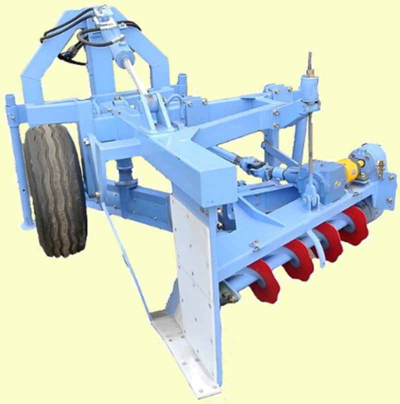
JIRCAS-2022/001

Cut-soiler constructed Preferential Shallow sub-surface drainage for mitigating salinization

User’s Guide



Japan International Research Center for Agricultural Sciences (JIRCAS)
Indian Council of Agricultural Research (ICAR)
ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI)

13th March 2023

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Published by

Japan International Research Center for Agricultural Sciences (JIRCAS)
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Abstract

In dryland, irrigation is essential for agricultural production. However, salinization induced by irrigation and insufficient leaching is a serious problem in arid to semi-arid regions. Indo-Gangetic plains (IGP) located in North part of India is currently suffering from serious salinization. The salt affected soil area extends to approximately 6.7 million ha. Of these, 3.78 million hectares are sodic soils. Development of sodicity and subsurface sodicity even in reclaimed soils of these semi-arid tropics is a chemical degradation process. When salt gets accumulated in the soil, a huge manpower and funds are required to reclaim such salt affected farmland. Therefore, as the first and important step of measures against salinization is the prevention of salt accumulation. The main causes of salt accumulation due to irrigation agriculture are use of high salinity water, excessive irrigation, and poor drainage. Therefore, applying technologies which save irrigation water and improve drainage function can be effective in preventing salinization. However, these technologies such as drip, sprinkler, sub-surface drainage require a lot of funds and maintenance cost. Considering this situation, in order to realize sustainable agriculture, it is necessary to establish low-cost water management technologies which farmers can practice with ease. Therefore, we decided to focus on utilizing tractor mounted machine for improving drainage function and modifying furrow irrigation to reduce the cost of measures.

Japan International Research Center for Agricultural Sciences (JIRCAS) and ICAR-Central Soil Salinity Research Institute (CSSRI) India are working in collaboration to develop low-cost techniques for the management of saline soils of India for sustainable agricultural production from 2018. The “Cut-soiler” a tractor mounted machine that constructs residue filled preferential shallow sub surface drainage was introduced to India under this collaborative project. In addition, as water-saving technologies, Permanent Skip Furrow Irrigation (PSFI) and Simplified Surge Flow Irrigation (SSF) were introduced and being evaluated.

In this User’s Guide, explains how to apply these technologies and shows their effectiveness on salt-affected farmland.

Keyword

Drylands, Salinization, Sub-surface drainage, Water-saving

Preface

Agriculture is by far the largest consumer of the Earth's available freshwater. Seventy percent of freshwater withdrawals from surface water and groundwater sources are for agricultural usage. This volume is consistently increasing as it has grown by three times in last 50 years. Asian countries share ~70% of the total surface and groundwater withdrawals of the world. Freshwater resources and global public goods should be conserved to meet the demand of the increasing world population and the consequent cereal consumption. These resources should be sustainably maintained through development and effective utilization of technologies and well-crafted regulations, especially in areas where resource availability is highly fluctuating.

Japan International Research Center for Agricultural Sciences (JIRCAS), Indian Council of Agricultural Research (ICAR) and ICAR-Central Soil Salinity Research Institute (CSSRI) India are working in collaboration to develop low-cost techniques for the management of saline soils of India for sustainable agricultural production. For this the Memorandum of Understanding (MoU) has been signed to undertake the research projects entitled, "Development of Sustainable Resources Management Systems in the water-vulnerable areas in India" and "Development of sustainable land management technologies under extreme weather conditions in drylands". The "Cut-soiler" a tractor mounted machine that construct residue filled preferential shallow sub surface drainage was introduced to India under this collaborative project. ICAR-Central Soil Salinity Research Institute has vast expertise and experience in management of salt affected soils and use of saline water in agriculture in India. JIRCAS and ICAR-CSSRI are undertaking a series of lysimeter (controlled) and field scale experiments for developing sustainable technological measures to improve resource use efficiency of salt affected soils since 2018. This User's Guide is based on the evidence and research outcome of this collaborative study.

It is my great pleasure to publish this User's Guide. I sincerely hope that this User's Guide will prove useful for the Indian farmers to manage soil salinity in their farmlands. Although JIRCAS's research collaboration with Indian institutes have only a short history, I expect it to expand and deepen, and hopefully lead to the development of sustainable and resilient food production systems that contribute to improving the lives of people in India and other countries.

Dr. HAYASHI Keiichi
Program Director, JIRCAS

भा.कृ.अनु.प.
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Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resources Management)

15.02.2023

Message

Soil salinization is a land degradation process that adversely affects agricultural lands and crop production on >900 M ha across globe and 6.73 M ha in India. Climate change is further posing a serious challenge by aggravating the salinization process. In this regard, ICAR-CSSRI has been engaged in developing and disseminating technologies such as salt leaching, and adopting improved agronomic, irrigation water and nutrient supply practices, alternate land uses and use of salt tolerant crops and varieties. Over the years, the technology was passed on to the state governments and as a result of which about 2.07 M ha area of alkali soils have been reclaimed till now.

But still there are lots of scope to improve our approach towards reclamation. When salt gets accumulated in the soil, a huge manpower and funds are required to reclaim such salt affected farmland. Therefore, as the first and important step of measures against salinization is the prevention of salt accumulation. The main causes of salt accumulation are use of high salinity water, excessive irrigation, and poor drainage. This demands, developing technologies which save irrigation water and improve drainage function can be effective in preventing salinization. At the same there is an increasing understating among the nations to collaborate towards finding alternative to these problems.

Japan International Research Center for Agricultural Sciences (JIRCAS) and ICAR-Central Soil Salinity Research Institute (CSSRI) India are working in collaboration to develop low-cost techniques for the management of saline soils of India for sustainable agricultural production from 2018. JIRCAS-ICAR-CSSRI launched a project on; "*Development of Sustainable Resource Management Systems in Water Vulnerable Regions of India*" that has been a great experience for all involved. It has been filled with new learnings, international solidarity, and the start of a vision for how collaborative spirit in the agricultural science might achieve big things for productive utilization of the salt affected lands. This experience is reflected in this monograph that contains a cross-section of writings from the project-detailing the research with a summary of learnings for research experiences in the salt affected areas.

The efforts of Dr. RK Yadav, Dr Gajender and whole team in compilation, editing and publishing of this User's Guide are commendable. I am convinced that the information furnished in this report will provide valuable insights to the readers about the current R&D efforts, trends and constraints in salinity management in agriculture.

(S.K. Chaudhari)

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Preface

Soils, made up of inorganic and organic compounds, liquid, gases, living organisms, and soluble salts, are a natural surface feature of the landscapes. Salts are present usually in small amounts in all waters, soils and rocks. Under certain conditions, these salts accumulate by process of salinization. Thus, soil salinization is the accumulation of water-soluble salts within soil layers above a certain level that adversely affects crop production, environmental health, and economic welfare. Soil salinity is generally described and characterized in terms of the concentration and composition of the soluble salts. Even though soluble salts are inherent in all soils, there are many processes (such as weathering of soil minerals, salt added through rains, agronomic practices such as fertilizer and pesticide application and irrigation with poor-quality waters, saline groundwater intrusion with water table fluctuations, dumping of industrial and municipal waste, etc.) that contribute to the buildup of salts in profile. In coastal areas, due to increase in sea level, seawater intrusion onto land deposits a large amount of salts in soil. Salt is also carried through wind and deposited on vegetation and soil in these areas. Thus, all soil types with diverse morphological, physical, chemical and biological properties may be affected by salinization.

Soil salinity is one of the major and widespread challenges in the recent era. It hinders global agricultural production, food security, biodiversity, and environmental sustainability in the arid and semi-arid regions of the world. Globally, more than 900 million hectares of land, accounting for nearly 20% of the total agricultural land and 33% of the irrigated agricultural lands is affected by salinity. Furthermore, waterlogged and coastal areas are vulnerable to salinity development often due to sea water intrusion and inundation, which again relate to global climate change. The salt stress in soil is becoming prominent due to the ever-increasing global population pressure, intensive agricultural practices and climate change over decades. New challenges are set to be faced either due to changing climate or land use anomalies, leading to exponential increase in the area under salinity in the coming decades.

The Central Soil Salinity Research Institute (CSSRI), an Indian Council of Agricultural Research (ICAR) Institute at Karnal, Haryana (India). During its journey of more than 50 years, since its inception in 1969, it has made impressive contributions in development of technologies for reclamation and management of salt affected soils and poor quality waters. We can speak on behalf of the entire project team that the JIRCAS-ICAR-CSSRI project has been a great experience for all involved, filled with new learnings, international camaraderie, and the start of a vision for how collaborative spirit in the agricultural science might achieve big things for the salt affected areas. We hope that the publication would be of immense use to researchers in planning their future line of research.

This user's guide summaries the experiences of salinity management using novel approaches in which crop residue is utilized to construct preferential shallow sub surface drains using Cut-soiler. Further it is providing an insight on the operation of Cut-soiler machine by the end users.

Authors

Acknowledgments

The academic information provided in this User's Guide was outcome of collaborative research between Japan International Research Center for Agricultural Sciences (JIRCAS), Indian Council of Agricultural Research (ICAR) and Central Soil Salinity Research Institute (CSSRI). The research has been implemented with great support of ICAR and CSSRI team involved in this project. We are grateful to the contributions of the concerned organizations and several individuals.

We are also deeply indebted to many other organizations and individuals for their assistance, including, but not limited to, the *KVKs (Kirish Vigyan Kendras)* located nearby the project experimental sites in Haryana and Punjab, *Progrowers producer company limited*; *SGT University, Gurgaon*; *Japan Embassy*; *Japan International Cooperation Agency (JICA)*; and *Institute for Rural Engineering, National Agriculture and Food Research Organization (NARO), Japan*.

This is only a partial list of the organizations, agencies, and personnel to whom we would like to offer our heartfelt gratitude.

Finally, we would like to express our appreciation for logistical support obtained, in planning, execution, data recording, analysis and interpretation of the results, from all the project team staff of ICAR-CSSRI, Karnal, India.

Contents

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Abbreviations

CSSRI	Central Soil Salinity Research Institute
FAO	Food and Agriculture Organization of the United Nations
ICAR	India Council of Agricultural Research
JIRCAS	Japan International Research Center for Agricultural Sciences

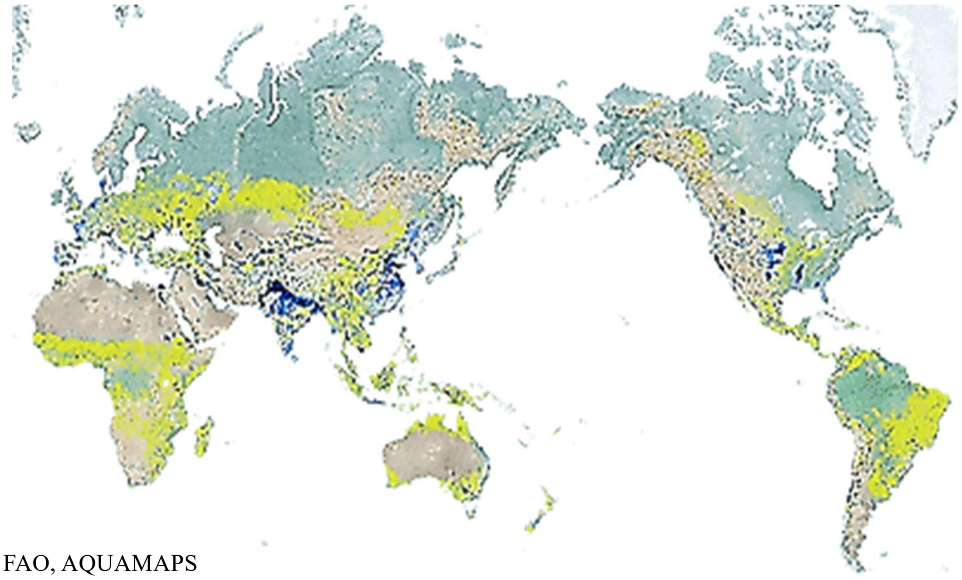
Terms used in the User's Guide

Groundwater level:	distance between the surface of groundwater and that of the soil surface
Root zone:	soil layer in which crops extend their roots to absorb soil moisture
Infiltration loss:	unused water that infiltrates the soil below 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 collected sub-surface drainage water to the open drainage
Filter material:	Permeable material which is set above the perforated pipe that facilitates 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:	In this User's Guide, facility which accelerates to remove infiltrated water/shallow groundwater by burying pipe at 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 drainage pipe then convey drain water to downstream
Supplementary drain:	Drain which assists a function of water way to the main sub-surface drainage for making quick drainage from surface layer
Water content:	Ratio of the water to the dry weight of the soil

1. Introduction

1.1 Background

Irrigated agriculture had enhanced agricultural productivity and significantly contributed to the global food security. Especially in arid and semi-arid regions with low precipitation, irrigation is essential for agricultural production. **Figure 1-1** is showing the percent irrigated area in different regions of the world.



