Japan International Research Center for Agricultural Sciences (JIRCAS)
Farmers’ Council of Uzbekistan (FC)

Shallow sub-surface drainage for mitigating salinization

Technical Manual

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PREFACE

Agricultural productivity in Central Asia increased dramatically during the middle of the 20th century, owing to the large-scale development of irrigated land. The government has dedicated additional energy and resources enable to farming in arid and semi-arid regions. Although inadequate water management and poor drainage has led to widespread salinization, among the Central Asia region in Uzbekistan, which has caused serious damage to agricultural production in large area.

Several measures can be taken to mitigate salinization, including water-saving strategies (e.g., drip, sprinkler), leaching, flushing, laser leveling, dredging of open drainage systems, installation of sub-surface drainage, and removal of surface saline soil. However, almost all of these measures involve initial cost, which is the main barrier to their application. As a result, the only low-cost measure that is available to farmers is leaching during the winter after cotton has been harvested. Yet, even the efficacy of leaching has declined by hard soil layer owing to compaction from the long-term use of agricultural machinery. Therefore, appropriate countermeasures are urgently needed.

From 2008 to 2012, the Japan International Research Center for Agricultural Sciences (JIRCAS) had implemented ***"The Research Project on Measures against Farmland Damage from Salinization"***, which focused on farm-based salinization mitigation strategies that could be used in areas with high groundwater levels. Ultimately, guidelines were developed, publicly disseminated through seminars, and distributed to Uzbekistani stakeholders, who had been negatively affected by salinization.

From 2013 a new research project was initiated by the Joint Research Agreement with Farmers Council of Uzbekistan, it focused on sallow sub-surface drainage technology to improve the efficacy of leaching and also drainage blocks that can block the influence from surrounding fields.

This technical manual was compiled as a result of this research activity (from 2013 to 2017), which was subsidized by the Japanese Ministry of Agriculture, Forestry and Fisheries, and is intended to be widely used by government officials and farmers.

In addition, the development of this technical manual was largely supported by the Japanese Ministry of Agriculture, Forestry and Fisheries; Japan Embassy; Japan International Cooperation Agency; as well as related research institutions; and by three Water Consumers' Associations (Yangiobad, Axmedov, and Bobur) from the Syrdarya Region of Uzbekistan.

Here, I express my appreciation to all of them for their cooperation.

February 1st, 2017

Dr. Satoshi Tobita
Program Director
JIRCAS

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CONTENTS

ABBREVIATIONS

AFI	Alternate Furrow Irrigation
FC	Farmers’ Council of Uzbekistan
FAO	Food and Agriculture Organization of the United Nations
HGME	Hydro-geological Melioration Expedition
JICA	Japan International Cooperation Agency
JIRCAS	Japan International Research Center for Agricultural Sciences
JRA	Joint Research Agreement
RIIWP	Scientific Research Institute of Irrigation and Water Problem
TDS	Total Dissolved Solids
TIIM	Tashkent Institute of Irrigation and Melioration
WCA	Water Consumers’ Association

TERMS USED IN THE MANUAL

Groundwater level:	distance between the surface of groundwater and that of the soil
Root zone:	soil layer in which crops extend their roots to absorb soil moisture
Infiltration loss:	unused water that infiltrates the soil under the root zone
Main sub-surface drainage:	Part of durable drain which intakes and transfers infiltration water/groundwater in sub-surface drainage system
Collecting drain:	Pipe for sending drainage water in sub-lateral drains
Drainage outlet:	Facility to drain collecting sub-surface drainage water to the open drainage
Filter material:	Permeable material which is set above the perforated pipe and let facilitate to infiltrate collected water in the field
Preferential flow:	Unequal water flow passing the pores formed in soil
Relief well:	Facility of controlling drainage water at the downstream of sub-surface drainage system
Shallow sub-surface drainage:	Under this manual, facility which accelerates to remove infiltrated water/shallow groundwater by burying pipe in around 1.0 m from the ground surface
Sub-lateral drain:	It is synonymous with main sub-surface drainage. Facility which consists of filter material and pipe to absorb/convey water. It absorbs infiltrated water/groundwater to perforated drain pipe, then convey drain water to downstream
Supplementary drain:	Drain which assist a function of water way to the main sub-surface drainage for making quick drainage from surface layer
Water content:	Ratio of the water for the dry weight of the soil

INTRODUCTION

I. Background

During the 1960s of the Soviet Union era, large-scale irrigation was developed in Central Asia, in the Amudarya and Syrdarya river basins, which had previously been steppe or desert. This large-scale development enabled cultivation in these areas without the most optimal irrigation facilities. However, the salt content of the irrigation water accumulated in the farmland, and groundwater levels increased, as a result of excessive irrigation and poor drainage. Because this type of irrigation is still being used in some regions, more than 50 years later, salinization has become a serious problem for sustainable agriculture and is continuing to expand. Furthermore, in the Central Asian plains, most soils already contain naturally high levels of salt, which makes the potential danger of secondary salinization that much more concerning (Shirokova et al. 2006)[1)].

Several measures can be taken to mitigate salinization, including water-saving irrigation and improving drainage. However, in reality, the only practical measure that is available to farmers is leaching, the efficacy of which is limited by poor drainage and hardened soil, owing to soil compaction from the long-term use of agricultural machinery.

II. Purpose of JIRCAS research

From 2008 to 2012, the JIRCAS conducted research that was focused on identifying methods by which farmers could mitigate secondary salinization in the Syrdarya Region of Uzbekistan. As the result, the JIRCAS compiled the "***On-farm mitigation measures against salinization under high ground water level conditions Guideline 2013***", which was distributed throughout the region of Uzbekistan that is most negatively affected by salinization and also published on the JIRCAS website.

(http://www.jircas.affrc.go.jp/english/manual/salinization/Rus_index.html)

Then, in 2013, the JIRCAS initiated a new project that focused on developing low-cost drainage technology to improve the efficacy of leaching. From the point of view of adaptation and extension by government officials, Water Consumers' Associations (WCAs), and farmers, it is extremely important that the technology is affordable. The first purpose of the research was to identify effective, low-cost technology that could improve farmland permeability. One effective technology for improving farmland permeability is the use of sub-surface drainage. However, the conventional application of this method bears a high cost, owing to the costs of purchasing drainage pipe and burying it. Therefore, the JIRCAS attempted to introduce sub-surface drainage that was installed using a special tractor attachment, which was expected to lower the cost. In addition, try to clarify the effect in the area surrounded by the drainage (about 3 m deep) that can block the influence from the surrounding field (drainage block) as well because measures in a part of the farmland are affected by the use of water in the neighboring field.

Another main goal of the project was to compile the findings in a technical manual.

Targets of this manual and research:

- Target areas:
  irrigated farmland and drainage block in arid or semi-arid regions
- Target groups:
  government officials, WCA, farmers
- Project area:
  Syrdarya Region, Uzbekistan
  Mirzaobod District (Axmedov WCA, Yangiobad WCA)
  Oqoltin District (Bobur WCA)

Fig 1. Location of Project area

This technical manual compiled as a result of this research activity (from 2013 to 2017), which was subsidized by the Japanese Ministry of Agriculture, Forestry and Fisheries. In order to improve the usefulness of this technical manual, the JIRCAS is continuing its survey and research until 2018 and plans to amend this manual with its findings.

III. How to use this manual

The main purpose of this technical manual is to provide information to governmental officials, WCAs, and farmers about sallow sub-surface drainage technology which developed as one of the perforated dredgers in Japan (Cut-drain). These information was obtain from verification studies under high-risk salt accumulation. At the same time, in order to promote a better understanding of secondary salinization, the mechanisms of salinization, mitigation measures, and monitoring methods are also described.

In Chapter 1, the negative effects and mechanisms of salinization are described. Meanwhile, in Chapter 2, general mitigation measures are described, and methods for preventing and alleviating salinization are distinguished and discussed. Then based on the JIRCAS research, the causes, effects, and monitoring of salinization are discussed (Chapter 3), as are the effectiveness, relevance, and procedure of sallow sub-surface drainage (Chapter 4); and in Chapter 5, Summary and several recommended of sallow sub-surface drainage is described.

REFERENCES

1) Y.I. Shirokova and A.N. Morozov (2006): "Salinity of irrigated land of Uzbekistan: causes and present stage." Springer, Sabkha Ecosystems Volume II: West and Central Asia, 249-259.

Chapter 1
SALINIZATION

1.1 What is salinization?

Salinization is the accumulation of salts in the root zone of agricultural soil that reduces crop yields by preventing plants from absorbing enough moisture. When salinization has affected a landscape, warning signs such as the occurrence of sick or dying trees, declining crop yields, and colonization by salt-tolerant weeds are often observed. Salinization reduces the productivity of crops, making it impossible to sustain agriculture, and also affects the health of rivers and streams, sometimes making the water too salty for humans or animals to drink. Furthermore, these effects can extend downstream from the source of saline water. As a result, salinization is one of the contributors to the degradation of agricultural land, and without appropriate mitigation, salinization will worsen, in severe cases requiring that the land be abandoned. Salinization is caused by salt accumulated in the farmland, therefore suppression of salt accumulation and removal of accumulated salt are effective as countermeasures.

Fig. 1.1.1 Salinization

Salt accumulation can be divided into two types, with primary salinization occurring naturally (e.g., in salt lakes, saltpans, salt marshes, and salt flats) and secondary salinization resulting from human activities, usually related to land development and agricultural activities. This technical manual addresses secondary salinization because this type is strongly related to irrigation agriculture, especially in arid and semi-arid areas.

In Central Asia, Salinization due to irrigated agriculture is serious, among them, in Uzbekistan, cotton and wheat cultivation by the government order is still going, where, cultivation by the surface irrigation with low water application efficiency is done in a large farmland. As a result, nearly 40% of the irrigated farmland is affected by salinization (Table 1.1.1).

Table 1.1.1 Salinized land in Central Asia

Country	Irrigated area (ha)	Area affected by salinization	
		(ha)	(%)
Uzbekistan	4,198,000	2,141,000	51
Kyrgyz	1,021,400	49,503	5
Tajikistan	742,051	23,235	3
Kazakhstan	2,065,900	404,300	20
Turkmenistan	1,990,800	1,353,744	68
Central Asia	10,018,151	3,971,782	39.6

Source: Irrigation in Central Asia in figures (FAO, 2013, FAO Water report 39, p68)

1.2 Mechanisms of salinization

There are mainly two factors of salt accumulation under irrigation agriculture, namely the introduction of salt with irrigation water and the elevation of groundwater levels, as a result of excessive irrigation and poor drainage.

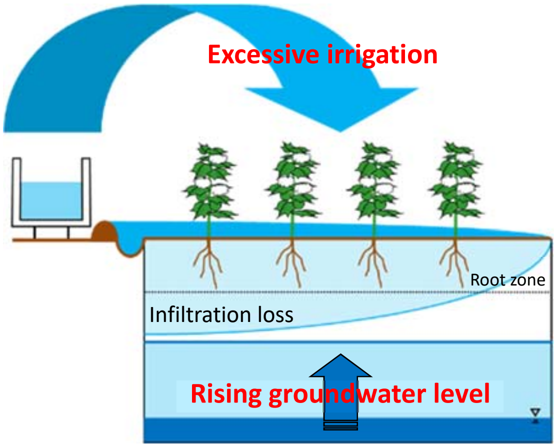


Fig. 1.2.1 Cause of salt accumulation

Irrigation alters the natural water balance since the large volumes of irrigation water are not fully utilized by crop plants and, instead, infiltrate the underlying soil. The maximum attainable efficiency of irrigation is about 70%, and the actual efficiency is usually less than 60%. This means that at least 30% of the irrigation water, and usually more than 40%, is not taken up by crop plants, and most of this excess water becomes stored underground, where it can considerably alter the natural hydrology of local aquifers. In addition, because many aquifers cannot absorb or transport this water, the water table frequently rises up close to the soil surface, a phenomenon that is commonly known as "*waterlogging*" or "*capillary* rising" is occur.

In most soils with shallow water tables, groundwater rises into the root zone by capillarity rising and, if the water contains salts, becomes a continuous source of salt exposure. The rate of salt accumulation in soils from uncontrolled shallow groundwater depends on irrigation management, depth of the water table, soil type, and climatic conditions.

1) Waterlogging

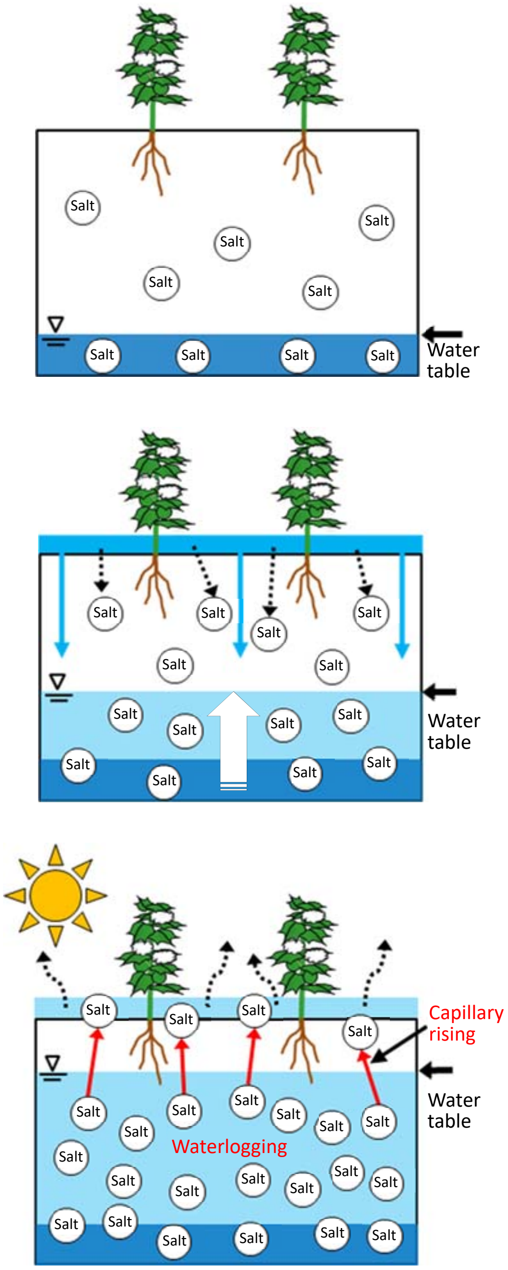
Water logging is damaged by soil saturation due to flooding or rise of groundwater table. Farmland is regarded as waterlogged when the water table is too high for farming, reduces yields, impedes the use of farm equipment, and compacts the subsoil.

Waterlogging is detrimental to agricultural because it:

- reduces oxygen which crop required in the root zone
- accelerates salinization due to capillary rising of salty groundwater
- reduces the effectiveness of leaching.

2) Capillary rising

Capillary rising is the upward flow of soil moisture that occurs without the influence of pressure, and it is affected by the physical properties of the soil. When the water table approaches the soil surface, saline soil moisture is transferred from the groundwater to the soil surface by capillary rising, where it evaporates, thereby depositing salt in the root zone (Fig 1.2.2).



In central Asia, the soil, irrigation water, and groundwater contain relatively high levels of salt.

Excessive irrigation and poor drainage can elevate the water table, and the inflow of salt from irrigation water increases the salinity of the groundwater and upper soil layer.

When the water table rises further, the upper soil layer is saturated and capillary rising occurs. As a result, saline soil moisture moves from the groundwater to the soil surface, where the water evaporates, leaving the salts behind.

Fig. 1.2.2 Process of salt accumulation

1.3 Classification of salinization

Before initiating anti-salinization mitigation measures, it is important to determine the salinization level. The main indicators of this are electrical conductivity (EC) and total dissolved solids (TDS), which have been adopted widely.

1) Electric conductivity

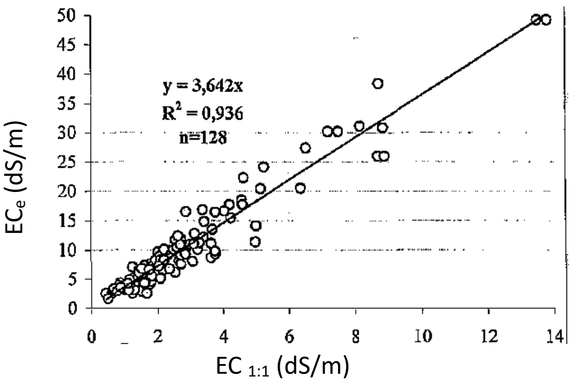
EC is a measure of the strength of an electric current in an aqueous solution, and higher levels of salinity increase a solution's EC. In addition, EC is expressed in dS/m (deci-Siemens/meter), µS/cm (micro-Siemens/centimeter).

Table 1.3.1 Types of electrical conductivity

Type	Method of measurement
ECw	Electrical conductivity of water
ECsw	Electrical conductivity of soil water
ECe	Electrical conductivity of an extract of saturated soil paste
$EC_{1:1}$	Electrical conductivity of a mixture of 1 part (by weight, e.g., grams) air-dried soil with 1 part (by volume, e.g., milliliters) distilled water
$EC_{1:5}$	Electrical conductivity of a mixture of 1 part (by weight, e.g., grams) air-dried soil with 5 parts (by volume, e.g., milliliters) distilled water

Conversion from EC1:1 to ECe

$EC_{1:1}$ is widely adopted in Uzbekistan, but the evaluation of soil salinity is usually described using ECe. In order to establish a formula for converting the two measures, the Research Institute of Irrigation and Water Problems (RIIWP) analyzed soil samples from the Syrdarya, Djizak, Khorezm, and Surkhandarya regions of Uzbekistan and from the Republic of Karakalpakstan. On the basis of their analyses, the average conversion for practical usage from $EC_{1:1}$ to ECe is ECe = 3.64 × $EC_{1:1}$ (Fig. 1.3.1).



Source: Scientific Research Institute of Irrigation and Water Problems in Uzbekistan

Fig. 1.3.1 Conversion from $EC_{1:1}$ to EC_e

The most practical indicator of salinization is ECsw because it represents the salinity of the water in the soil. However, specialized instrumentation (e.g., a porous suction cup) is required to extract soil-water samples. Instead, $EC_{1:1}$ and $EC_{1:5}$ are more commonly used to measure and compare soil salinity since the methods can be applied rapidly to either wet or dry soils, and soil samples collected in the field can be analyzed later in a laboratory.

2) Total dissolved solids

TDS represents the concentration of a substance dissolved in water. It measures the weight per volume and is generally measured in units of g / L (grams / liter), mg / L (milligrams / liter), ppm (parts per million).

Substances include carbonates, bicarbonates, chlorides, sulfates, calcium, magnesium, sodium, organic ions, other ions, etc. In general, minerals solved in water are present in ionic state. Ions are electrolytic substances which through electricity flows, and it is also possible to measure the total amount of dissolved substances from the strength of the current flowing through the aqueous solution.

3) Classification of saline water

The salinity of water can vary greatly in the world. For example, the ECw of seawater is 50.00 dS/m. Meanwhile, the absolute potable limit for humans is 0.83 dS/m, whereas the limit for dairy cattle is 10.00 dS/m (Table 1.3.2).

Table 1.3.2 Water salinity levels

Source/Use	EC_w (dS/m)
Distilled water	0.00
Desirable potable limit for humans	0.83
Absolute potable limit for humans	2.50
Limit for mixing herbicide sprays	4.69
Limit for poultry	5.80
Limit for pigs	6.60
Limit for dairy cattle	10.00
Limit for horses	11.60
Limit for beef cattle	16.60
Limit for adult sheep on dry feed	23.00
Highest reading for underground water in Forbes*	24.00
Seawater	50.00
The Dead Sea	555.00

Source: Taylor 1993 * Nicholson & Wooldridge 2003

The principal salinity classification of water by EC is shown in Table 1.3.3.

Table 1.3.3 Salinity water level

Salinity level	EC_w (dS/m)
Non-saline water	<0.7
Saline water	0.7-42.0
Slightly saline	0.7-3.0
Medium saline	3.0-6.0
Highly saline	>6.0
Very saline	>14.0
Brine	>42.0

Source: Handbook on Pressurized Irrigation Techniques (FAO, 2007)

4) Classification of salt-affected soil

Salt-affected soil is classified as either saline or sodic soil, depending on the amount and composition of salt it contains (Table 3.1.4). Saline soil is characterized by high levels of soluble salt, generally it is known as salt accumulated soil. whereas sodic soil is characterized by high levels of adsorbed sodium ions (exchangeable sodium percentage, ESP). Meanwhile, saline-sodic soil possesses properties of both saline and sodic soil. The soils of arid regions are rich in chlorides (e.g., calcium chloride, magnesium chloride, and sodium chloride), as well as carbonate salt and sulfuric acid salt, and the pH of the saturated extract solution (pHe) obtained after adjusting the soil paste is weakly alkaline (pH 7 to 8). When the salts of sodium carbonate (e.g., sodium bicarbonate or sodium carbonate) are present at high levels, soil pHe can exceed 8.5. In saline soil, the high salinity of the soil solution inhibits growth by interfering with water absorption by the plant. In addition, when the ESP of sodic soil exceeds 15%, the physical properties of the soil are deteriorated, owing to the collapse of the soil structure, and both nutrient absorption and cohesive soil dispersion are inhibited as a result of high pH. Together, these effects degrade the soil environment and, subsequently, significantly inhibit crop growth.

In this way, the causes, effects, and methods of prevention and remediation for salt affected soil vary widely. Therefore, it is necessary to clarify the status and cause of salinization in order to determine appropriate soil management strategies. The suitability of salinization countermeasures also depends on the type of salt-affected soil so it is necessary to classify the soil before conducting mitigation measures. For example, leaching is effective for saline soil, but in sodic soils, calcium materials should be added, in order to improve soil permeability.

Table 1.3.4. Classification of salt-affected soil

Soil Salinity Class	pHe	ECe (dS/m)	SAR	ESP (%)
Saline soil	<8.5	>4.0	<13	<15
Sodic soil	>8.5	<4.0	>13	>15
Saline-sodic soil	<8.5	>4.0	>13	>15

pHe: pH of saturated soil paste.

ECe: electrical conductivity of saturated soil paste.

SAR: sodium adsorption ratio, expressed in meq/L, mmol$_c$/L, or mmol/L.

$$\mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\frac{\mathrm{Ca^{2+} + Mg^{2+}}}{2}}} \text{ (meq/L, mmol}_c\text{/L)}, \quad \mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\mathrm{Ca^{2+} + Mg^{2+}}}} \text{ (mmol/L)}$$

ESP: exchangeable sodium percentage.

$$\mathrm{ESP} = \frac{\mathrm{exNa}}{\mathrm{CEC}} \times 100\%$$

where exNa is exchangeable sodium and CEC is cation exchange capacity, or

$$\mathrm{ESP} = 100\% \times \frac{(-0.0126 + 0.01475 \times \mathrm{SAR})}{\{1 + (-0.0126 + 0.01475 \times \mathrm{SAR})\}}$$

according to USSL (1954) and others.

Salt-affected soil (Table 1.3.4) is categorized on the basis of pHe and ECe (Fig 1.3.2).

