Impacts of Perforated Sheet Pipe Installation on Some Soil Properties

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2021

Declaration

I hereby declare that this submission is my own work in its entirety and that to the best of my knowledge, it contains no material previously published or written by other person nor materials extend has been accepted for the award of any other degree or diploma of the university of higher learning, except where due acknowledgement has been made in the text.

Yinn Mar Soe Date

I certify that the declaration above by the candidate is true to the best of my knowledge and that this report is acceptable for evaluation for the degree of *Doctor of Philosophy*.

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Abstract

One of the possible solutions to increase agricultural production under climate change is improving water use efficiency (WUE). It can be achieved by saving water and increasing soil water storage. Modern irrigation and drainage technologies intend to promote WUE. Moreover, these practices provide some benefits of controlling water quality, reducing soil salinity, and conserving soil erosion. Recently, it is highlighted that the improvement of drainage is still required, and this can solve the future food demand strategically.

Agricultural drainage is to remove excess water from farmland, and to create a better environment for crops. In agriculture, surface, subsurface drainage and combination of both ones are common field practices. Recently, it is expected that shallow subsurface drainage can accelerate the ability of drainage. Besides, it enables us to prevent water logging in root zone, higher groundwater table, and soil salinity. Shallow subsurface drain such as perforated sheet-pipe has been widely installed at rice paddy fields in Japan for about forty years.

Subsurface drainage enables to change physical, chemical and biological properties of soils due to water table fluctuation and above human induced practices including different cropping, land use, and water management. Under installation of sheet-pipe, it has not been clarified yet where drainage water passed through and why & how the sheet pipe functions. And when do these impacts appear after installation? Hence, the assessment of effective management and performance on such a shallow drainage system in paddy fields is new and becomes essential.

The main objective of this study is to investigate the impacts of the sheet-pipe installation on changes in soil properties. Thus, we conducted three-field experiments separately in different regions of Japan. To confirm the performance of the sheet-pipe, we set up the preliminary trials in Kagoshima, Japan. The first research was conducted in Oita to investigate the impacts of some soil-characteristic changes and differences by the sheet-pipe for one rice cropping. Then, we continued to investigate the effects of the installed sheet-pipe on paddy soils for long-term in Fukuoka and Oita, Japan.

Some soil properties are expected to change and to be different under the sheet-pipe installation. To investigate these changes and some differences, we studied at Kunisaki, Oita. Two sets of soil samples were collected just after installation of sheet-pipe and after a rice cropping of the same field. Regarding the drainage stream sites along the sheet-pipe (upstream, midstream, downstream) at the field, distances from the sheet-pipe (0 m, 1 m, 2 m), and soil depths (10 cm, 25 cm, 45 cm), we studied changes and differences of some soil properties such as soil bulk density, soil organic carbon content, saturated hydraulic conductivity (-log Ks), macro-pores, mesopores, and plant-available water. During a rice cropping, we could not find significant impacts on some soil properties by the sheet pipe except larger pores. We observed larger mesoporous portion at 0 m and 1 m distance from the sheet-pipe at deeper soil layers (both 25 cm and 45 cm depth). As a result of the short term impact, the difference in macro-pores was not so significant. However, an increase in mesopores was supposed leading to develop macro-pores and cracks.

To understand the long-term impacts of the sheet pipe on some paddy soils, we made research at two places with different paddy soils and converted paddy soil. Using (3 × 3 × 2) factorial design with three replications, we collected soil samples on farmland at Hisayama, Fukuoka, and Usa, Oita, Japan. In this study, the ages of installed sheet-pipe in Hisayama and Usa were seven years and fifteen years, respectively. This design based on three-stream sites (upstream, midstream, and downstream of the fields), three distances from the sheet pipe (0 m =above, 1 m and 2 m), and two soil depths of 10 cm and 25 cm, respectively.

We measured thirteen items of soil properties. As a result, there was some improvement in air-filled capacity and infiltration above the installed sheet pipe. Also, the soil bulk density near the sheet-pipe became smaller with a significant increase in soil organic carbon, and soil aggregation. All these characters promoted formation of soil macropores in deeper soil layer. The increase in porosity, especially in these macropores of soils allowed more water and air to pass through. These macro-pores assumed as cracks generated by the installed sheet-pipe under long-terms.

In sum, a change in larger mesopores near the sheet-pipe (0 m and 1 m) at the deeper soil layers, especially at downstream site was a short-term impact by the installed sheet-pipe. These pores were supposed leading to the development of small cracks including macropores for the long-term. In the long-term study, variations in soil physical and hydraulic properties were more noticeable than those in chemical properties. Major improvements were soil bulk density, aggregation, organic matter, saturated hydraulic conductivity, and air-filled capacity. These changes were observed near the sheet-pipe (at 0 m distance and 25 cm soil depth). An increase in total soil pores, especially macropores contributed to an improvement of air-filled capacity and much water passing through.

Our study enlightens that an increase in mesopores by short-term study and macro-pores by long-term study seem to be small cracks generated by the installed sheet-pipe. The development of such soil characteristics enhances to change in some hydrological, physical, and chemical properties of paddy soils.

Key words: paddy rice, perforated sheet-pipe, some soil properties, shallow subsurface drain.

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Yinn Mar Soe

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Table of Contents

List of Tables

List of Figures

List of Abbreviation and Acronyms

AFC	-Air-filled Capacity
ANOVA	-Analysis of Variance
BD	-Bulk Density
CO_3	-Carbonate
EC	-Electrical Conductivity
f	-Porosity
FC	-Field Capacity
-log Ks	-Negative Logarithm of Saturated Hydraulic Conductivity
MaP	-Macro Pores
MeP	-Meso Pores
SOC	-Soil Organic Carbon
pF	-Water Retention
pH	-Negative Logarithm of Hydrogen Ions Concentration
R^2	-Coefficient of Determination
SP	-Sheet Pipe Distance
SD	-Soil Depth
SS	-Stream Sites
StoP	-Storage Pores
SWC	-Soil Water Characteristic Curve
TP	-Total Pores

Chapter 1

Introduction

1.1 Research Background

1.1.1 Subsurface Drainage as A Sustainable Water Management Tool

Based on United Nations (2019)'s prediction, the world population will increase to 9 billion by 2050. As a consequence, food demand for the hunger world and agricultural water withdrawal will increase. Currently, the global water requirement is competing with other uses such as domestic, sanitation, industry, energy, and recreation. On the other hand, water requirement in food production is imposed coupling with environmental stresses such as floods and droughts.