Source: FAO, AQUAMAPS

🟩 < 2% irrigated or, rainfed 🟦 2-10% 🟦 10-25% 🟦 25-50% 🟦 50-75% 🟦 75-100%

Figure 1-1 Percentage of irrigated area in different regions of the world

Irrigation has dramatically improved agricultural productivity, but improper water management such as over-irrigation and poor drainage has caused salinization. Salinization is one of the major abiotic stresses that reduce agricultural productivity and cause soil degradation. The area estimation of salt affected soil varies depending on the report, but it is generally about 1 billion ha, which is equivalent to about 7 % of the land area of the earth.

Table 1-1 Countries with the largest areas salinized by irrigation

Country	Area (M ha)
Pakistan	7.00
China	6.70
United States of America	4.90
India	3.30
Uzbekistan	2.14
Iran (Islamic Republic of)	2.10
Iraq	1.75
Turkey	1.52

AQUASTAT different years and Ghassemi (1995)

Source: Agriculture and water quality interactions, a global overview (2011)3)

Salinization has increased dramatically in recent decades (Ruth et al., 2012)1), causing large economic loss. It is estimated that an economic loss of 27.3 billion dollars is likely to ensue if salinization occurs in 20 % (about 60 million ha) of about 310 million ha of irrigated farmland (Qadir et al., 2014) 2).

FAO estimates the salinization area due to irrigation for each continent to be approximately 30 million ha worldwide. Pakistan, China, the United States, India, Uzbekistan, etc. are listed as countries with large salinization area (**Table 1-1**) (Mateo and Burke., 2011)3).

Following are the most known regions where salt-induced land degradation occurs (Joint research centre of European commission, 2018)4):

1. Aral Sea Basin (Amu-Darya and Syr-Darya River Basins) in Central Asia
2. Indo-Gangetic Basin in India
3. Indus Basin in Pakistan
4. Yellow River Basin in China
5. Euphrates Basin in Syria and Iraq
6. Murray-Darling Basin in Australia
7. San Joaquin Valley in the United States.

FAO reported that 1 - 2 % of irrigated farmland is lost every year due to salinization, the impact of which is particularly significant in arid and semi-arid regions land (FAO, 2002)5). **Figure 1-2** shows the global distribution (%) of salinization caused by irrigation.

Source: FAO, AQUAMAPS 🟨 < 2% 🟧 2 - 5% 🟥 > 5%

Figure 1-2 Proportion (%) of land salinized due to irrigation

As shown above, salinization is a serious issue in arid and semi-arid regions. Therefore, establishment of sustainable countermeasures against salinization is urgently needed.

1.2 JIRCAS-ICAR-CSSRI collaborative research

In order to develop sustainable technological measures against soil salinization, Japan International Research Center for Agricultural Sciences (JIRCAS) has been conducting a collaborative research in India since 2018 under ***"Development and sustainable resources management systems in water-vulnerable areas of India".*** The collaborative research partner institute in India is the Indian Council of Agricultural Research (ICAR) - Central Soil Salinity Research Institute (CSSRI), Karnal. The ICAR is a nodal agency for agricultural research and development in India. It works under Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmer's Welfare (Govt. of India). ICAR-CSSRI is a specialized institute for the research and development on management of salinity problem in India since 1970 as a premier salinity research institute. ICAR-CSSRI has made significant progress in developing piped sub-surface drainage technology to improve drainage function for salinity management. However, there are some constraints such as the need for heavy machinery, the high cost, the requirement for safe treatment of large volumes of high-salinity effluent, and large area requirement for execution that need community approach. Therefore, this collaborative project especially aimed to develop low-cost and easy to use technologies for management of dryland salinity and surface waterlogging. We focused on residue filled preferential shallow sub-surface drainage system using Cut-soiler, a tractor mounted machine developed in Japan. Furthermore, taking measures against salt loading from irrigation and depletion of water resources due to poor quality groundwater irrigation, water-saving irrigation techniques were also examined. This User's Guide contains compiled output of 4 years collaboration research (from 2018 to 2021).

1.3 How to use User's Guide

The main purpose of this User's Guide is to provide information to governmental officials, agricultural researchers, extension staffs and farmers about residue filled preferential sallow sub-surface drainage technology using Cut-soiler. This information was obtained from the series of scientific studies conducted in lysimeters and fields at representative salt affected sites in India that has high risk of salt accumulation. It also aims to promote a better understanding of mechanism of salinization and its management strategies.

REFERENCES

1. Ruth, C.M., Kira, G.C., James, C. B., James, E. D. (2012). Identification and characterization of a salt stress-inducible zinc finger protein from Festuca arundinacea. BMC Research Notes. 5, 66. doi: **https://doi.org/10.1186/1756-0500-5-66**
2. Qadir, M., Quillérou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R. J., Drechsel, P., Noble, A. D. (2014). Economics of salt-induced land degradation and restoration. Natural Resources Forum 2014. 38, 282-295. doi: **https://doi.org/10.1111/1477-8947.12054**
3. Mateo, S, J., and Burke, J., (2011): Agriculture and water quality interactions, a global overview, SOLAW Background Thematic Report-TR08, FAO, Rome, pp. 11-24
4. Joint research centre of European commission (2018): World Atlas of Desertification, Third Edition, Rethinking land degradation and sustainable land management, pp. 1-248
5. Food and Agriculture Organization of United Nations (FAO) (2002): The salt of the earth, hazardous for food production
6. Food and Agriculture Organization of United Nations (FAO) and Earthscan (2011): The State of The World's land and Water Resources for Food and Agriculture (SOLAW), Managing systems at risk, FAO, Rome, Earthscan and London, pp.19-60, 101-134

2. Salinization

2.1 What is salinization

Salinization occurs through the accumulation of salts in the root zone that prevents crop plants from absorbing enough water and interferes in balanced nutrition, leading to reduction in yields. When salinization affects 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 is one of the contributors to the soil degradation, and without appropriate control measures, salinization tends to worsen, and in severe cases cultivation may have to be abandoned. It is important to suppress salt accumulation and remove accumulated salt from rhizosphere soil profile for mitigating salinization.

Figure 2-1 Salt accumulation

Salinization can be broadly categorized in two types; 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 (e.g., irrigation and excessive fertilizer application). This User’s Guide aims to address secondary salinization which is strongly related to agricultural irrigation, especially in arid and semi-arid regions.

<u>Mechanisms of salinization</u>

There are mainly two factors of salt accumulation under irrigated agriculture, input of salts from irrigation water and rising groundwater levels due to poor drainage (**Figure 2-2**). In surface irrigation such as border irrigation, furrow irrigation, large amount of irrigation water is not fully utilized by crops, the excess water infiltrates to the deeper layer below root zone. The maximum application efficiency of surface 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 crops, and most of this excess water is stored underground with salts. In addition, because many aquifers cannot absorb or transport this water, the water table frequently rising up close to the soil surface, then, a phenomenon that is commonly known as "*waterlogging*" or "*capillary* rising" occurs. In most soils with shallow water tables, groundwater rises up to the root zone through capillarity rise and, if the water contains salts, it becomes a continuous source of salt exposure. The extent of salt accumulation in soils from uncontrolled shallow groundwater depends on irrigation management, depth of the water table, soil type, and climatic conditions.

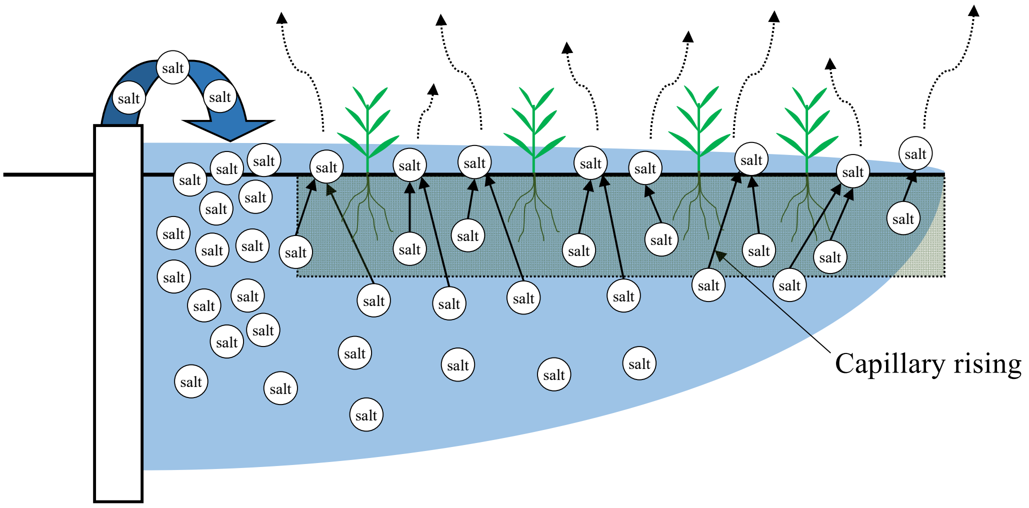


Figure 2-2 Main cause of salt accumulation on irrigated agriculture

Waterlogging

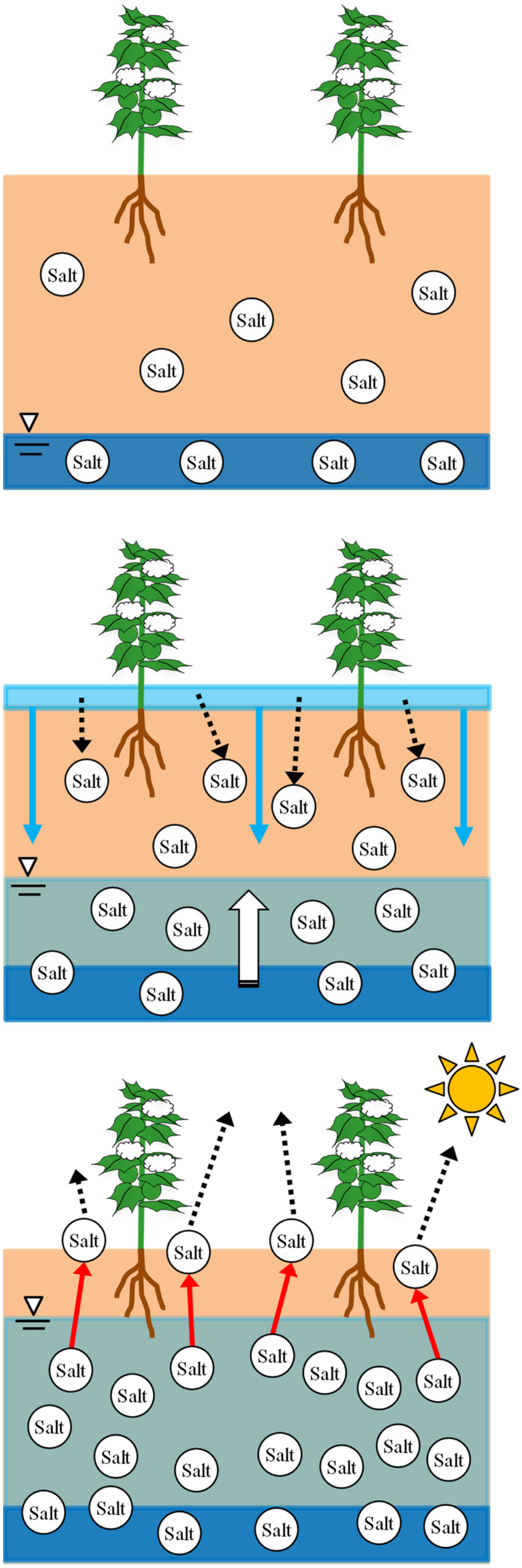
Waterlogging is caused by soil saturation due to flooding or rise of groundwater table. Farmland is regarded as waterlogged when the water table is too high for farming, reduces yields, impedes the use of farm equipment, and compacts the subsoil.

Waterlogging is detrimental to agriculture 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.

Capillary rise

Capillary rise 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 towards the soil surface, saline soil moisture is transferred from the groundwater to the soil surface by capillary rise, where it evaporates, thereby depositing salt in the root zone (**Figure 2-3**).



Originally, soil and irrigation water contain the salt.

Groundwater level rises due to poor drainage or excessive irrigation. Then, the groundwater salinity become higher due to inflowing of irrigation water containing salt and resolution of salt form upper soil layer.

When the groundwater level rises further, capillary action occurs, ground water moves to soil surface and evaporate leaving the salt.

Figure 2-3 Process of salt accumulation

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.

Electrical 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 2-1 Types of electrical conductivity

Type	Method of measurement
EC_w	Electrical conductivity of water
EC_{sw}	Electrical conductivity of soil water
EC_e	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

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.

