep subsurface drainage systems, however, longer perforated pipes are installed per unit area and so construction is not necessarily less costly than for a deep drainage system. The drain-drilling machine (hereinafter referred to as "the drilling machine"), and the constructed drainage (Cut-drain) have been developed recently in Japan to reduce the construction cost of shallow subsurface drainage (Kitagawa et al., 2010). The drilling machine makes a cavity at approximately 60–90 cm depth using only the traction force of a tractor. Two blades, front and rear (Cutting blades), cut the soil. The bottom blade (push-up blade) lifts up the vertically-long cut soil chunk, and the side-cutter excavates a cavity immediately next to the cavity made by the lifted soil chunk. This method is applicable to relatively firm soils (**Fig. 1** and **Fig. 2**). Employing this method results in a more stable cross-section than cavities made by mole drains placed immediately underneath the construction line. Cut-drains can be applied to the following three drains: (1) direct drainage system that connects the cavity with open ditch drainage, (2) supplementary drain that connects the cavity with main drain (perforated pipe and hydrophobic materials such as rice husk) and (3) drilling and pipe drainage in which drainage pines are installed.

Fig. 1 Drain-drilling machine and cavity of Cut-drain



Blade (a) and (b) cut and lift the soil, creating a gap underneath by push-up blade (c).

Side-cutter (d) shapes a soil block and moves it sideways into the gap.

A water conduction cavity (subsurface drainage) (e) is created.

Fig. 2 Process of making cavity of Cut-drain

Conventional soil layer improving techniques that insert and drag machinery in soil include subsoil breaking and mole drain systems using drilling machines. Subsoil breaking aims to decrease soil hardness by breaking hard soil layers and increasing permeability and plays a major role in allowing the expansion of crop root systems in arid regions. Mole drain systems aim to form a water-running cavity and are employed in Europe and in Asian monsoonal countries to drain water but, knowledge of cavity construction for arid areas is very limited. It is extremely difficult to form a firm cavity when it is possible to break soil, because the construction employing insert-and-drag style machinery would face large tractive resistance, particularly in areas where the soil has low moisture content and cavities cannot be constructed below the plastic limit. Therefore, a certain level of soil moisture content is needed to be able to construct cavities for mole drains. Very little research, however, has studied the drilling machine construction mechanism in terms of soil moisture content.

1.2 Problems with Cut-drain and research objectives

1.2.1 Problems with Cut-drain application

Previously, we constructed experimental shallow subsurface drainage (within 90 cm depth) in the Sydarya Region of Uzbekistan with the aim of removing percolating water following leaching as well as groundwater near the soil surface. However, there was a phenomenon where a cavity could not be constructed because the drilling machine was lifted above the soil surface during the passage of the cutting blade through the soil (Okuda et al., 2015b).

Furthermore, some cavities collapsed after irrigation or leaching operation in the fields where Cut-drains had been constructed. There were some differences in the conditions of the collapse, whereby in some cases part of the cavity remained, and in others the cavity completely collapsed. Soil of the collapsed parts were soft and so it was thought that these partial cavities would retain some function in water drainage despite having a decreased cross-sectional area. However, a collapse would greatly undermine its function. The collapse was thought to have occurred because of a large amount of preferential flow of irrigation and leaching water entering the cavity and the soil collapsing under its own weight following the wall of the cavity being eroded. Preferential flow was thought to have occurred through some of the rough cracks and gaps created by the passing cutting blade. The soil of the field researched in this study had low water permeability and hence, preferential flow could increase the runoff rate and facilitate draining through subsurface ditches. In the shallow subsurface drainage system intended to remove percolation water after leaching, preferential flow which results in excessive water leaking would not only decrease the cross-sectional area of drainage, but also lower the effect of salt leaching because the time during which leaching water and soil is in contact will decrease.

Therefore, the problems in applying Cut-drains in the Syrdarya Region are 1) lifting of the drilling machine, and 2) cavity collapse following construction.

1.2.2. Research objectives

In Japan, soil plasticity does not usually decrease as the lower soil layer dries and hence it is rare that a drilling machine cannot be operated. This research aims to clarify the soil moisture conditions for which the drilling machine does not lift, and the tractor can be operated such that the cavity can be constructed at the desired depth in a stable manner. In addition, a method was tested to prevent excessive preferential flow and so avoid the degradation of drainage function and decrease in removed salt during leaching.