In the world, one in nine people still does not have enough food. Around 2.8 billion people face water scarcity at least one month every year (FAO *et al.*, 2020). Besides, all forms of life suffer from environmental pollutions, including land, water, and air (Iyyanki and Manickam, 2017). To solve these issues, Integrated Water Resource Management guides to manage renewable and nonrenewable water resource effectively. As water is a strategic driver of economic and social development, sustainable water management leads to maintaining harmony with the natural environment (Kumar *et al.*, 2019).

An unbalance environment due to extreme floods and droughts exposes a problematic plan for cultivation activities on-farm water management practices. These include micro and macro scales (WIF2, 2016). Based on this recognition, Watanabe (2016) proposed to modify the design and operation criteria for irrigation and drainage schemes. In addition, regional water management schemes should meet food security as well as climate change impacts.

Over decades, water use of agriculture has partly solved “more crop per drop” using deficit irrigation. The primary aim is to save water. Recently, root zone water management has been highlighted as a vital role, in which to improve soil water storage has labeled as a desirable one. Furthermore, it is known that soil water storage relies not only on irrigation but also on good drainage (Scheumann, and Freisem, 2002; Schultz *et al.*, 2009).

For drainage development, the international center for rural development approached with some strategies (ICID, 1996). The main tactic was to increase water use efficiency and water-saving by drainage. In this strategy, institutional reforms, government support for modernization, rehabilitation, and reclamation proposed as some implementing issues. Based on some reports, an increase in stakeholder participation was also necessary to succeed. Thereby, the transfer of systems, taking responsibilities, modernization, and cost recovery were influencing factors for that success. Most developed countries have already overcome lots of such issues with well drainage management. However, developing countries are still far from emerging such issues (Schultz, 2001). Hence, ICID and many international organizations are promoting the application of drainage technology, especially in the rural development planning of the developing countries. In their implementations, applying an improved science of drainage, generating new ideas & thoughts, disseminating the findings of (traditional and modern) lifeline for the sustainable application of drainage are involved. A significant output is solving the regional problems with strongly networking (Schultz, and Wrachien, 2002; Schultz, 2003).

Drainage water management is the practice of using water control structures such as surface ditch and or subsurface tile or mole to manage the water table in an agricultural field. By draining the excess water, the soil near the root zone becomes free from water-logging and well aerated. Besides, the soil structure changed to retain much water in the soil profile for use by the main crop. Other benefits of drainage are that it may reduce pollution from other dissolved and sediment attached substances, reduce downstream sedimentation, and reduce storm-water surges of freshwater into the estuarine area (Strock and Dalzell, 2014). Besides, the drained soil becomes warmer and this provides earlier germination and growth in spring. With drainage, the number of arable lands suitable for crop production is significantly increased (MRR, 2016).

Subsurface drainage means the process of directing excess water away from plant root zones naturally or artificially. Properly drained soils reduce water stress on crops. It promotes root development necessary for maximizing yields and the quality of crop production. It also allows for well-timed farm machinery operation. Besides, it has some benefits for minimizing soil compaction, controlling salinity, and decreasing annual variability in crop production. There are some opportunities for land conservation with minimum tillage on the drained land (Oosterban, 2017).

To extend much use of subsurface drainage in developing countries, analysis of subsurface drainage is still necessary. By doing so, subsurface drainage helps to ensure the productivity of agricultural land. It also maintains the conservation of natural resources in land reclamation projects (Chahar *et al*., 2008). In the past, the use of a shallow drainage system had some positive impacts on the prevention of waterlogging. However, controlling soil salinization and its undesirable effects were uncertain (Christen and Skehan, 2001). Thus, the best management practices on different soils are still required to develop by the installed shallow subsurface drains (Christen and Hornbuckle, 2000). Nijland *et al*. (2005) also suggested that such shallow drainage on different soils for specific purposes and their impacts with short and long terms should conduct as future studies.

1.1.2 Managing Soils with Subsurface Drainage in Agricultural Production

Managing soil is essential not only to crop production (Horn and Fleige, 2009) but also to environmental protection (Ball *et al.,*1999). When soils are under compaction with poor drainage and aeration, agricultural production will face limited land preparation, traffic-ability, and crop growth & development. Under severe floods and drought, crop production was lost (FAO, 2006b).

In soil management tools, it is necessary to understand different functions in the soil-biosphere. Also, these functions are considered in improving crop production (Scheffer and Schachshaffel, 2002). These are; i) regulation of biogeochemical cycles, ii) changes in microorganism habitat, and iii) improvement of the medium for plant roots. Subjecting to the action of external forces (e.g. tillage and compaction), internal forces (e.g. wetting, drying cycles, and soil freezing), and biological activity (e.g. bio-pore formation by earthworms) change soil properties instantly. Facilitating drainage is one of the soil-water management tools (wetting and drying soils). Now we accept that subsurface drainage accentuates the variation of soil properties, such as percolation and storing the fluid in soil (Horn *et al,* 1994; Dörner and Horn, 2006).