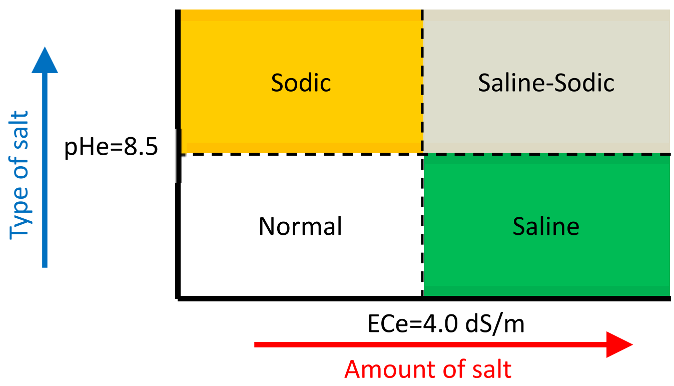


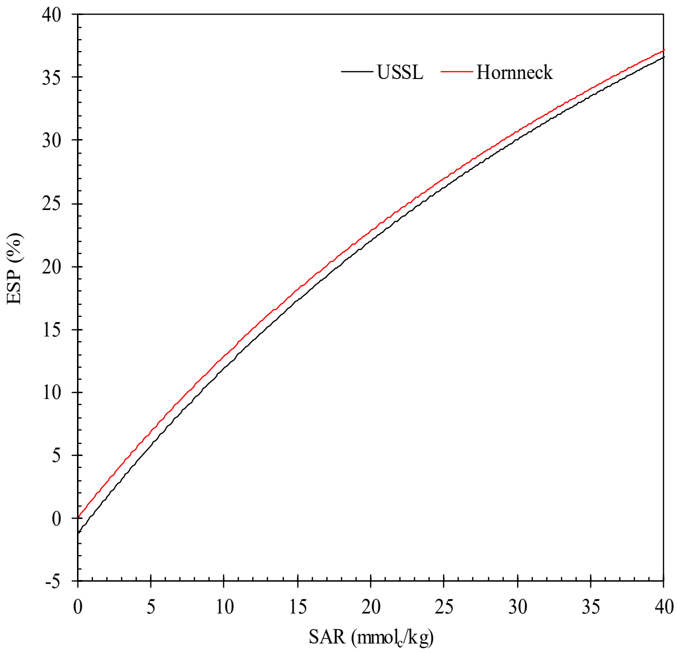
Fig 1.3.2 Classification of salt-affected soil, based on pHe and ECe

Calculating EPS from the SAR

The calculation formula of Hornneck et al. (2007) shown below is simplified by dropping the term of calculation formula by USSL.

$$\mathrm{ESP} = \frac{1.475 \times \mathrm{SAR}}{\{1 + (0.0147 \times \mathrm{SAR})\}}$$

When comparing the two calculation results, although there is almost no difference, the calculation formula of USSL is evaluated, in that it derived the relationship between ESP and SAR from experimentally obtained results.



SAR	ESP	
	USSL	Hornneck
0.1	-1.12502	0.147283
0.2	-0.9744	0.294135
0.3	-0.82424	0.440557
0.4	-0.67452	0.586551
0.5	-0.52524	0.732119
0.6	-0.37641	0.877263
0.7	-0.22802	1.021984
0.8	-0.08006	1.166284
0.83	-0.03576	1.209493
0.84	-0.021	1.223887
0.85	-0.00625	1.238278
0.86	0.008499	1.252664
0.87	0.023245	1.267046
0.9	0.067454	1.310166
1.0	0.214539	1.453632

The principal soil salinity level by soil EC is shown in Table 1.3.5

Table 1.3.5 Soil salinity level by soil EC

Soil Salinity level	EC_e (dS/m)	$EC_{1:1}$ (dS/m)	$EC_{1:5}$ (dS/m)		Effect on Crop Plants
			Loam	Heavy Clay	
Non-saline	<2	<0.6	<0.2	<0.2	Salinity effects are negligible
Slightly	2-4	0.61-1.15	0.2-0.3	0.2-0.4	Yields of sensitive crops may be restricted
Moderately	4-8	1.16-2.30	0.4-0.7	0.5-0.9	Yields of many crops are restricted
Highly	8-16	2.31-4.70	0.8-1.5	1.0-1.8	Only the yields of tolerant crops are satisfactory
Extremely	>16	>4.70	>1.5	>1.8	Only yields of very tolerant crops are satisfactory

Source:
(a) Based on USDA (1954) categories: Used by CSIRO Canberra and others in Australia.
(b) Units used in Western Australia
(c) Groundwater from within potential rooting distance of plant (bores). Suitability for “tree” growth.
(d) From D Bennett and R George, DAWA Bunbury.
(e) “Irrigation” water used in pot trials. http://www.agric.wa.gov.au/content/lwe/salin/smeas/salinity_units.htm
(f) Salt-Affected Soils and their Management (FAO, 1998)

5) Crop tolerance

Soil salinity causes poor, uneven, and stunted crop growth; reduces yields, depending on the degree of salinity; and reduces the availability of water to plants in the root zone, owing to the osmotic pressure of the saline soil solution. However, crops vary in their tolerance to salt exposure, as indicated by the percentage yield decreases shown in Table 1.3.6.

Table 1.3.6 Salt tolerance of various crop species

Crop	Salinity								
	0%		10%		25%		50%		MAX
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Barley[4] (*Hordeum vulgare*)	8.0	5.3	10.0	6.7	13.0	8.7	18.0	12.0	28.0
Cotton (*Gossypium hirsutum*)	7.7	5.1	9.6	6.4	13.0	8.4	17.0	12.0	27.0
Sugar beet[5] (*Beta vulgaris*)	7.0	4.7	8.7	5.8	11.0	7.5	15.0	10.0	24.0
Wheat[4),5] (*Triticum aestivum*)	6.0	4.0	7.4	4.9	9.5	6.4	13.0	8.7	20.0
Safflower (*Carthamus tinctorius*)	5.3	3.5	6.2	4.1	7.6	5.0	9.9	6.6	14.5
Soybean (*Glycine max*)	5.0	3.3	5.5	3.7	6.2	4.2	7.5	5.0	10.0
Sorghum (*Sorghum bicolor*)	4.0	2.7	5.1	3.4	7.2	4.8	11.0	7.2	18.0
Groundnut (*Arachis hypogaea*)	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.5
Rice (*Oryza sativa*)	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11.5
Corn (*Zea mays*)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10.0
Broad bean (*Vicia faba*)	1.6	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12.0
Cowpea (*Vigna sinensis*)	1.3	0.9	2.0	1.3	3.1	2.1	4.9	3.2	8.5
Beans (*Phaseolus vulgaris*)	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.5
Beets[5] (*Beta vulgaris*)	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15.0
Broccoli (*Brassica oleracea italica*)	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	13.5
Tomato (*Lycopersicon esculentum*)	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	12.5
Cucumber (*Cucumis sativus*)	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10.0
Cantaloupe (*Cucumis melo*)	2.2	1.5	3.6	2.4	5.7	3.8	9.1	6.1	16.0
Spinach (*Spinacia oleracea*)	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15.0
Cabbage (*Brassica oleracea capitata*)	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12.0
Potato (*Solanum tuberosum*)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10.0
Sweet corn (*Zea mays*)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10.0
Sweet potato (*Ipomea batatas*)	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	10.5
Pepper (*Capsicum frutescens*)	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.5
Lettuce (*Lactuca sativa*)	1.3	0.9	2.1	1.4	3.2	2.1	5.2	3.4	9.0
Radish (*Raphanus sativus*)	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	9.0
Onion (*Allium cepa*)	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.5
Carrot (*Daucus carota*)	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.1	8.0
Beans (*Phaseolus vulgaris*)	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.5

1) ECe is the electrical conductivity of the saturation extract of the soil reported in mmhos/cm at 25 °C.
2) ECw is the electrical conductivity of the irrigation water in mmhos/cm at 25 °C. This assumes a leaching fraction of 15–20% and an average salinity of soil water taken up by crops of about three times that of the irrigation water applied (ECsw = 3 × ECw) and about two times that of the soil saturation extract (ECsw = 2 × ECe). From the above, ECe = 3/2 × ECw. New crop tolerance tables for ECw can be prepared for conditions that differ greatly from those assumed in the guidelines. The following are estimated relationships between ECe and ECw for various leaching fractions: LF = 10 (ECe = 2 ECw), LF = 30% (ECe = 1:1 ECw), and LF = 40% (ECe = 9 ECw).
3) Maximum ECe is defined as the maximum electrical conductivity of the saturated soil extract that can develop because of the listed crop withdrawing soil water to meet its evapotranspiration demands. At this salinity, crop growth ceases (100% yield decrease) because of the osmotic effect and reduction in crop water availability to 0.
4) Barley and wheat are less tolerant during the germination and seedling stages. ECe should not exceed 4 or 5 mmhos/m.
5) Sensitive during germination. ECe should not exceed 3 mmhos/cm for garden beets and sugar beets.
6) Tolerance data may not apply to new semi-dwarf varieties of wheat.
7) An average for Bermuda grass varieties. Suwannee and Coastal are about 20% more tolerant; Common and Greenfield are about 20% less tolerant.
8) Average for the Boer, ~Yilman, Sand, and ~Veeping varieties. Lehman appears about 50% more tolerant.
9) Brood-leaf birdsfoot trefoil appears to be less tolerant than narrow-leaf.

Source: Reported by Maas and Hoffman (1977) and Maas (1984), Bernstein (1964) and University of California Committee of Consultants (1974).

Chapter 2
PREVENTION AND REMEDIATION OF SALINIZATION

2.1 Preventative measures

Secondary salinization, which results from agricultural irrigation, has two main causes. The first is the introduction of salt that is contained in the irrigation water, and the second is the elevation of groundwater tables, which promotes capillary rising. In order to prevent salinization, it is necessary to limit both the influx of salt and the height of groundwater tables.

Here, typical preventative measures against salinization are introduced:

1) Irrigation

Irrigation is not fully efficient since some proportion of the water is always lost to canals or the underlying soil. Seepage into the soil facilitates the elevation of groundwater tables, and shallow groundwater tables are risky because they can return salts to the root zone. Therefore, both the losses of irrigation water and the level of groundwater tables must be strictly controlled.

In Central Asia, more than 20 years after independence from the Soviet Union, extensive furrow irrigation is still used, in spite of its low efficiency. As a result, over-irrigation is common, and the salinity of the soil is increasing. Therefore, more efficient irrigation technology, such as drip and sprinkler irrigation, should be introduced. However, this would require an initial investment, which is difficult for many farmers to make. In these cases, various water-saving modifications of furrow irrigation can be used instead.

- Alternate furrow irrigation (AFI)

  The basis of AFI (Fig. 2.1.1; FAO 1988)[1)] is that two rows of plants can be watered using a single furrow. The advantage of AFI is that it reduces the amount of water applied and decreases infiltration loss by non-irrigated furrows and lateral flow. Mitchell et al. (1993)[2)] reported that AFI uses only 50% of the water used for normal furrow irrigation.

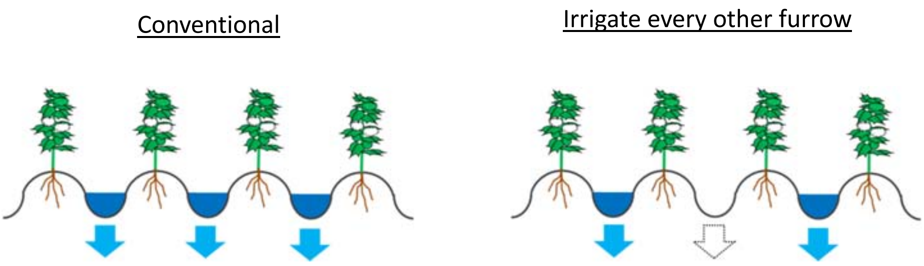


Fig. 2.1.1 Concept of alternate furrow irrigation

Irrigation test of AFI method

In order to clarify the water- saving effect of AFI method, a comparative irrigation test was conducted at a farmland in Syrdarya. The test area (155 m²), which has a ridge length of 50 m and a width is 3.1 m, was irrigated by ordinary furrow irrigation method (conventional) and AFI method. In the test, the amount of irrigation water supplied and the cotton yield were measured. The results showed that AFI method reduced the volume of irrigation water by 48 %, and although no statistically significant difference was observed, the cotton yield increased by about 11%.

Fig. 2.1.2 AFI method

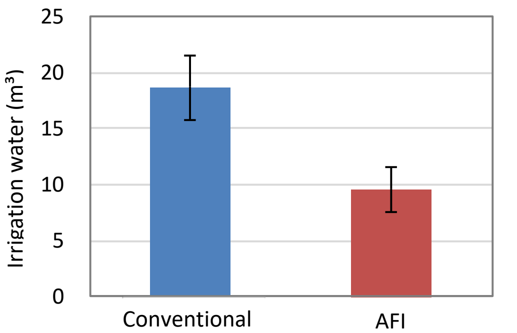


Fig. 2.1.3 Amount of irrigation water

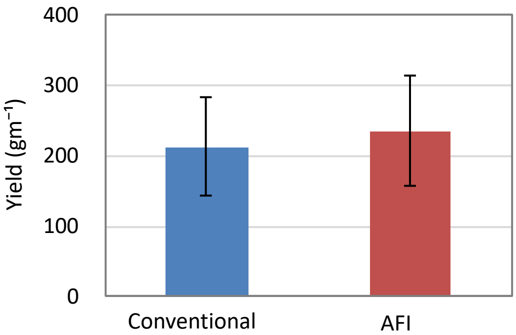


Fig. 2.1.4 Cotton yield

- Surge flow irrigation

The surge flow method involves irrigating intermittently instead of continuously. The advantage of this method is that it decreases infiltration loss by reducing the soil permeability that results from cyclic irrigation. The water flow of the second water supply is faster than that of the first water supply since the first water supply reduces the soil permeability. In the farmland, irrigation is performed divided into multiple times according to the ridge length. (Fig. 2.1.2). The reduction in infiltration is caused by four physical processes: consolidation, owing to soil particle migration and reorientation; air entrapment; the redistribution of water; and channel smoothing (Alan R. Mitchell et al. 1994)[3].

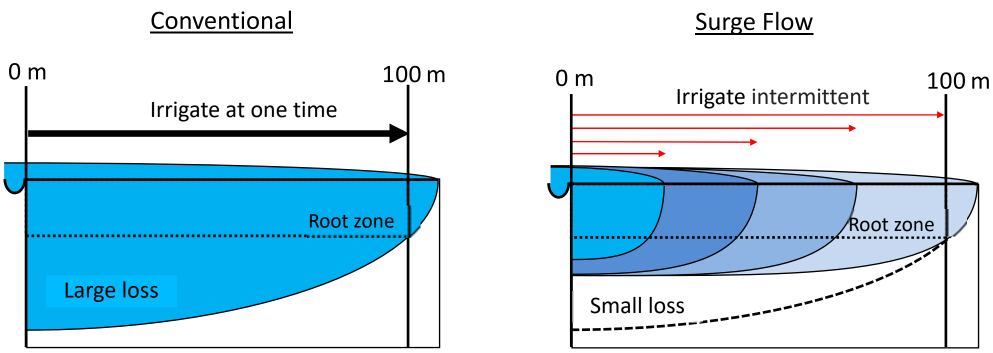


Fig. 2.1.5 Concept of surge flow irrigation

Simplified Surge Flow method

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. On the other hand, in the Simplified SF, water supply for a single ordinary furrow irrigation (conventional method) is just divided into two.

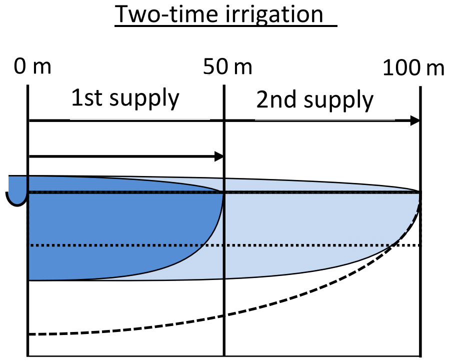


Fig. 2.1.6 Simplified Surge Flow method

In the comparative irrigation test between the conventional furrow irrigation method and the Simplified SF on a 100 m furrow (slope: 1/800) at a farmland in Syrdarya, 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 by 11%.

Fig. 2.1.7 First supply (slow)

Fig. 2.1.8 Second supply (fast)

- Cut back irrigation

In a sloping field, at the ends of irrigation furrows, much water is lost in the form of runoff, and this loss can account for as much as 30 percent of the inflow, even under good conditions. Therefore, in order to remove runoff water, shallow drains should be installed at the ends of fields. Without such drainage, there is also a possibility that plants can be damaged by waterlogging. Cut back irrigation is preventing excessive runoff water by reducing inflow of irrigation water once the irrigation water has reached the end of the furrows (FAO 1988)[1).

2) Drainage

Regardless of whether it is introduced to farmland by irrigation or rainfall, water infiltrates the soil and is stored in the soil's pore space. When all the pores are filled, the soil is considered saturated, and any further irrigation will not be absorbed by the soil, thereby resulting in pools of water on the soil surface.

Long-term saturation of the upper soil layer is detrimental to plant health since plant roots require air, as well as water, and most plants cannot withstand saturated soil for long periods (rice is an exception; FAO 1985)[4). It is also difficult to use machinery on overly wet farmland. In addition, more than necessary water caused canal seepage and floods, and the downward movement of water from saturated soil to deeper layers feeds the groundwater reservoir, which, in turn, increases the height of the groundwater table. Thus, as a result of heavy rainfall or continuous over-irrigation, the groundwater table can even reach and saturate part of the root zone, then capillary rising and water logging is occurred. Therefore, it becomes necessary to remove excess water from the soil surface and root zone.

In arid and semi-arid climates, salinization results when the groundwater table is not maintained at a safe depth (usually at least 1.5 to 2.0 meters). However, when drainage is adequate, salinization is related to water quality and irrigation management. Therefore, effective salinity control must include adequate drainage to control and stabilize groundwater tables.

- Drain (Surface drainage)

  Surface drainage normally involves shallow ditches that remove excess water from the soil surface and discharge the water to a larger and deeper collector. In order to facilitate the flow of excess water toward the drains, the field is given an artificial slope by land grading (leveling).

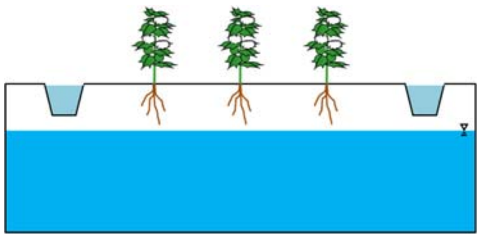


Fig. 2.1.9 Surface drainage

- Sub-surface drainage

  The main purpose of sub-surface drainage is to remove excess water from the root zone and to maintain a lower groundwater table. It typically involves deep open drainage or buried pipe drains.

  - Deep open drainage

    Excess water from the root zone flows into the deep open trenches (Fig. 2.1.4). The disadvantage of deep open drainage is that the trenches take up a large area of the farmland and that expensive machinery is needed for construction. In addition, the construction of deep trenches also necessitates the construction such as

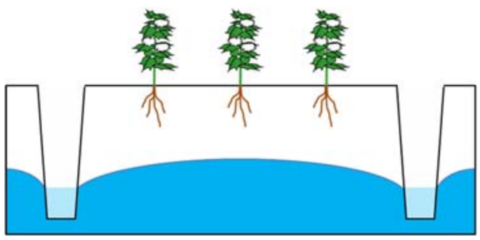


Fig. 2.1.10 Deep open

numerous bridges and culverts for road crossings and access to the fields and frequent maintenance (weed control, repairs, etc.).

- Buried pipe drains

Pipes that have many small holes are buried below the fields, and excessive soil water enters the pipes, after which it is transferred to collector drain (Fig. 2.1.5). These drain pipes are made of clay, concrete, or plastic and are usually installed in trenches using special machines. The clay and concrete pipes are typically 30 cm in length and 5-10 cm in diameter, whereas pieces of flexible plastic pipe are typically much longer, up to around 200 m. In contrast to open drains, buried pipes do not reduce the proportion of land available for cultivation and do not require frequent maintenance. However, installation costs may be higher, owing to the cost of materials, machinery, and skilled labor.

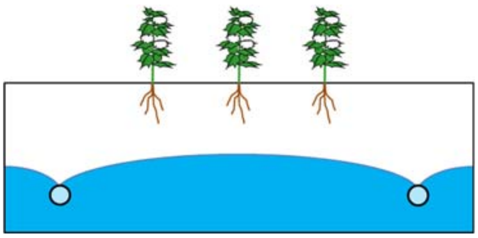


Fig. 2.1.11 Pipe drainage

- Vertical drainage

Vertical drainage is used to lower the groundwater table by digging wells into the highly permeability soil layers and removing deep groundwater.

<u>Vertical drainage in Uzbekistan</u>

In Uzbekistan, vertical drainage facilities were first constructed in the 1960s, and the number of facilities peaked during the mid-1990s. Since then, the facilities have been insufficiently updated and maintained, and the number and operating hours of the facilities are decreasing. However, vertical drainage is still used for lowering groundwater tables (Okuda, 2015)[5].

Fig. 2.1.12 Vertical drainage facility

- Bio-drainage

Trees that have strong water suction can be planted in lowland areas, along canals, and in fields to reduce groundwater tables. Planting these trees is also expected to provide a windbreak for the fields.

3) Land leveling

The unevenness of fields occurs as a result of the original undulation of the sites and annual farming activities. it makes negative effect to cultivation such as uneven germination. Therefore, land leveling is should be performed as a regular farming activity.

Fig. 2.1.13 Laser land leveling

In normal leveling, in order to achieve acceptable flatness, tractor operators must change and adjust the grader position constantly, according to the topography of the field. Therefore, leveling can require a lot of work, depending on the operator or farmer's experience. However, when using laser leveling, the adjustment of the grader is automated with a laser device, which makes it possible to level a field to within 5 cm of the desired design, without the need for an experienced operator.

The laser system consists of the following components:

- a laser transmitter,
  which emits a laser beam to establish a horizontal plane, the diameter of which can vary widely, from several meters to a kilometer, depending on the particular device used
- a laser receiver,
  which receives the radiation emitted from the laser transmitter and then converts it into electrical signals that are delivered to the control box
- a control box,
  which converts the electrical signals received from the laser receiver. The panel shows the location (above or below) to find the proper horizontal plane.

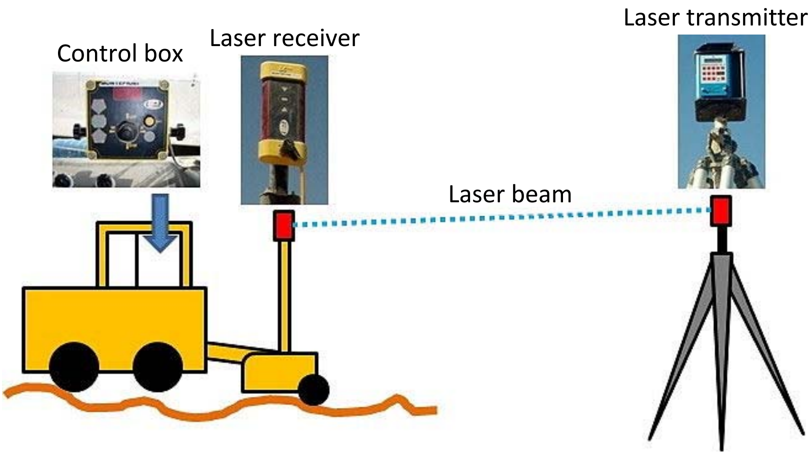


Fig. 2.1.14 Mechanism of laser leveling

4) Suppression of capillary rising (Inoue, 2012)[6)]

In arid and semi-arid regions, salinization that results from shallow groundwater tables is largely due to the capillary rising of dissolved salt by strong evaporation. Therefore, reducing, suppressing, or blocking capillary rising should be beneficial.

- Mulching

  One method for reducing the amount of evaporation from soil is to cover the soil surface with various materials, such as straw, dead leaves, gravel, sand, or vinyl sheets. In addition to retaining soil moisture, mulching can also be expected to prevent soil erosion, fertilizer runoff, weed problems, and extreme soil temperatures.

- Deep plow

  Capillary rising can be blocked by dry soil layer on surface soil formed by deep plowing.

- Capillary barrier

  Capillary rising can also be blocked by installing a gravel layer between the cultivation layer and the groundwater surface.

2.2 Remediation measures

In contrast to preventative measures, the purpose of remediation measures is to remove salt that has already accumulated.

1) When water resources are sufficiently available:

- Flushing

  Salt can be removed from the soil surface and move to areas outside of farmland by washing the salt downstream horizontally, using a large volume of running water. When using this method, it is important to reliably identify canals and drainage structures so that the removed salt is not transferred to neighboring farmland.

- Leaching

  Salt can be removed from the root zone by flooding fields and allowing the water to percolate into the farmland. Leaching is widely used because it is the most practical method for farmers, and usually, farmers utilize the strategy by applying more water than their crops need during the winter. To achieve sufficient percolation and to avoid raising the groundwater table, drainage systems should be functioning adequately, and hardpan breaking and sub-surface drainage can be used to promote the leaching effect. In addition, land leveling is also important, in order to obtain equivalent results over the whole farmland.