2. Overview of the research area

Uzbekistan is surrounded by five inland countries, Kazakhstan to the north, Kyrgyz and Tajikistan to the east and southeast, Afghanistan to the south and Turkmenistan to the south and west. The area of Uzbekistan is 447 thousand km^2, which is approximately 1.2 times that of Japan. Desert and steppe areas occur in the west and account for 60% of national land, and the Tian Shan Range and the Pamir Mountains occupy the eastern part of the country, forming mountains and plateaus. The Amu Darya and

Syr Darya Rivers flow in the south and north of the country into the Aral Sea. The climate is continental, and temperatures are highly variable, with summers hot and dry and winters cold and wet. Annual precipitation is 100–250 mm in the desert areas, 200–545 mm in the foot of mountains or plain areas and more than 400 mm in the mountain areas (FAO, 2006). The Syrdarya Region is in the foothill plains area and is classified as a semi-arid climate because the dryness index is 0.32 (estimated value) and precipitation is 335 mm (average of previous five years). In summer, the temperature can exceed 40 °C, in winter it can be below -10 °C, and the rainy season of October–April brings precipitation.

Of Uzbekistan's farmland, 4.3 million ha had irrigation facilities in 2014 and according to interviews conducted with the Farmers' Council, 47% of irrigated farmland has experienced salt accumulation (EC_e > 2 dS m^{-1}). In the Syrdarya Region, 98% of irrigated farmland (280 thousand ha) has been damaged by salt accumulation. Apart from the Syrdarya Region, almost all irrigated farmland has experienced salt accumulation in the Xorazm Region, and more than three-quarters of irrigated farmland in the Bukhara, Navoiy, and Jizzakh Regions and the Republic of Karakalpakstan have experienced salt accumulation.

Farmland in the Syrdarya Region is located between branch irrigation canals typically made of U-shaped concrete and branch open channel drainages made of soil (3.0–4.5 m depth). The width between the irrigation canal and drainage is approximately 450 m in most farmland. Temporary water ditches are constructed to irrigate between furrows before the irrigation period. The farmland appears to be evenly elevated, however, there are many undulations and hence, irrigation water is not efficiently distributed, and this is one of the reasons for excessive irrigation. In addition to irrigation canals, deep subsurface drainage system (2.5–3.0 m depth) or vertical drainage (a drainage system in which pumping pipes are installed to lift groundwater from the deep soil layer) are introduced to control the groundwater level. Farmlands are nationally owned and leased to farmers, on which cotton, and wheat are produced through contracts as a part of governmental production schemes.

The research sites are farmland in the Syrdarya Region, cultivated by farmers of the local Water Consumers' Association (WCA) as follows: Axmedov WCA of Mirzaabad District, and Yangiobad WCA and Bobur WCA of the Oqoltin District (**Fig. 3**). The research sites are alluvial soil which has low permeability, and the soil profile of 1 m depth mainly consists of loam soil (L), sandy loam soil (SL) and clay loam soil (CL), according to the soil texture classification of the International Society of Soil Science standards. Cut-drains can be constructed in L and CL but not SL soil. The soil texture of each WCA slightly differ. Axmedov WCA has L and SL, Yangiobad WCA has L, SL and CL, and Bobur WCA mainly has CL and L. The soil permeability index and dry bulk density of Bobur WCA are shown in **Table 1**.

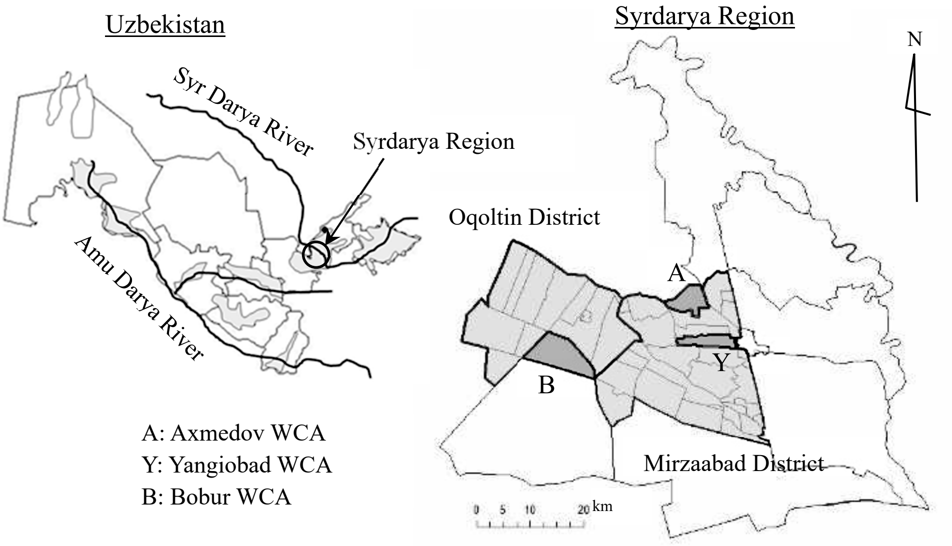


Fig. 3 Location map of research sites

Table 1 Physical properties of soil in the experimental field*

	Soil permeability index ** (cm s^{-1})	Dry bulk density (g cm^{-3})
Top soil (0-20 cm)	1.7×10^{-4}～1.1×10^{-5}	1.59±0.06
Hard pan (30 cm)	1.3×10^{-5}～4.3×10^{-6}	1.71±0.03
Subsoil (40-100 cm)	1.1×10^{-3}～9.1×10^{-5}	1.48±0.06