Regarding artificial drainage, it is recognized that changing in soil structure and its dependent properties are not constant. For example, if the stable aggregates are destroyed during installing, we observed negative changes. However, some positive improvements occurred under tile drainage with different soil managements (Madramootoo *et al,* 2007). There were some examples of changing soil structures by the artificial drains. These affect not only for soil bulk density, but also a reduction or an increase of hydraulic conductivity (Hopkins, 2002; Huffman *et al.,* 2013). Consequently, water table changes observed (Schutz, 2003). Although these changes are depended on soil pore volume and pore continuity (Osunbitan *et al.,* 2005; Moret and Arrúe, 2007), quantification of different soil pores and roles of these pores by drainage are still unknown.

In the world, twenty-five million hectares of agricultural land has become unproductive due to irrigation-induced waterlogging and salinity. Fifty percent of the world's irrigated land suffers from drainage problems. Two hundred fifty million hectares of rain-fed cropland need improved drainage (Smedema *et al.*, 2000). The development of integrated management on drainage on agricultural land becomes important. Thus, FAO (2007) considered some actions for improving drainage. These were to prevent the accumulation of water in crop-root zones, to reduce soil erosion from the stagnant muddy water, and to remove the toxic materials in the croplands.

The subsurface drainage in agricultural fields allows for soil improvement with physical, chemical, and biological characteristics. It provides suitable conditions for annual cropping through soil physical improvements. It also permits crop diversification with changes on soil structure through influencing saturated hydraulic conductivity and the effective porosity of soil (Talukolaee *et al.*, 2018). Moreover, subsurface drainage helps to reduce high water tables. By these means, better aeration of the root zone and the development of a deeper root structure ensured to increase crop production.

Drought stress later in the growing period and early spring seeding could be managed with subsurface drainage. Through subsurface drainage, the availability of nutrients increased and the risk of delayed harvesting reduced. Moreover, less damage to equipment, and less overlapping of inputs during field operations could be expected under subsurface drainage. Effective weed control was also observed by subsurface drainage (Fausey *et al.*, 1987).

Subsurface drainage improved the agricultural soils and their environment. It reduced the movement of sediment, nitrates, phosphorus, and some pesticides in the drained water and favored soil traffic-ability, field operations (Kornecki *et al.* 2001). Under the long term subsurface drainage, it had some improvements on soil properties together with conservation tillage. Groundwater table management with subsurface drainage has a distinct control in the reduction of soil salinity (Tiwari and Goel, 2017).

Some influences of subsurface drainage were observed at the upper soil layer. Changes in soil physical properties, such as soil bulk density, soil organic carbon content, aggregation, pH, and CEC near the installed pipe were some examples of influences by the subsurface drains (Vopravil *et al.*, 2017; Wealge *et al.*, 2019). Iron transformation, sulphate accumulation, leaching sodium, calcium, magnesium, and chloride were distinct under the installed subsurface drain in low-lying acid sulphate soils (Mathew *et al.*, 2001).

Such improvements are proposed as indicators for the success of subsurface drainage. Thus, Abdel-Dayam *et al.*, (2004) pointed a view that managing soils with subsurface drainage has been contributing to large increases in crop production in different parts of the world.

1.1.3 Prospects of Shallow Subsurface Drain in Paddy Soils

Paddy soils are managed by a singular way for the wet cultivation of rice including flooding, puddling, and maintaining a layer of standing water for the development of crop growth. Surface drainage, drying the fields, and re-flooding for the next rice crop is usually practiced in paddy soils (Ponnamperuma, 1972). Lowland paddy rice requires 24%–30% of the total world’s fresh water withdrawals (Bouman and Van Laar, 2006). Only 500–1,000 liters of water uses to produce 1 kg of rough (unmilled) rice by transpiration. Much water in rice fields, lost by evaporation, seepage, and percolation. Hence, rice production in paddy soils must be viewed in the light of the emerging water crisis (Bouman, 2018).

Mostly, rice grows in Asia, especially in developing countries. Nowadays, these countries stand with the rapid growth of economies. Much water requirement for agriculture activities in these countries strictly competes with industry, energy, and household uses.

Current global climate change impacts on paddy productions with a great distinct. Paddy fields are the chief source of agricultural methane, CH_4 emissions (Kimura *et al*., 2004; IPCC, 2014). 11% of global methane is emitting from paddy fields. It describes as one of the principal greenhouse gases. Its annual emission ranges between 493 and 723 Mt CO_2-eq yr^{-1} in 2010. Another major greenhouse gas (GHG) emitting from rice fields is nitrous oxide, N_2O. Its emission is associated with soil water and nitrogen status (Wang *et al*., 2011; Skinner *et al.*, 2014). However, globally rice production is not a significant source of N_2O emissions under anaerobic paddy conditions, in which a complete reduction of N_2O into N_2 occurs (Granli and Bøckman, 1994). These facts alarm us how to grow rice with effective water management in various outlooks.

Recent studies introduce some potential application of a modified water management system with dual purposes for subsurface irrigation and shallow subsurface drainage in paddy fields. Schult *et al*. (2007) remarked the improved drainage in paddy land (application of shallow subsurface drain) as one of the solutions to meet about 15% of the food demand through improving rice production over the next 25–30 years. Also, JASPiP (2014) proposed that installing the shallow subsurface drain helped to convert from lowland to upland and to facilitate the land operation for machinery use. Under the paddy soils in Iran, Talukolaee *et al*. (2018) assumed that a better rice yield by the installed shallow subsurface drain was related to an improvement of soils including an increase in saturated hydraulic conductivity and effective porosity.

Alternate wetting and drying (AWD), surface drainage with so-called shallow subsurface drainage, has some benefits in rice production. There were many scientific reports of uniform rice seedling establishment (Singh *et al.*, 2008) under such kind of water management scheme. Ease of weed control (Jabran and Chauhan, 2015) also observed. Furthermore, an improvement of rice morphological characters, achieving maximum grain yield (Avil Kumar *et al.* 2006; Yang and Zhang, 2010), and maximizing the water productivity of rice (Carrijo *et al.*, 2018) occurred. Besides, there was a minimizing of freshwater use (Rezaei *et al.*, 2009) in AWD. In terms of grain quality, AWD helps to reduce arsenic (As) content in rice grain that is a focal concern of health nowadays (Yang *et al.*, 2017).