Total dissolved solids

TDS represents the concentration of a substance dissolved in water. It measures the weight per unit 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 dissolved in water are present in ionic state. Ions are electrolytic substances which can conduct the 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.

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 2-2**).

Table 2-2 Water salinity levels

Source / Use	ECw (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
Seawater	50.00
The Dead Sea	555.00

Source: Taylor 1993

The principal salinity classification of water by EC is shown in **Table 2-3**.

Table 2-3 Salinity level of water

Salinity level	ECw (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)

Classification of salt-affected soil

Salt-affected soils are classified as either saline or sodic soil, depending on the amount and composition of salt it contains (**Table 2-4**). Saline soil is characterized by high levels of soluble salts, 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 soils. The soils of arid regions are rich in chlorides and sulphates (e.g., sodium, calcium and, magnesium), 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, as a consequence of more water potential, by the plants. 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 2-4 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, $\mathrm{mmol_c}$/L, or mmol/L.

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

$$\mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\frac{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}}{2}}} \qquad (\mathrm{meq/L},\ \mathrm{mmol_c/L})$$

$$\mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}}} \qquad (\mathrm{mmol/L})$$

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 2-4**) is categorized on the basis of pHe and ECe (**Figure. 2-4**).

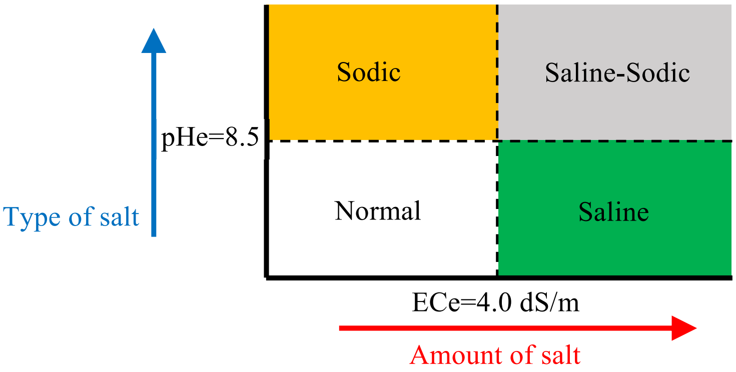


Figure 2-4 Classification of salt-affected soil, based on pHe and ECe

The principal soil salinity level by soil EC is shown in **Table 2-5**

Table 2-5 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	Yields of tolerant crops are satisfactory
Extremely	>16	>4.70	>1.5	>1.8	Yields of high 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)

Crop tolerance

Soil salinity causes poor, uneven, and stunted crop growth; reduces yields, depending on the degree of salinity. It also 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 2-6**.

Table 2-6 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*	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 = 0.9 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 loss) 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.

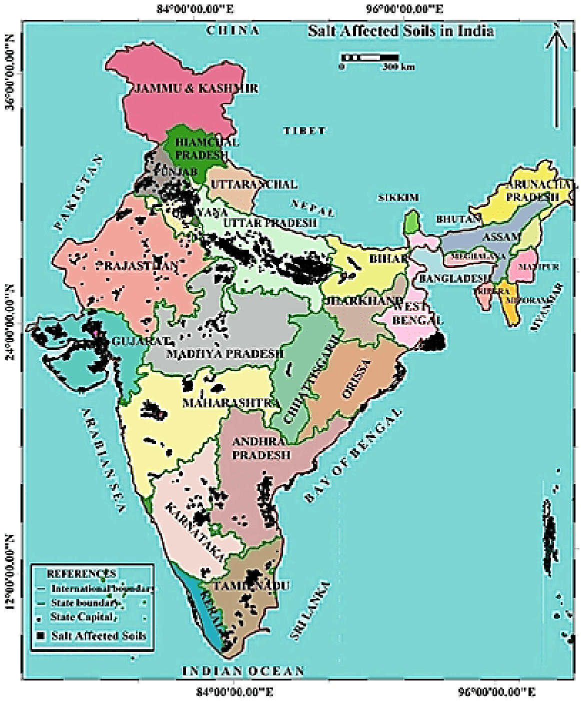
8) Average for the Boer, ~Yilman, Sand, and ~Veeping varieties. Lehman appears about 50% more tolerant.

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).

2.2 Salinization in India

In India, the extent of salt affected soils is 6.7 million ha, and 32 - 84 % of the groundwater resources are poor quality. This represents a serious threat to country's ability to increase food production to meet the expanding needs. India loses annually 16.84 million ton of farm production valued at Rs 230.2 billion due to salt affected soils (Mandal et al., 2010; Sharma et al., 2015). Around 6.727 million ha area in India, which is around 2.1% of geographical area of the country, is salt-affected, of which 2.956 million ha is saline and the rest 3.771 million ha is sodic (Arora et al., 2016; Arora and Sharma, 2017).



No.	States	Saline	Sodic (ha)	Total
1	Andhra Pradesh	77,598	196,609	274,207
2	Andaman & Nicobar Island	77,000	0	77,000
3	Bihar	47,301	105,852	153,153
4	Gujarat	1,680,570	541,430	2,222,000
5	Haryana	49,157	183,399	232,556
6	Karnataka	1,893	148,136	150,029
7	Kerala	20,000	0	20,000
8	Madhya Pradesh	0	139,720	139,720
9	Maharashtra	184,089	422,670	606,759
10	Orissa	147,138	0	147,138
11	Punjab	0	151,717	151,717
12	Rajasthan	195,571	179,371	374,942
13	Tamil Nadu	13,231	354,784	368,015
14	Uttar Pradesh	21,989	1,346,971	1,368,960
15	West Bengal	441,272	0	441,272
	Total	**2,956,809**	**3,770,659**	**6,727,468**

State wise Area (ha) of Salt-Affected Soils in India

Figure 2-5 Salt-affected soil in India

Around 2.347 million ha of the salt-affected soils occur in the Indo-Gangetic plains of the country, of which 0.56 million ha are saline and 1.787 million ha are sodic (Arora and Sharma, 2017). Nearly 75% of salt-affected soils in the country exist in the states of Gujarat (2.23 million ha), Uttar Pradesh (1.37 million ha), Maharashtra (0.61 million ha), West Bengal (0.44 million ha), and Rajasthan (0.38 million ha) (Mandal et al., 2018).

2.3 Measures against salinization

1) Preventative measures

When salt gets accumulated in the farmland, a huge manpower and funds are required to remove that salt from the farmland. Therefore, as the first and important step of measures against salinization is the prevention of salt accumulation.

Water-saving

In irrigated agriculture on dry and semi-drylands, irrigation water often contains salts. Surface irrigation, especially border irrigation is widely used in India, but if irrigated excessively due to poor management, a significant quantum of salts is added to the farmland, resulting in higher salt accumulation.

Drainage improvement

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 accumulation of water on the soil surface.

Long-term saturation of the upper soil layer is detrimental to plant growth since plant roots require air, as well as water, and most plants cannot withstand saturated soil conditions 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 by canal seepage and floods, and the downward movement of water from saturated soil to deeper layers feed 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 a part of the root zone, then capillary rise and water logging occur. Therefore, it becomes necessary to remove excess water from the soil surface and root zone.

In arid and semi-arid climates, salinization happens when the groundwater table is not maintained below a critical depth (usually at least 1.5 to 2.0 meters). On the other hand, when drainage is adequate, salinization is because of the other factors such as water quality and irrigation management. Therefore, effective salinity control must include adequate drainage to control and stabilize groundwater tables.

Land leveling

The unevenness of fields occurs as a result of the original undulation of the sites and annual farming activities. It has negative effects such as uneven germination of crops. Therefore, land leveling should be performed as a regular farming activity.

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, land leveling requires a proper attention, 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.

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.

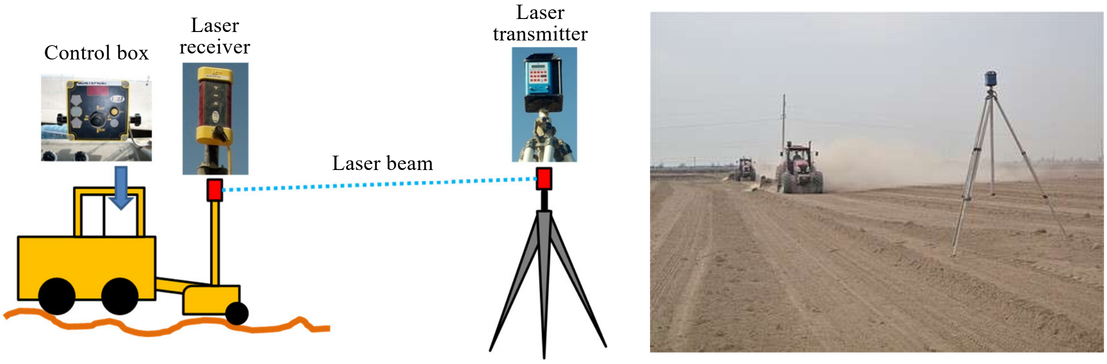


Figure 2-6 Mechanism of laser leveling

Suppression of capillary rise

In arid and semi-arid regions, salinization that results from shallow groundwater tables is largely due to the capillary rise of dissolved salt by high evaporation. Therefore, reducing, suppressing, or blocking capillary rise is effective measure against salinization.

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 prevent soil erosion, fertilizer runoff, weed problems, and extreme soil temperatures.

Deep plow

Capillary rise can be checked by dry soil layer on surface soil formed by deep plowing.

Capillary barrier

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

2) Remediation measures

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

(When water resources are sufficiently available)

Flushing

Salt can be removed from the soil surface and moved 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 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 deeper layers. Leaching is widely used because it is the most practical method for farmers. 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 uniform results over the whole farmland.

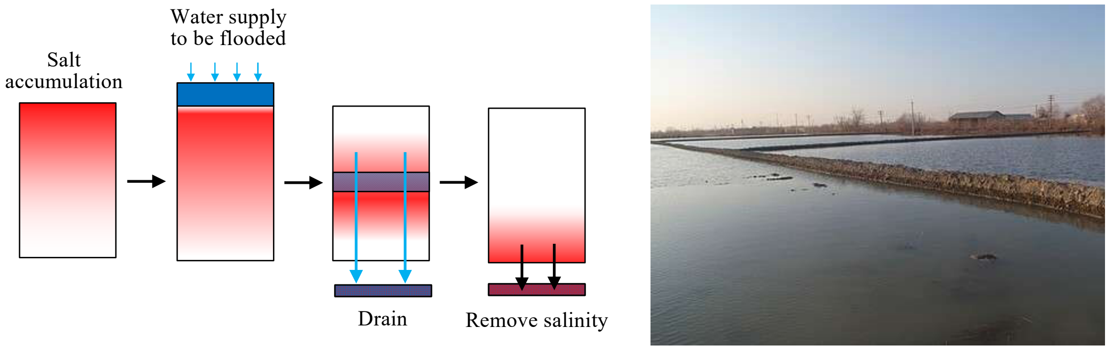


Figure 2-7 Leaching (Uzbekistan)

Application of soil-improvement chemical amendments

Sodic soils can be improved by removing sodium ions that are adsorbed to the cation exchange sites of soil clay particles. However, it is difficult to remove sodium ions from soil using water. Since the permeability of viscous sodic soil is reduced, so 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 exchange sites using soil-improvement amendments 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 amendments. It is advisable to adopt this practice in water scarce areas prior to onset of monsoon season.

Scraping

Soil can be scraped from areas where salt crust occurs as high salt concentrations 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 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 the hardpan using a special tractor attachment (Figure 2-8).

Sub-soiler Deep plow

Figure 2-8 Sub-soiler and Deep plow

Phytoremediation

Salt can also be removed from farmland soil by planting salt, alkali-tolerant or Halophilic plant species that take up 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.

3. Shallow sub-surface drainage

3.1 Type of drainage

Drainage improvement is one of the effective measures to remove soil salinity from the farmland as well as mitigate salt accumulation. There are several types of drainage.

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 towards the drains, the field is given an artificial slope by land grading (leveling).

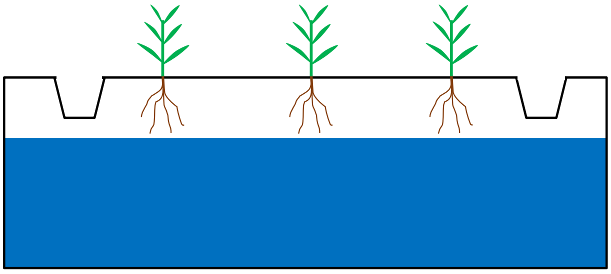


Figure 3-1 Surface drainage

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 (**Figure 3-2**). The disadvantage of deep open drainage is that it is expensive, the trenches take up a large area of the farmland and heavy machinery is needed for construction. In addition, the construction of deep trenches also necessitates the construction of numerous bridges and culverts for road crossings and access to the fields and frequent maintenance (weed control, repairs, etc.).