*) Soil sampling point is Bobur WCA Pakhtakor Farm, October 2009

**) falling head permeability test

3. Research method

3.1 Understanding soil moisture content suitable for the formation of cavities

The soil moisture conditions suitable for Cut-drain construction were studied in the fields of three WCAs by comparing how the cavities were made in different periods of time with different soil moisture contents.

Water content was determined when monitoring mass basis soil moisture content because this is relatively easy to measure and the local engineers in Uzbekistan can easily analyze the acquired soil samples. Soil samples were taken in areas surrounding the Cut-drain construction sites and water content measured by drying the samples at 105 °C for 24 h. Soil layers were classified into five categories: 1) surface soil (0–20 cm depth), 2) a soil layer around 30 cm depth that contains hard soil (20–40 cm), 3) a layer above the Cut-drain cavity (40–60 cm) and 4) two layers below 60 cm (60–80 and 80–100 cm, respectively). Two periods of time were selected which were firstly, after leaching in March–April, and secondly, the dry season, in June–August. March and April are the months before sowing cotton seeds and hence, the surface soil is sufficiently dry for tractors to operate, but some water remains in the lower layers. Soils are dry in June and August, but soil moisture content is relatively stable in irrigated farmland as well as fields with higher groundwater levels.

Cut-drains were constructed using a farmer-owned tractor (Case IH MXM140Pro or New Holland TS130) with a drilling machine attached.

3.2 Experiment on preventing preferential flow

Furrows were irrigated beforehand, where the drilling machine's cutting blades pass, to test a method of constructing cavities at high soil moisture content and investigate its effect in preventing the occurrence of preferential flow. In this method, it was expected that soil pores would fill with soil particles and big cracks would be elastically closed by plasticity of the soil. The experiment was conducted in Axmedov WCA.

The experimental furrow was 10 m long and the Cut-drain was constructed under irrigation conditions as follows:

(a) 10 cm irrigation plot – irrigated with water equivalent to 10 cm water depth, applied in a furrow with width 0.9 m (0.9 m × 0.1 m × 10 m = 0.9 m^3) and the Cut-drain constructed two days later.

(b) 3 cm irrigation plot: irrigated with water equivalent to 3 cm water depth, applied in a furrow with width 0.9 m (0.9 m × 0.03 m × 10 m ≈ 0.3 m^3) and the Cut-drain constructed on the same day.

(c) no-irrigation plot-control; Cut-drain was constructed with no irrigation water applied.

The three treatments, (a)–(c), were applied to three furrows each, making a total of nine furrows. Soil samples were collected before and after Cut-drain construction to measure water content from layers 1-5 as classified previously as 0–20, 20–40, 40–60, 60–80 and 80–100 cm.

Approximately one week after Cut-drain construction, an infiltration experimental plot (1.0 m length) was prepared between furrows to investigate water infiltration. The infiltration experiment was conducted in a total of 18 plots with two plots each on all the furrows of treatments (a)–(c). A gauge (wooden stick with a scale) was installed to measure the change of water depth over time. The change in infiltration rate was observed after irrigating with approximately 10 cm of water. More water was irrigated for further observation if infiltration proceeded in the experimental plot. Furrow banks were covered with plastic and the fields surrounding the experimental plots were also irrigated when the experiment started to prevent horizontal infiltration towards the outside of the experimental plots. In addition, control plots without Cut-drains were situated next to plots with Cut-drains, and irrigation conditions as used for adjacent treatments (a), (b) or (c) were used to allow comparison of their infiltration conditions. Infiltration was observed for approximately 4 h after irrigation started, and an approximate expression was derived from plotting the cumulative amount of infiltration (D) against time (t). The cumulative infiltrations at 30 and 60 min after onset of irrigation were calculated from this expression, and the difference was converted into a value per unit time and considered as infiltration capacity (Kanmuri et al., 2007).

The occurrence of preferential flow was recorded by observing any water flow out to the cavity at the soil profile. An observation pit of 1.0 m depth was dug next to the infiltration experimental plot so that the cavity was exposed to the pit. For the opposite side of the observation pit from the examined exposed cavity experimental plot, the cavity was closed by soil in order to prevent percolating water flowing against the pit (**Fig. 4**).