Fig. 2.2.1 Leaching

Guideline for leaching in Uzbekistan

In Syrdarya region, Uzbekistan, following guideline of leaching is showing for farmers.

- Leaching volume

Table 2.2.1 Recommend volume of water for leaching

Degree of salinization	Water volume (m^3/ha)
Weak (EC_e: 2-4)	2,500
Moderated (EC_e: 4-8)	3,000
Strong (EC_e: >8)	3,000 (first time)
	1,000 (second time)

Source: Hydro-geological Melioration Expedition in Syrdarya Region

- Leaching schedule

  In cotton fields, the ideal time for leaching is during November and December. However, when considering the region's climate, it can probably be applied until

January 30th. During the autumn, when the cotton is harvested, the groundwater table reaches its lowest level, since the fields are not irrigated. These conditions are favorable for leaching. However, it is difficult to conduct leaching during this period since the irrigation canals are not fully restored.

- Preparation for leaching
  - Plow to 35-40 cm after cropping.
  - Smooth plowed farmland with land smoothers.
  - Improve drainage function.
  - Check groundwater level using an observation well.
  - Divide field into plots, according to surface shape, using the following list:

Table 2.2.2 Plot slope and size

Slope (%)	Size
<0.2	0.25 ha (50 m × 50 m)
0.2-0.4	0.16 ha (50 m × 33 m)
0.4-0.6	0.12 ha (50 m × 25 m)
0.6-1.0	0.08 ha (50 m × 17 m)

Source: Hydro-geological Melioration Expedition in Syrdarya Region

Leaching should be initiated in areas with the highest salinity, and also be initiated on the sides of plots that are furthest from drainage canals or wells. The flow of water into the canal should begin from lowland to upward, and the distance between the main canals should be as short as possible (e.g., 100-150 m) in order to allow the water to flow smoothly. Leaching should continue through the day and night, but, owing to the darkness, pre-prepared areas (up to 0.5-1 ha) can be leached during the night in order to reduce water usage. The flow of water in temporary canals along with small plot should not fall below 30 L/s, and when water depth approaches 25 cm, the addition of water should be stopped.

- Application of soil-improvement agents

Sodic soils can be improved by removing sodium ions that are adsorbed to the cation exchange sites of soil particles. However, it is difficult to remove sodium ions from soil using water, and since the permeability of viscous sodic soil is reduced, the sodium ions are unlikely to move downward in the soil. Therefore, it is necessary to first remove the adsorbed sodium ions from the soil using soil-improvement agents and then to wash the detached sodium ions out of the farmland using leaching etc. Water-soluble calcium materials such as gypsum ($CaSO_4 \cdot 2H_2O$) and calcium chloride ($CaCl_2 \cdot 2H_2O$) are two examples of soil-improvement agents.

2) When water resources are lacking:

- Scraping

  Soil can be scraped from areas where salt crust occurs or high salt concentrations are known and then moved to areas outside of the farmland.

- Hardpan breaking

  The long-term use of farming equipment compacts the soil at a depth of 20-50 cm. In the case of the Axmedov WCA, from the Syrdarya region of Uzbekistan, the bulk density reaches 1.6-1.8 g/cm^3. This hardpan layer decreases the effect of leaching and inhibits the growth of plant roots. Therefore, it is desirable to break up the hardpan using a special tractor attachment (Fig. 2.2.2).

Fig. 2.2.2 Sub-soiler

- Phytoremediation

  Salt can also be removed from farmland soil by planting salt, alkali-tolerant or Halophilic plant species that absorb salt from the soil. This method can also improve soil permeability, as the plant roots penetrate the soil, and even deep layers of soil can be improved if the roots of the plants reach them.

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Chapter 3
MONITORING OF SALT ACCUMULATED SOIL AND THE IDENTIFICATION OF CAUSES

3.1 The aim of monitoring and the methods employed

In order to ascertain the degree of salt accumulation observed in arid and semi-arid areas, and the effect of leaching methods that alleviate salt concentration in the root zone, it is important to assess salinity through monitoring. In this clause we will report on methods of ascertaining the degree of salt accumulation in three target areas of varying size (soil profiles, cultivated fields, regions) and include examples of surveys carried out by the Japan International Research Center for Agricultural Sciences (JIRCAS).

1) Ascertaining the Salt Conditions in Soil Profiles of Irrigated Farmland

Fluctuations in the water table and the salinity of irrigation water and groundwater can affect changes in soil salinity in the root zone. Monitoring soil moisture and salinity in irrigated farmland makes it possible to determine appropriate irrigation time, requirement and duration in consideration of leaching, thereby making sustainable agriculture that properly manages the salinity of the root zone a reality.

Total dissolved solids (TDS) and electrical conductivity (EC) are used to assess the salinity of irrigation water, and in order to determine soil alkalinity, it is necessary to calculate the sodium adsorption ratio (SAR) of the soil from measurements of sodium (Na^{+}), calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion concentrations. These ion concentrations require chemical analysis of soil samples in a laboratory. By contrast, although it is difficult to perform detailed analyses of chemical constituents when monitoring soil moisture and salinity in an agricultural setting, the total amount can be assessed using EC.

An alternative to measuring soil salinity using soil samples is to use one of the portable devices on the market that can simultaneously measure soil moisture, EC, and soil temperature, such as the ECH_2O with the 5TE sensor (Decagon, USA) (Fig. 3.1.1, left) or the WET2 (Delta-T, UK) (Fig. 3.1.1, right). These sensors tend to overestimate soil moisture as salinity increases, so calibration is required according to soil characteristics.

Fig. 3.1.1 Soil moisture, EC sensor（left: 5TE, right: WET2）

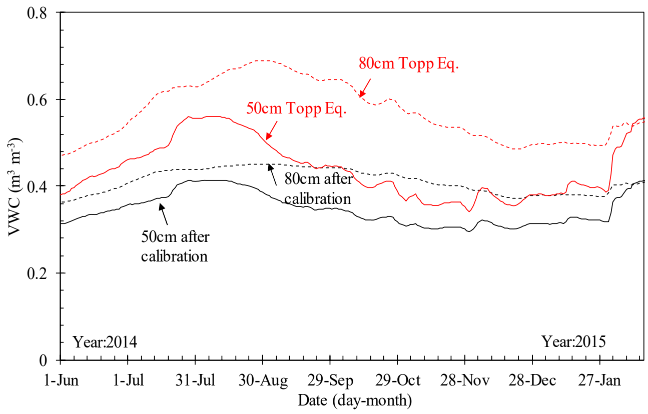
Overestimation of soil moisture by 5TE sensors

Changes in volumetric water content (VWC) as measured before and after calibrating the 5TE sensors installed at depths of 50 and 80 cm at the Axmedov site are shown in the figure below. Although the saturated VWC of the soil at the location was on the order of 0.4 $m^3\ m^{-3}$, prior to sensor calibration a maximum VWC of 0.7 $m^3\ m^{-3}$ was displayed because of the influence of soil salinity, so overestimation of soil moisture was apparent. This was because the Decagon unit, for example, uses the well-known Topp equation (Topp et al., 1980) without modification to convert the dielectric constant to VWC as the calibration method for mineral soil.

$VWC = 4.3\times10^{-6}\times\varepsilon_a^3 - 5.5\times10^{-4}\times\varepsilon_a^2 + 2.92\times10\text{-}2\times\varepsilon_a - 5.3\times10^{-2}$

(ε_a = dielectric constant)

When calibrating these sensors, it is best to refer to previous research or the calibration methods prepared by the various manufacturers.



2) Ascertaining Salt Accumulation in Cultivated Land

The spatial distribution of soil salinity in cultivated land is usually uneven, and a uniform distribution is, as a rule, never observed. This non-uniformity is affected by variations in water management, the physical properties of the soil (e.g., water permeability) and the salinity of the groundwater. In order to appropriately manage irrigation for sites with salt accumulation, mapping the spatial distribution is an important step toward identifying the mechanism of the non-uniformity. To achieve this, it is essential to survey salinity at multiple points.

Measuring soil salinity using soil samples is the most accurate and reliable method to date. However, when sampling multiple points, there is a major increase in time, cost, and labor involved in the series of processes that comprise testing as a whole because of the large quantity of soil samples that must be collected, transported, prepared, and tested. One way to overcome these problems is to use the electromagnetic induction method (EIM), which makes it possible to measure soil salinity without requiring the apparatus to be in contact with the soil. Among the devices that use EIM is the EM38 Ground Conductivity Meter (Geonics, Canada) (Fig. 3.1.2). It is also possible to measure the EC of soil with devices that measure EC using probes that are inserted directly into the soil, such as the 2265FSTP Fieldscout Direct Soil EC Meter (Spectrum Technologies, USA), which can measure EC at a designated depth up to a depth of 60 cm (Fig. 3.1.3).

The EC values measured by the EM38 or the 2265FSTP are referred to as the apparent electrical conductivity of the soil (EC_a), which reflects the physical state of the pathways of electrical conductance of the solid, liquid, and gas phases of the soil, which are affected by soil moisture content and the electrical conductivity of soil particle surfaces. Accordingly, each instrument should be calibrated to allow measurement of the EC of the saturation extract EC_e.

Fig. 3.1.2 EM38 Ground Conductivity Meter

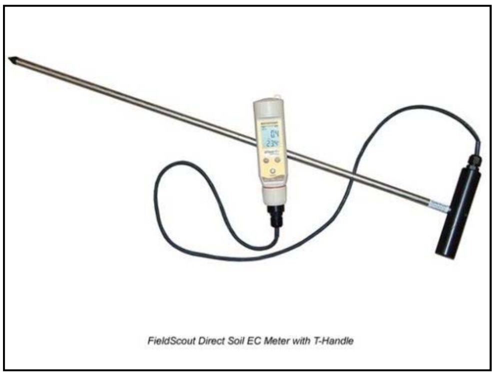


Fig. 3.1.3 2265FSTP Field scout Direct Soil EC Meter

3) Ascertaining Salt Accumulation over a Broad Area

At present, the most large-scale method of global environmental monitoring is remote sensing from a satellite. For example, Landsat satellites are equipped with Thematic Mapper sensors that have a resolution of 30 m with an image size of 185 × 185 km. Although it is difficult to directly estimate salt content and salinity using the raw general-purpose satellite data, quantitative evaluation of salt accumulation using remote sensing is quite possible if appropriate ground-truth data is collected to enable calibration of remote-sensing data and assist in its interpretation and analysis.

On the other hand, with the hydrogeological melioration expedition (HGME), observation wells were sunk at a rate of one for every 150 ha to monitor groundwater level and salinity, and regular soil salinity monitoring was carried out at one location in every 50 ha, with data for certain areas being entered into a geographic information system (GIS) database for the region and used to make maps (Fig. 3.1.4). These maps enable salt accumulation on a regional scale to be ascertained.

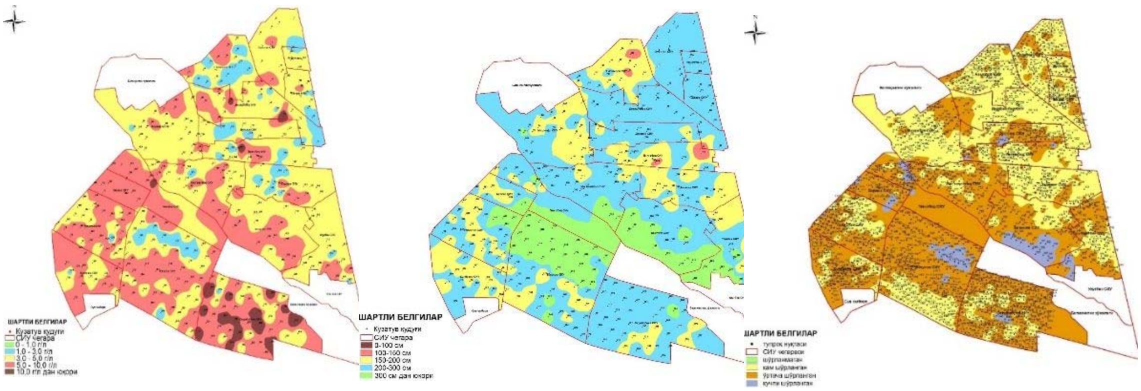


Fig. 3.1.4 GIS map in Mirzaobod District by HGME
(from left side, saline in groundwater, groundwater table, saline in soil, April 2013)

3.2 Survey items required for identifying the cause of salt accumulation

After soil salinity measurements have been obtained with the monitoring methods described above, these results are used to gain an understanding of horizontal and vertical soil salinity distribution trends. These results only show the temporary state at the time of measurement, and do not contain enough information to identify the cause of salt accumulation.

For this reason, in order to identify the cause of soil salinization in the region from among a number of different potential causes, it is important to continue monitoring for a certain period of time and to understand basic information that is specific to that region, including factors such as the weather, irrigation water and groundwater quality and soil characteristics. We will now present some aspects to consider when seeking to identify the causes of salt accumulation, along with a few specific examples.

1) Classification of Salt-Affected Soil

As the classification of salt-affected soil has already been described in Chapter 1, please refer to that section. The salt-affected soil classifications for cultivated land surveyed in Mirzaobod District, Syrdarya Region are shown in the box below.

Classification of salt-affected soil in cultivated land surveyed in Mirzaobod District, Syrdarya Region

Soil samples were collected from depths of 5 to 80 cm in cultivated land at Axmedov and Yangiobod and analyzed. On the basis of the results, the salt-affected soil in these sites was classified as saline soil. Soil samples were taken from Axmedov in May 2014 and May 2015.

WCA	EC_e (dS/m)	pH_e	SAR ($mmol_c$/L)	ESP (%)
Axmedov	2.1～10.6	8.0～8.3	0.3～3.1	0.4～4.4
Yangiobod	5.3～25.8	7.5～8.5	1.0～4.9	1.4～6.7

2) Soil Profile Survey

Soil profile surveys are carried out to determine factors that inhibit productivity, such as soil fertility and salt accumulation, and to clarify land use and soil management policies. At the same time, by observing the soil profile in detail, it is possible to ascertain the characteristics of the soil and the process of soil formation. When conducting the survey, it is important to observe and document the history that is fixed in the soil profile as it appears to the five senses (sight, sound, smell, taste, and touch).

Precipitates with diverse morphological characteristics can be observed in the soil profile in arid regions. The main soluble salts that can be seen in the soil are the chlorides, sulfates and carbonates of sodium, magnesium and calcium. The solubility of these salts in water varies according to their type.

Solubility of Soluble Salts

Calcium chloride (74.5) > magnesium chloride (54.6) > sodium chloride (36.0) > magnesium sulfate (35.1) > sodium carbonate (21.5) > sodium sulfate (19.5) > calcium sulfate (0.255) > calcium carbonate (6.17×10-4)

Values are the solubility in grams of compounds in 100 g of water at 20°C. (Source: Chronological Scientific Tables)

As a rule, the more soluble salts occupy the lower layers of the soil. Calcium carbonate, which is not very soluble, exists as a precipitate near the surface of the soil. Calcium carbonate is usually a deposit of fine white particles or an amorphous white deposit, and regions of accumulation can be easily identified as they effervesce upon contact with dilute hydrochloric acid.

Results of a soil profile survey in cultivated land surveyed in Mirzaobod District, Syrdarya Region

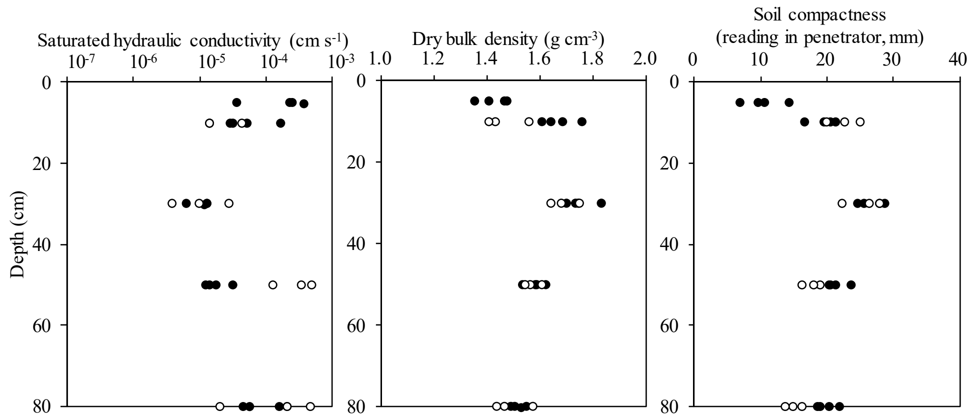
When a soil profile survey was conducted of cultivated land in Axmedov and Yangiobod, flecks of what was suspected to be calcium carbonate were observed at a depth of 30 to 40 cm below the surface.

It is advisable to measure soil hardness when surveying the soil profile. Soil hardness can be used for reference when determining the capacity of the soil to bear crops due to its effect on the soil's permeability to air, water, and plant roots, as well as the ease of using agricultural machinery. There are cone-type and rod-type soil hardness testers for measuring soil hardness.

If soil samples are taken after examining the soil profile, then the physical and chemical properties of the soil can be analyzed in a laboratory. Samples for general analysis should be collected in polyethylene bags. Samples for water permeability and other physical tests should be collected using a 100 ml metal cylinder. Samples for general analysis should be air-dried, pulverized and sifted prior to being submitted for analysis.

Physical properties of soil in cultivated land surveyed in Mirzaobod District, Syrdarya Region

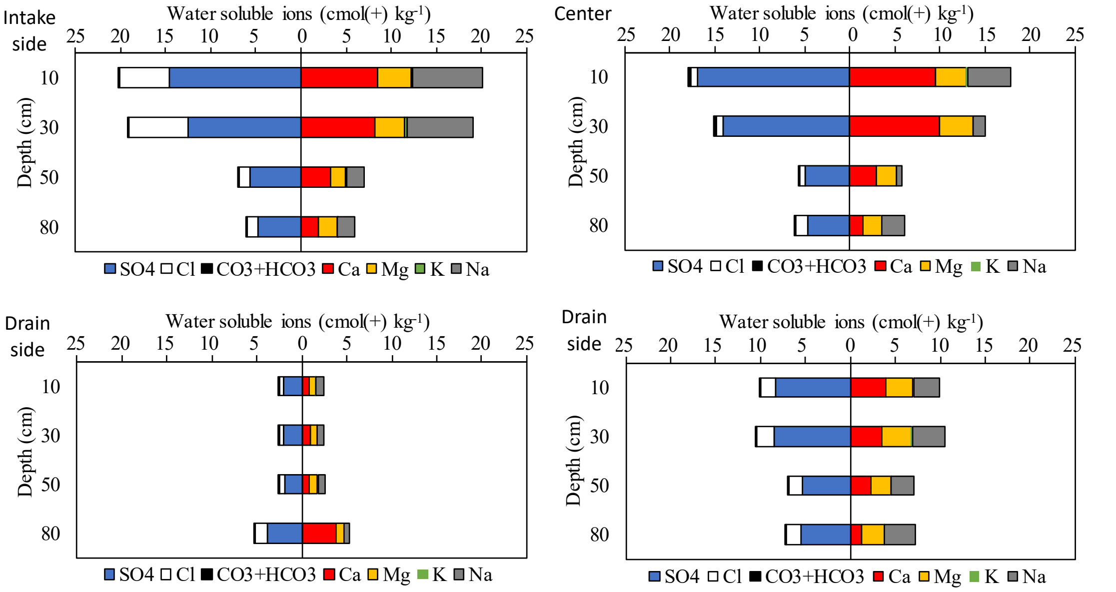
The saturated hydraulic conductivity (falling head method), dry bulk density and soil hardness of soil at a depth of up to 80 cm in cultivated land in Axmedov and Yangiobod were measured and values at a depth of 30 cm were found to have anomalous values as compared with those of other layers. This showed that a hardpan had formed immediately under the worked soil due to the tread pressure of large tractors. Soil samples were taken in Axmedov in May 2014 and May 2015.



Note: white color mark shows in Axmedov, black color mark shows in Yangiobod.

Chemical properties of soil in cultivated land surveyed in Mirzaobod District, Syrdarya Region

The water soluble ion concentration (soil and water ratio 1:5) of soil at a depth of up to 80 cm at four locations within cultivated land in Axmedov was measured. Salinity distribution in the cultivated land was found to be uneven with salt accumulation observed in the soil from the top layer of the soil to a depth of 30 cm, from the area of the water inlet to the central part of the cultivated land. There was a high proportion of Ca^{2+} and SO_4^{2-} ions. Soil samples were taken in late May 2014.



3) Irrigation Water and Groundwater Water Quality

Generally, in arid and semi-arid lands, the salinity and SAR of rivers and groundwater is in many cases high and it is difficult to access good quality water sources. Using such water sources for irrigation leads to crop damage or soil degradation. The quality of irrigation water is determined on the basis of EC and SAR values. Standards for comparison are in Diagram of the Classification of Irrigation Waters, USSL (1954) (Fig. 3.2.1), and Guidelines for Interpretations of Water Quality for Irrigation, FAO (1985) (Table 3.2.1).

The C_1 to C_4 values on the horizontal axis in Fig. 3.2.1 show salinity according to EC values, while the S1 to S_4 values on the vertical axis show alkalinity according to SAR values. Irrigation water is classified into 16 different classes and the dangers of each class are shown in Appendix •. Alternatively, please refer to Diagnosis and Improvement of Saline and Alkali Soils, p.79–81.

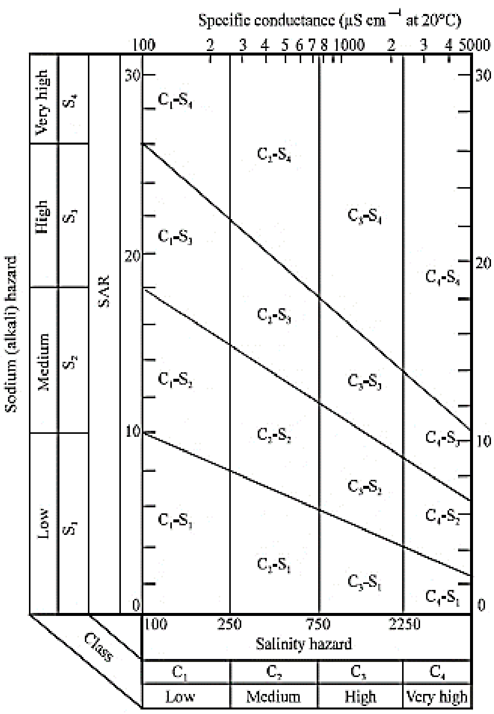


Fig. 3.2.1 Diagram of the Classification of Irrigation Waters (USSL,1954z)

Table 3.2.1 Guidelines for Interpretations of Water Quality for Irrigation

Potential Irrigation Problem		Units	Degree of Restriction on Use		
			None	Slight to Moderate	Severe
Salinity (affects crop water availability)					
EC_w or		dS/m	< 3.0	0.7- 3.0	> 3.0
TDS		mg/L	< 450	450 – 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluate using ECW and SAR together)					
SAR	= 0 – 3 and EC_w =		> 0.7	0.7- 0.2	< 0.2
	= 3 – 6		> 1.2	1.2- 0.3	< 0.3
	= 6 – 12		> 1.9	1.9- 0.5	< 0.5
	= 12 – 20		> 2.9	2.9- 1.3	< 1.3
	= 20 – 40		> 5.0	5.0- 2.9	< 2.9
Specific Ion Toxicity (affects sensitive crops)					
Sodium (Na)					
	Surface irrigation	SAR	< 3	3 – 9	> 9
	Sprinkler irrigation	me/L	< 3	> 3	
Chloride (Cl)					
	Surface irrigation	me/L	< 4	4 - 10	> 10
	Sprinkler irrigation	me/L	< 3	> 3	
Boron (B)		mg/L	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous Effects (affects susceptible crops)					
Nitrogen (NO_3-N)		mg/L	< 5	5 – 30	> 30
Bicarbonate (HCO_3)		me/L	< 1.5	1.5 – 8.5	> 8.5
pH			Normal Range 6.5 – 8.4		

Results of an assessment of irrigation water, drainage water and groundwater in Mirzaobod District, Syrdarya Region

Water samples were taken from the main irrigation canals (13 locations), drainage canals (19 locations) and HGME observation wells (27 locations) in Mirzaobod District and chemically analyzed. Samples were taken in June 2013. When irrigation water was evaluated according to the USSL diagram and classified as C_3-S_1, it was determined that there was a high risk of soil becoming saline. On the other hand, groundwater samples taken from observation wells were high in Na^+, Cl^- or SO_4^{2-}, suggesting that depending on the location, there is the danger of soil becoming alkaline due to an increase in sodium salts caused by a rise in groundwater level.