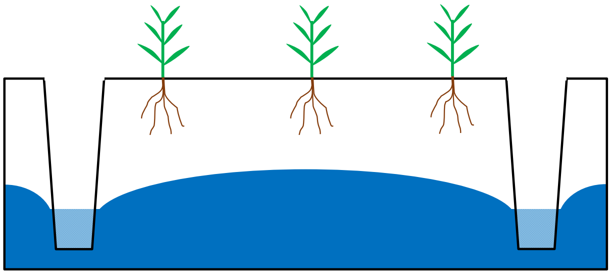


Figure 3-2 Deep open drainage

Buried pipe drains

Pipes that have many small holes are buried below the fields, and excessive soil water enters into the pipes, after which it is transferred to collector drain (**Figure. 3-3**). 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 are higher, owing to the cost of materials, machinery, and skilled labor.

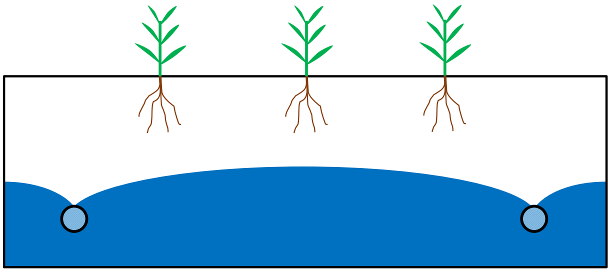


Figure 3-3 Pipe drainage

Vertical drainage

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

Bio-drainage

Trees that have strong water suction and very high transpiration rate 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.

3.2 Shallow sub-surface drainage

Sub-surface drainage has advantage such as not reduce the farmland area. However, it is difficult for farmers to construct by themselves because it requires a lot of funds and labor. Therefore, this kind of construction is mainly undertaken in large scale projects implemented by government and/or other agencies but these are not enough to cater the need of salinity management. In order to realize sustainable land management (SLM) that can control soil salinity, low-cost technology which could be implemented at field scale by individual farmer is the need of hour.

Keeping in view the seriousness of salinity problem and urgent need for cost effective easy to use management technologies, under this collaborative study, we mainly focused on “shallow sub-surface drainage” which has been developed in Japan for multiple use of paddy field. This technology is observed to enhance sub-surface drainage function by tractor running with special attachment named “Cut-soiler”. This shallow sub-surface technology is also expected to be effective for removing soil salinity from the field by providing preferential flow to drain out the excessive water from the root zone. The details on Cut-soiler specifications, structure, operating method and salt removal effect are provided in the following section.

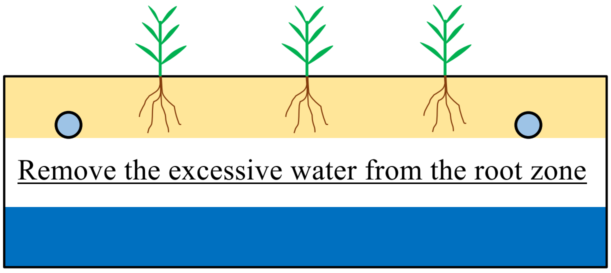


Figure 3-4 Shallow sub-surface drainage

3.3 Cut-soiler

Structure of Cut-soiler

Cut-soiler (KKSR-02) is a special tractor mounted machine as attachment which constructs residue filled shallow sub-surface drainage by using surface crop residue. It is mainly consisted of blade and frame. Its overall length, width and height, and weight are 2,000, 1,500 and 1,650 mm, and 700 kg, respectively.

Figure 3-5 Outlook of Cut-soiler

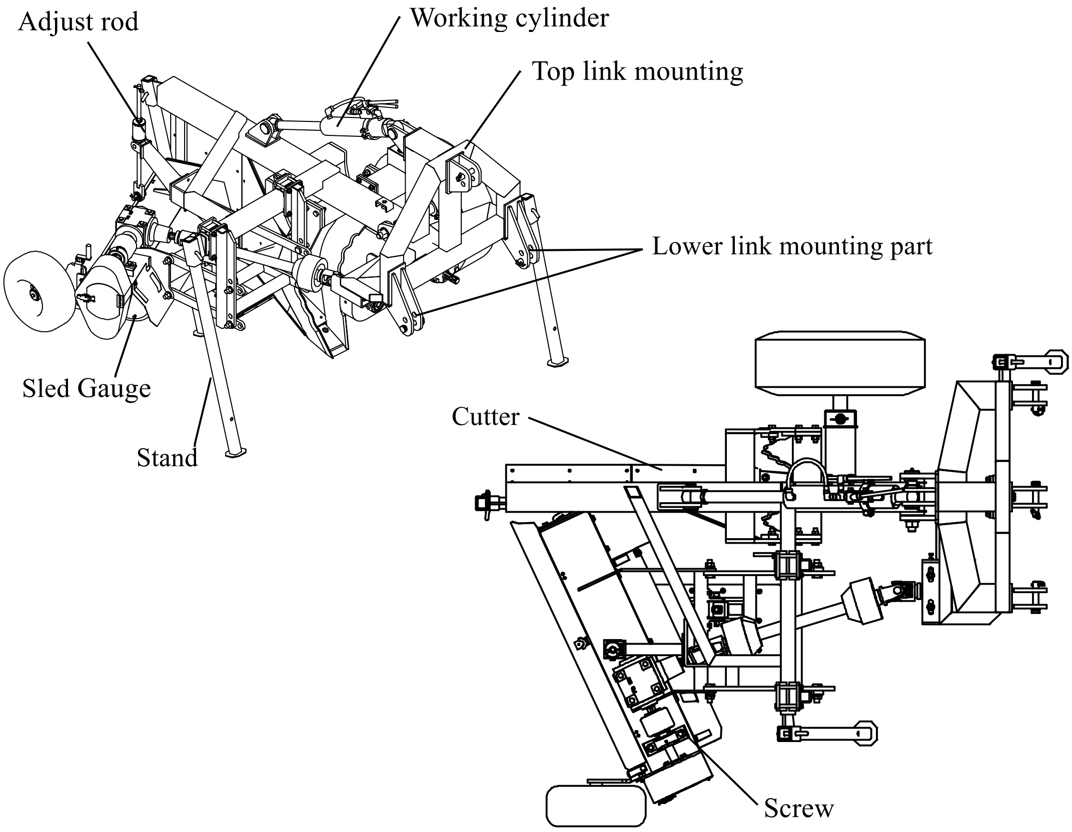
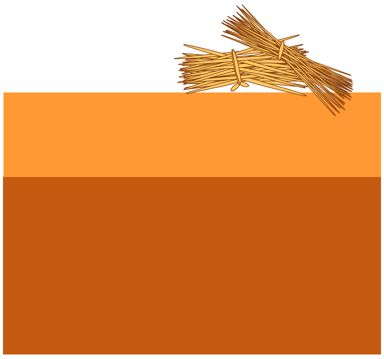


Figure 3-6 Structure of Cut-soiler

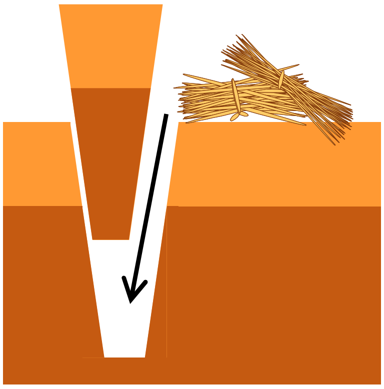
Mechanism of Cut-soiler

Cut-soiler machine cuts the soil and opens V-shape furrow by lifting the Cut soil and fills it back by placing the surface scattered filling material such as straw and residue at bottom followed by overlaying the lifted soil. The steps for construction of Cut-soiler preferential shallow sub surface drains are as follows:

1. The filling material which is preferably a hydrophobic material that retains lesser moisture such as crop residues, straw that are generated as byproduct of agriculture and materials such as compost are spread over field.
2. Cut-soiler attached to the tractor and cuts the inverted triangular soil mass (V shape), lifts it to create a sub-surface trench space at a depth of 40 to 60 cm to place the filling material.
3. The filling materials such as crop residue scattered on the surface may require making medium fine size using mulcher etc that is suitable for Cut-soiler drain filling. Cut-soiler scraps/sweeps the surface material spread over a width of 120 cm and push it to the trench opened by Cut-soiler to construct a vertical groove filled with filling material at the desired sub-surface depth.



Leave shredded residue (straw, stems and leaves) and compost on the field just after harvesting

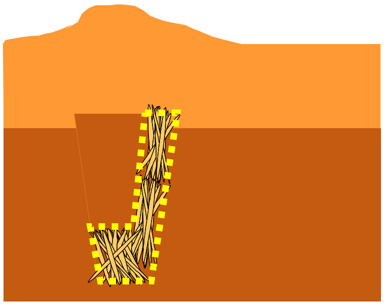


By running the Cut-soiler with a tractor, the soil is cut into inverted triangular (V shape) and lifted to open trench with grooves.

At the same time, collect the surface materials and push toward cutter to drop them into the groove created in the trench opening.

The lifted soil fallen back above the filling material in the groove that created a continuous drain at desired depth.

In this process, the core-soil does not come out to the surface. Materials can be filled in trenches below the core-soil with minimal excavation.



The soil is backfilled, creating a groove-shaped shallow sub-surface drainage with materials buried and filled in the subsoil.

Since the soil rises after construction, the filed should be leveled with a disk harrow/rotary and leveler etc.

Figure 3-7 Mechanism of sub-surface drainage construction

Applicable conditions

1. The execution of Cut-soiler drain construction may not be feasible in soils with gravel layers or layers with many pebbles larger than 5 cm or buried wood 5 cm in diameter.
2. The Cut-soiler is suitable for use in crop fields, farmland, and grassland type of land use systems.
3. As paddy fields continuous standing water, drains should be used as auxiliary drains connected to existing drains.
4. Cut-soiler drain 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.

Appropriate amount of materials

1. For using residue of wheat or rice as filling material, it is necessary to set the cutter of the combine harvester in such a way that the crop residue should be cut into ~10 cm pieces. Alternatively, it is necessary to cut the residue in small pieces on the ground surface with a crusher such as a flail mower or mulcher.
2. The straw quantity of 100 to 200 kg is appropriate for 10 a (100 m^2). To utilize more residue than that, the running speed of the machine should be slowed down and adjusted for the material so that it does not get entangled in the machine.
3. The appropriate amount of compost as filling material is 2 t to 4 t per 10a. In the case of drain re-construction in a short period of time, should be 8 t per 10a as upper limit for environmental conservation.
4. When using other filling materials such as wood chips or volcanic ash, homogeneously spread them on the ground surface and the thickness of the material should be less than 2 cm.

For successful operation

1. The recommended speed of the tractor for Cut-soiler drainage construction is 2 to 4 km/h.
2. The standard lateral spacing between Cut-soiler drains are 2.5 to 5 m (According to field conditions).
3. The base frame of the Cut-soiler should be parallel to the ground during operation and can be adjusted using the top link.
4. The required depth of the drain should be adjusted by adjusting "cutter depth adjustment wheel", "sled in front of the auger", and "auger depth adjustment wheel" by calibrating the Cut-soiler machine in the actual field conditions several times.
5. The optimal auger adjustment for horizontal scrapping is about 1 to 2 cm deep from the ground surface and it should be even on the left and right sides.
6. The cutter excavation depth can be adjusted between 40 to 60 cm with the tractor's 3-point linkage, "depth adjustment wheel", and "sled in front of the auger".

<u>Construction method with or without existing sub-surface drainage</u>

1. With an existing drain
    - The ideal execution technique is illustrated as either Example 1 or Example 2.
    - Execution should be started from shallower part towards the slope if the drain is installed at shallow sub-surface. The construction should be across the direction of the existing drains; connections may be built by crossing at right angles at a downstream part where the existing drains get deeper.

For Cut-soiler drain construction in existing drains, the optimum lateral interval is 5 m.

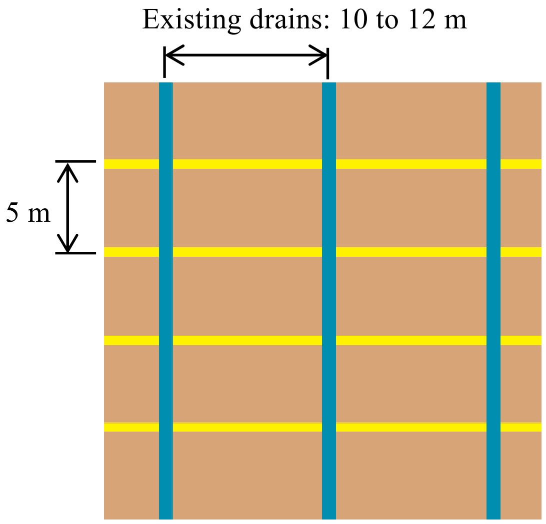


Figure 3-8 Example 1: Construction of Cut-soiler drains across the existing drains

For construction of Cut-soiler drains at 45 degrees across the existing drains. Here also the recommended lateral spacing is 5 m.