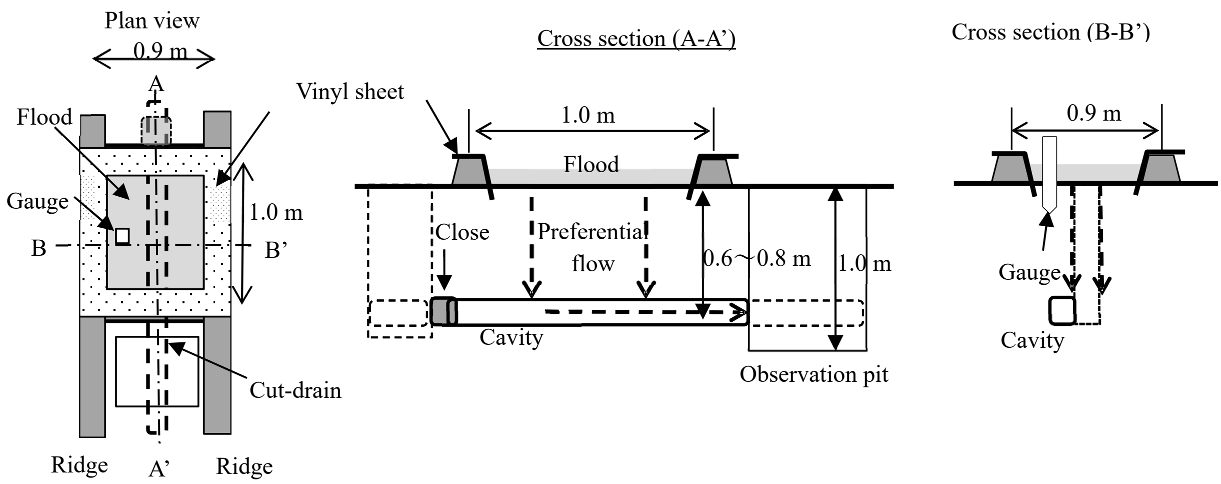


Fig. 4 Drawing of infiltration experimental plan

4. Results and discussion

4.1 Soil moisture content suitable for cavity construction

The results of the construction of Cut-drains in three WCAs and soil moisture content measured at different soil depths (water content) are shown in **Fig. 5**.

Some resistance was observed when inserting the drilling machine into the soil during construction in March–April after leaching and before cotton seeds were sown. The Cut-drain was constructed at a depth of 60–90 cm by adding a load of 100–120 kg to the base frame of the machine. Observation of the soil profile following construction showed that cavities successfully formed in all the plots. Water content of the three WCAs (using averages of each WCA) were 16–18, 18–19, 18–23, 25–29 and 29–31% in layers 1–5, respectively.

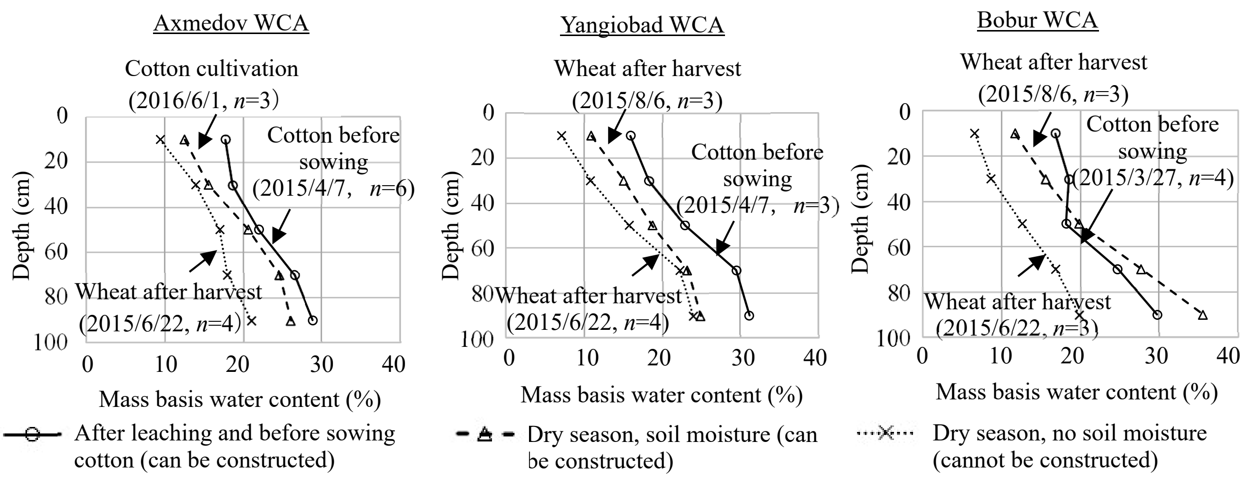
In the field where soil moisture was relatively maintained, it was possible to construct Cut-drains by putting some weight onto the base frame as used in the field before sowing the cotton seeds. The reasons why soil moisture was retained were: 1) leaching water remained in Axmedov WCA, 2) irrigation water was supplied in Yangiobad WCA and, 3) the groundwater level was high in Bobur WCA. When operating the tractor, its wheels were temporarily idling when passing points with hard soil, however, it was able to proceed, and traction was always possible. Upon inspection, it was revealed that cavities were successfully formed in all inspected soil sections. Water contents were 11–13, 15–16, 19–21, 23–28 and 25–36% for layers 1–5, respectively.