	EC_w (dS/m)	pH	Ca^{2+}	Mg^{2+}	Na^+ (mmol$_c$/L)	Cl^-	SO_4^{2-}	HCO_3^-	SAR
Irrigation water	1.4 - 1.6	8.1 - 8.5	5.7 - 7.9	4.8 - 6.8	3.8- 5.5	2.1 -3.1	10.6-14.8	1.5 - 2.5	1.6 -2.1
Drainage water	1.4 -22	7.6 -8.8	8.1 -30.5	5.5 -76.3	4.2 -207.9	2.5 - 168.3	13.6 -161.7	0.2- 4.6	1.6-28.4
Ground water	1.7 -63	7.3 - 9.5	0.1 -41.3	3.4 -214.7	4.6 -861.2	2.6 - 877.9	2.8 -665.2	0.7-45.3	1.2-80.0

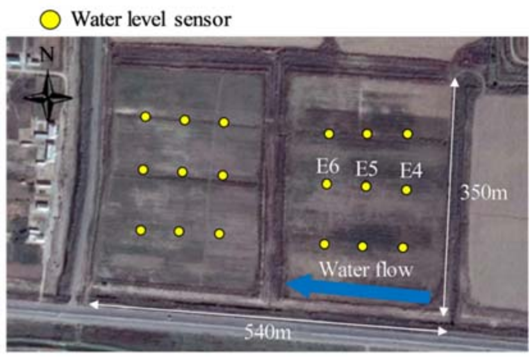
4) Fluctuations in Groundwater Level

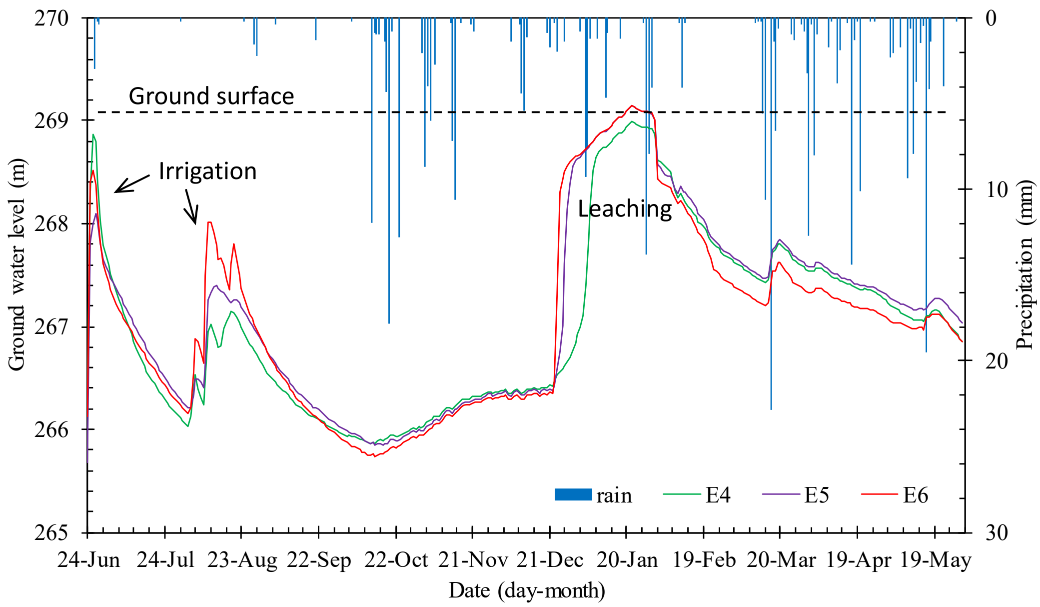
Salt damage occurs when the volume of water permeating into the groundwater system is greater than the volume being discharged from the groundwater system. When this groundwater input/output balance collapses, the groundwater level rises. This results in the groundwater dissolving soluble salts in the lower layers of the soil and allows water with a high salt concentration to reach the root zone through capillary action.

In cases where the direction of groundwater flow is unclear, or when there are seasonal fluctuations, it is necessary to regularly ascertain the groundwater level and to gain an understanding of the depth from the surface to which the groundwater will rise through water supply events, such as irrigation and leaching.

Fluctuations in groundwater level in experimental fields in Yangiobod

Hydrographs (U20-001-04, HOBO) were installed in observation wells in experimental fields to monitor groundwater levels. The monitoring period was from June 2015 to May 2016. Results indicated that there was a rise in groundwater level due to irrigation and leaching. Furthermore, while the increase in groundwater level at the time of irrigation was temporary, the groundwater level at the time of leaching was stationary for approximately one month near the surface of the soil.



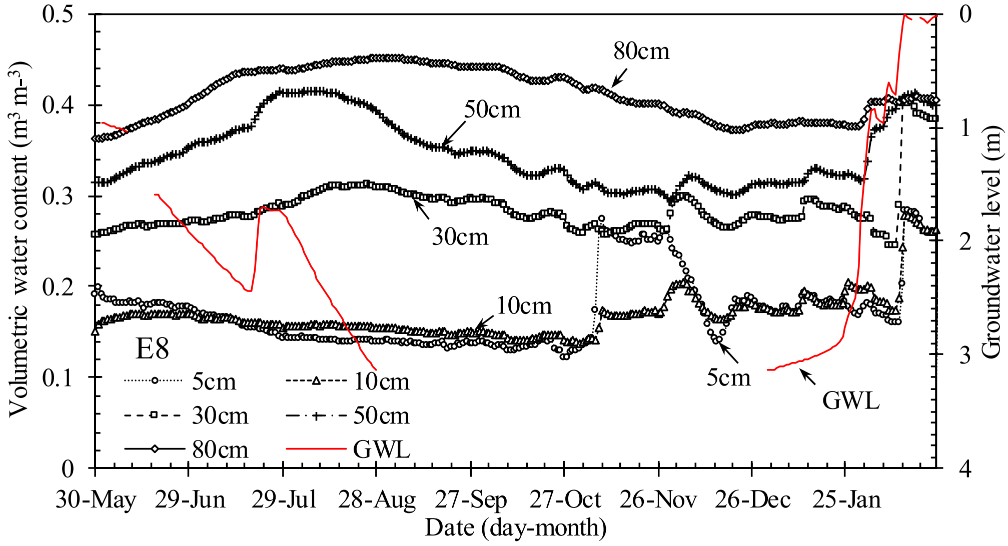


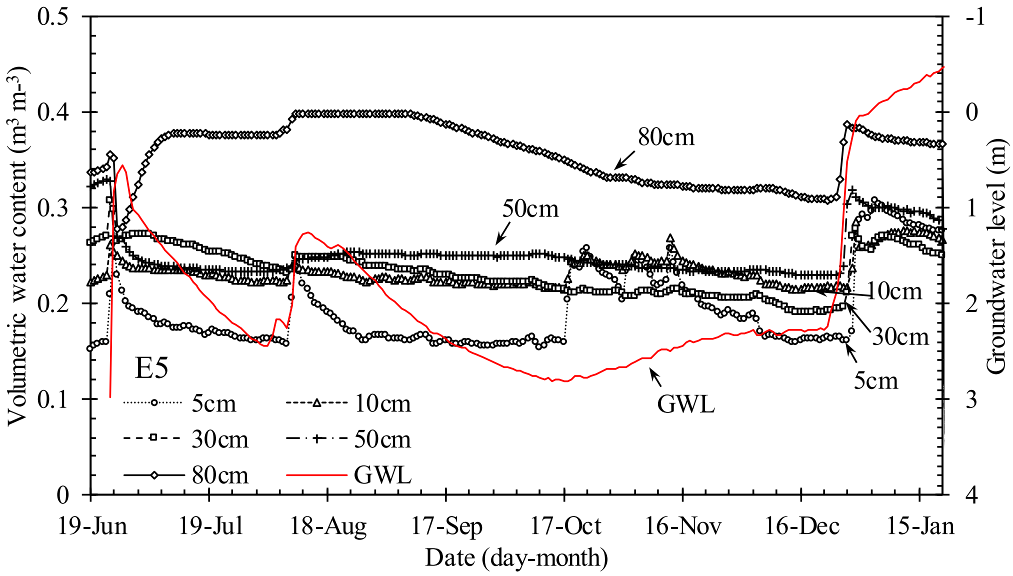
5) Soil Moisture and Fluctuations in Soil Salinity

When salts accumulate on the surface of the soil and irrigation or leaching occurs, these salts are dissolved in water and move into the soil. On the other hand, when groundwater contains salts, salts are carried to the surface of the soil and accumulate through the upward movement of water in the soil accompanying evaporation from the surface of the soil. The main factor in the upward movement of salts at that time is the convective transport of water. As the movement of soluble salts occurs due to the movement of water within the soil, the measurement of fluctuations in soil moisture and soil salinity plays a role in understanding the phenomenon of salt accumulation.

Fluctuations in soil moisture in experimental fields in Axmedov and Yangiobod

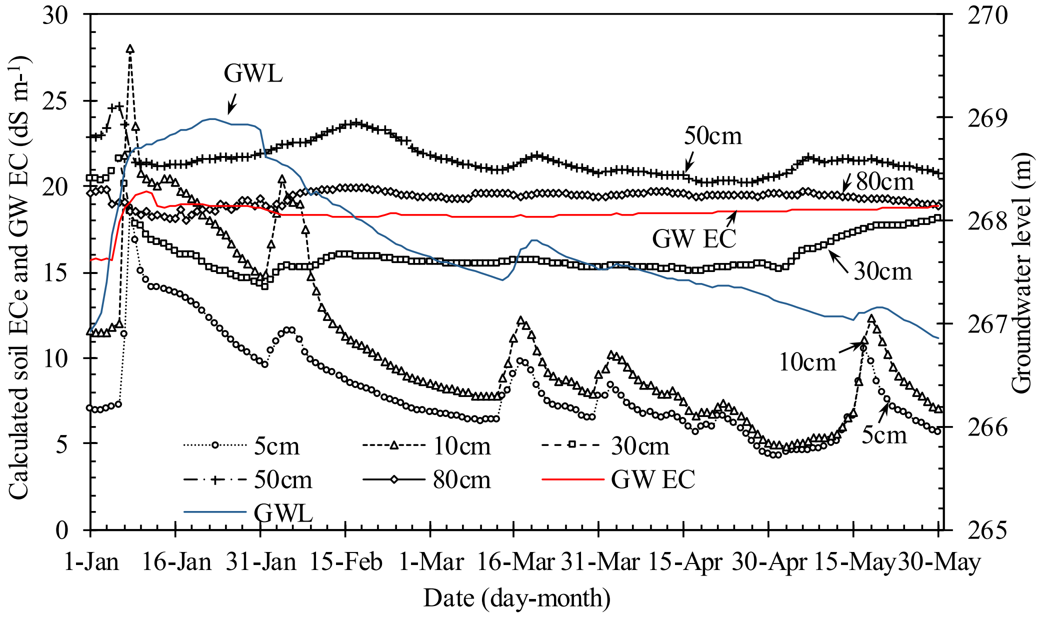
5TE sensors (Decagon, USA) were installed in experimental fields and soil moisture was monitored. The measurement period was from May 2014 to February 2015 for the Axmedov site and from January 2015 to January 2016 for the Yangiobod site. Soil moisture at a depth of 80 cm in the center of the field was close to the saturated volumetric water content in both the Axmedov and Yangiobod sites, even during the period between September and mid-October when the groundwater level falls to approximately 3 m from the surface of the soil, indicating constant soil moisture and tendency toward poor drainage.





Fluctuations in soil salinity after leaching in experimental field in Yangiobod

5TE sensors (Decagon, USA) were installed in the experimental field and soil EC was monitored. The monitoring period was between January 2016 and May 2016. Leaching was carried out on January 7, 2016; the groundwater level rose and the surface of the soil was flooded. Although soil EC_e at a depth of 5 cm and 10 cm decreased over time, soil EC_e in horizons at a depth of greater than 30 cm remained at basically the same level as soil salinity prior to leaching, even when the groundwater level fell. Furthermore, the soil EC_e of lower strata was almost the same as groundwater EC.



3.3 Causes of salt accumulation in experimental fields

On the basis of the survey and analysis results shown above, we endeavored to identify the causes of salt accumulation in the experimental fields. Below is a summary of the survey and analysis results for each item.

Survey Item	Survey/Analysis Results
Salt-affected soil classification	Classified as saline soil including Ca and Mg salts.
Soil profile characteristics	There were flecks of calcium carbonate at a depth of 30–40 cm. A hardpan had formed in the soil horizon and water permeability was poor. In terms of the composition of the salts contained in the soil, there were Mg<Na<Ca cations and a predominance of SO_4 anions.
Irrigation water/groundwater characteristics	Irrigation water is being used that poses a high risk of causing the soil to become saline. Groundwater had a predominance of Na, Cl and SO_4 ions, suggesting the danger of the soil becoming alkaline.
Groundwater fluctuations	Leaching water, from leaching that was carried out in winter, was present in the surface of the soil for approximately one month.
Fluctuations in soil moisture/salinity	Soil moisture was maintained at almost constant saturation in the lower strata of the soil. Although the salinity of the surface layer of the soil decreased due to leaching, salinity in the lower strata of the soil showed a tendency to remain at a high level.

Soil analysis showed that salt damage appeared to have been caused by Ca and Mg salts, rather than Na salts. Furthermore, in evaluating the ion composition of irrigation water and groundwater, and the water-soluble ion composition in the soil, it is likely that the origin of the salts contained in the soil is from both irrigation water and groundwater.

At present, leaching is being carried out during the winter with the aim of sinking down salts in the soil to lower strata. However, the hardpan acts as an impermeable layer to influence the penetration of leaching water, and likely hinders the salt removal effect. When leaching water or irrigation water is supplied to the strata above the hardpan, stagnant water temporarily forms on the hardpan. As the hardpan is shallow, at a depth of 30 cm, the stagnant water makes its way to the surface of the soil via capillary action, driven by the intense evaporation on the surface; in addition, there is migration and subsequent accumulation of water-soluble salts in the surface layers of the soil. Since Na salts are the most water soluble, they tend to accumulate in the surface layers of the soil. Below the hardpan, the groundwater level rises to less than 1 m on account of the supply of leaching water and irrigation water. The salts contained in groundwater at that time are transported upward together with soil moisture due to the increase in temperature. However, as evaporation is restricted due to the influence of the hardpan, calcium sulfate salts, which have a low level of solubility (0.208 g/100 g H_2O at 20°C), remain and accumulate in the hardpan. It is expected that such calcium sulfate accumulation will further reduce the water permeability of the hardpan.

Countermeasures for the above-mentioned salt accumulation mechanisms are shown in Fig. 3.3.1. We believe that these countermeasures will be effective at breaking up the hardpan, which in turn will make it possible to effectively leach and remove the salts in the worked soil, and transport them to the drainage canal.

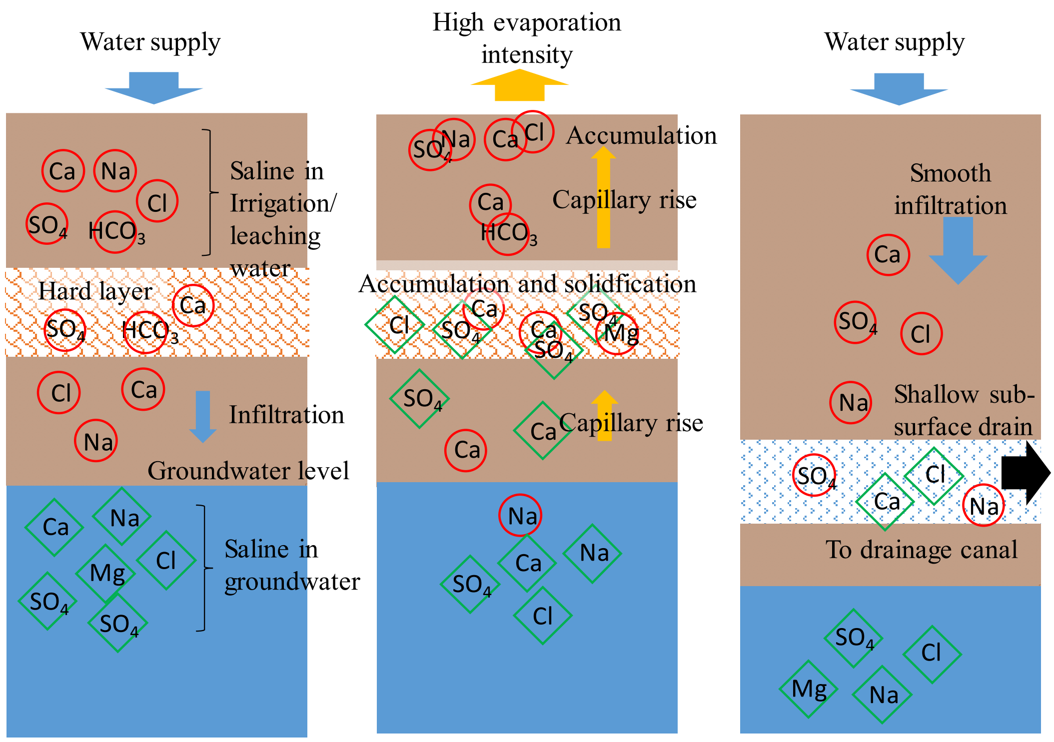


Fig. 3.3.1 Salt accumulation mechanisms in the experimental fields and the expected improvement effect by countermeasures

Therefore, to ascertain the influence of these countermeasures, we took unmixed soil samples using a soil core sampler both before and after the breaking up of the hardpan at the sites with salt accumulation. In the laboratory, we measured the total dissolved solids (TDS) in the leachate in the case of 300 mm flooding. The results indicated that although the leaching water quickly permeated downward and salt was removed when the hardpan was broken up, the 35.4% of the TDS was in the leachate after the leaching process. On the other hand, even without breaking up the hardpan and the longer time (about 72 days) needed for the leaching water to penetrate, about the same volume permeated as when the hardpan was broken up. However, in the field, a long period was not necessary for the leaching water to infiltrate the soil. Since the salts in the strata below the clay layer were difficult to remove, it is conceivable that the leaching water removed salt in strata that were shallower than the hardpan and transported them in a horizontal direction, or selectively to areas with high water permeability.

Chapter 4
USING SHALLOW SUB-SURFACE DRAINAGE TO REDUCE SALT ACCUMULATION IN IRRIGATED FARMLAND

4.1 Positioning of shallow sub-surface drainage in this manual

1) Purpose

Drainage systems are an effective means of reducing excessive salt accumulation on farmlands by facilitating the conveyance of salts down through the soil profile via the lowering of groundwater levels during leaching, which prevents salts from accumulating in the plow layer during the crop cultivation period. To lower groundwater levels, drainage canals (collectors), and vertical and deep sub-surface (2.5–3.0 m deep) drainage systems should be constructed. In fields where such measures are operating effectively, after leaching, salty infiltration water flows out of the field into drainage canals, which reduces the capillary rise of groundwater and thereby reduces salt accumulation at the soil surface. However, salt accumulation cannot be reduced in some fields due to:

- Higher water levels in drainage canals due to slope collapse, sediment deposition, weed overgrowth, and so on, in the canals
- Higher groundwater levels due to lower vertical drainage operating rates
- Higher groundwater levels due to lower discharge rates of sub-surface drainage systems
- Higher groundwater levels as a result of water inputs, such as excessive irrigation and leaching
- Reduction of the effects of salt removal as a result of lower soil permeability due to the presence of a hardpan or other factors

The shallow sub-surface drainage types discussed in this manual target shallow groundwater* in fields at high risk of salt accumulation, with the goal of reliably removing salts via directing post-leaching infiltration water into drainage canals and thus improving field drainage performance in a relatively shallow soil layer (60–90 cm below soil surface).

*Shallow groundwater refers to a type of groundwater that is present close to the ground surface, has a freely changeable groundwater level, and is not under pressure (i.e., unconfined groundwater).

2) Characteristics of shallow sub-surface drainage

Compared with conventional sub-surface drainage, which is normally installed at depths of 2.5–3.0 m, shallow sub-surface drainage can more effectively drain infiltration water from a field, even when water levels in drainage canals are high.

For shallow sub-surface drainage, perforated pipes (minimum diameter 50 mm) are often used as the main sub-surface drains, but this approach requires a high-density installation to secure sufficient drainage function, and the construction cost per unit area is high even if cost per unit length is lower.

Here, we discuss sub-surface drainage technology that use auxiliary sub-surface drains with high rate of discharge, which reduce the density of perforated pipes and lower costs.

Typical auxiliary sub-surface drains include mole drains (40 cm below the surface, diameter 6–10 cm), drains containing hydrophobic materials (rice husk or other material that are buried after drilling) and sub-soil breaking. Mole drains, which are often combined with a main sub-surface drain, are inferior in terms of water-path durability. A drain-drilling unit that can drill hollows that are more structurally stable than mole drains has recently been developed (hereafter, the drain-drilling unit will be referred to as "the drilling unit", and the sub-surface drains created using the machine as "cut-drains".) In this manual, these cut-drains are used as auxiliary sub-surface drains. Here, cut-drain is defined as "auxiliary sub-surface drain" connected to main sub-surface drain, although it can function like a perforated pipe with high discharge and be regarded as a partial substitute for the pipe.

Designs for sub-surface drains that use deep sub-surface drainage, conventional shallow sub-surface drainage, and shallow sub-surface drainage using cut-drains are shown in Fig. 4.1.1.

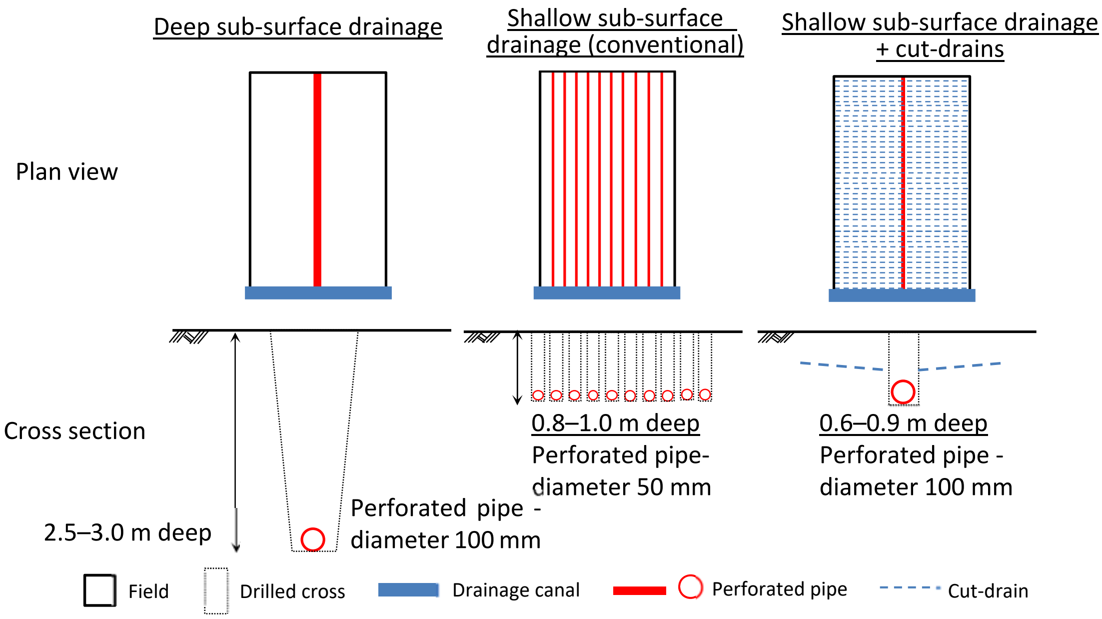


Fig. 4.1.1 Differences in design of sub-surface drainage

Cut-drains are a low-cost, shallow sub-surface drainage technology developed in Japan (Fig. 4.1.2), which are constructed with a cut-drain drilling unit attached to the back of a tractor. This allows farmers to quickly and easily construct cut-drains—sub-surface drains with the same rate of discharge of running water as main sub-surface drains—without the need for additional materials, and thus represents a comparatively simple means for creating fields with good drainage (Kitagawa, et al. 2010[1)], Okuda, et al. 2015[2)]).