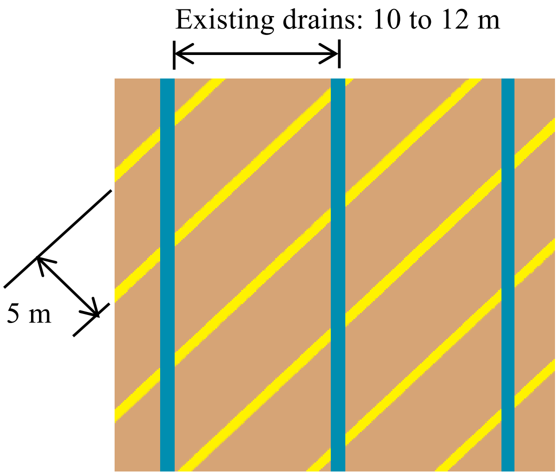


Figure 3-9 Example 2: Construction of Cut-soiler drains at 45 degrees across the existing drains

2. Without existing drain
   - If the main drainage canal is made up of concrete or other materials, and the Cut-soiler drain outlet cannot be created, then via Example 3, make an outlet sump by digging a large hole near to the joint of the drainage canal and construct the Cut-soiler drains ending towards this hole. Connect this sump hole to the drainage canal for water discharge.
   - The outlet should be connected to the drainage canal by providing desired slope for water flow as shown in Example 4.

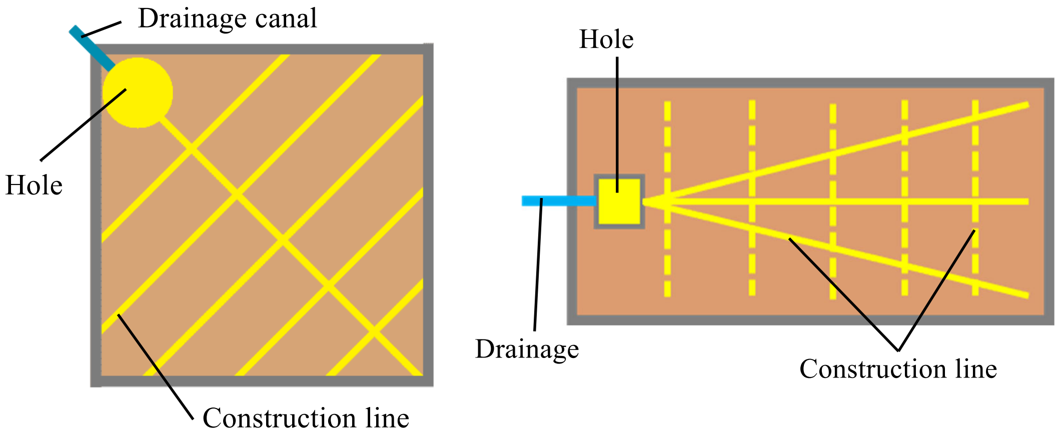


Figure 3-10 Example 3: If an outlet cannot be created because the drainage canal is made of concrete or other materials

To protect the outlet end from collapse, insert a resin pipe for drains (with holes of 50 to 75 mm in diameter) approximately 2 m.

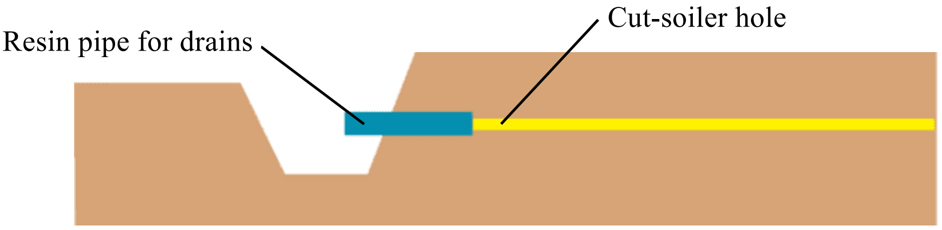


Figure 3-11 Example 4: Resin pipe protected outlet

<u>Cut-soiler attachment to tractor order</u>

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.

Precautions

1. Select a flat and solid place when attaching/detaching the Cut-soiler and keep alert towards any danger.
2. Do not let any person stand around the tractor or between the tractor and the Cut-soiler.
3. Do not get under the Cut-soiler or place your foot under it.
4. Pay adequate attention to avoid getting your hands caught between the parts when locking the lower link shaft.
5. Be sure to attach the protective covers. Non-compliance may result in accident and fatality.
6. Do not let people get close to the tractor and the Cut-soiler during operation.
7. Do not turn while the equipment is inserted into the soil during work.
8. Stop the PTO when lifting the equipment with the 3-point linkage or when retracting the work equipment cylinder.
9. Do not drive faster than necessary, start suddenly, brake suddenly, or make sharp turns.
10. Do not touch moving parts such as rotating parts.
11. When the driver adjusts the work equipment or removes tangles from the rotary, be sure to apply the tractor's parking brake, stop the engine, and cut off power transmission to the PTO shaft.

Maintenance

1. 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 accident and even fatality.

2. 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.
    - Check that the auger is not deformed, damaged, or clogged with foreign matter.
    - Check the connection and looseness of the PTO cylinder, chain, etc.
    - Make sure that the moving parts are filled or coated with the appropriate grease.

3.4 For safe operation

1. Do not use this Cut-soiler for purposes other than those described in this User's Guide.
2. Necessary items for the assembly, operation, and maintenance of the Cut-soiler are described in this User's Guide. Please read carefully and understand this User's Guide for correct and effective handling of the product.
3. Please contact the person in charge for any unclear points.

Danger/Warning

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

Before operation

1. 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
2. Wear clothes appropriate for work. Headbands, mufflers, and towels around the waist may be caught in the machine.
3. 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 manufacturer or the service agent nearest to your office/work place.

During operation

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

After operation

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

3.5 Effect of Cut-soiler

In order to clarify the salt removing effect of Cut-soiler, the Cut-soiler drains were constructed manually in semi controlled lysimeter facility at ICAR-CSSRI, Karnal and by using Cut-soiler in a field experiment at village Nain located in Panipat, Haryana (India) under the collaborative research between JIRCAS and ICAR-CSSRI, Karnal.

Lysimeter experiment

The research site was located at the ICAR-CSSRI in Karnal, Haryana (29°42' N latitude and 76°57' E longitude and an altitude of 243 meter above mean sea level). The annual mean temperature was 23.1 °C, but with monthly maximum temperature of 39.1 °C (May), and monthly minimum temperature of 6.7 °C (January), indicating a significant variation in monthly temperature. The annual rainfall was 758 mm, with approximately 80% of the annual rainfall occurring during the rainy season from June to September. The experiment was conducted in split-split plot design with two replications. It comprised of 24 treatment combinations laid out in individual lysimeter plots (each of size 2 m x 2 m). Cut-soiler simulated preferential drainage was applied in 12 plots along with control (without Cut-soiler) in another 12 plots as main plot treatments. The two soil types i.e. sandy loam saline soil and heavy texture non-saline were applied in sub plots. Sandy loam saline soil was collected from the surface (0-60 cm) soil layer and lower soil layer (60 to 90 cm depth) from the *Nain* experimental field. Heavy texture soil was collected by similar method from village Sambhli (Karnal, Haryana). The soils were filled by placing lower layer soil at bottom in designated lysimeter plots. The salinity of sandy loam soil in terms of electrical conductivity (EC) with water suspension in the ratio of 1:2 was 6.03–7.47 dS m^{-1} for the upper layer and 8.13 dS m^{-1} for the lower layer, and the soil particle density was 2.699 g cm^{-3} for the upper layer and 2.734 g cm^{-3} for the lower layer.

Table 3-1 Saline soil texture for upper and lower soil layers

Soil layer (cm)	Texture Clay (%)	Silt (%)	Sand (%)	Soil type
Upper layer (0–60)	5.5	13.0	81.0	Sandy loam
Lower layer (60–90)	17.3	18.8	63.8	Loam

The residue filled V shape drains were prepared to simulate the effect of Cut-soiler preferential drainage in the field. For drainage outlet, a resin pipe (5.5 cm diameter) was installed in the concrete frame of the lysimeter at a depth of 60 cm. The filter material was placed at the inside end of drainage pipe. The filter material (15 cm wide and 15 cm highwas placed around the drainage pipe. Then, the upper soil layer of respective type soils was filled up to ground surface level, and the surface soil was agitated along the line of the Cut-soiler.

Three salinity levels of water irrigation treatments viz., 4, 8 and 12 dS m^{-1} were applied as per crop water requirement in sub-sub plots. The mustard (Var. CS-58) and pearl millet (Var. HHB-197) were sown on 18 November, 2018 (Winter; Rabi season) and 29 July, 2019 (Rainy; Kharif season), respectively. Crop yields and electrical conductivity (ECe) of various treatments were measured at the beginning and end of each growing season. Treatments were statistically compared by analysis of variance (ANOVA) for split- split plot design using SAS 9.2 software (SAS Institute, 2001) at $p \leq 0.05$.

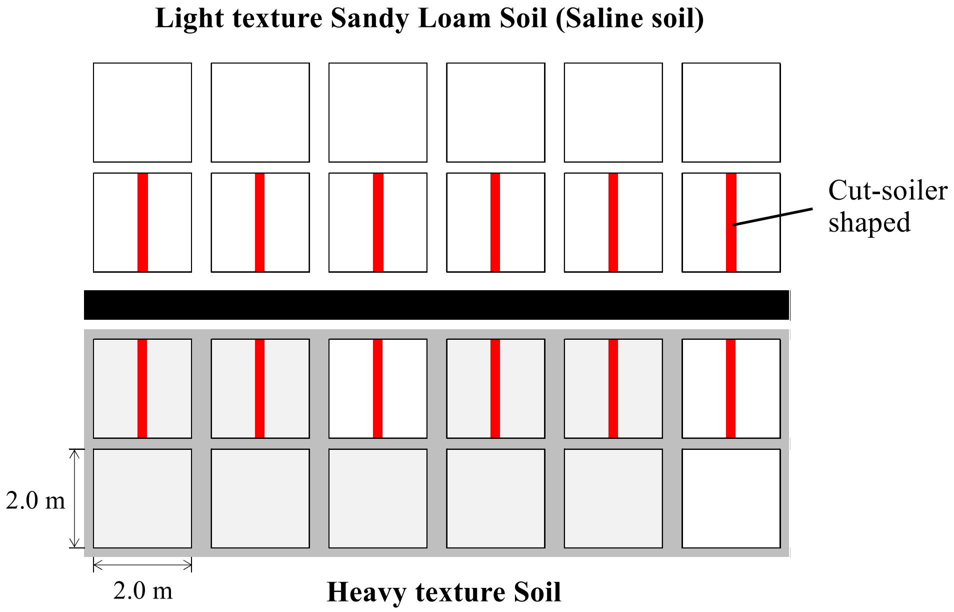
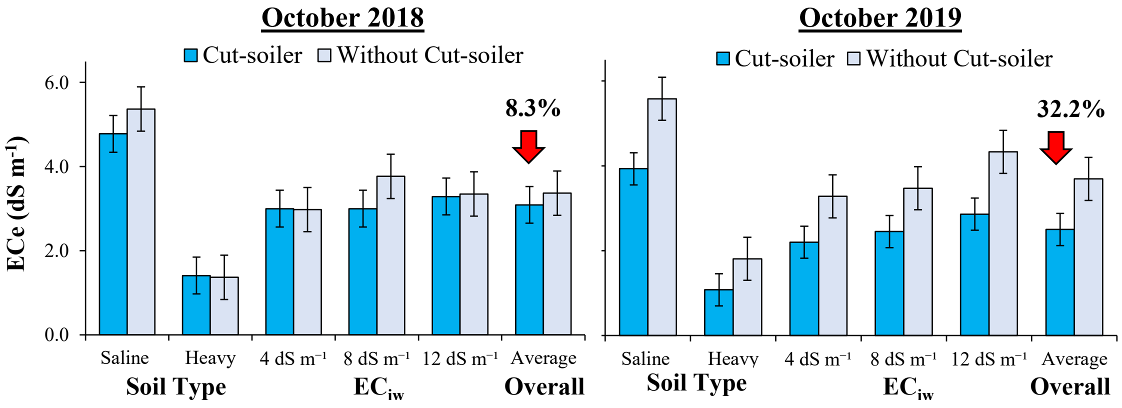


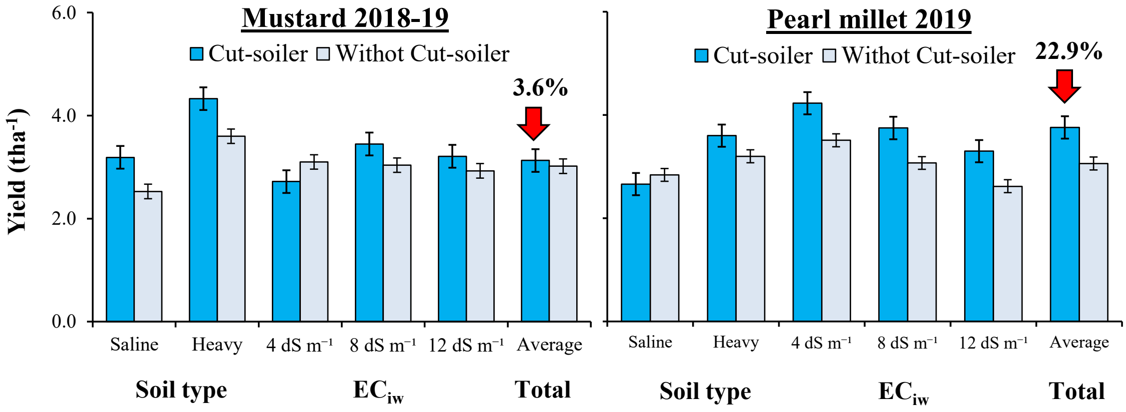
Figure 3-12 Plot layout of lysimeter

Result of soil salinity and yield at lysimeter experiment

The preferential drainage through subsurface drains constructed by Cut-soiler reduced 32% salinity under Cut-soiler drainage over without Cut-soiler across the soil types and irrigation water salinity. The saline soil filled plots had higher ECe (Electrical Conductivity of extract of saturated paste of soil) (5.07 dS m^{-1}) than the heavy textured non-saline soils (1.39 dS m^{-1}). The reduction in soil salinity in Cut soiler plots was higher in saline soil i.e. ~11% and with 8 dS m^{-1} salinity of irrigation water (20.4%) in October 2018 and this increase was higher with 12 dS m^{-1} EC$_{iw}$ in October 2019. The study found that saline irrigation water up to 8 dS m^{-1} could be used without any salt loading. The lower salinity resulted in marginal increase in mustard yield in maiden season and 22.9% increase in pearl millet yield in successive season. Therefore, the Cut-soiler based preferential sub surface drainage may be a possible solution for salt removal from saline soils and preventing salt accumulation with application of saline irrigation water for sustainable crop production in salt affected areas having saline groundwater.