When the experiment was conducted on the field after wheat was harvested in the dry season (no irrigation water was applied), it was not possible to construct Cut-drains because the machine lifted, even with weight added to the base frame. Water content decreased by 8% on average compared with those measured before cotton seeds were sown (7–9, 9–14, 13–17, 17–22 and 20–24% for layers 1–5, respectively).

Water contents were lower in fields where Cut-drains were not constructed in the dry season than in fields where Cut-drains were constructed. It was assumed that between the values of water content for the two fields there was a lower limit of soil moisture condition for which Cut-drains could be constructed. The median of water content of both fields in the three WCAs were 9–11, 12–15, 15–19, 21–23 and 24–25% for layers 1–5, respectively (values from Bobur WCA were from the third and lower layers only and the median was calculated using the field where construction was not possible and the field before the cotton seeds were sown where construction was possible). It was estimated that these soil moisture conditions were the lower limits of soil moisture that allows construction of Cut-drains in the research fields.

The tractor was able to run, without the drilling machine attached, on soil where soil moisture was retained on the surface due to irrigation. However, with the drilling machine attached, the wheels were idling, and construction could not continue. The threshold water content was 24%. The tractor wheels were idling temporarily when the tractor operated on the field where surface soil was dry in the dry season because soil was very hard in some places and resistance force was strong.

Therefore, we concluded that the water content similar to that after leaching and before cotton seeds were sown was one of the soil moisture conditions in which Cut-drains could be constructed without any problem in the Syrdarya Region. However, it should be noted that some modifications were required such as adding weight to the base frame, to insert the drilling machine into soil in each season.



Note) Analysis results are shown at the midpoint of each layer

( ) Date is Cut drain construction and soil sampling date, *n* is sampling number

Fig. 5 Soil moisture under construction of Cut-drain

4.2 Experiment on preventing preferential flow

4.2.1 Soil water content when Cut-drain is constructed

The experiment was conducted in Axmedov WCA. (a) The 10 cm irrigation plot was irrigated on 30

May 2016, and (b) the 3 cm irrigation plot was irrigated on 1 June and Cut-drains were constructed on 1 June in all the experimental plots of (a), (b) and the control plots (c) (**Fig. 6**). Water contents of the plots when constructing Cut-drains are shown in **Fig. 7**. Water contents of plots (a) and (b) were 23–24, 20–21, 22, 25 and 27% for layers 1–5, respectively. Compared with plot (c), the corresponding rates were 10–11, 6–7, 1, 0 and 2% higher (**Fig. 7**). There were no significant differences for layers 3–5 among plots (a), (b) and (c), and there was indication that irrigation water affected soil moisture mainly in layers 1 and 2.

(a) Irrigation 10 cm

0.9 m^3 input (5/30)

Cut-drain construction on the second day after irrigation (6/1)

(b) Irrigation 3 cm

0.3 m^3 input (6/1)

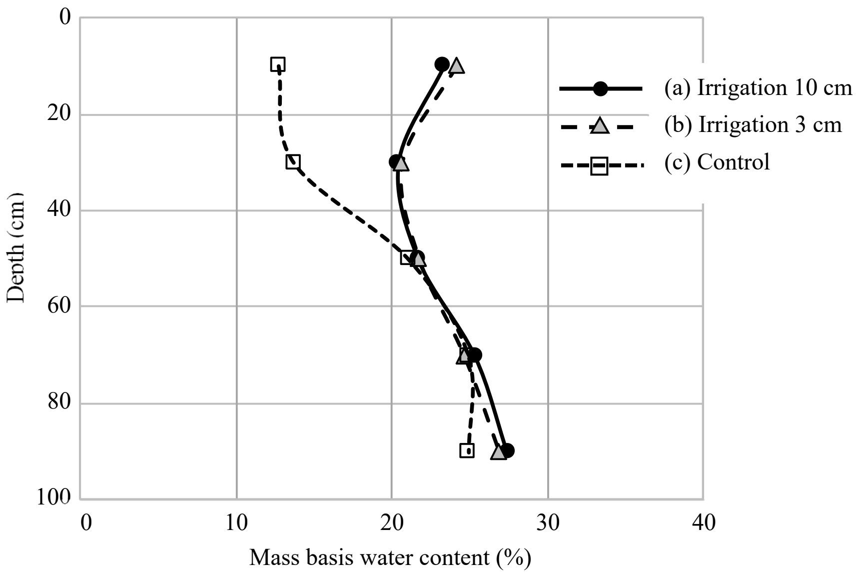
Cut-drain construction on irrigation day (6/1)