The development of the cut-drain technique and how it is used in Japan are presented in Appendices 1 and 2, respectively.

Drilling unit

Drilling unit attached to a tractor

Cavity created

Fig. 4.1.2 The drilling unit and a cut-drain

4.2 Shallow sub-surface drainage system structure

1) How sub-surface drainage works

A shallow sub-surface drainage system consists of a main sub-surface drain (lateral drain: lateral pipe and hydrophobic materials), a collecting drain (unperforated pipe), auxiliary sub-surface drains, an outlet, a lock and a riser (Fig. 4.2.1). The form and drainage conditions of the target field must be evaluated prior to final system design and componentry to ensure maximum efficiency and ease of maintenance. Auxiliary sub-surface drains are distributed throughout the field and connected to the lateral drain. Post-leaching infiltration water received by the auxiliary sub-surface drains flows into the lateral drain, then into the collecting drain and finally into the drainage canal.

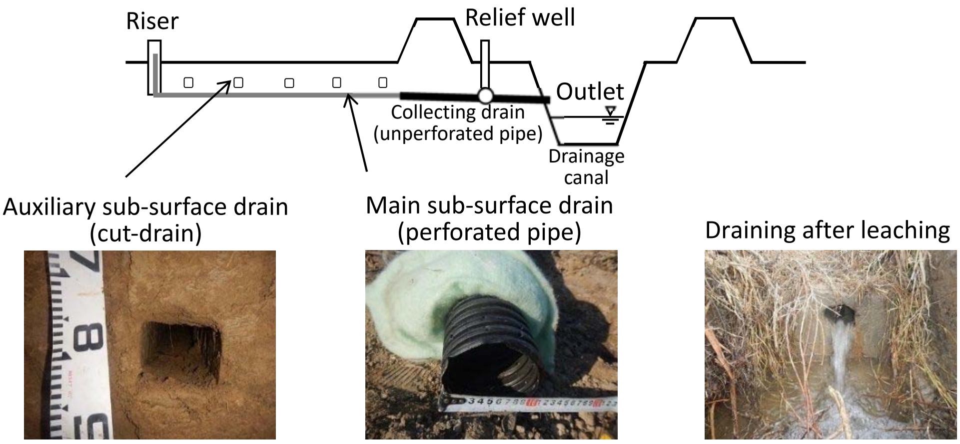


Fig. 4.2.1 Structure of a shallow sub-surface drainage system

2) Sub-surface drainage volume

Development of a shallow sub-surface drainage system requires determination of the sub-surface drainage volume during leaching. Sub-surface drainage volume is defined as that necessary to remove excess water via sub-surface drainage over a specified drainage time (MAFF 2000)[3)]. Leaching water following flooding is categorized into water that remains at the soil surface, water that flows into surrounding drainage canals, water that enters the groundwater, water that flows out via sub-surface drains, and water that evaporates. In this manual, design sub-surface drainage volume is presented as the daily amount of water that is removed via shallow sub-surface drains, information that is used to determine the extent of the intervals between cut-drains, and the diameters of the perforated and collecting pipes.

The standard range of sub-surface drainage volume is 10–50 mm/d for farmland; the actual volume is determined by referring to data from fields with similar characteristics, as well as factors like the size of the target area, economic efficiency, and so forth.

3) Structure of a shallow sub-surface drainage system

a. Main sub-surface drain (lateral drain)

The main sub-surface drain directs groundwater and post-leaching infiltration water in the field into collecting drains or drainage canals and consists of perforated pipes, covering material, and hydrophobic

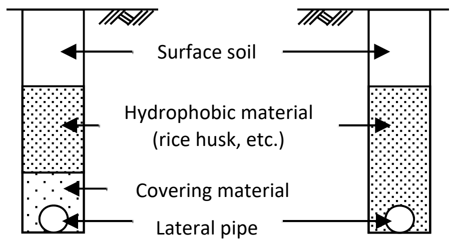


Fig. 4.2.2 Cross-section of the main sub-surface drain

material. Lateral pipes collect surrounding groundwater and infiltration water, and filter them from the field. The covering material, which is composed of a permeable material that overlays the lateral pipes, helps to filter the water flow into the pipes and also serves to sustain water absorbability by increasing the water absorption area. Hydrophobic materials are positioned above the covering material and serve to direct water collected from the field into the lateral pipes, as well as secure the flow of infiltration water by acting as a large path. The covering material and the hydrophobic materials often consist of the same type of material, and are collectively referred to as the hydrophobic materials (Fig. 4.2.2) (The Agricultural Upland Development Association 1989)[4].

As the main sub-surface drain, and in terms of soil texture and soil permeability, among other factors, either lateral pipes or hydrophobic materials may be installed (MAFF 2000)[3]. If lateral pipes are not installed, materials such as bamboo, brushwood, and crushed stone can be used to ensure permeability.

b. Collecting drain

The collecting drain connects to the downstream end of the lateral drain and discharges infiltration water collected from auxiliary sub-surface drains and the lateral drain into the drainage canal. The collecting drain does not require the use of perforated pipes, as it does not directly receive water from the field surface.

c. Auxiliary sub-surface drains

Auxiliary sub-surface drains direct the infiltration water originating from the surface (e.g., leaching water, rainwater) to the lateral drain. Auxiliary sub-surface drains are connected to the hydrophobic materials of the main sub-surface drain in order to guide collected infiltration water to the main sub-surface drain.

The length of a cut-drain is limited by the gradient of the land and the depth of the main sub-surface drain, but typically extends for an adjustable range of up to 200 m in flat areas (Kitagawa et al. 2010)[1]. As the length of a cut-drain increases, the catchment area per main sub-surface drain also increases. Construction of a cut-drain can, however, result in the occurrence of preferential flow, which may cause collapse of the hollow. As such, cut-drains should be designed to incorporate measures that minimize the possibility of preferential flow (see 4.3.3. and 4.4).

d. Outlet and relief well

The outlet is located at the downstream end of the sub-surface drainage system installed in the drainage canal; when discharge volume requires adjustment during leaching, the relief well is opened. To prevent the outlet and relief well from being damaged by construction machinery during dredging operations in the drainage canal, the machinery operator must be informed of their locations prior to the commencement of dredging. Locks are classified into riser and faucet types (Fig. 4.2.3) (MAFF 2000)[3].

- Riser-type relief well

  To adjust discharge volume, the sub-surface drain is opened/closed by an apparatus vertically inserted from the ground surface into the lateral pipe or collecting pipe. A concrete pipe or a similar structure should be installed to protect riser locks from damage by livestock or other means.

- Faucet-type relief well

  The drainage canal-side exit of the lateral pipe or collecting pipe (i.e.,

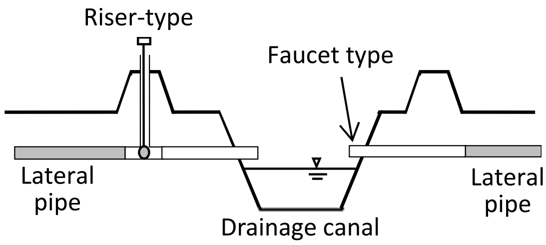


Fig. 4.2.3 Locks

outlet) is closed with a lid, with discharge volume adjusted by opening or closing the lid.

e. Riser pipes on the main sub-surface drain

Lateral drains cannot be seen from the ground surface, requiring the installation of a concrete manhole on the upstream side of the lateral pipe, which is connected to the lateral drain. This allows for identification of the location of the drain from above the ground surface, as well as for access to the pipe for cleaning and maintenance when its drainage functioning has been compromised (e.g., accretion of sand) (MAFF 2000)[3].

4) Drainage methods

There are two drainage methods in sub-surface drainage: direct drainage, in which the lateral drain is directly connected to the drainage canal, and collecting drainage, in which multiple lateral drains are connected to the drainage canal (MAFF 2000)[3].

a. Direct drainage

This is a drainage method whereby the terminal outlet of the lateral drain is directly connected to the drainage canal (Fig. 4.2.4). If the outlet is connected to a large-scale branch drainage canal with high banks, the amount of earthwork associated with excavating and backfilling increases. Therefore, if there are a large number of outlets, a small-scale drainage canal is constructed within the field, to which the outlets are connected, and the drainage canal is then connected to the drainage canal outside the field. An appropriate location must be determined prior to construction of a drainage canal within a field to avoid interference with farming operations.

Although application of a direct drainage approach to cut-drains is possible, there is increased risk of scour collapse near the outlet when under high discharge; moreover, even with soil types resistant to collapse (e.g., heavy clay), soil near the outlet is prone to drying and cracking, increasing the risk of hollow collapse. If, out of necessity, direct drainage is used for cut-drains, measures should be taken to prevent blockage by soil collapse; for example, a 2-m synthetic resin pipe could be attached to the outlet (Kitagawa et al. 2010)[1].

b. Colleting drainage

This approach involves the connection of multiple lateral drains to the drainage canal (Fig. 4.2.5). The small number of outlets simplifies maintenance, and there is no need to construct additional drainage canals within the field, which negates the potential for interference with farming operations.

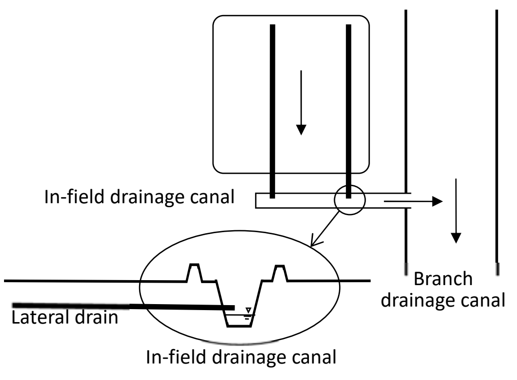


Fig. 4.2.4 Direct drainage method

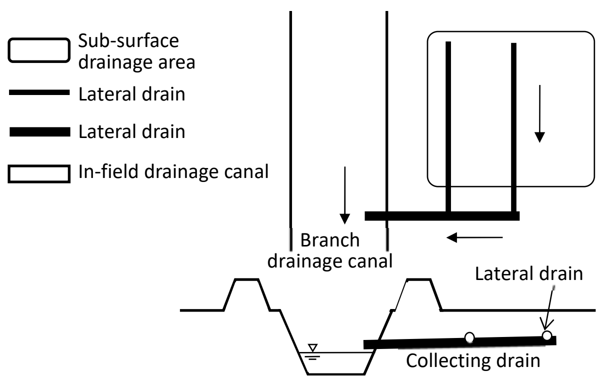


Fig. 4.2.5 Collecting drainage method

5) Layout of the main sub-surface drain and auxiliary sub-surface drains

The gradient of the field is the main factor to be considered when designing the layout of the main sub-surface drain and auxiliary sub-surface. There are two primary ways in which the main sub-surface drain and auxiliary sub-surface drains may cross: orthogonally and in a herringbone (Fig. 4.2.6) (S.K. Gupta 2013)[5].

a. Orthogonal type

This is defined as when the auxiliary sub-surface drains connect to the main sub-surface drain at right angles, and is most often used in a leveled field without undulations and with a uniform gradient. Cut-drains, which are constructed at a constant depth from the ground surface, must therefore be arranged in consideration of the land gradient, so that water flows toward the main sub-surface drain.

b. Herringbone type

In this layout, auxiliary sub-surface drains are connected to the main sub-surface drain at angles that accord with field undulations. This design is most often used in fields where water in the auxiliary drains will flow in the opposite direction to that desired when the orthogonal type is used.

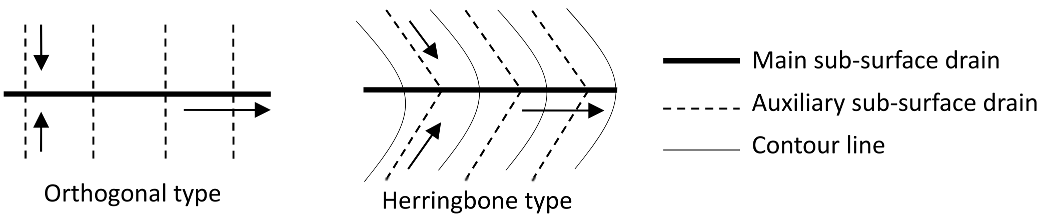


Fig. 4.2.6 Conceptual diagram of sub-surface drainage systems

4.3 Design and implementation of a shallow sub-surface drainage system

When installing a shallow sub-surface drainage system in a field, it is necessary to examine field conditions and to survey the field prior to designing the drain network, in order to ensure that the system will drain infiltration water properly. Unlike open channels, shallow sub-surface drainage systems rely on buried pipes, which makes it difficult to identify the source of the problem when water flow is disrupted. During construction, thorough altitude management should be implemented for excavated ditches to ensure that the gradients of the ditches follow the contours of the field, and close attention should be paid to pipe connections; pipes should also be carefully inspected for imperfections and damage. Furthermore, in places where the burial depth of a lateral pipe is shallow, the length of the blades of the drilling unit must be adjusted so as not to damage the pipe.

The designer and builder of the drainage network should be mindful of the points listed below regarding the various components of a shallow sub-surface drainage system:

1) Main sub-surface drain (Lateral drain)

a. Materials

To ensure consistent infiltration and influent water flow through lateral drains, perforated pipes of specific cross-section size, strength, durability, and water absorbency, and that are highly practical and cost effective, must be selected (MAFF 2000)[3]. Perforated pipes wrapped with non-woven fabrics or nets should be used to prevent dirt from entering the pipes.

b. Installation depth of pipes

For connection to cut-drains (at depths of 0.6–0.9 m), pipes should be installed 0.8–1.0 m below the ground surface. Pipes should be arranged so that they incline from the upstream side to the downstream side, and are even and straight. The height of the outlet to which a pipe is connected is, in principle, above the water level in the drainage canal; thus, given that water levels in the drainage canal rise as a result of leaching in winter, past water levels must be determined in order to establish the height of the outlet.

c. Gradient and diameter of pipes

One advantage of positioning the outlet in the lower position in the drainage canal is that the gradient of the connecting pipe can be steepened, which increases the flow rate and thus allows for the use of smaller-diameter pipes. At the same time, such positioning increases the amount of earth that must be excavated in the downstream end; as such, upstream pipe depth is relatively shallow, which complicates connection with the cut-drains and increases the risk of the pipe being damaged by the drilling unit. A low gradient, however, may reduce the discharge capacity of the pipe. If the discharge capacity of the pipe becomes too low and the pipe is carrying water at full capacity for an extended period, then the pipe will need to be replaced by larger-diameter pipes. Because pipe diameter greatly influences construction costs, the optimal pipe diameter should be determined via a comprehensive analysis of the period during which the pipe is expected to carry water at full capacity, the pressure gradient of the pipe, and its cost effectiveness.

The discharge capacity of a pipe can be calculated via Manning's Equation, which uses the sub-surface discharge during leaching, the area over which leaching is carried out, the gradient of the pipe, and the roughness coefficient for the pipe as variables.

Calculation (example)

The velocity of flow v (m/s) can be calculated using Manning's Equation:

$$v = \frac{1}{n} R^{2/3} I^{1/2}$$

where *n* is the roughness coefficient of the pipe, *R* (m) is the hydraulic radius (cross section/wetted perimeter of flowing water), and *I* is the gradient. Assuming a corrugated pipe with a diameter of 100 mm and a roughness coefficient of 0.016 installed at a gradient of I = 1/800, and 80% water depth, a cross section of 0.0067 m^2, and a wetted perimeter of 0.22 m, the velocity of flow *v* is calculated as:

$v = (1/0.016) \times (0.0067/0.22)^{2/3} \times (1/800)^{1/2} = 0.22$ m/s

Thus, discharge capacity is calculated as: Q = 0.0067 × 0.22 = 0.0015 m^3/s (1.5 L/s).

Assuming a sub-surface drain discharge of 12 mm/d and a catchment area of 1.0 ha, the discharge of the sub-surface drain q is calculated as 120 m^3/d (1.38 L/s).

Because Q is higher than q, the water volume of the sub-surface drain discharge would thus flow at a rate equivalent to 80% of the pipe diameter.

2) Installing the main sub-surface drain

The process of installing the main sub-surface drain is shown in Fig. 4.3.1.

a. Establishing the drain line

The locations of the outlets, collecting drains, and lateral drains are determined according to the design of the shallow sub-surface drain network. Prior to the installation of the lateral and collecting pipes, the survey sites should be set along the drain line at minimum intervals of 20 m in order to manage the burial depths of the pipes during installation.

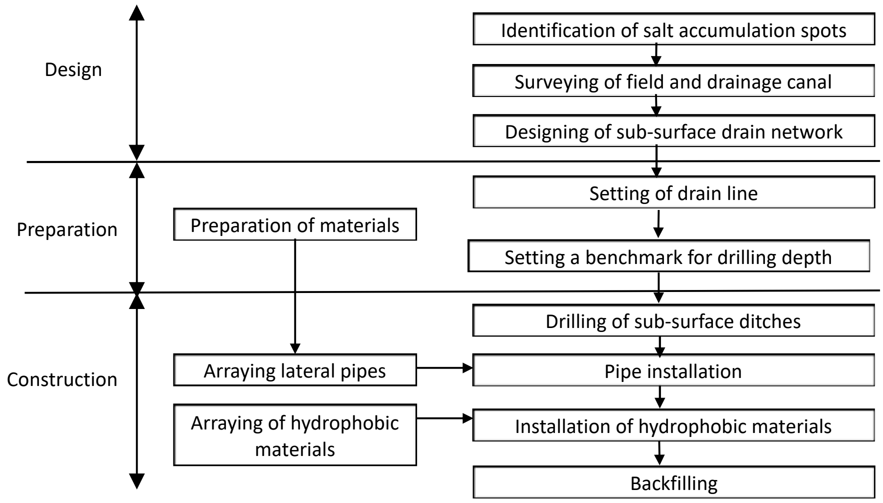


Fig. 4.3.1 Construction flow of the main sub-surface drain

b. Excavation of ditches

Excavation may be done manually, by machinery, or by combination of the two. The amount of earth excavated is in proportion to the width, depth, and length of excavation. Given the cost of excavation and the amount of hydrophobic materials needed, excavation width should be as narrow as possible.

Machine excavation is more efficient than manual excavation for digging longer ditches. An excavation unit with an attached bucket or a trencher is commonly used; if a bucket is used, it should be as narrow in width as possible.

Water ingress into the bottom of the ditch during excavation significantly constrains construction work; to avoid this, ditch-digging should be performed at times when groundwater levels are deeper than the bottom of the ditch and rainfall/snowfall is low. In addition, excavation should be done in the downstream-to-upstream direction so that water does not accumulate in the ditch.

When excavating a ditch, the depth must be monitored to avoid the occurrence of a reverse gradient and excessive unevenness. Because unevenness is more likely to occur when bucket excavation is used, excavating depth should be checked at each of the survey points immediately after excavation to check their accuracy with the depths specified in the design. Following machine excavation, the ditch bottom should be leveled manually to ensure that depths over the entire length of the ditch matches those specified in the design plans. Such manual work requires an excavation width of at least 40 cm, and should be guided by, for example, stretching a leveling line on one side of the ditch for use as a reference. The leveling line used should be light and strong, and be fixed at intervals no longer than 10 m to prevent the line from sagging.

c. Pipe installation

Verification of the excavation depth is followed by the installation of pipes. Care should be taken to prevent the collapse of the ditch walls during pipe installation to prevent dirt from collecting underneath the pipes while they are being installed, and pipes should be tightly connected to one another to prevent slippage and leaking.

d. Installation of hydrophobic materials

Rice husk, crushed stones (gravel), wood chips, and similar material may be used as the hydrophobic materials (MAFF 2000)[3]. Hydrophobic materials are added until the thickness is adequate for the auxiliary sub-surface drains to be directly connected to the pipe. Considering the compressibility of the materials, a large amount of hydrophobic materials should be put in and then compressed. Enlargement of the cross section of the excavated ditch (e.g., due to collapse of the ditch walls) influences the input volume of the hydrophobic materials; these materials should be added immediately following pipe installation.

e. Backfilling

Once the hydrophobic materials are in place, the ditch should be backfilled with the excavated earth. Backfilling should be done manually and with care so as to avoid damaging the pipes. The top of the backfill should be higher than the surrounding ground level to take into account subsequent subduction of the backfilled earth.

3) Collecting drains

Installation of collecting drains, as with lateral drains, requires management of the bottom depth during excavation to ensure appropriate pipe gradient. A lateral drain and a collecting drain should be connected via a branched pipe, with connections tight enough that pipes will not slip and will prevent water leakage. If lateral drains are present on both sides of a collecting drain, the layout should be designed in such a way that the junctions are apart from one another to stop water from flowing into the same spot in the collecting drain (JIID 1993)[6]. Because the terminal outlet is prone to damage by livestock, excavation machinery, and so forth, it must be protected by concrete or steel.

4) Auxiliary sub-surface drains (cut-drains)

a. Construction of cut-drains

Cut-drains are the hollows (10 cm × 10 cm) created at an underground depth of 60–90 cm. Achieving a constant gradient of the hollows is not possible if the field is uneven; therefore, it is imperative that cut-drains be created on a leveled field, which requires that the undulations of the field be identified beforehand to reduce the influence of field contours as much as possible, and that the layout of cut-drains be designed and installed in such a way so that water in the hollows flows toward the lateral drain. In farm fields, furrows created for conventional irrigation purposes should have a gradient; cut-drains oriented in the same direction as that of a furrow will therefore have the same gradient as the furrow. For cut-drains, a high flow rate

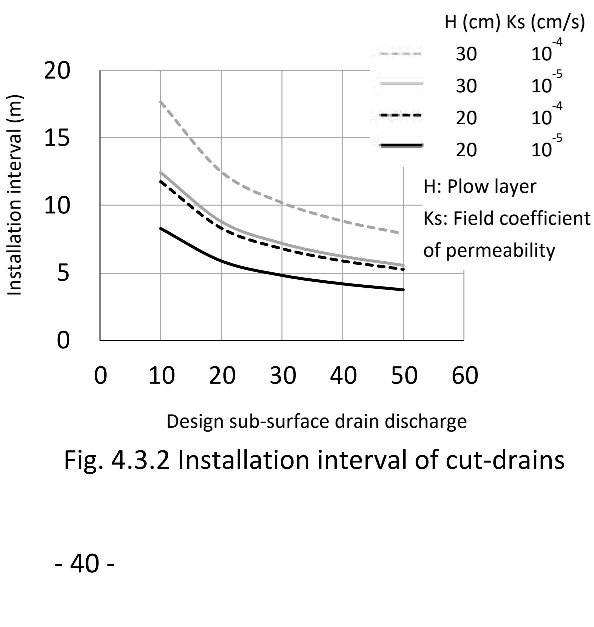


Fig. 4.3.2 Installation interval of cut-drains

increases the risk of erosion of the inner hollow wall; therefore, steep gradients should be avoided when installing cut-drains, and ideally, gradients should be between 1/500 and 1/1000.

The installation interval of cut-drains is calculated based on the design sub-surface drain discharge, the field coefficient of permeability, and the plow layer thickness. Assuming a design sub-surface drainage discharge (D) of 10–50 mm/d, a field coefficient of permeability (Ks) of 10^{-4}–10^{-5} cm/s, and a plow layer thickness (H) of 20–30 cm, the installation interval would be between 4 and 18 m (Fig. 4.3.2).

The flow capacity of a cut-drain differs with the steepness of the gradient; for example, the relationship between gradient (1/500–1/1000) and flow volume for water depths of 30%, 50%, and 70% are shown in Fig. 4.3.3.