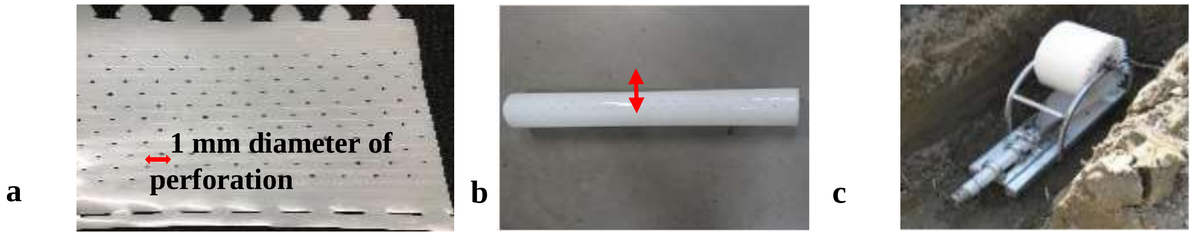
Thus, the world water council (2018) encouraged to develop the effective water management scheme in the agricultural field including paddy. It also highlights the application of shallow subsurface drainage and irrigation as a better control scheme of water regarding the crop requirement. In addition, incorporated uses of subsurface drainage (including both deep and shallow) in many management levels should consider for future applications (Wanninger, 1999; Abdel-Dayam *et al.*, 2004).

1.1.4 What is A Sheet Pipe and How to Install in A Field?

Climate change with extreme floods & droughts nowadays overstresses rice production. Many kinds of literature exposed these solutions with different technologies (IPCC, 2019). In the case of India, waterlogging was combatted with subsurface drainage (Ritzema *et al.*, 2008). Japan extended subsurface shallow drainage systems in large size paddies for crop diversification to adapt to climate change (Ogino and Murashima, 1993). Shallow subsurface drains with sheet pipe in paddy fields can manage the soil with improving water use efficiency, including soil water storage (JASPiP, 2014). Thus, this association developed dual purposed with sheet-pipe to function both shallow subsurface irrigation and drainage. It named as SPIDI (Sheet Pipe Subsurface Drainage and Irrigation technology).

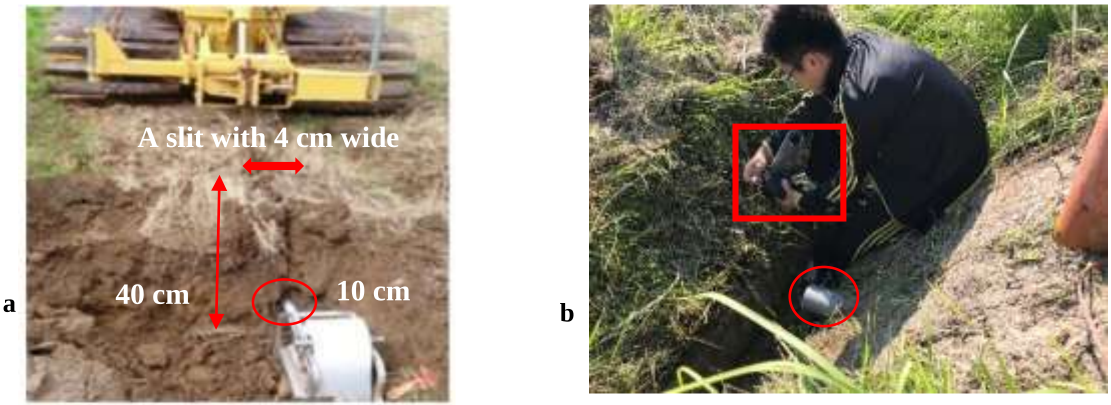
Sheet-pipe is a long & perforated plastic sheet (Figure 1.1 a) and made from polyethylene. The diameter of perforation is about 1 mm, and there are 532 pores in 1 m length. It has a rolling nature (Figure 1.1 b) with 7 kg weight per roll. It turns into a pipe with 50-70 mm in diameter when two ends of the sheet have folded during installing drainpipe in the field (Figure 1.1 b).

The perforated sheet-pipe can be installed in the field using the bulldozer with a mole drainer (Figure 1.2 a). First, the land is marked to install the sheet pipe with proper spacing. In this study, the spacing between two sheet-pipes is about 4 m. Then the land is vertically cut with a mole drainer assembled with the bulldozer according to the mark with consideration of the ground level (Figure 1.2 a). The mole drainer leaves a hole of 7-10 cm in diameter and a slit with a 4 cm width. After that, the sheet-pipe has installed at a depth of around 40 cm in line with the drain cutting.



532 holes m^{-1} **50-70 mm in diameter** **7 kg roll^{-1}**

Figure 1.1 Features of perforated sheet-pipe



Monitoring drainage with camera

Figure 1.2 Installation of perforated sheet-pipe drains in a paddy field

Sheet pipe is installed at a shallower soil depth, whereas the conventional tile drain is generally installed at least from 120 cm to 180 cm deep in the soil (Christen and Ayars, 2001). The addition of soil envelopes such as organic materials, straw, or gravels is not necessary around the sheet-pipe drains, whereas conventional pipes require the addition of such transition materials. Moreover, the installation of sheet-pipe is convenient in any irregular fields containing gravels, while traditional drains can only be in mostly uniform grounds with deep fine-textured soils. Installation of sheet pipe in agricultural land can be expected in time and labor efficient because of ease in transportation. An expectation of the installed sheet-pipe in the paddy field helps to improve soil aeration by an increase in ventilation inside the pipe (JASPiP, 2014).

Another significant character by the installed perforated sheet-pipe is assuming the generation of the vertical leg cracks. By inserting the sheet-pipe, there is a formation of a slit at the soil surface. Near the cylindrical channel from the pipe, there could be some fractures or cracks. These cracks can serve as a direct pathway of water from the soil surface to enter the perforated sheet-pipe. It makes to ensure quick drainage and drying (JASPiP, 2014).