(c) Control

Non-irrigation (6/1)

Construction of Cut-drain in dry condition (6/1)

Fig. 6 Cut-drain construction under different irrigation conditions



Note) Analysis results are shown at the midpoint of each layer

Fig. 7 Soil moisture under each irrigation condition

4.2.2 Effect of irrigation on tractor operation

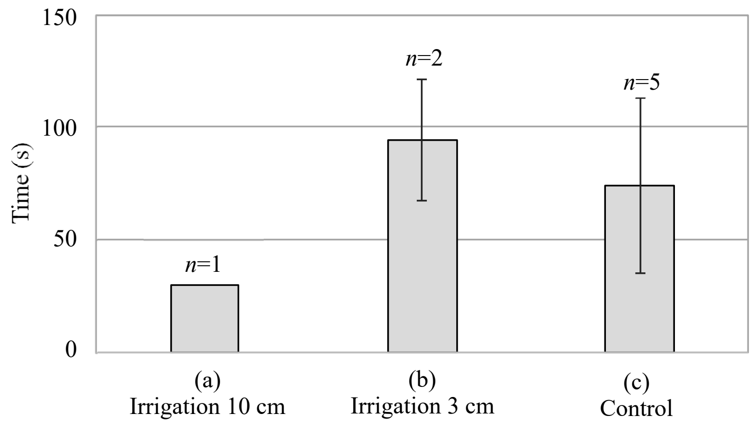
When constructing Cut-drains, a concern is that tractor wheels could be idling when soil moisture content is high in the soil between the furrows where the wheels run. In plot (a), which had high water content, it was expected that soil between furrows where the wheels run would also have a higher water content. Therefore, in plot (a), water content of soil was measured between the furrows next to the irrigated furrows. This showed that the water content of layers 1 and 2 were 12% and 15%, respectively, on the day that soil was irrigated. However, contents increased on the two days following irrigation and layer 1 was 17% and layer 2 was 19%, which is an increase of 4–5% in both layers. These soil moisture conditions were similar to those after leaching and before cotton seeds were sown. There is not considered to be any problem constructing Cut-drains for 10 cm of irrigation, although soil moisture content increased in the surrounding furrows. Furthermore, as an issue of irrigation management, it was expected that water could leak into surrounding furrows when furrows were shallow and the distance between them was short. If soil moisture in furrows where wheels run becomes too high, the wheels could be idling. In the case where the amount of irrigation water at the level of plot (a) is applied, it is necessary to confirm existence of the cross-sectional area for irrigated water as well as to manage the amount of irrigation, to prevent any water leaking.

4.2.3 Conditions in which preferential flow occurs

A water infiltration experiment was conducted 8–9 days after the construction of Cut-drains plots of (a)–(c) (six plots each, making a total of 18 plots). The results showed that eight plots experienced preferential flow after irrigation started, with one plot in (a), two in (b) and five in (c). A large amount of water infiltration was observed.

The irrigated water at experimental plots where preferential flow occurred disappeared very soon after the flow occurred. The periods of time from starting the experiment until preferential flow occurred were within 30–132 s, and no tendency was found such as plot (c) collapsing at an earlier time (**Fig. 8**). Thus, the path of preferential flow and the conditions of soil pores from the surface layer to the cavity is not uniform.

The observation of pits showed that in plots (a), infiltrated water oozed earlier from the upper section of soil than from the cavity, but soon after, water leaked from the cavity. In plots (b), infiltrated water leaked only from the cavity. In plots (c), water leaked from the cavity in four plots, but the remaining plot had no water leaking. The surroundings of this last plot were studied and showed that water infiltrated into the part of the Cut-drain on the other side of the pit, and this was thought to be due to preferential flow. Leaked water was observed in the pits, however, almost all cavities were retained. It is likely that the cavities were retained because of the small amount of water flow.