Changes in soil salinity ECe (dS m^{-1}) from October-2018 to October-2019



Grain yield (t ha^{-1}) of mustard (2018-19) and pearl millet (2019)

In addition, dielectric soil moisture sensors (5TE, METER) were installed at depths of 12, 50, and 80 cm from the ground surface during the soil back-filling to lysimeter.

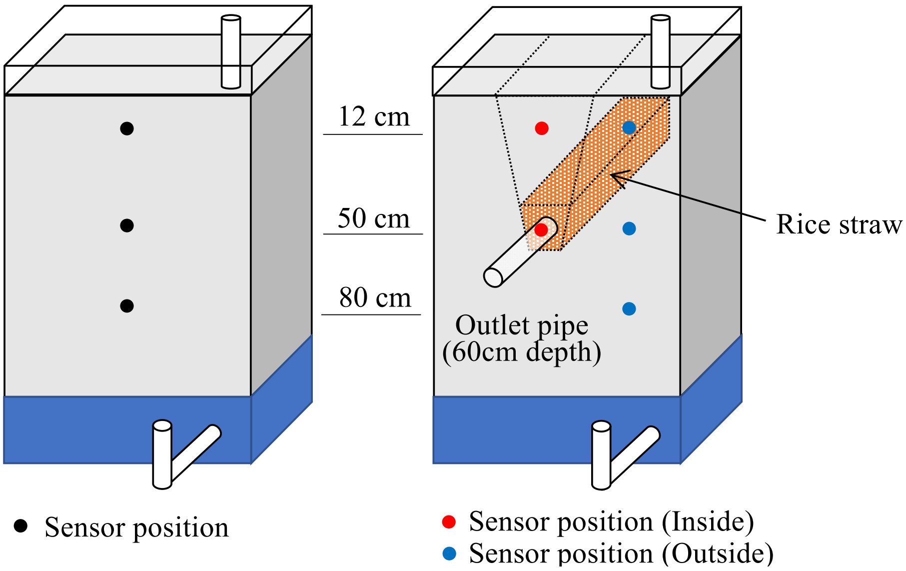
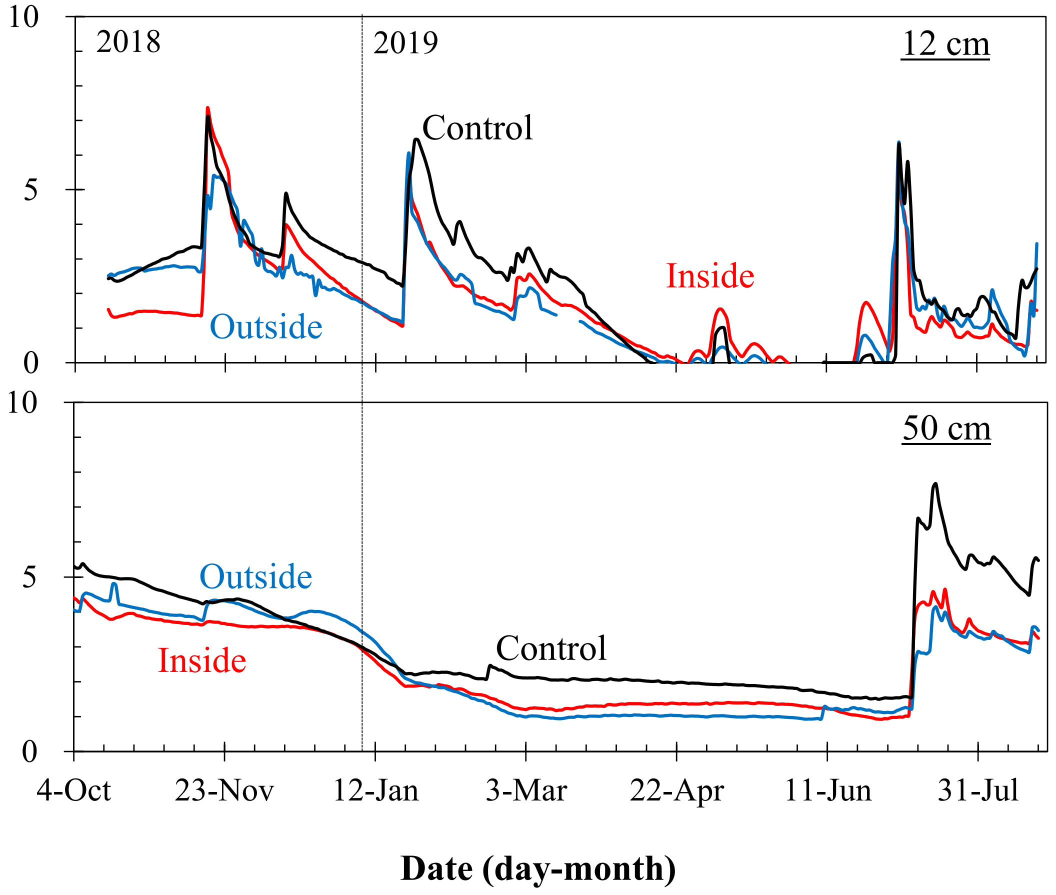


Figure 3-13 Layout and installation of 5TE sensors in lysimeters

Results of sensor monitoring at lysimeter

The irrigation water was applied during the dry season, and the EC peak with Cut-soiler at 12 cm depth was 18.7% lower than without Cut-soiler. In the rainy season, the EC with Cut-soiler at 50 cm depth (depth filled by crop residue) decreased in response to rainfall and was 38.2% lower than that without Cut-soiler.

These results indicate that salts were dissolved by irrigation or rainfall and the drained water containing dissolved salts flowed through the outlet pipe of the Cut-soiler.



Calculated saturated EC with and without the construction of material-filled shallow subsurface drainage at each depth (12 cm and 50 cm)

Field experiment (Nain)

The experiment was conducted in the ICAR-CSSRI experimental field located in Nain village, Panipat district, Haryana State, India (29°19’5.56” N, 76°47’51.10” E). The farm area of Nain is 10.8 ha, elevation is around 230 m. The bulk density of the surface layer (0-10 cm) is approximately 1.4 gcm^{-3}, in middle layer (10-40 cm) is 1.5 gcm^{-3}, lower layer (40-80cm) is 1.6 gcm^{-3}. The texture of surface soil is sandy loam, the silt and clay contents increased from surface to lower depth. The irrigation water source is mainly saline groundwater (EC $>$ 10 dS m^{-1}) (Mandal et al., 2013). Monthly average temperature in the Haryana region increases up to over 35 °C in June then decreases to approximately 15 °C in January. The annual precipitation during experimental period was approximately 940 mm, of which approximately 710 mm occurred in July to September. On the other hand, precipitation is low from October to December, it is around 25 mm. The soil at the study site is sandy loam (Mandal et al., 2013).

In this study, five Cut-soiler construction line interval (2.5, 5, 7.5 and 10 m, and control – without Cut-soiler) treatments with three replications were laid out randomly in 15 plots. Each plot size was 900 m^2 (30 m × 30 m). The Cut-soiler was constructed in the east-west direction in June 2018. The outlets of the individual Cut-soiler construction lines were connected to the drainage channel, which collected and conveyed the water discharged from outlets. The treatments were different lateral spacing of Cut-soiler drains (2.5, 5.0, 7.5, and 10 m) and without (control) (**Fig 3-14**).

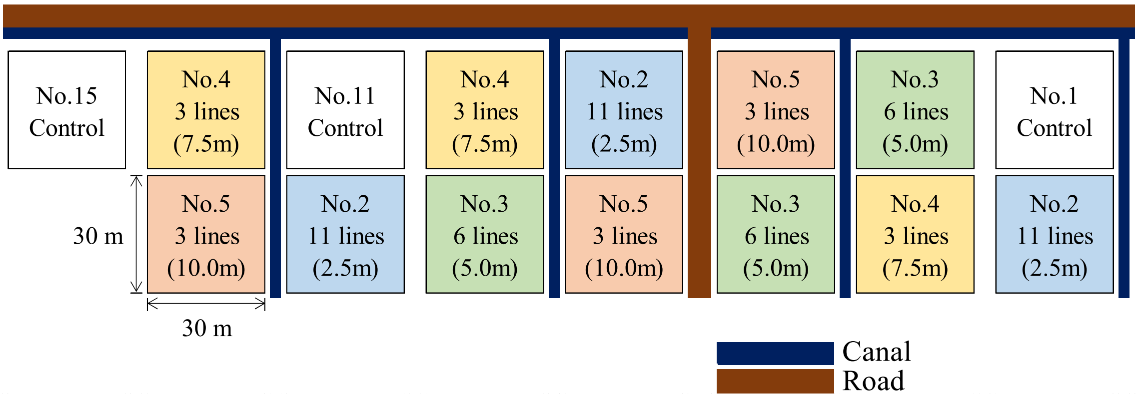
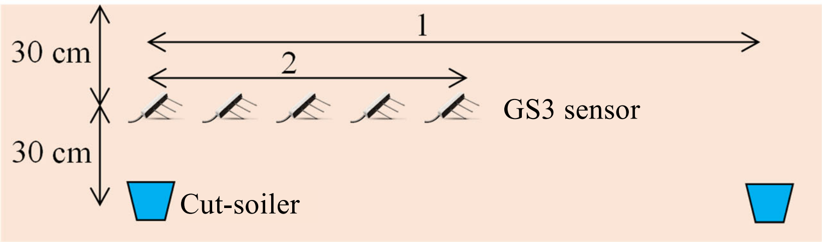


Figure 3-14 Layout of field experiment (*Nain*)

After the construction, pearl millet and mustard were cultivated in the rainy season (July-October) and winter season (October-April), respectively.

The EC of soil water and soil were monitored using dielectric moisture/salinity sensors (GS3 Greenhouse Sensor, METER Inc.).