1.2 Functions of Sheet Pipe as Shallow Subsurface Drain in Paddy Fields (Preliminary Study)

1.2.1 Introduction

Using perforated sheet-pipes as a shallow subsurface drain is a new technology to apply in paddy field and there are few papers to cite that. And hence, it is necessary to confirm its effectiveness & inefficiency logically and scientifically. Most studies of subsurface drains emphasize on designs and layouts with performance and function evaluations.

This study aimed to investigate the soil moisture changes as drainage characteristics and functions of the newly installed sheet-pipe. From these functions and performance, we evaluated the waterlogged days at different soil depths.

1.2.2 Materials and Methods

1.2.2.1 Study Sites and Field Trials Set-up

This study carried out from the 10th of October 2018 to the 2nd of December 2018. We selected two fields at Kagoshima prefecture, Kyushu, in Japan (Figure 1.3). The first field trial site, S1, was at Isashi-Hishikarimode, Kagoshima, with the geographic coordination of 32° 14′ N,130° 37′ E. Its elevation was 170 m above sea level. The second one, S2, located in Yasui-Cho, Aira-Gun, Kitaka, Kagoshima, with the geographic coordination of 31° 57′ N, 130° 43′ E. Its elevation was 188 m above sea level. All fields were almost flat with less than 1% slope. The history of all fields has continuous rice cultivation with proper management by farmers. We compared the soil moisture changes with and without installed sheet-pipe conditions at each study site. The area with sheet-pipe drains in S1 was 0.22 ha and without one was 0.34 ha. Those in S2 were 0.1 ha and 0.6 ha, respectively.

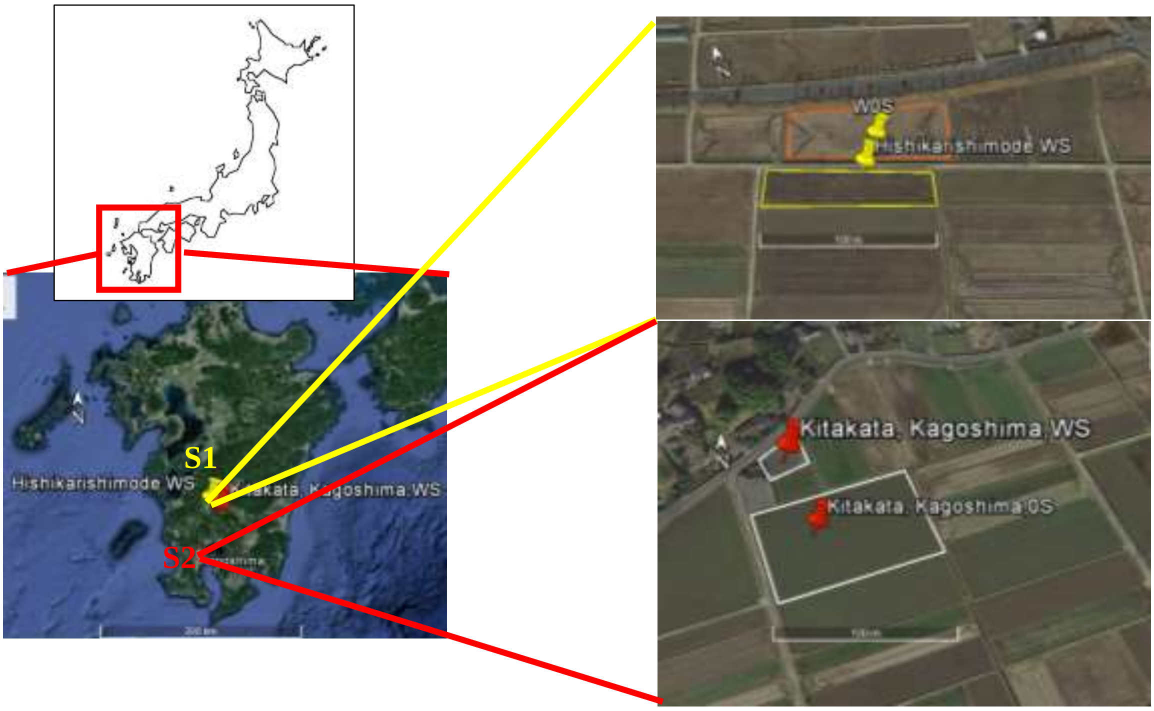


Figure 1.3 Map of study sites

S1 is the first field trial site at Isashi-Hishikarimode and S2 is at the second field trial site at Kitaka, Kagoshima. WS means field with perforated sheet-pipe and W0S means field without perforated sheet-pipe.

Firstly, to monitor soil moisture status in each field, a total of nine soil moisture sensors (ECH2O EC-5, Decagon) with Em 5b data logger (Decagon) were equipped at the three soil depths**;** 5 cm, 15 cm, and 30 cm, respectively. Then, one Motion Activated Cameras (Mac200DN) was also fixed at the outlets of a drain in each field to record the drainage time and condition (Figure 1.2 c). Although weather stations (HOBO micro RX station, ONSET) were set up in each site to collect the micro-climate data accurately, some connection errors were observed during this study. Thus, the meteorological data acquired from the nearest weather station in Kagoshima. Soil texture was classified with field method (McDonald *et al.*, 1998).

In the laboratory, the soil moisture characteristic curve had already prepared for dry, field capacity, and saturated conditions before conducting field trials. Thus, soil moisture sensors showed above 0.494 $cm^3\ cm^{-3}$ for Isashi-Hishikarimode and 0.483 $cm^3\ cm^{-3}$ for Kitakata indicated the saturated condition.