To avoid compaction by the excavation machine during the installation of lateral drains, cut-drains should ideally be installed after lateral drains are in place; however, it is important that care be taken to avoid damaging the lateral drains with the blades of the drilling machine during installation.

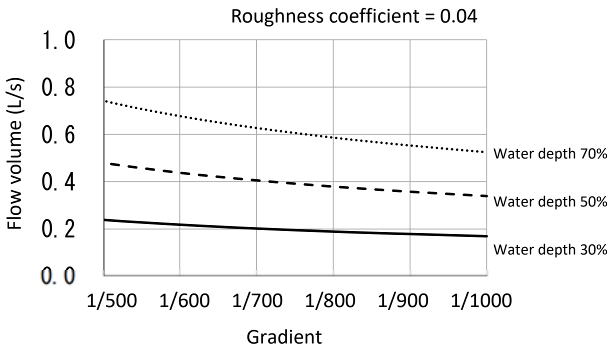


Fig. 4.3.3 Gradient and flow volume of a cut-drain

Calculation of the installation interval and discharge rate of cut-drains (example)

The installation interval of sub-surface drains can be calculated using the following equation (MAFF 2000)[3)]:

$$S = 2H\sqrt{\frac{k}{D} \times 86.4} \qquad (1)$$

where *S* is the interval between the lateral drains (m), *H* is the plow layer thickness (cm), *k* is the permeability coefficient for determining the lateral drain interval (cm/s), *D* is the design sub-surface drainage discharge (mm/d), and 86.4 is a unit conversion coefficient.

The permeability coefficient (*k*) is obtained by correcting the field permeability coefficient measured for the plow layer (*ks*):

$$k = \alpha \cdot ks \qquad (2)$$

where *α* is the correction coefficient for the field permeability coefficient and approximate values are given for different orders of the field permeability coefficient (Table 4.3.1).

Table 4.3.1 Approximate correction coefficient (α)

Ks's order	Approximate α value
10^{-3} cm/s	50
10^{-4}	100
10^{-5}	500
10^{-6}	1,000

Assuming a design sub-surface drainage discharge *D* of 12 mm/d, a plow layer thickness *H* of 20 cm, a field permeability coefficient *ks* of 10^{-5} cm/s, and a permeability coefficient for determining the interval of lateral drains *k* of 5×10^{-3} cm/s, an interval for sub-surface drains *S* of $2 \times 20 \times (5 \times 10^{-3}/12 \times 86.4)^{1/2} = 8$ m is obtained.

If the cut-drain length is 100 m, at intervals of 8 m, with a gradient of 1/1000, at a water depth of 30% (3 cm), and a roughness coefficient *n* of 0.04, then Manning's Equation can be used to determine the velocity of flow *v* and the flow volume *Q*, which in this example would be *v* = 0.06 m/s and *Q* = 0.17 L/s, respectively.

If the design sub-surface drainage discharge is 12 mm/d, the drainage area *A* is

calculated as follows: the installation length (100 m) × the interval (8 m) = 800 m^2, and the discharge q is calculated as follows: 0.012 × 800/86400 = 0.00011 m^3/s (0.11 L/s).
Since Q is higher than q, then in this instance the cut-drain has the ability to convey the design sub-surface drainage discharge at a water depth of 3 cm.

b. Structure of cut-drains and drilling methodp40

Cut-drains are formed via a unique drilling method. First, two blades (front blade (1) and rear blade (2)) are inserted into a field, which then lift a soil cuboid by 10 cm, creating a gap underneath. A side cutter (3) then shifts an adjacent 10 cm soil block sideways into the newly created cavity, leaving a water conduction hollow (4), which serves as a sub-surface drain (Figs. 4.3.4 and 4.3.5). The cut-drain drilling unit is attached to and towed by a tractor, and creates a deeper hollow than conventional methods. Cut-drain drilling is thus a simple technique that farmers can easily incorporate into their routine farming practices.

There are two ways the cut-drain unit drills hollows: drilling from the ground surface and drilling from inside a drainage canal (Fig. 4.3.6). With the former method, cut-drains can be drilled from both the upstream and downstream side, and is used when constructing auxiliary sub-surface drains, which are connected to a lateral drain. With the latter method, cut-drains are drilled only from the drainage canal, and thus cut-drains are used to directly discharge water into the drainage canal (Okuda et al. 2015)[2)].

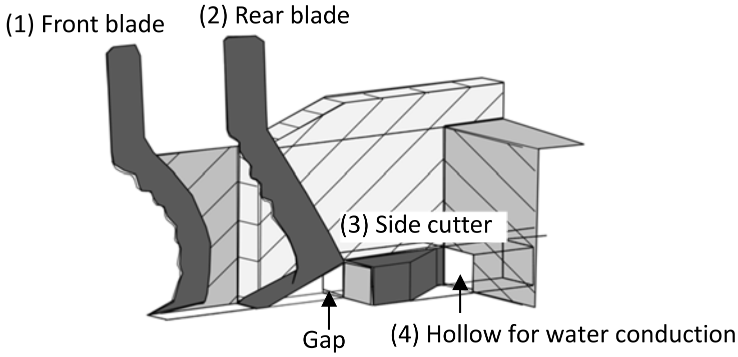


Fig. 4.3.4 How to create cut-drains (roles of blades)

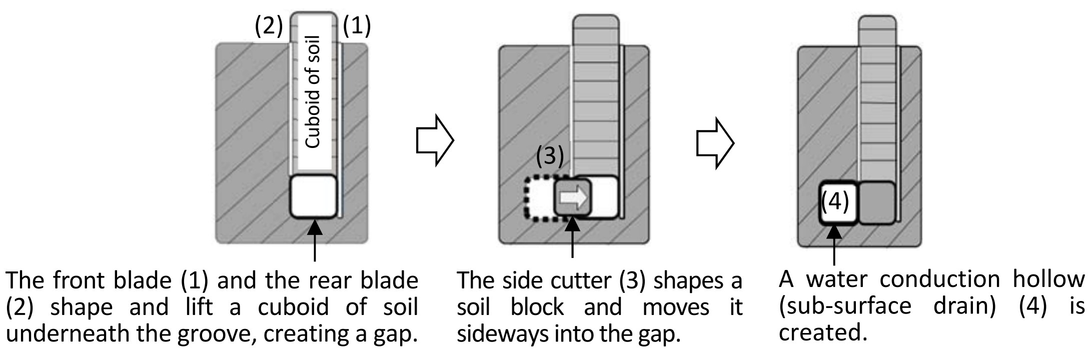
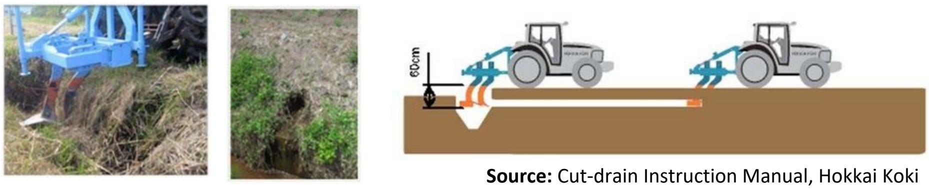


Fig. 4.3.5 Movements of soil masses during the construction of a cut-drain

<Drilled from the ground surface>

<Drilled from the drainage canal>



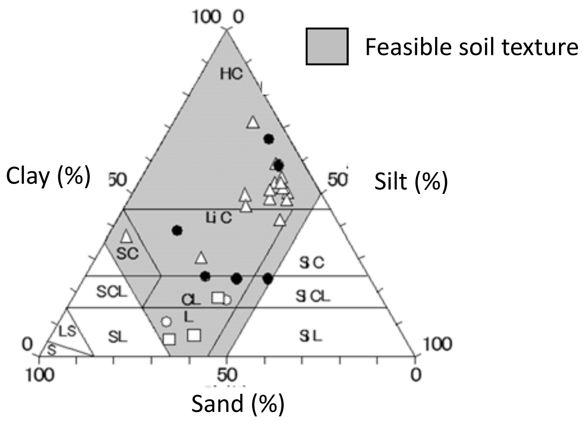
Source: Cut-drain Instruction Manual, Hokkai Koki

Fig. 4.3.6 How to drill a cut-drain

c. Considerations in using cut-drains

● Feasible soil texture

Because cut-drains are hollows and not pipes, the feasibility of the hollows and the risk of soil collapse due to water discharge through them, among other issues, must be considered before they are created. In Japan, the feasibility of cut-drains is high in soil types such as clay and peat (Fig. 4.3.7). On the other hand, sand and other soil types with high silt content, such as S, LS, SC, SCL, SL, SiC, SiCL, and SiL (internationally recognized soil texture types), are unsuitable; for fields with soil texture type L, for instance, cut-drains do not last long and must be reinstalled every few years (Kitagawa et al. 2010)[1].



●: Low-lying land soil ○: Low-lying soil with less durability □: Feasible volcanic soil △: Feasible plateau land soil

Source: Institute for Rural Engineering, National Agricultural and Food Research Organization

Fig. 4.3.7 Soil texture types suitable for cut drains

● Depth of cut-drains

The upper part of the drilling unit's blades has holes for adjusting the position of the blades (Fig. 4.3.8), with each blade having four holes. The lowest hole is primarily for preventing the blade from touching the ground by holding it up high while the drilling unit is being moved, although this hole position can also be used for shallow drilling (Fig. 4.3.9). Using one of the remaining three holes, the lengths of the blade sections that are inserted into the soil are adjusted to 60–120 cm. Tractive resistance increases as the inserted portions of the blades move deeper, increasing the risk of blade deformation. Therefore, the third hole from the top is most often used (Fig. 4.3.10) to create hollows at a depth of 60–90 cm.

● Uplift of the drilling unit

During the construction of cut-drains, a tractor can tow the drilling unit if soil moisture is moderate (Fig. 4.3.11), but topmost soil layers contain little moisture and lack elasticity during periods of dryness. At such times, it is not uncommon that the blades fail to deform the soil upon contact and do not penetrate deeply into the soil (Fig. 4.3.12). In such cases, measures to prevent uplifting of the drilling unit must be taken, such as the use of side cutter with an anti-uplift board and the addition of a 100–120 kg load on the base frame (Figs. 4.2.13 and 4.2.14).

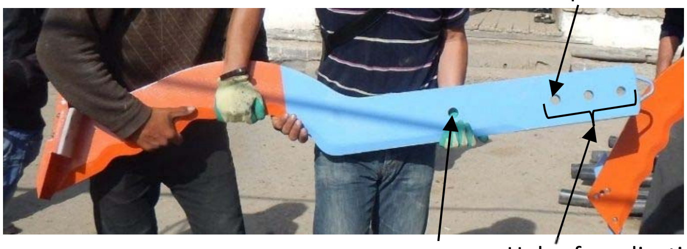


Fig. 4.3.8 Blade of the drilling unit

Fig. 4.3.9 Blade position during relocation

Fig. 4.3.10 Blade position during drilling

Fig. 4.3.11 Towing under moderate soil moisture condition

Fig. 4.3.12 Uplifting the drilling unit

Fig. 4.3.13 Side cutter with anti-uplift board

Fig. 4.3.14 Drilling with a load

● Spinning out of tractor wheels

Even if the blades can be inserted into the soil, if the soil is compacted, the tractor may not be able to tow the drilling unit without its wheels spinning out; conversely, the wheels may also spin out if the soil surface is extremely wet. March to April is one of the more suitable periods for constructing cut-drains, as typically during this time the soil retains water beneath the surface but the soil surface dries. Cut-drains can be created even during dry periods, however, by increasing soil moisture via irrigation and then proceeding once the surface is dry.

● Occurrence of preferential flow caused by the construction of cut-drains

Preferential flow may occur in the vertical air gaps above a cut-drain formed by the blades of the drilling unit. If a large amount of preferential flow originating from leaching and irrigation water flows into the air gaps, roof collapse caused by the weight of such water and soil collapse due to scour may occur, decreasing the efficiency of water conduction through the cut-drain. One preventative measure that can be adopted to minimize the occurrence of preferential flow is to increase soil moisture prior to cut-drain construction, which increases the fluidity of soil particles during construction and thereby closes air gaps in the soil. Increasing soil moisture can be accomplished by furrow irrigation, which is performed only along the cut-drain construction line, with water kept from the adjacent furrows where the tractor will run. If a large number of cut-drains are planned, irrigation must be initiated several days prior. However, a large amount of irrigation water also means higher risks of overflow and water leakage; therefore, sufficient furrow heights and between-furrow depths must be established before irrigation. When towing the drilling unit after irrigation, care should be taken to ensure that the blades pass the central line between furrows, where soil moisture is higher.

This technique does not completely eliminate the possibility of preferential flow; moreover, if dry weather persists, cracks may occur in sections where air gaps were blocked. If this technique has been used to construct cut-drains during a period of dryness, avoidance of excessive irrigation before leaching may be necessary and, if preferential flow has occurred during irrigation, air gaps in such parts must be blocked to prevent the collapse of the hollow until leaching is initiated.

4.4 Application in dry areas (case example)

Below we present an example of shallow sub-surface drain construction from Syrdarya region in Uzbekistan.

1) Layout of shallow sub-surface drains

A soil analysis conducted for the research field confirmed salt accumulation in the center of the field. It was decided therefore that shallow sub-surface drains would be constructed in the center of the field. The planned area was 4.0 ha (200 m × 200 m) with the planned drainage system consisting of two main sub-surface drains (perforated pipes + rice husk, No. 1 and No. 2) and 40 auxiliary sub-surface drains (cut-drains) (Fig. 4.4.1).

The main sub-surface drains were connected to the drainage canal, which was located in the northern section of the field, and the outlet was positioned on the branch drainage canal in the western part of the field. A survey conducted on and around the field revealed that the bottom of the drainage canal was shallower in some sections than the designated depth of the main sub-surface drains; therefore, a method that excavates drains more deeply or a collecting drainage method were considered. With the former method, sediment is more likely to be deposited by slope collapse or by other means, interfering with discharge from the main sub-surface drains; a collecting drainage design was thus adopted, with the collecting drains connected to the branch drainage canal.

The gradient of the main sub-surface drains toward the drainage canal in the field was set at 1/800. The bottom height of the lateral drains was set so that their depth was 1.0 m at the point with the lowest altitude on the lines of the main sub-surface drains (Fig. 4.4.2). Based on the depth and gradient of the lateral drains, the bottom height at the connecting point between the main sub-surface drains and the collecting drains was approximately 1.3 m below the ground surface. Based on the water levels in the branch drainage canal near the outlet in the leaching season, the height of the outlet was set at approximately 1.5 m below the ground surface.

Both of the main sub-surface drains (No. 1 and No. 2) were 200 m in length, with the two sub-surface drains separated by 100 m; discharge areas for both encompassed 2 ha (200 m × 100 m). Cut-drains were constructed in an east–west direction perpendicular to the two main sub-surface drains, and in the same direction as the furrows of the field during the irrigation season. The gradient was such that water in the cut-drains flows toward the main sub-surface drains.

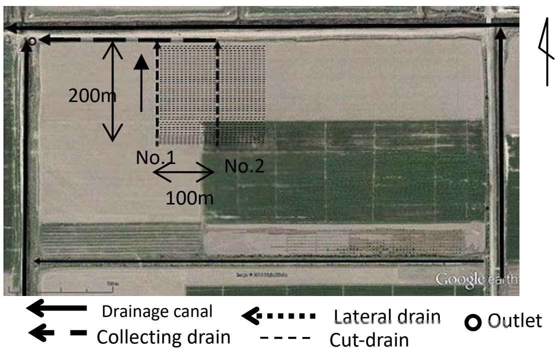


Fig. 4.4.1 Design of the shallow sub-surface drainage system (example)

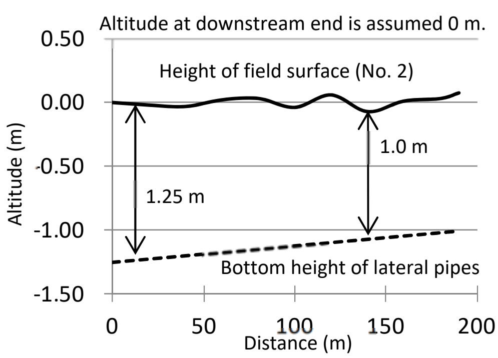


Fig. 4.4.2 Relationship between field surface and gradient of the sub-surface drain pipes

2) Design of shallow sub-surface drainage and deep sub-surface drainage (case study)

A comparison of deep sub-surface drainage and shallow sub-surface drainage systems is shown in Fig. 4.4.3. Using a deep sub-surface drainage project that was installed near the study area as a reference (Fig. 4.4.4), earth volume was compared between two sub-surface drainage types (Table 4.4.1). This particular deep sub-surface drainage system is large-scale and required a deep excavation depth; as such, the volume of earth to be moved for installation of a shallow sub-surface drainage system using cut-drains as auxiliary sub-surface drains (Fig. 4.4.5) is approximately one-twentieth of that moved for installation of the deep sub-surface drainage system. Even considering that a shallow sub-surface drainage system requires the input of hydrophobic materials and the construction of cut-drains, cost projections are estimated to be approximately 30% that of the deep sub-surface drainage system.

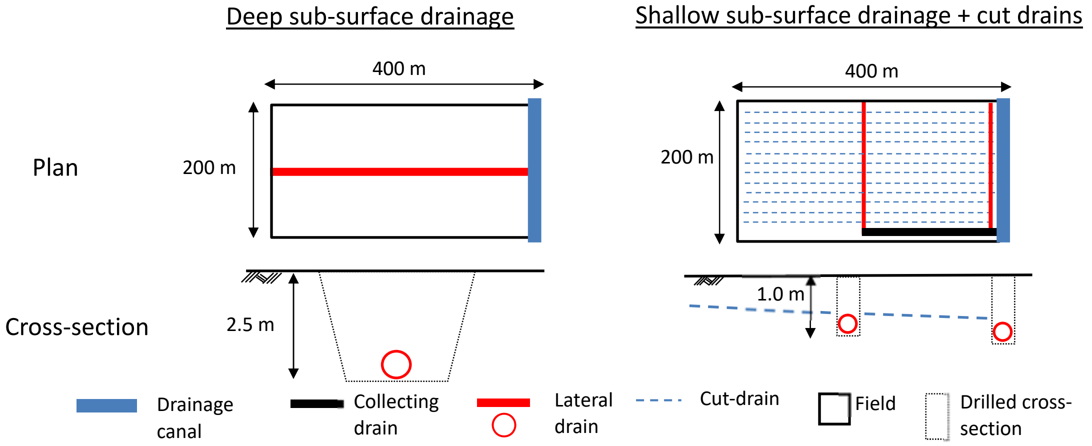


Fig. 4.4.3 Comparison of deep sub-surface drainage and shallow sub-surface drainage system designs

Table 4.4.1 Comparison of deep sub-surface drainage and shallow sub-surface drainage system designs

Type	Field area 200 m × 400 m, field gradient 1/1000				
		Depth	Interval	Length	Construction note
Deep sub-surface drainage	Lateral drain	2.5 m	200 m	400 m × 1	8 m^3 per 1 m of pipe
Shallow sub-surface drainage	Lateral drain	1.0 m	200 m	200 m × 2	0.4 m^3 per 1 m of pipe; hydrophobic materials; cut-drains
	Collecting drain	1.2 m	-	200 m	
	Auxiliary sub-surface drain	0.7 m	5 m	400 m × 40	

Note) Figures for deep sub-surface drainages are estimates.

Cross-section of deep sub-surface drain

Lateral drain to be installed

Fig. 4.4.4 Installation of a sub-surface drain at a depth of 2.5 m

Lateral drain in a shallow sub-surface drain

Installation of a hydrophobic material (Rice husk)

Construction of auxiliary drains (cut-drains)

Hollow of a cut-drain

Fig. 4.4.5 Construction of a shallow sub-surface drain

3) Levels of soil moisture suitable for the construction of cut-drains

In soils lacking elasticity, the blades of the drilling unit may break through the soil and lift the drilling unit to the soil surface. Analysis of ideal soil moisture levels for the construction of cut-drains in the research field indicated that the minimum soil moisture rates (water content) at depths of 0–20 cm, 20–40 cm, and 40–60 cm were 10%, 15%, and 18%, respectively (Fig. 4.4.6).

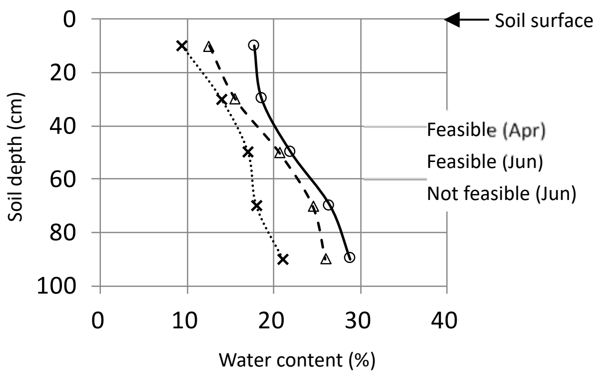


Fig. 4.4.6 Soil moisture and cut-drains

4) Measures to minimize the potential for preferential flow caused by the construction of cut-drains

Furrow irrigation tests were conducted to gauge the potential for preferential flow following construction of the cut-drains (Fig. 4.4.7). Compared with non-irrigated sections, preferential flow occurrence was lower on the irrigated sections the day of and 2 days after irrigation (Fig. 4.4.8). Even when preferential flow was observed, the hollow did not collapse when water volume was low. Collapse of the hollows can therefore be controlled by reducing the occurrence of preferential flow and by reducing water inflow into the hollows.

When a cut-drain was constructed on the day of irrigation, the amount of water equivalent to a depth of 3 cm spread over the entire furrow (90 cm × 3 cm × furrow length) was irrigated, which increased soil moisture to a depth of 40 cm. Conversely, a cut-drain constructed 2 days after irrigation, with an amount of water equivalent to a constant depth of 10 cm was irrigated, had little effect on soil moisture at depths of 40 cm or deeper (Fig. 4.4.9). In these tests, water leakage from the irrigated furrows was observed, with water that flowed into the adjacent furrows causing the tractor to occasionally spin out.

Irrigation in a furrow

Construction of a cut-drain immediately after irrigation

Fig. 4.4.7 Measures to reduce the occurrence of preferential flow

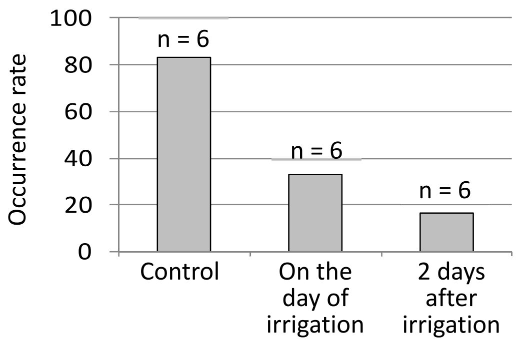


Fig. 4.4.8 Occurrence rate of preferential flow under different irrigation conditions

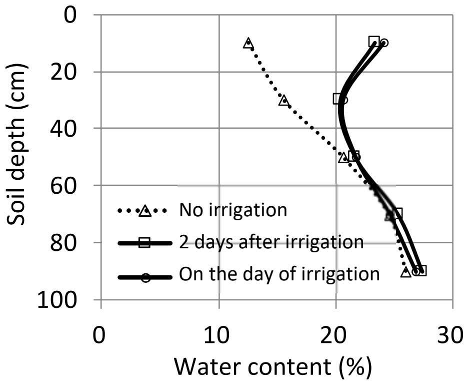


Fig. 4.4.9 Soil moisture after the implementation of anti-preferential flow measure

5) Application to the drilling installation of pipes

The drilling unit can be used to install small-diameter pipes. The hollow created using a cut-drain drilling unit has a cross-section of 10 cm × 10 cm, and a small-diameter pipe can be installed while a hollow is being formed by attaching the pipe to the side cutter of the unit. In the experimental field, a PVC pipe with a diameter of 50 mm and a length of 100 m was installed without difficulty (Fig. 4.4.10). Prior to pipe dragging, a 1.0 m-deep soil cross-section should be prepared and a guide pipe of a larger diameter than that of the pipe to be installed inserted 1.0 m from the soil cross-section to prevent the soil wall from collapsing.