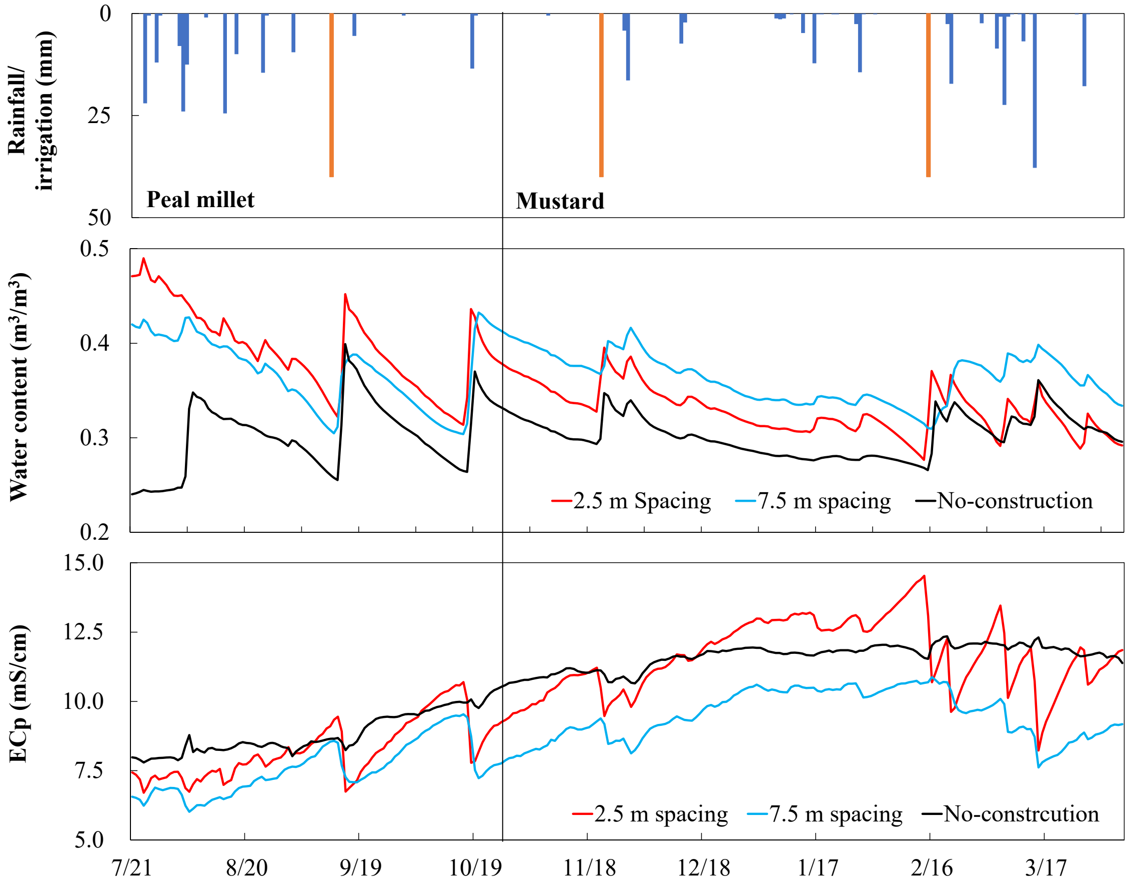
Interval 1 is 2.5 m and 7.5 m
Interval: 2 is 1.25 (2.5 m spacing) and 3.75 m (7.5 m spacing)
GS3 sensor was installed at 30 cm soil depth in no Cut-soiler construction plots

Figure 3-15 Sensors (GS3) location

The distance of sensors 1 and 2 shown in **Figure 3-15** was 2.5 m and 1.25 from Cut-soiler lines constructed at 5 and 2.5 m lateral interval spacing. And 3.75 m was in the case of 7.5 m spacing. The sensor was installed at a soil depth of 30 cm. Em50 data loggers (METER Inc.) were used for data collection.

Result of sensor monitoring at experimental field (Nain)

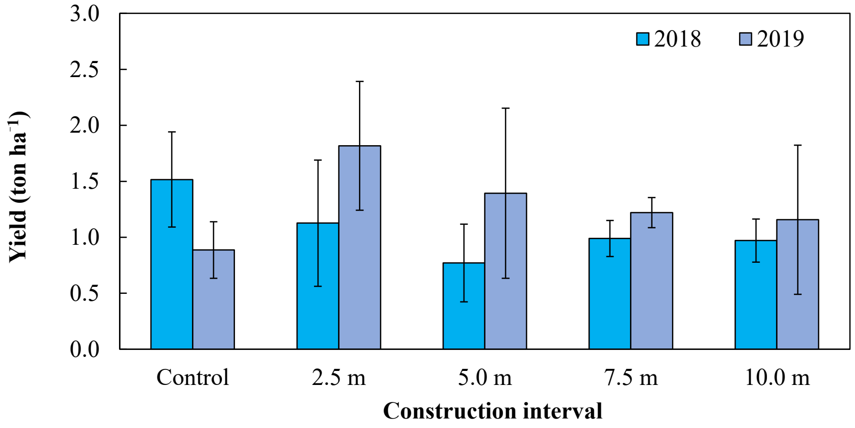
Water content was higher in the plots with 2.5 and 7.5 m interval compared to without Cut-soiler. The improvement of the drainage efficiency based on the Cut-soiler construction could not be verified. However, the EC in the same plots decreased after rainfall and irrigation, as it remained lower than that in plots without Cut-soiler. These results confirm that Cut-soiler contributes to decreasing soil salinity after rainfall and irrigation.



Rainfall and irrigation (top) and consequent fluctuations of the soil water (middle) and soil solute (bottom) contents during pearl millet and mustard cultivation from 2019 to 2020

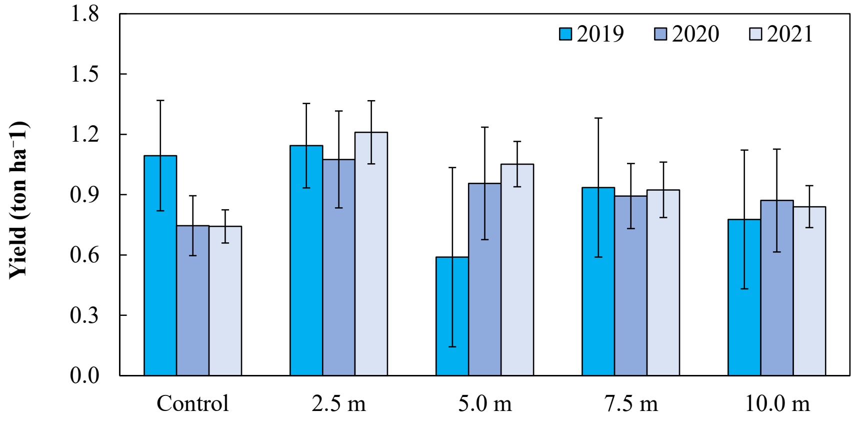
Result of Yield survey at experimental field

Yields of pearl millet in 2018, immediately after construction of the Cut-soiler, were lower in all treatment (Construction interval; 2.5, 5.0, 7.5, 10.0 m) plots than in the Control (without Cut-soiler). However, in 2019, one year after construction, the yield improved in all treatment compared to the Control (without Cut-soiler), and in the test plot with a construction interval of 2.5m, it increased by 105%.



Yield of Pearl millet at each construction interval (2018-2019)

On the other hand, the mustard yield in 2019, immediately after construction, improved by 5% in the 2.5 m plot compared to the Control, and decreased in the other plots. After that, from 2020 to 2021, the yield improved in all plots compared to the Control plot. Especially in the 2.5 m plot, it increased by 44% in 2020 and by 63% in 2021.



Yield of Mustard at each construction interval (2019-2021)

These results was showing, the construction interval of 2.5 m would obtain high effect by Cut-soiler.

4. Water-saving

Water-saving is one of the effective measures to prevent salinization. Drip and/or sprinkler systems are having high water use efficiency, but it is difficult for farmers to adopt them because of high initial investment and maintenance cost of these technologies. Considering these drawbacks, it is essential to improve the current surface irrigation methods for water-saving with low-cost technologies. The following section describes the low-cost water saving surface irrigation methods in general and the tested irrigation methods in specific.

Furrow irrigation

In India, border irrigation is widely used by the farmers. However, its application efficiency is low, resulting in addition of a lot of salts to the farmland. Introduction of furrow irrigation is the easy method to improve application efficiency. Introduction of furrow irrigation is just making ridges and furrows. Furrow irrigation could save approximately 10 % of irrigation water compared to border irrigation.

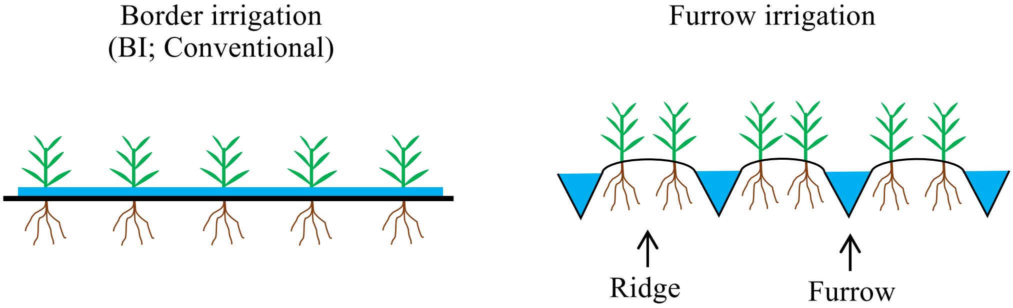


Figure 4-1 Border irrigation and Furrow irrigation

4.1 Skip furrow irrigation (SFI)

Skip Furrow Irrigation (SFI) is another relatively easy and low-cost water-saving method of furrow irrigation (Leininger et al., 2019, Horst et al., 2007). SFI can save water by applying irrigation only in every alternate furrow instead of all furrows (**Figure.4-2**).

Lateral compensative infiltration, driven by enhanced suction under non-irrigated furrows by SFI, may help to maintain yields (Onishi et al., 2021). Horst et al., (2007) reported that approximately 29 % of irrigation water was saved using SFI without a significant reduction in cotton yield.

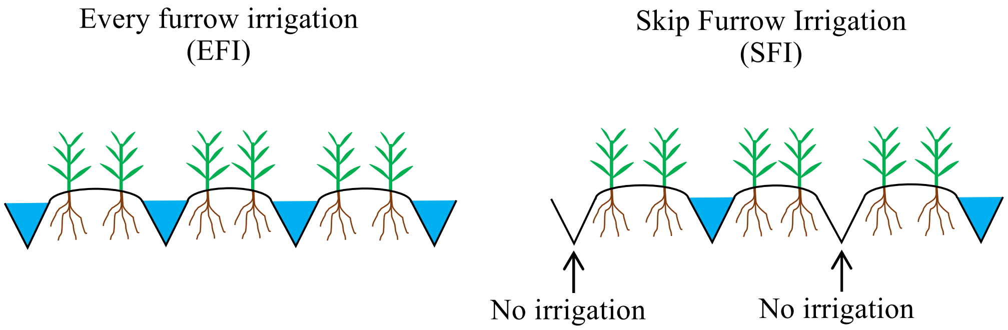


Figure 4-2 Concept of every furrow irrigation (EFI) and skip furrow irrigation (SFI)

In ordinary SFI, irrigated furrow is alternated at every irrigation event, but salinity tends to accumulate in the center of the ridge (Brouwer et al., 1985). To avoid this, Permanent skip furrow irrigation (PSFI) which irrigate same furrow at every irrigation event is effective. The salinity of the ridge under PSFI tends to accumulate at side of the ridge (Onishi et al., 2018).

A field experiment was conducted in Mustard (October to April) during the three dry seasons from 2018 to 2021. Five Cut-soiler constructed drainage interval treatments each with three replications making a total 15 of plots (each 30 x 30 m^2) were set up. The 5 treatments included without drain (Control), and construction of shallow sub-surface drainage with Cut-soiler at 2.5, 5.0, 7.5 and 10.0 m lateral intervals. Such every plot was divided into 3 equal sub-plots of 10 x30 m^2, and irrigated with BI, EFI and PSFI. (**Figure.4-3**).

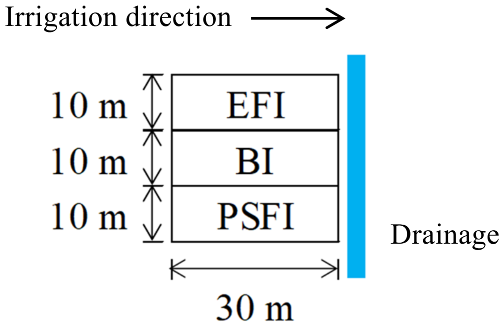
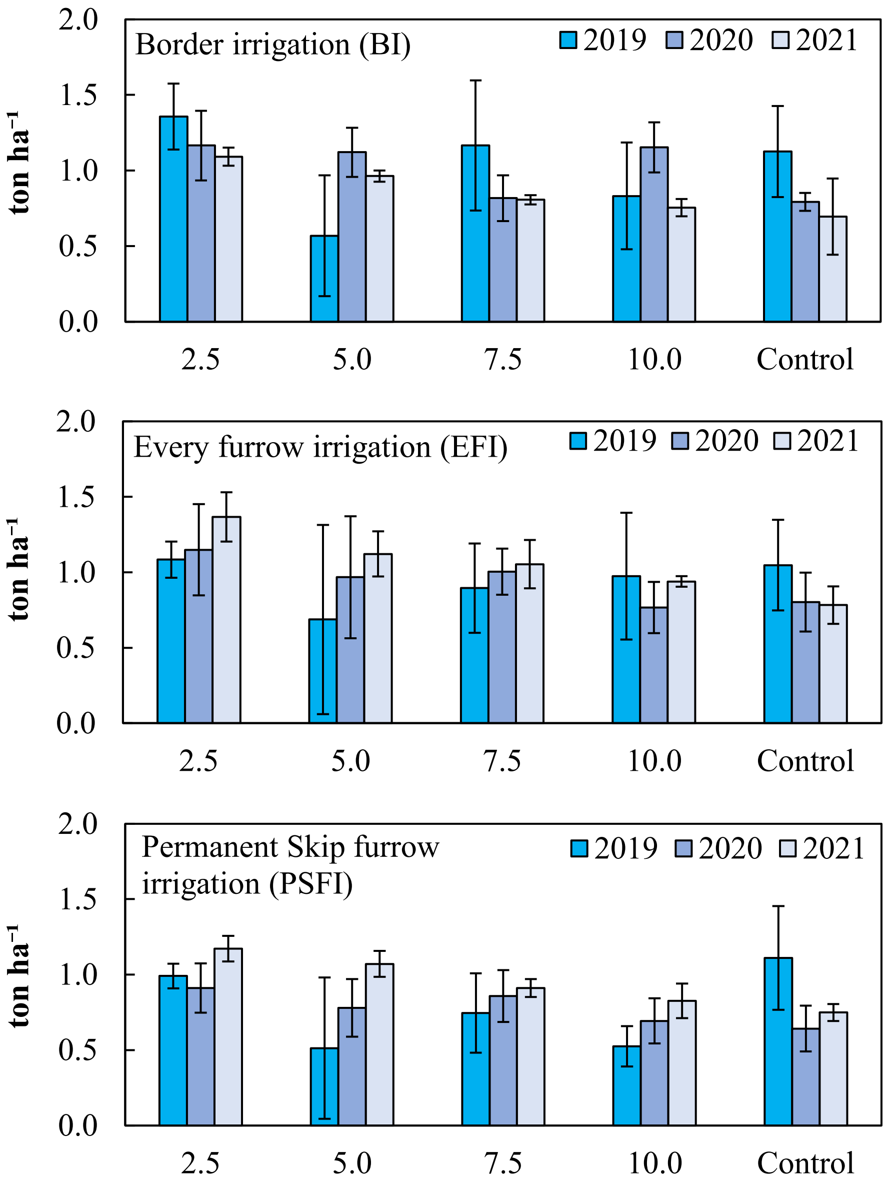