1.2.2.2 Data collection and Analysis

All collected data were stored in the Microsoft excel-2010 version. The graphs of distinct rainfall and drainage events were produced by matching with soil moisture changes. In the field, soil moisture contents were recorded as 20 minute intervals. These data were analyzed an average of three sensors by using a Microsoft-Excel program. All recorded videos (.avi) from motion-activated cameras were converted to photographs (.jpg) to analyze the drainage image.

Rainfall events were identified regarding continuous rainfall amount larger than or equal to 10 mm. Water-logged days were counted based on the saturated soil moisture contents of each soil depths in two sites.

During the data collection, soil moisture sensors showed at and above saturation, these days were counted as waterlogging. It is well-known that most vegetable crops cannot withstand more than 48 hours of water-logged condition (Ransom and Mattern, 2011). Regarding the report of Setter and Waters (2003), soils with a prolonged saturation within a 30 cm root zone are detrimental to crop plants. Thus, days showing soil moisture content above field capacity were collected as waterlogging. Percent recovery from waterlogging was determined with no consecutive days for saturation at a given soil depth as 100 %, which compared to those without installed sheet-pipe.

1.2.3 Results

Table 1.1 Soil texture and soil moisture at saturation of two study sites

Soil depths	Isashi-Hishikarimode (S1)		Kitakata (S2)	
	Soil Texture	Soil moisture at saturation (cm^3 cm^{-3})	Soil Texture	Soil moisture at saturation (cm^3 cm^{-3})
5 cm	Sandy loam	0.43	Sandy loam	0.38
15 cm	Clay loam	0.49	Sandy Clay Loam	0.44
30 cm	Clay loam	0.49	Sandy Clay loam	0.48

Soil textures of both study sites were different regarding soil depths (Table 1.1). Subsoil layers of Isashi- Hishikarimode (S1) had a heavy textural class, and clay content in Kitaka (S2) seemed to be lower than that of S1. Soil moisture contents at field capacity for each depth reflected the textural condition of each site. At deeper layers of S1, it had much moisture at saturated condition (0.49 cm^3 cm^{-3}) for clay loam and less moisture in S2 (0.44 and 0.48 cm^3 cm^{-3}) for sandy clay loam.

According to the rainfall data (Figure 1. 4 and 1. 5 a, b, and c), there were seven events of distinct rainfall (≥ 10 mm) in this study. However, it could record five significant events of drainage as the results of photographs Figures 1.6 and 1.7.

1.2.3.1 Soil moisture changes

Changes in soil moisture content at different soil depths of both study sites immediately increased after rainfall (in Figures 1.4 a, b, c, and Figures 1.5 a, b, c). Regarding the rainfall amount, the upper layer of S2 never showed a longer time of water-logged condition, whereas that of S1 showed at event-2 and 3.

At the beginning of rainfall, we observed much moisture content at the upper layers compared to that of lower layers in both study sites (event-1). During continuous precipitation, soil moisture content at the installed sheet-pipe was lower than that of without ones. However, there were different fluctuation points between soil moisture trends with and without installed sheet-pipe. After continuous rainfall, both sites without installed sheet-pipe showed stable water content, and it could be seen clearly in 15 cm soil depths and 30 cm soil depths. It indicated that these soil layers became saturated or oversaturated conditions. However, the installed sheet-pipe of both sites produced the immediate response of decreasing soil moisture trends at all soil depths. These decreasing trends were an indicator of drainage. As the texture of S1 was clay loam, the moisture fluctuation gaps were broader in S1 than in S2 (Figure 1.4 c and 1.5 c). From these trends, the stored soil moisture amount seemed to be more in S1 than in S2.

Figure 1.6 and 1.7 show the soil moisture changes at different drainage events under the sheet-pipe installed condition of both sites. While it was draining, the trends of soil moisture content at the lower layers increased more than those of the upper layer. At 15 cm and 30 cm soil depths, we observed more stagnant tendencies of soil moisture status without sheet-pipe under continuous rainfall. While excess water was draining via the perforated sheet-pipe, 30 cm soil depths showed saturation. In contrast, the trends of soil moisture contents at 15 cm and 5 cm were decreasing.

1.2.3.2 Drainage Function

At drainage event-1 (Figures 1.8 a and 1.9 a), soil moisture content at all soil depths of both sites changed abruptly from 12:00 to 16:48 due to continuous