Attachment of a pipe

Dragging starts at the soil cross-section
(The thicker pipe at the front is a guide pipe.)

Dragging of a pipe

A pipe drawn into the hollow (diameter 50 mm)

Fig. 4.4.10 Installation of a sub-surface drain pipe using the drilling unit

4.5 Benefits of shallow sub-surface drainage

The benefits of using shallow sub-surface drainage systems include:

- After leaching, infiltration water with high salt concentrations flow out of the field.
- After leaching, groundwater levels quickly fall.
- Post-leaching reduction in soil salt concentrations is enhanced.
- Crop yield increases.

With regard to these benefits, the following results were observed in the research field:

1) Drainage of leaching water

Water levels in the branch drainage canal to the side of the field where shallow sub-surface drainage had been introduced were lower than in the outlet, with the exception of periods over a few days when peak water levels occurred in the branch canal during the leaching period and infiltration water with a high salt concentration was being discharged from the field.

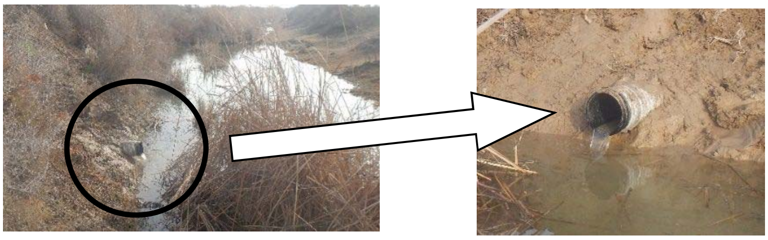
Based on our observations in the two times leaching activities, outflow from the outlet and the salt content of the discharged water (total dissolved solid: TDS) was estimated during the observation period (47 d). Leaching removed 1.5 t/ha and 14.3 t/ha of TDS from the field (corresponding to 3% and 25% of TDS in the layer of 0-60 cm) through 1^{st} leaching and 2^{nd} one, respectively (Table 4.5.1 and Fig. 4.5.1).

Table 4.5.1 Discharge from the outlet

	Input	Discharge	
Discharged water (m^3/ha) 1st year*	3,080**	350	11% of the total input flowed out of the field.
2nd year*	3,880**	1,590	41% of the total input flowed out of the field.
Discharged salt, TDS (t/ha) 1st year*	2.3***	3.8	1.5 t/ha flowed out of the field.
2nd year*	3.3***	17.6	14.3 t/ha flowed out of the field.

* Leaching period: 1st year Dec. 25, 2015 to Jan. 12, 2016, 2nd year Dec. 25, 2016 to Jan. 11, 2017
** Leaching water volume 1st year 2,500 m^3/ha, rainfall 580 m^3/ha, 2nd year 3,220 m^3/ha, rainfall 660 m^3/ha
*** TDS in leaching water and rainfall

The research field after leaching



Outlet on the wall of the drainage canal

Fig. 4.5.1 The research field during leaching and the terminal outlet

2) Effect on groundwater levels

Groundwater levels were lower in the field where the shallow sub-surface drainage system was introduced than in the control field following input of leaching water.

Changes in groundwater levels after leaching were compared between three points: a point away from the lateral drain (40 m away, Point A); a point near the cut-drain (2.5 m away, Point B); and a point near the lateral drain (3.6 m away, Point C). Leaching was carried out between January 3–5; average groundwater levels over the 10 d after leaching were 20 cm at Point A, 89 cm at Point B, and 68 cm at Point C below the ground surface; groundwater levels at Point B and Point C were 50–70 cm lower than at Point A (Fig. 4.5.2).

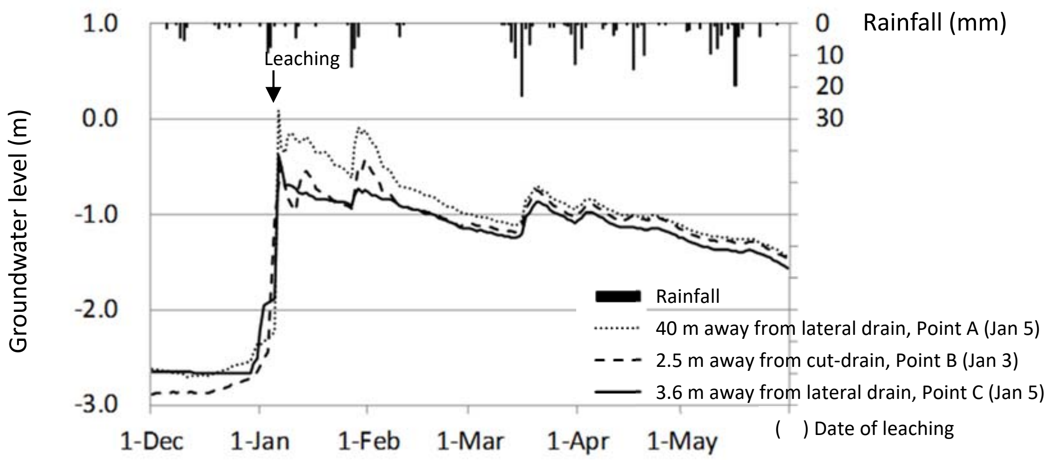


Fig. 4.5.2 Changes in groundwater level after leaching

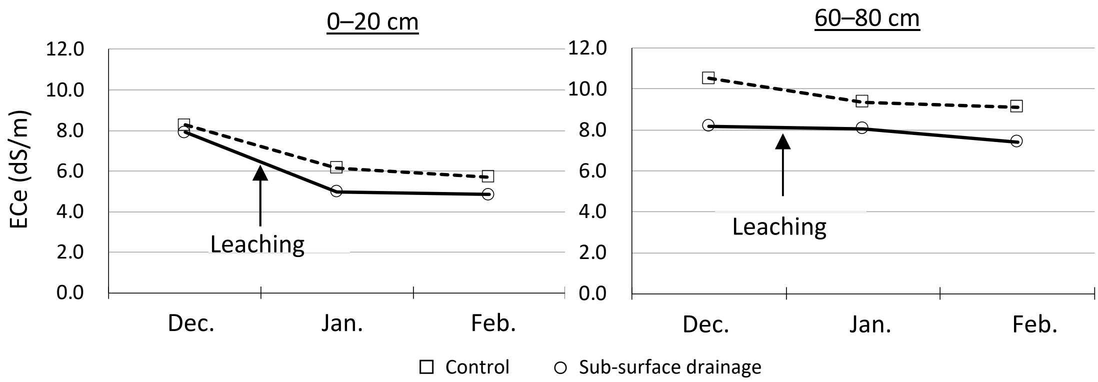
3) Reduction of soil salinity

Leaching removed more salt from the surface layer of the field with shallow sub-surface drainage than from the control field, but did not have any effect on soil salinity in lower layers.

Soil salinity (ECe) in two soil layers—the surface layer (0–20 cm, the main root zone) and the layer below the cut-drain (60–80 cm)—immediately before leaching (December), immediately after leaching (January), and before sowing (February) are shown in Fig. 4.5.3.

Soil salinity were consistently lower in the surface layer of the field in which the shallow sub-surface drainage system (and deep tillage) was installed compared with the control field. Comparisons between December and January—the months when the effects of leaching were most obvious—demonstrated that the soil ECe reduction rates in the field with shallow sub-surface drainage and the control field were 37% and 26%, respectively (based on the assumption that the rate in December was 100%).

On the other hand, in the layers below the cut-drain (60–80 cm), soil salinity was lower in the control field. This may be due to the flow of infiltration water following leaching out of the field in which the shallow sub-surface drainage system was installed, thereby reducing the rate of downward infiltration in this field.



Leaching period: Dec. 25, 2015 to Jan. 9, 2016

Fig. 4.5.3 Changes in soil salinity before and after leaching

4) Increase in crop yield

Cotton yield was higher in the field with shallow sub-surface drainage than in the control field.

Research on the effects of soil salinity on crop yield has generally demonstrated that crop yield declines as soil ECe increases. In this section, the results of our observations on the relationship between soil ECe and cotton yield in three research fields in Syrdarya (Farm A, Farm B, and Farm Y, Fig.4.5.4) are discussed.

On average, cotton yield was 2.1 t/ha (minimum 0.3 t/ha, maximum 4.5 t/ha) and ECe at harvest was 9.4 dS/m (minimum 2.9 dS/m, maximum 18.3 dS/m) (Fig. 4.5.5). Although there was some variation in the data, a negative correlation was observed between soil ECe and cotton yield; generally, an increase of 1 unit of soil ECe reduced cotton yield by approximately 4% (0.2 t/ha). However, soil salinity is not the sole reason for the decrease in yield since no correlation between ECe and cotton yield was also observed in some of the data; it indicates the involvement of factors other than ECe in yield variation.

On Farm A and Farm Y, where a shallow sub-surface drainage system had been introduced, the system resulted in an increase of cotton yield by approximately 20% (Fig. 4.5.6).

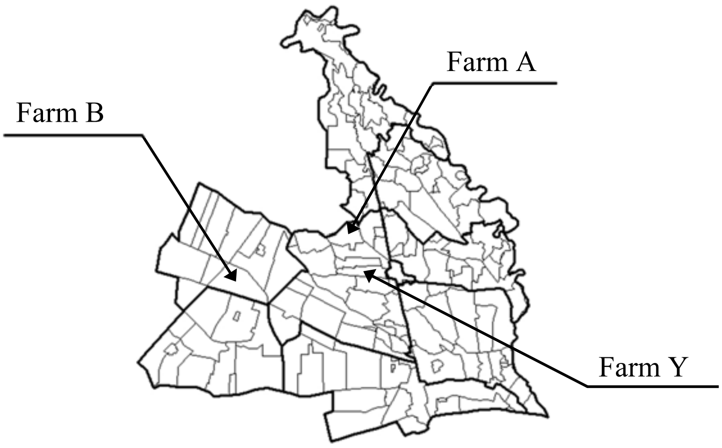


Fig. 4.5.4 Location map of research field in Syrdarya region

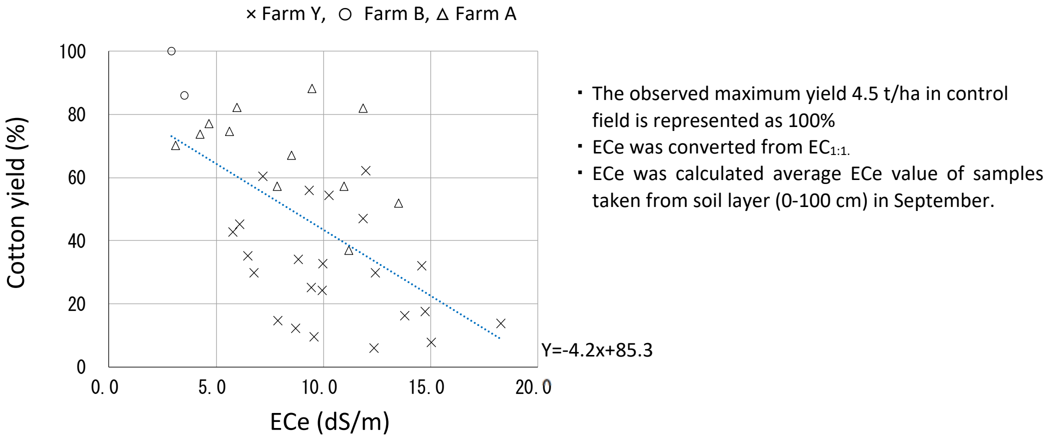


Fig. 4.5.5 Soil salt concentration and cotton yield (2016-2017)

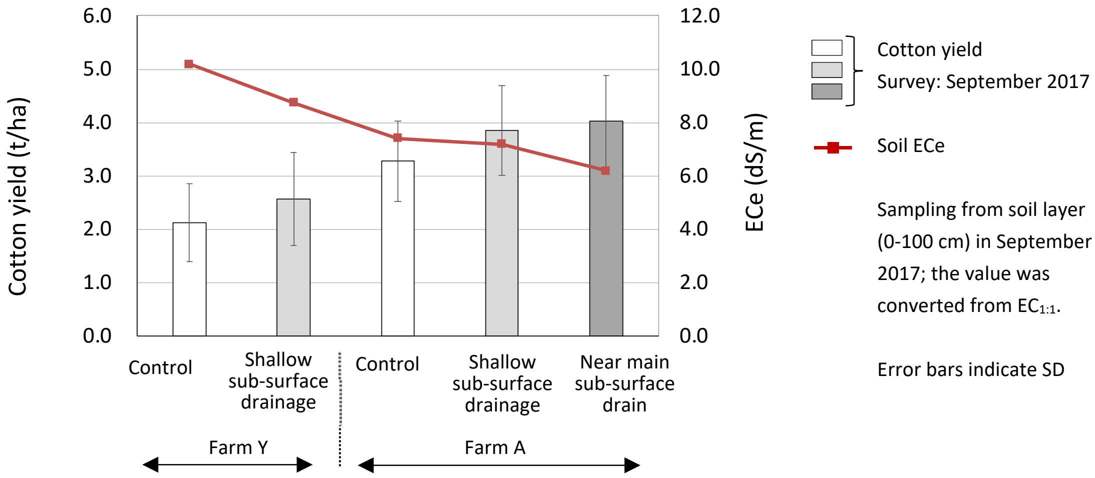


Fig. 4.5.6 Cotton yield in the field with sub-surface drainage

References

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2) Okuda Yukio, Goto Koki, Kitagawa Iwao（2015）, A Trial of Desalinization by Using Mole-Drain in Republic of Uzbekistan, Journal of JSIDRE, 83（7）, pp7～10（in Japanese）

3) Ministry of Agriculture, Forestry and Fisheries（MAFF） of Japan（2000）, Planning and Design Criteria for Land Improvement Project, Planning "Sub-surface Drainage", 184（in Japanese）

4) The Agricultural Upland Development Association（1989）, Sub-surface Drainage Q&A Precedent,468（in Japanese）

5) S.K. Gupta, Manual Subsurface Drainage for Waterlogged Saline Soil（2013）, CSSRI, 353

6) The Japanese Institute of Irrigation and Drainage （JIID）(1993), Engineering Manual for Drainage, Drainage

Chapter 5
SUMMARY AND RECOMMENDATIONS

Groundwater level or drainage water level can be maintained appropriately when existing drainage system is fully functional and the input of leaching water in winter is controlled. In case of sufficiently low water level, salinization could be mitigated through effective leaching. However, presently, a major gap is observed between the target and the current groundwater or drainage water level. Closing this gap is an important point to consider, and it is where agencies implementing desalination measures and research institutes involved in desalinization studies are expected to play a prominent role. While some improvements of field conditions have been realized because of each organization's efforts to achieve their targets, the reality is that there are still fields with problems that remained to be addressed in the future.

This manual recommends the use of shallow sub-surface drainage to mitigate salinization in fields with difficulties in achieving the above target; in those showing little improvement in groundwater or drainage water level; and in those with a high risk of salt accumulation. Generally, shallow sub-surface drainage technology requires a high density of perforated pipes, thus resulting in high construction cost; however, here, we plan to reduce this cost by using cut-drains developed in Japan.

We conducted a study to verify whether shallow sub-surface drainage technology (combining main sub-surface drainage and cut-drains) could expel salts contained in shallow groundwater and contribute to salt damage prevention and salt removal measures. The findings obtained through on-site verification tests are summarized below. As this was the first attempt to use cut-drains to remove salt from soil in an arid area, verification was carried out with some degree of trial and error.

5.1 Method for combining main sub-surface drainage and cut-drain

Even if cut-drains are created in soil with optimum moisture content, vertical voids may be created by the blade of the drain-drilling machine. A large volume of water may flow into these mole holes if irrigation water enters through the void and it becomes the preferential flow. As a result, if a mole hole collapses and soil accumulates in the mole hole, this in turn can lead to a reduction in drainage function. As it is unrealistic to expect cut-drain alone to function as shallow sub-surface drainage, it is more appropriate to combine them with the main sub-surface drainage.

In terms of combining these two methods, as mentioned in Chapter 4.4.4, it is economical to have the main sub-surface drainage cross at right angles to cut-drains. To explain this concept, it is helpful to liken these drains to the skeleton of a fish, with the spine being the main sub-surface drainage and the cut-drains being the small bones connected to the spine. In this particular case, it is desirable to have the main sub-surface drainage running perpendicular to the ridges, while having cut-drains running parallel to ridges. Normally, in cultivated land of uniform inclination or cultivated land where there are no irregular undulations, crops are sown in ridges parallel to the profile of the land. As irrigation water flows along the ridges from the higher point to the lower point, via the created cut-drains parallel to the ridges, water can flow toward the main sub-surface drainage.

5.2 Precautions concerning the application of cut-drains

In situations where cut-drains are used in arid areas, as compared with cases where they have been used in Japan, some constraining factors that need to be considered for cut-drains construction are indicated below. Furthermore, in the Syrdarya region, in order to be able to use cut-drains that can also function as shallow sub-surface drainage, that is, to maintain the shape of the mole holes, it is necessary to take measures to ensure the suppression of preferential flow and the provision of less water for irrigation.

- Recommended Time to Create Drains

If drains are made when soil moisture is low and the soil is hard, the blades of the drilling unit that is pulled behind a tractor will ride up, disabling the unit to construct drains. According to test results, a soil moisture content of 10–18 % is ideal for making cut-drains. It is therefore desirable to create cut-drains in March or April after the end of the rainy season but before the surface of the soil begins to dry, or at the latest, before the sowing of cotton seeds.

- Recommended Depth of Drains

Although the length of the blade on the drilling unit can be adjusted to a depth of between 60 and 120 cm by manipulating the degree of insertion of blades through its holes, if too much of the blade is inserted into the ground, resistance increases, and there is the possibility that the blade will bend. When we created a mole hole at a depth of 120 cm, the upper part of the blade became deformed. Therefore, the blade should be adjusted so that the mole hole is formed at a depth of approximately 60–90 cm beneath the surface of the ground.

- Recommended Length of Each Drain and the Intervals between Drains

Although this applies not only to arid areas, it is desirable to create drains on leveled land, as it is difficult to keep drains at a constant depth on undulating sites. The length of cut-drains is constrained by the topography of the land and the depth of the main sub-surface drainage; however, cut-drains are normally up to 200 m long. Although the standard interval between cut-drains in Japan is 2.5–5 m, when taking into consideration the planned sub-surface drainage volume, the permeability coefficient of the site, and thickness of the topsoil, the interval may be calculated to be around 4–18 m.

- Durability of Mole Holes

According to the Cut-drain Manual (Hokkai Koki Corporation), the durability period of mole holes in type L soil (loam with clay content of 25–37.4 %) is 2 to 3 years; thus, it is necessary to recreate them every few years. In the Syrdarya region, leaching occurs every winter, large amount of water passes through the mole holes; this event is suspected to shorten their durability even further. As it is more appropriate to use cut-drains in combination with main sub-surface drainage, it is desirable to reconstruct cut-drains when the flow rate through the main sub-surface drainage is reduced.

- Causes of Mole Hole Collapse

In the experimental fields, mole hole collapse in cut-drains was caused by irrigation water flowing through voids formed vertically in the soil strata, however, there were cases where mole holes collapsed even though no voids were detected. We will now consider why these voids are formed vertically and whether mole holes collapse in the absence of voids. Further, as the soil conditions under which it is possible to use cut-drains are specified, the soil types and mineral composition of the clay involved will be examined.

In Japan, it is reported that cut-drains are suitable for use in clay and peat soil, but not soil that is high in sand and silt. The soil texture of the experimental field is approximately 15 % clay, 25 % silt and 60 % sand, which means that it is classified as loam (L) and clay loam (CL) according to the International Society of Soil Science. Although Fig. 4.3.7 indicates that the soil texture of the experimental fields is within the range deemed amenable for cut-drain use, it is, in fact, on the borderline. On the other hand, according to the Cut-drain Manual (Hokkai Koki Corporation, Appendix 2), soil consisting 50 % or more of sand with a clay content of less than 24.9 % (soil types S and SL according to the Association of Japanese Agricultural Scientific Societies) is unsuitable for cut-drains, which means that the soil in the experimental fields is not amenable for cut-drain use. The adoption of cut-drains was attempted locally in fields with a higher clay content (11–25 %), but the mole holes collapsed when irrigation water was applied. The shapes of the mole holes that collapsed were mostly round with no sharp corners regardless of soil type, indicating that there was a tendency for nearly all of the mole holes to be buried.

The geology of the Syrdarya region, where the experimental fields are located, is said to be mudstone from the Tertiary period, which is characterized by a high level of slaking and swelling. Clay minerals characterized by swelling include halloysite in the kaolin group, montmorillonite, beidellite and nontronite in the smectite group, and vermiculite. As cracks are also observed on the surface of the soil after it has dried out after irrigation, it is suspected that the clay minerals in the soil are montmorillonite and beidellite from the smectite group.

It is conceivable that the phenomenon whereby vertical voids are formed immediately after cut-drains are formed is greatly influenced the contraction of clay minerals during the drying-out process. On the other hand, with regard to the phenomenon whereby mole holes collapse in the absence of vertical voids, we believe that this is due to the influence of soil type or slaking, although this was not able to be confirmed.

5.3 Shallow sub-surface drainage construction costs

The construction costs for the combination of the main sub-surface drainage and cut-drains as shown in Chapter 4. 4.4.2 are 2,970,000 UZS/ha (1,050 USD/ha). The breakdown is shown as below. Works and materials vary depending of the size and leveling condition of the field area, condition of open drainage connection, etc.

Item	1,000 UZ/ha
Earthworks (drilling/backfilling)	390
Materials: sub-lateral drains (perforated pipe Φ100 mm, including shipping)	1,250
Collecting drain (non-perforated pipe Φ100–150 mm, including shipping)	630
Filter material (rice husk including shipping and installation)	250
Cut-drain construction (tractor operation, fuel, etc.)*	200
Cut-drain drilling unit rental**	80
Other (wages for manual labor)	170
Total	2,970***

* Calculated based on field experience (constructed in November–December 2015)

** Depreciation assuming estimated durability of seven years over an annual land area of 50 ha.

*** Exchange rate: 2,825 UZS/USD as of December 2015

5.4 Shallow sub-surface drainage technology effectiveness

With regard to the effectiveness of shallow sub-surface drainage technology, further study will be required to validate the reliability and reproducibility of results. The results of a survey carried out one year after the commencement of the validation trial are summarized below.

- Amount of Salt Removed

According to the results of the on-site validation trial, the level of salt removal obtained using the shallow sub-surface drainage technology, which is a combination of main sub-surface drainage and cut-drains, was expressed as 3-25 % TDS from the field in the leachate after the leaching process. As there were no control sites to compare results from the experimental sites with, the salt-removing effect of the above-mentioned technology has yet to be verified. When the above result was compared with the 35.4 % of the TDS in the leachate observed with the indoor permeability test (Chapter 3 3.3), there was a big difference. Due to the fact that there was only one drain for each 4 ha site, it is conceivable that not all the leaching water was collected at that drain, and that water was leaking from other places. As the volume of salt removed varied according to the level of salinity of each site, it is difficult to compare the results between on-site and laboratory tests.

- Reduction in Soil Salinity

According to the results of the on-site validation trial, a comparison of the salt removal effect in the surface layer of the soil revealed that soil salinity after leaching was lower in the site where the shallow sub-surface drainage technology was introduced than in a similar site where the technology was not employed. However, this salt removal effect could not observed in the lower layers of the soil. It is thought that one of the reasons for this was that water in the leaching process seeped into areas outside the site, thus less water infiltrated to the lower layers.

- Cotton Yield

According to the results of the on-site validation trial, an increase in cotton yield was observed in the site where shallow sub-surface drainage was introduced when compared to a site where it was not used. The use of shallow sub-surface drainage resulted in approximately 20 % increase in cotton yield.

5.5 Downstream environmental impact

There is a possibility that the salt discharged from the site where salt removal was carried out will accumulate in a river or a different site located downstream. For example, if the salt is discharged to the Aral Sea, this will lead to the environmental pollution of the Aral Sea. If the salt is discharged to the Syrdarya River, then the salinity will be higher downstream, posing a serious risk of exacerbating salt damage in those areas. In the region where JIRCAS conducted tests, the salt discharged from the site entered Aydar Lake and not the Syrdarya River, thus the risk of causing problems was thought to be low; however, no investigation has been carried out to date.