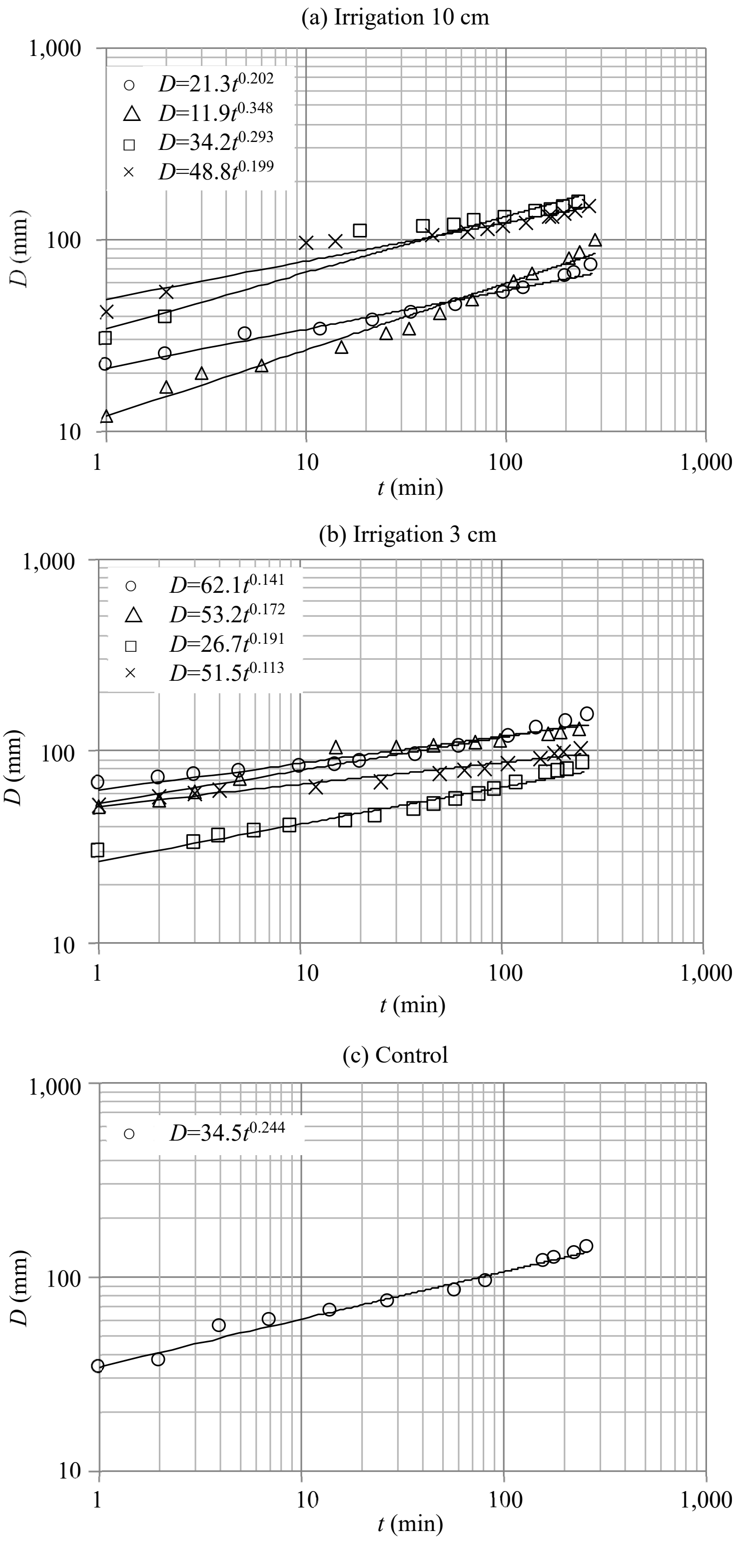
Note) Error bars are standard deviation

Fig. 8 Time required for the incidence of preferential flow in each experimental plot