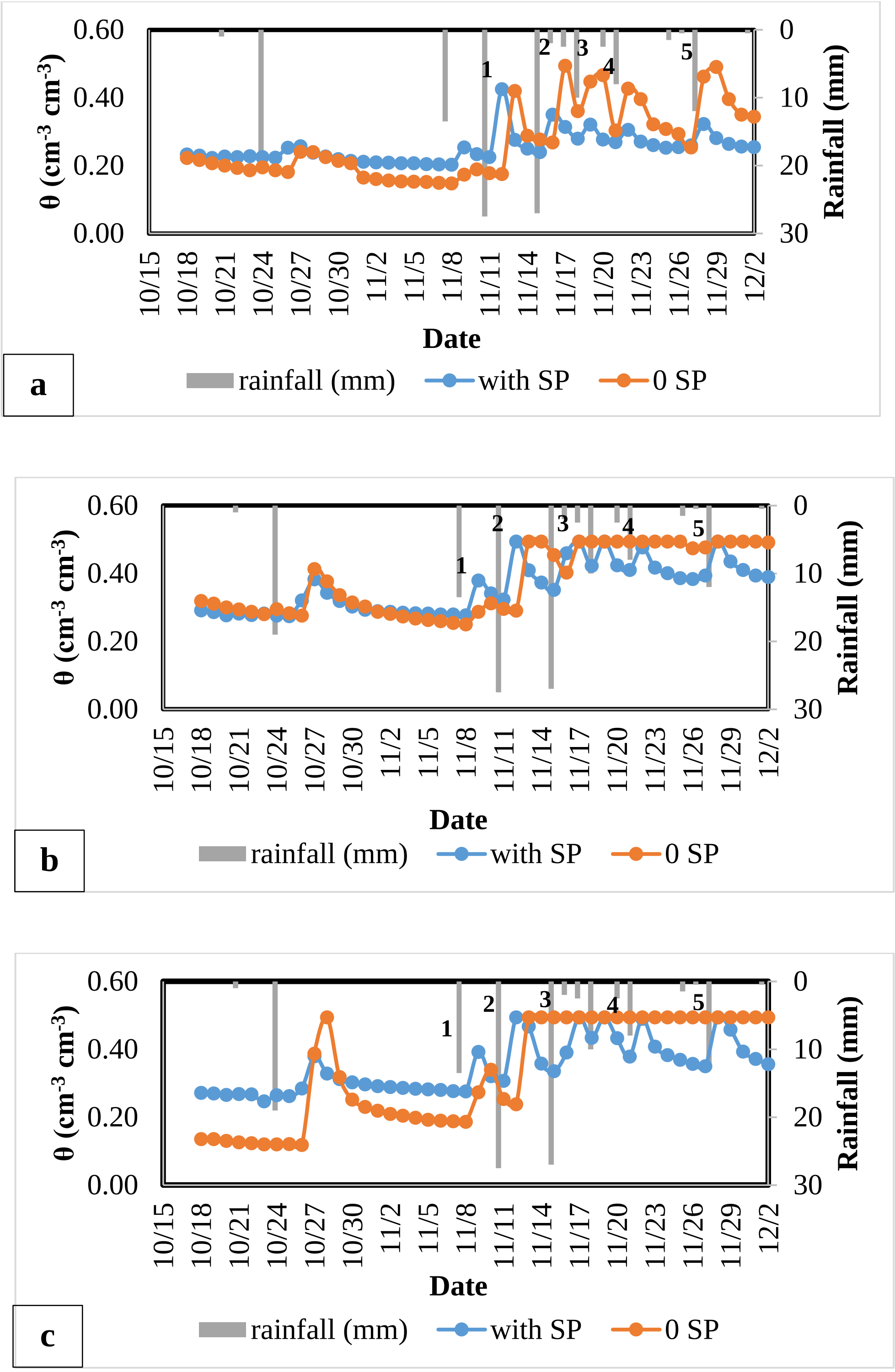


Figure 1.4 Comparison of soil moisture status at a) 5 cm, b)10 cm, and c) 30 cm soil depth between perforated sheet-pipe installation (with SP) and no-installation (0 SP) study in Isashi-Hishikarishimode, Kagoshima

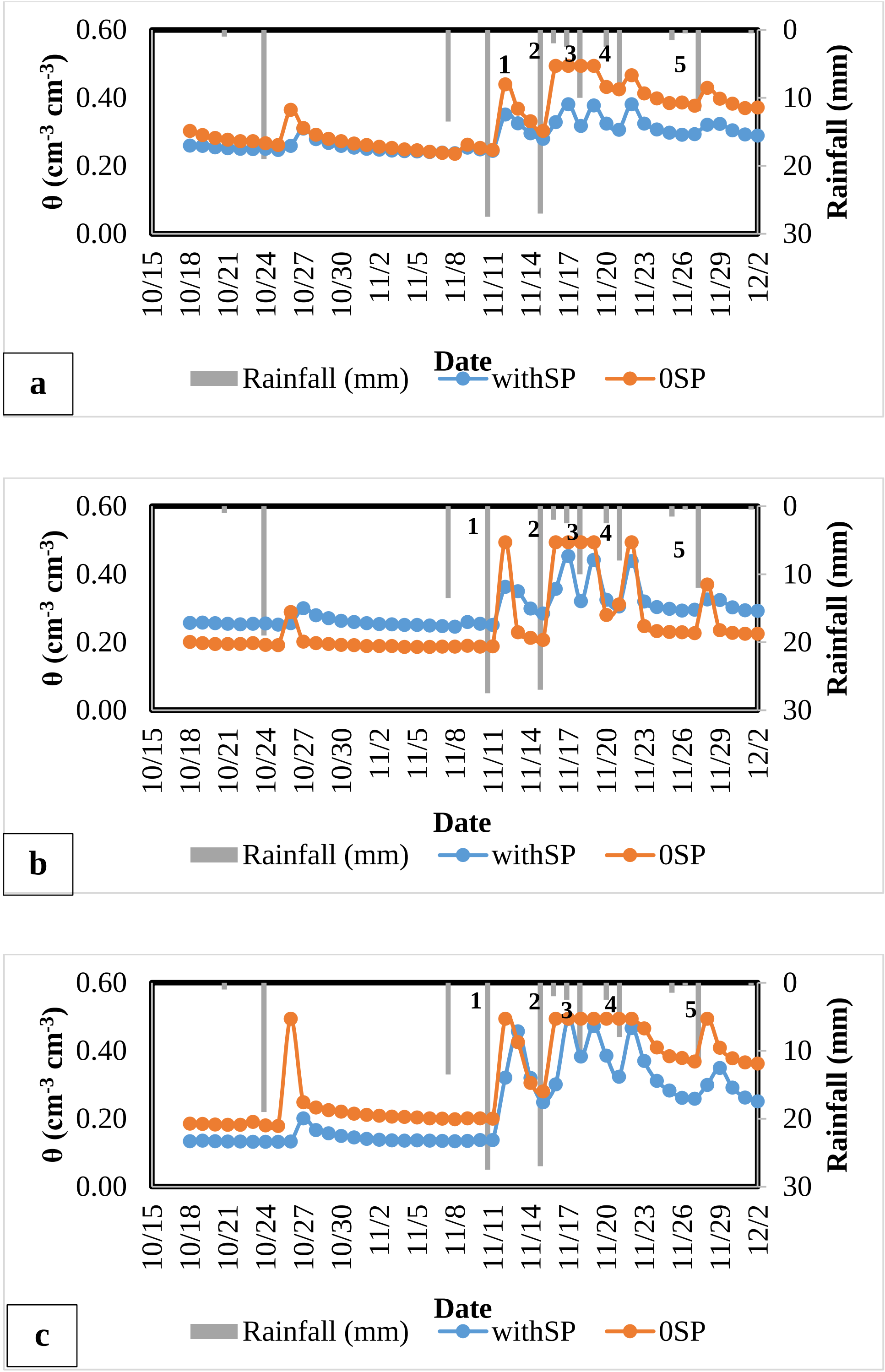


Figure 1.5 Comparison of soil moisture status, θ (cm^{-3} cm^{-3}), at a) 5 cm , b) 15 cm, and c) 30 cm soil depths between perforated sheet-pipe installation (with SP) and no-installation (0 SP) in Kitakata, Kagoshima