Figure 4-3 Irrigation treatments in each plot

The size of ridge and furrow was approximately 40 cm and 20 cm respectively, and mustard crop was planted in paired rows on each ridge. Irrigation water was supplied from tube well, the amount of irrigation water per one irrigation was approximately 50 mm (15.0 m^3 $plot^{-1}$) for BI, 45 mm (13.5 m^3 $plot^{-1}$) for EFI, and 23 mm (6.8 m^3 $plot^{-1}$) for PFSI respectively.

Water-saving with EFI and PSFI, Mustard Yield

The water application of EFI and PSFI were approximately 90 % and 45 % of BI, respectively. The results showed that the highest mustard yield was recorded in the plot with Cut-soiler at 2.5 m lateral spacing under PSFI and there was 42 and 56% increase in yield over Control in 2020 and 2021, respectively. It implied that the PSFI application did not cause adverse effect due to Cut-soiler drains construction. In terms of irrigation method, the yield in PSFI decreased by ~7% in both 2019 and 2020 but increased ~22% in 2021 over BI. Although PSFI saved around 50% water, there is a possible risk of reduction in yield. Therefore, adopting PSFI method, supplementary irrigation should be applied according to the growth conditions.



Mustard yield in various irrigation methods under Cut-soiler construction

4.2 Simplified Surge flow irrigation

Surge flow irrigation

Furrow irrigation is relatively easy and practically adoptable method. However, the slower pace of irrigation water advancement causes excessive runoff of surface water in furrow irrigation (Walker, 1989). In order to improve upon the drawbacks of furrow irrigation, surge flow irrigation (SF), one of the relatively easy and low-cost water-saving surface irrigation methods, was proposed by Stringham and Keller in 1979. Later in 1988, Stringham defined the SF as "intermittent application of irrigation water with a series of water supply and shutdown at regular or variable intervals" (Amer and Attafy, 2017). SF can save water by supplying irrigation water intermittently based on the principle that irrigation water infiltrate faster in dry soil than in wet soil. 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/subsequent water supply is faster than that of the first/previous water supply because the first water supply reduces the soil permeability and infiltration. In the farmland, irrigation is performed by supplying water in multiple times of surges according to the ridge length (**Figure. 4-4**). The reduction in infiltration is caused by four physical processes: consolidation/compaction, owing to soil particle migration and reorientation; air entrapment; the redistribution of water; and channel smoothing (Alan R. Mitchell et al. 1994).

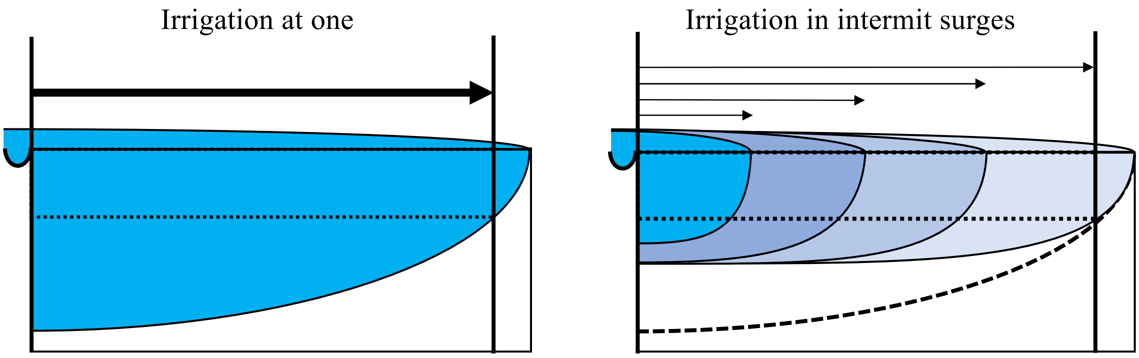


Figure 4-4 Concept of Surge flow irrigation (SF)

According to the field experiment at Central Fergana Valley in Uzbekistan, 21% of water-saving was obtained with SF (Horst et al., 2007). Nevertheless, installation of water supply pipe and switching valve is required even in SF. This type of requirements is still posing as barriers to farmers in introduction of SF. Considering the labor and economic state of farmers in developing countries, Onishi et al. (2017) proposed the “Simplified SF (SSF)”. This method is quite simple and works on the principle of simply dividing the water supply into two phases at 1-day interval. In this method, irrigation water supply is allowed to advance only up to midpoint of the furrow (SSF-1) in 1st phase, followed by the 2nd phase of next day irrigation to supply water to the entire furrow (SSF-2) (**Figure. 4-5**). Their observations suggested that SSF can save 10-20% water under 1.7 Ls^{-1} inflow rate (Onishi et al. 2017, 2019).

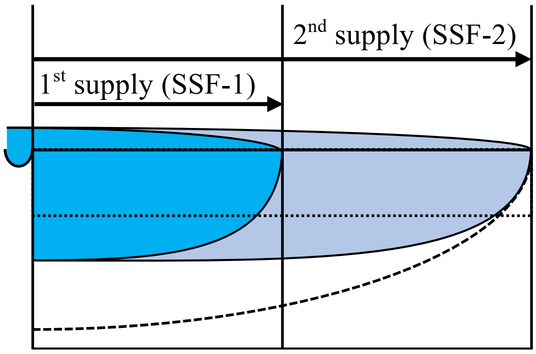


Figure 4-5 Concept of Simplified Surge flow irrigation (SSF)

The application of SSF and associated reduction in infiltration losses under furrow irrigation on the salt-affected land in upper IGP of India was verified in this study. A field experiment was conducted at ICAR-CSSRI experimental farm Nain (29° 19′ 06″ N, 76° 47′ 51″ E; 230 m ASL) in Panipat district of Haryana, India. The irrigation experiment was conducted on the northeastern side of the Nain Experimental farm in November 2019. The soil of the experimental field is sandy loam with variable salinity (ECe: 10 to 82 dS m^{-1}). The texture of the surface soil was sandy loam, and the silt and clay contents increased with depth. The bulk densities of the surface (0 -10 cm), middle (10 - 40 cm), and lower (40 - 80 cm) soil layers were 1.4, 1.5, and 1.6 gcm^{-3}, respectively. The source of irrigation water was groundwater, which has a high salinity (EC > 10 dSm^{-1}) (Mandal et al., 2013).

Furrow irrigation (Control) and SSF were applied to five furrows each of 30 m length. Furrows with approximately 20 cm width were made manually. Irrigation water was supplied from tube well, and the inflow rate was 2.9 Ls^{-1} (**Figure. 4-6**).

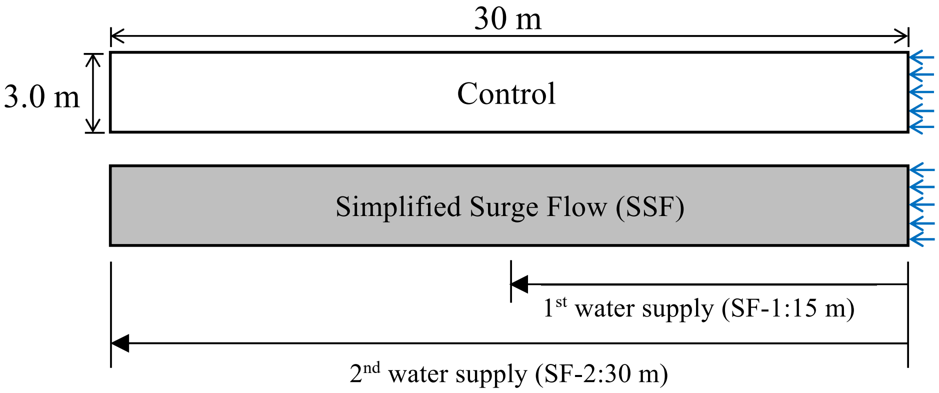
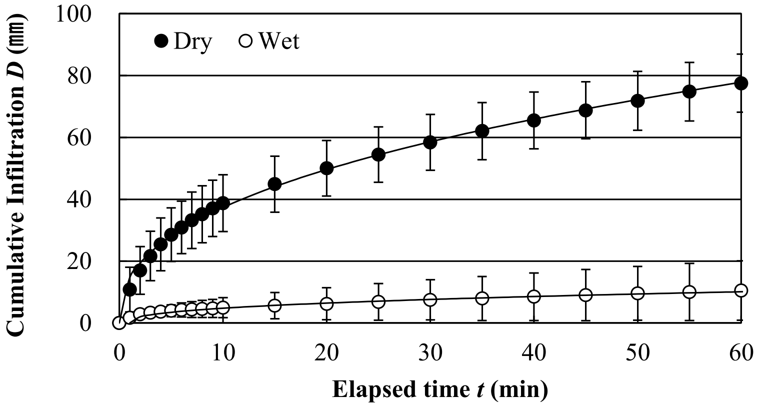


Figure 4-6 Plot layout

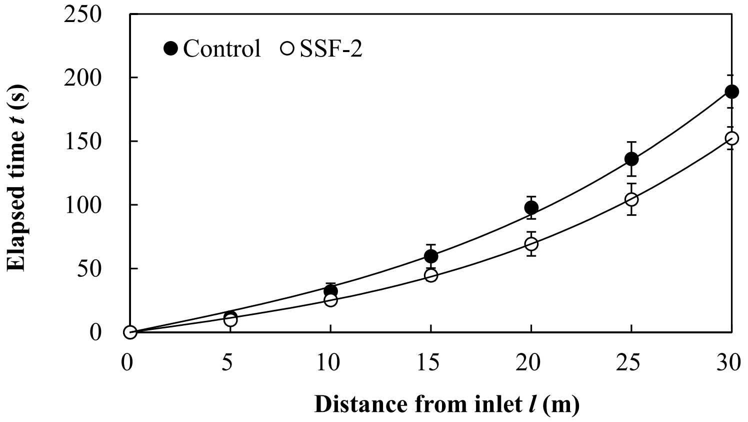
In Control, water was supplied up to the end of furrow at one time. On the other hand, in the SSF, water was supplied up to midpoint (15 m) of the furrow length at first day (SSF-1), and then next day, water was supplied up to end (30 m) (SSF-2). The ends of all the furrows were blocked, and when irrigation water reached the end of the furrow, the water supply was stopped.

Water-saving with Simplified surge flow (SSF)

The amount of cumulative furrow infiltration after 60 minutes in dry and wet soil was 78 mm and 11 mm, respectively. Overall, it was 87% lower in wet soil than that of dry soil. The time for irrigation water to reach the end of 30 m length furrow under control and SSF-2 were 189 and 152 seconds, respectively. Thereby it shortened by 20% in SSF-2 than that of Control. The estimated cumulative infiltration in Control and SSF was 564 and 412 mm, respectively. SSF recorded 27% lower amount of infiltration water than that of Control. These results indicated that SSF can be a useful method to use water efficiently by the farmers of water scarce regions.



Cumulative infiltration of wet and dry furrows



Water advance time of Control and SSF-2

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 reduce loss of water due to runoff, shallow drains should be made at the ends of fields. Without such drainage, there is also a possibility that plants can be damaged by waterlogging. Cut back irrigation can help in preventing excessive runoff of water by reducing inflow of irrigation water once the irrigation water has reached the end of the furrows (FAO 1988)[1].

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Cut-soiler constructed Preferential Shallow sub-surface drainage
for mitigating salinization

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