4.2.4 Conditions of water infiltration where preferential flow was prevented

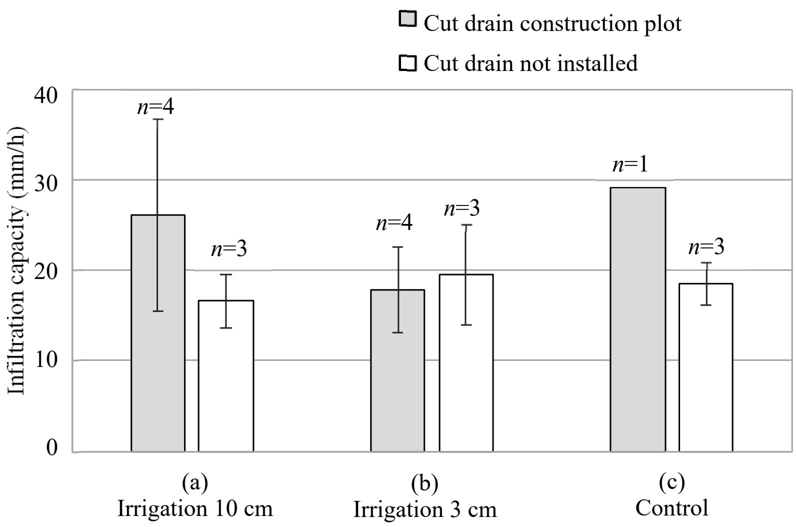
Ten of the experimental plots, being (a) five plots, (b) four and (c) one, showed that no collapse occurred, and irrigated water was retained for more than 4 h with no water leaking into the pits. The relationship between D and t is shown in **Fig. 9**. Calculations showed that the infiltration capacity of plots (a) was 26 mm h^{-1} (average of four plots, with one plot eliminated due to no measurement), that of plots (b) was 18 mm h^{-1} (average of four plots) and that of plots (c) was 29 mm h^{-1} (one plot). The highest capacity was found in plots (c), followed by (a) and (b). However, the order of infiltration capacity was the same and hence there are no significant differences among these values. The infiltration capacities of no Cut-drain construction plots of (a)–(c) were 17-, 19- and 18-mm h^{-1} (average of three plots), respectively. No difference was observed between (a) and respective no Cut-drain construction plots as well as between (b) and respective no Cut-drain construction plots (**Fig. 10**).

Thus, after Cut-drains were constructed, there was no significant difference among infiltration capacities of plots where no water leakage was observed, and therefore it was expected that the capacities were similar in the first 4 h after irrigation to that of the field without Cut-drains.



Note) (a) One point in the irrigation 10 cm is missing due to water leakage at the surface.
Accumulative infiltration volume (D) is the value obtained by subtracting evaporation

Fig. 9 Relationship between infiltration time (t) and accumulative infiltration volume (D)



Note) Error bars are standard deviation
Cut drain construction zone (a) one point of irrigation 10 cm zone is missing

Fig. 10 Infiltration capacity of plots maintained under ponded condition

4.2.5 Evaluation of the method to prevent preferential flow

Before construction of Cut-drains, when irrigation was applied between furrows where the cutting blade passes, the frequency of preferential flow was lower than in the absence of irrigation, and therefore, this method may prevent the sudden entry of leaching water and prevent the collapse of cavities as well as the decrease of a salt leaching effect. In addition, there were no significant differences in soil moisture content between (a) and (b) when Cut-drains were constructed. This indicates that even if system (b) was chosen, if water is limited, or the drainage section area cannot be secured and the amount of irrigation water cannot be well managed, a similar effect could be expected.

5. Conclusion

Constructing Cut-drains in arid and semi-arid areas of Uzbekistan can be challenging because the drilling machine can be lifted when the soil is extremely dry. Therefore, three WCAs in the Syrdarya Region were studied in terms of the soil moisture conditions for which Cut-drains could be constructed during the season when the soil surface was dry. The results showed that the estimated lowest limits of water content were 9–11% in the surface soil layer (0–20 cm) and 12–15% in the 20–40 cm layer. This is a soil moisture limit for the Cut-drain construction below the possible soil plastic limit, and this knowledge could be generalized for other similar construction methods.

The highest limit of water content in the surface soil, however, is based on the soil condition for which tractor operation is ensured, and as for the lower soil layer (60–90 cm depth) it is expected to maintain the soil moisture content at which the constructed cavity will not collapse under its own weight. In the future, we will study the highest limit of water content at which the cavity can be sustained, and the plastic limit will also be studied so that the recommended water content acquired can be quickly and easily applied to farmland with different soil properties.

Cut-drain construction can result in preferential flow from water leaking through the cracks made by the cutting blades as well as through soil pores, if a large amount of water is applied through irrigation and leaching. If a large amount of preferential flow runs into the cavity, the soil wall can be excavated, and the cavity can collapse, which degrades the highly functional water flow of the Cut-drain. The time duration in which leaching water and soil are in contact is also shortened and the salt leaching effect decreases. To prevent the preferential flow that causes problems, a method was studied to irrigate furrow (where the cutting blade passes) beforehand. After construction, a water infiltration experiment was conducted to confirm preferential flow, and this was less frequent than when no irrigation water was applied. It is expected that this method will help prevent some preferential flow.

In the experiment on a method to prevent preferential flow, approximately one week elapsed from when the Cut-drain was constructed until the infiltration experiment was conducted. It is possible that a longer dry period could result in a further lowering of capability to reduce the frequency of preferential flow. In the future, we will study this method at the beginning of the rainy season when tractor operation is not hindered, to evaluate the period for which a better effect could be anticipated.

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