TABLE OF CONTENTS & AUTHOR LIST

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The authors are grateful to following individuals for their cooperation and insightful comments that helped to improve this manual.

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Appendix 1

1. Background and history of the development of cut-drains

There is growing pressure in Japan for increasing production of upland crops, such as soybeans, wheat, and vegetables; at the same time, however, the frequency and intensity of both localized continuous and torrential rainfall are on the increase. As such, the drainage performance of farmlands must be improved, which requires a greater reliance on effective drainage infrastructure, such as sub-surface drains (consisting of drainage pipes and rice husk at a depth of 1 m). Such drainage structures have been incorporated into public installations; however, the extent of farmland area that can be included in such projects is limited. In addition, the effectiveness of sub-surface drains declines over time, posing a major challenge to farmers that use them.

Mole drains and subsoil breakage are common methods used by farmers to improve drainage performance in their fields, but these methods drain water through hollows and cracks shaped without the use of additional materials and, unlike sub-surface drains, cannot drain water from fields as they are created at a very shallow depth. This has led farmers to increasingly call for simple and affordable drainage solutions that are as effective as conventional sub-surface drains that require additional materials.

In response, the Institute for Rural Engineering (IRE) of the National Agriculture and Food Research Organization and Hokkai Koki Corporation have jointly developed and put into commercial use the cut-drain, a sub-surface drain-drilling unit that can use a unique drilling mechanism to construct durable water-conduction hollows at depths of up to 70 cm without the need for additional materials. Moreover, farmers can easily operate the unit by attaching it to a tractor. Currently, IRE and Hokkai Koki are promoting the benefits of the unit to producers.

2. Drainage performance of cut-drains and their effect on agricultural production

Cut-drains, like conventional sub-surface drains, direct water to a main drainage canal. Cut-drains have a peak discharge rate of 5 mm/h, which is equivalent to conventional sub-surface drains, and therefore function as effectively as traditional sub-surface drains. When installed in a field, cut-drains prevent the occurrence of surface ponding in rainy seasons, thereby helping to maintain environmental conditions conducive for the germination, tiller, and growth of cereals during early periods of plant development. Moreover, cut-drains help to maintain the growth of upland crops; soybeans, for example, have a low tolerance to excessive moisture (Photo 1). In suitable soils, cut-drains may sustainably increase upland-crop yields by 5–40%.

Field with cut drains

Field without cut drains

Photo 1 Drainage performance of cut drains and their effect on crops

Source: Kigatawa Iwao (2016), Mole-drilling Machine “Cut-drain” for Easy and Speedy Constructing Sub-surface Drainage without Material, Farming and Horticulture

Appendix 2

Drain-drilling machine

Cut-drain

KCDS-01 (1-gang type)

Instruction manual

Recommended for the following tractors:

- Crawler-type tractors, 60 PS and higher
- Tire (four-wheel drive) tractors, 70 PS and higher

We support agriculture with craftsmanship.

Hokkai KOKI

Hokkai Koki Corporation

22-4, Hoji, Kitami-shi, Hokkaido 099-1587

TEL 0157-36-6806 FAX 0157-36-6809

Introduction

Thank you for purchasing our Cut-drain.

- Do not use this Cut-drain for purposes other than those described in this instruction manual.
- Necessary items for the assembly, operation, and maintenance of the Cut-drain are described in this instruction manual. Please read carefully and understand this manual for correct and effective handling of the product.
- Please contact the person in charge for any unclear points.

Table of contents

- Details of the examples and drawings of the specifications, comments, or explanations in this document may be changed or improved without prior notice.

(1) For safe operation

⚠ Danger/Warning

- Carefully read and understand the instruction manual of the machine before using; otherwise, operating the machine may result in death or serious disability.
- Always store the instruction manual close to the machine. Operation/maintenance based only on individual judgment may result in unexpected accidents.
- Do not use the machine for purposes other than draining.
- Do not modify the machine.
- If you lend the machine to a third party, explain the handling procedure, functions, and points of operation indicated in this instruction manual. Hand over the instruction manual as well.

Before operation

- Do not operate or engage in drain work under the conditions below.
  - When you are sick, tired, or taking medicine
  - When you are drunk
  - When you are in poor physical condition for other reasons
- Wear clothes appropriate for work. Headbands, mufflers, and towels around the waist may be caught in the machine.
- Conduct work inspection to prevent accidents and operation failure. Do not disassemble indiscriminately if you are not sure how to do it, and address your request for repairs to us or the service agent nearest your office.

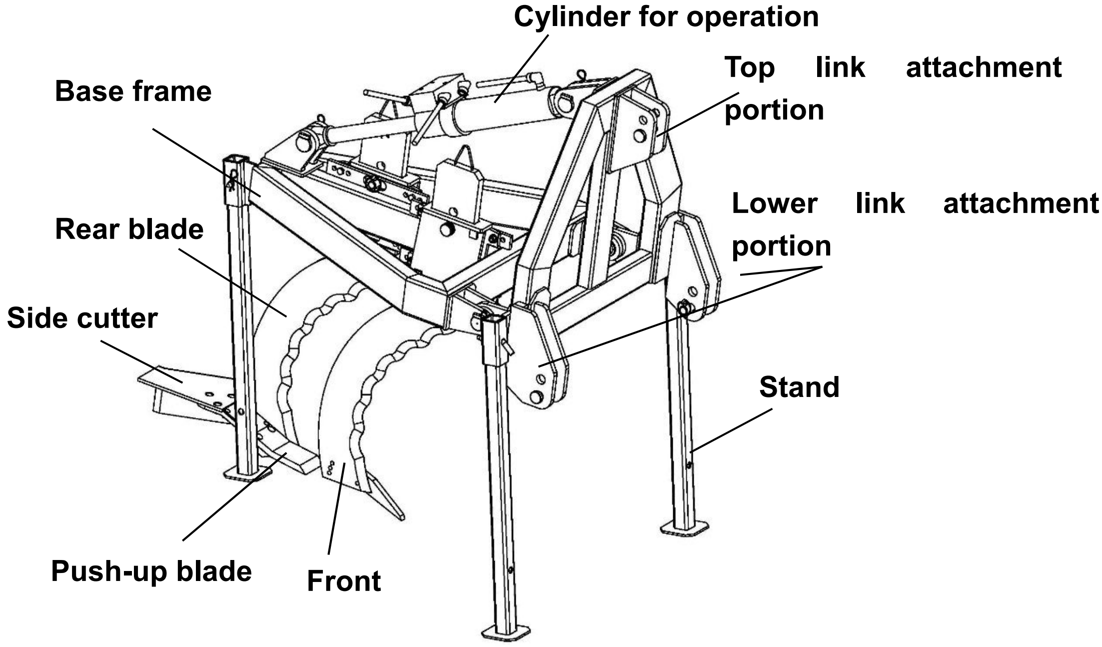
During operation

- Follow the instruction manual of the tractor for the operating method and operation guideline for the tractor.
- If a person stands between the tractor and the machine when you move or attach/detach the Cut-drain, such a person may be caught between components, which could lead to a serious accident.
- Do not climb on the main unit or place an object on it.
- Do not get under the machine or place your foot under it.
- Pay adequate attention to children; do not let them close to this machine.

After operation

- When cleaning, maintaining, or inspecting the machine, make sure that all moving elements have stopped.
- If there is any defect, repair it. If defects are left unfixed, they may cause troubles or unexpected accidents during the next time the machine is operated.

(2) Names and installation methods of components



⚠ Danger/Warning

- Select a flat and solid place when attaching/detaching the Cut-drain, and be alert toward any danger.
- Do not let any person stand around the tractor or between the tractor and the Cut-drain.
- Do not get under the Cut-drain or place your foot under it.
- Pay adequate attention to avoid getting your hands caught between the parts when locking the lower link shaft. Non-compliance may result in death or injury.

◆Attachment procedure

1. Connect the main unit lower link.
2. Connect the top link.
3. Connect the cylinder hose for operation.
4. Lift the entire unit, use the stand for support, and fix or remove the components.
5. Check the movement of the cylinder for operation.

(3) Maintenance

⚠ Danger/Warning

- Select a place that does not interfere with the traffic and is safe during inspection/maintenance. Select a flat and solid place where the machine does not move or topple, and use a wheel chock at the front wheels of the tractor.
- Pull the parking brake, shift the TPO gear lever to “Neutral,” and stop the engine during inspection/maintenance.
- Non-compliance may result in death or injury.

◆Inspection of loose bolts/nuts and hoses

- Inspect the bolts/nuts of each component for looseness, especially the bolts for attaching blades.
- Check for scratches or cracks on the hose of the hydraulic cylinder.

(4) Precautions during operation and proper operation method

⚠ Danger/Warning

- Do not let people get close to the tractor and the Cut-drain during operation.

★ Do not conduct rotating operation with the blades installed when driving the tractor.

◆ **For successful operation**

- The recommended speed of execution during construction work with the tractor is 2 to 4 km/h.
- The standard drilling intervals are 2.5 to 5 m.
  (This standard can be set according to the situation.)

★ Adjust the base frame of the Cut-drain to be parallel to the ground during operation using the top link.

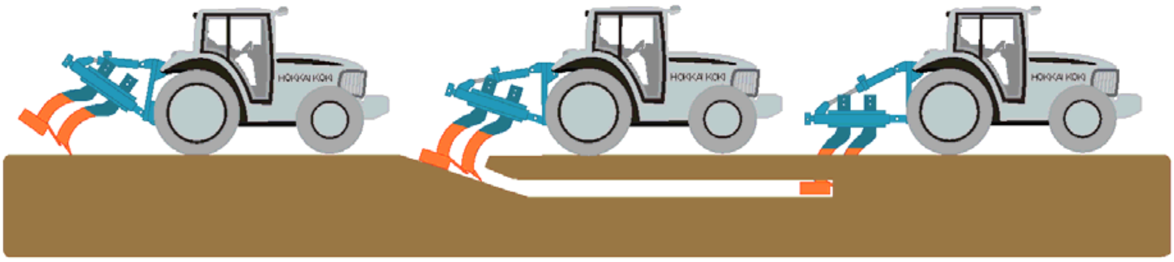
◆ **Applicable conditions**

- The Cut-drain is not applicable if the soil includes 50% or more sand or if the soil texture is S/SL (according to the method of the Association of Japanese Agricultural Scientific Societies). If the soil texture is L, the period of drainage durability is as short as less than two years up to three years; as such, measures such as re-execution of construction work every few years should be taken.
- The execution of construction work may not be feasible in gravel layers or layers with many pebbles larger than 5 cm or buried wood 5 cm in diameter.
- The Cut-drain is mainly used for converted fields, farmland, and grassland.
- As paddy fields have to be flooded, drains should be used as auxiliary drains connected to existing drains.
- Construction work in a paddy field should be executed in an oblique direction or the direction favoring the short side, with consideration for connections with existing drains.

Examples of execution of construction work

(1) How to apply the Cut-drain from the soil surface

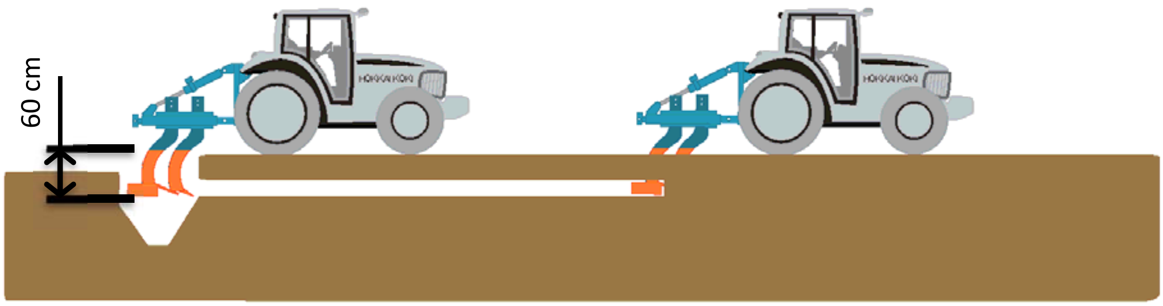
1. Shorten the cylinder.
2. Put in the Cut-drain by extending the cylinder.



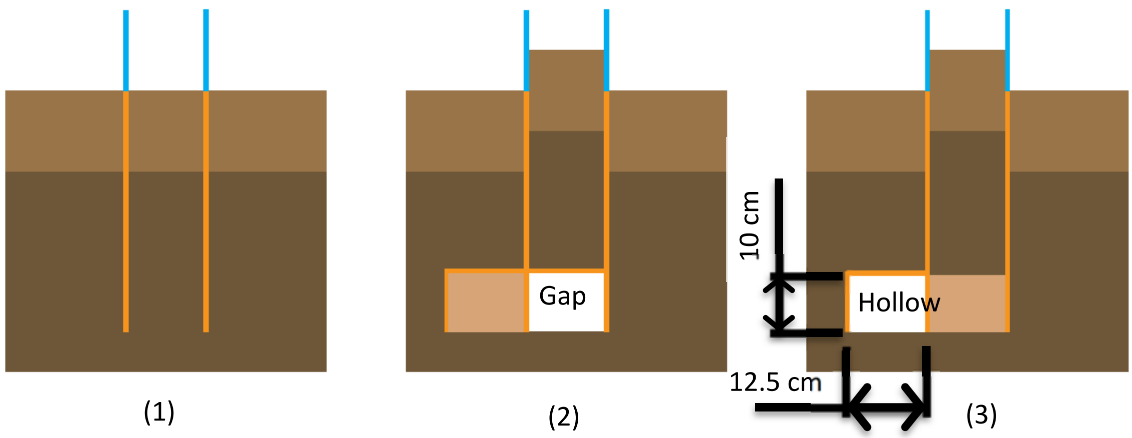
(2) How to apply the Cut-drain from a ditch

1. Place the Cut-drain in the ditch, and start the work.

(The orange part is 60 cm in depth.)



[Overview of the Cut-drain] Hollow: 10×12.5 cm



◆Construction techniques

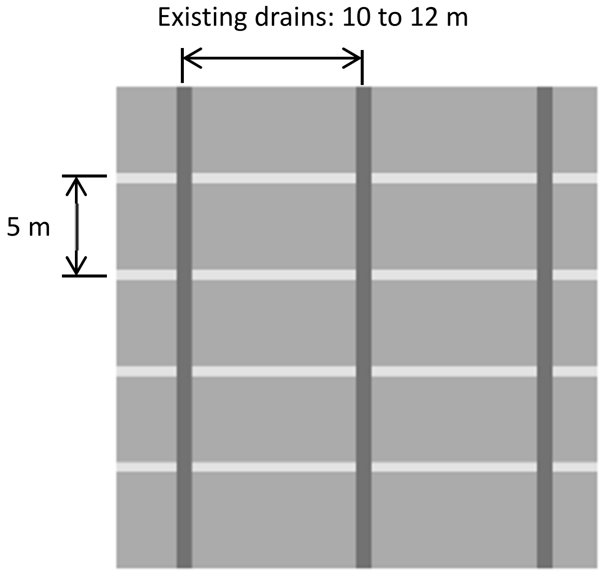
(1) When there is an existing drain

-The ideal execution style may be either Example 1 or Example 2.

-Execution may be started at a shallow part if the drain is buried at a shallow position. Execution may also be according to the same direction as the existing drain; connections may be built by crossing at right angles at a downstream part where the existing drain becomes deep.

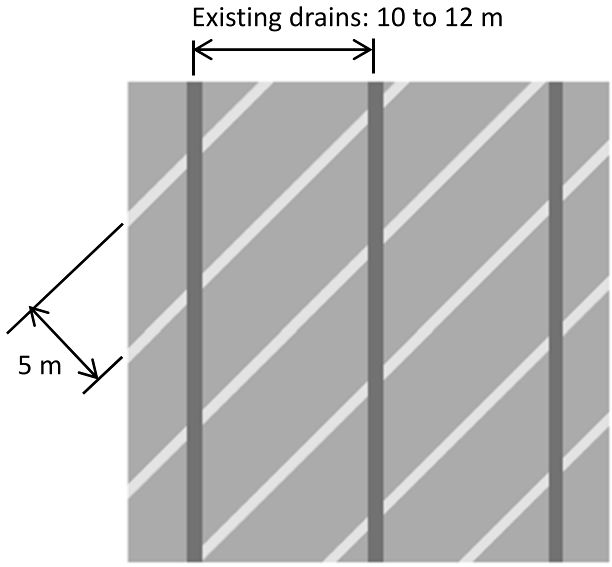
Example 1: Insert by crossing existing drains

In crossing existing drains, 5 m intervals are ideal.



Example 2: Insert by crossing existing drains at 45 degrees

In crossing existing drains at 45 degrees, 5 m intervals are recommended.

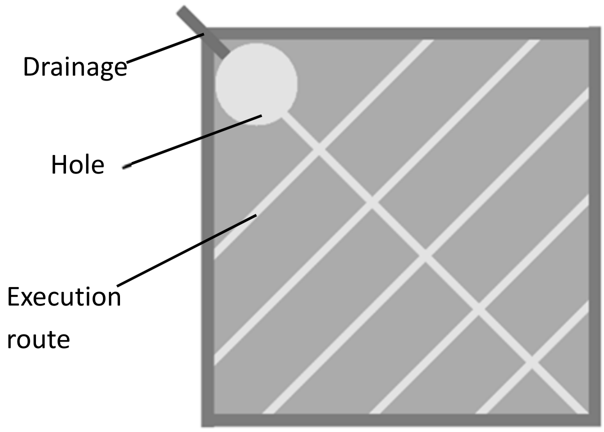


(2) When there is no existing drain

- If a drainage canal is made of concrete or other materials, and an outlet cannot be created via Example 3, create an outlet by digging a large hole around the joint of the drainage canal and then executing the Cut-drain from this hole. Dig a small hole in the drainage canal for water discharge from the gap of the concrete joint.
- Create an outlet by executing from the slope of the drainage canal as shown in Example 4.

Example 3: If an outlet cannot be created because the drainage canal is made of concrete or other materials

Dig a large hole around the joint of the drainage canal. Execute the Cut-drain from this hole to create an outlet.



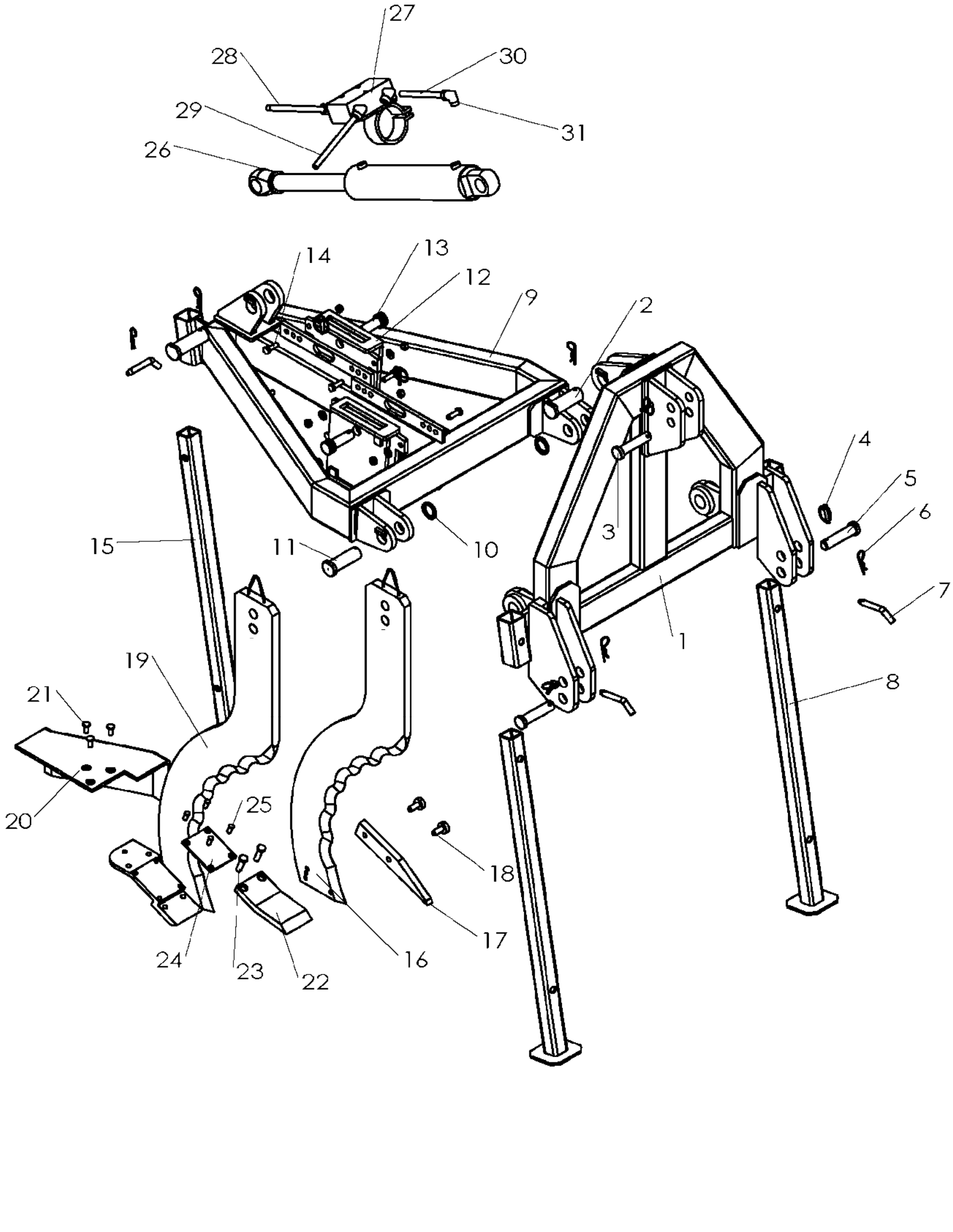
Example 4: Improvement of the outlet

As the outlet is the part that could most easily collapse, insert a resin pipe for drains (with holes of 50 to 75 mm in diameter) approximately 2 m from its end to protect the drain for a long period.

Other characteristics of the Cut-drain

- Can be used in emergency situations, such as removing surface puddles caused by continuous rain
- Can be executed according to the different soil conditions of farmland and cultivated fields in different areas

(5) Parts list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Number	Part number	Part name	Quantity	Unit price	Remarks
1	KD-1-0001	Front frame	1		
2	KD-1-0002	Cylinder pin	2		
3	KD-1-0003	Top link pin	1		
4	KD-1-0004	Reach pin	5		
5	KD-1-0005	Lower link pin	2		
6	KD-1-0006	Hook pin	5		
7	KD-1-0007	Stand lock pin	3		
8	KD-1-0008	Front stand	2		
9	KD-1-0009	Base frame	1		
10	KD-1-0010	Ring	2		
11	KD-1-0011	Frame mounting pin	2		
12	KD-1-0012	Blade holder	2		
13	KD-1-0013	Blade mounting pin	2		
14	KD-1-0014	M12 hexagon head bolt	8		Washer, nut
15	KD-1-0015	Base stand	1		
16	KD-1-0016	Front blade	1		
17	KD-1-0017	Point blade	1		
18	KD-1-0018	M16 flat head bolt	2		
19	KD-1-0019	Rear blade	1		
20	KD-1-0020	Side cutter	1		
21	KD-1-0021	M12 flat head bolt	3		Washer, nut
22	KD-1-0022	Push-up blade	1		
23	KD-1-0023	M16 carriage bolt	2		Washer, nut
24	KD-1-0024	Push-up plate	1		
25	KD-1-0025	M8 slick bolt	4		Washer, nut
26	KD-1-0026	Hydraulic cylinder	1		
27	KD-1-0027	Check valve	1		
28	KD-1-0028	Hydraulic hose A	1		3/8, 500 mm
29	KD-1-0029	Hydraulic hose B	1		3/8, 1,950 mm
30	KD-1-0030	Hydraulic hose C	1		3/8, 2,050 mm
31	KD-1-0031	Coupler	2		3/8
32	KD-1-0032	Special-purpose paint	1		Blue





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