(a) 12.11.2018 **13.11.2018**

(b)17.11.2018 **18.11.2018**

(c)19.11.2018 **(d) 22.11.2018**

(e) 28.11.2018 **29.11.2018**

Figure 1.6 Records of each drainage event in Isashi-Hishikarishimode, Kagoshima

(a) 12.11.2018

13.11.2018

(b)17.11.2018

18.11.2018

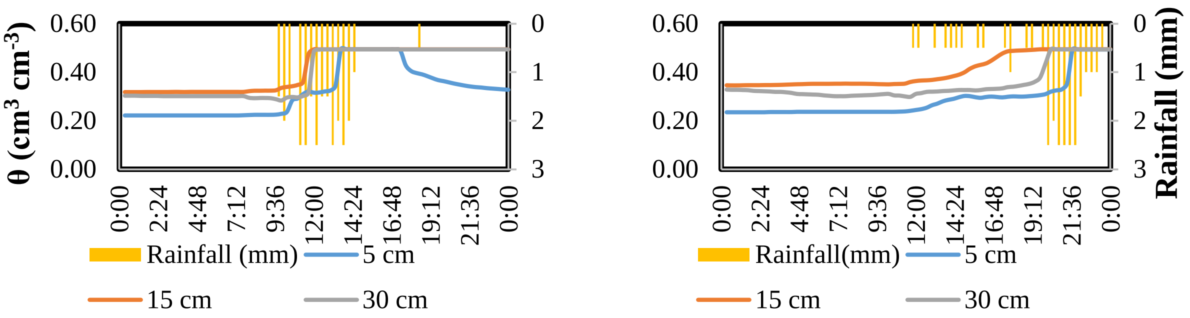
(c) 19.11.2018

(d)22.11.2018

(e)28.11.2019

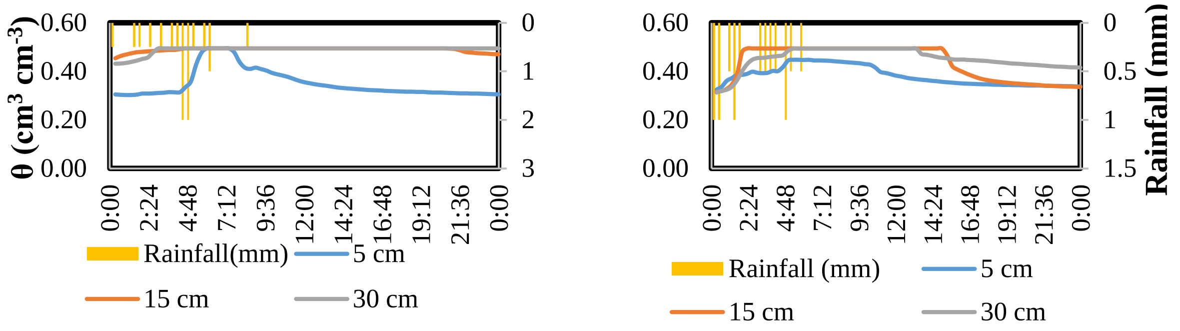
29.11.2018

Figure 1.7 Records of each drainage event in Kitakata, Kagoshima



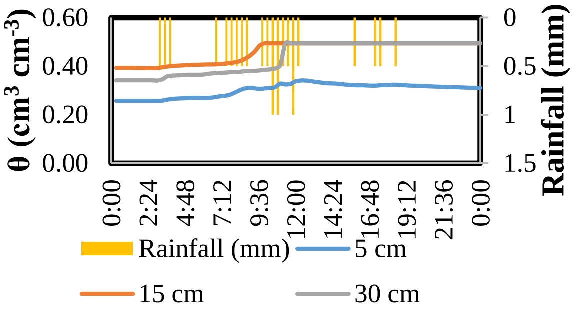
12.11.2018
(a)

16.11.2018
(b)



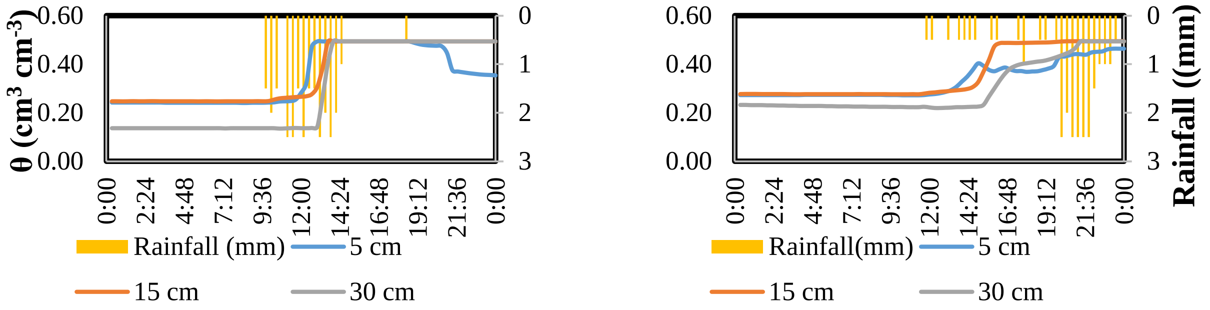
19.11.2018
(c)

22.11.2018
(d)



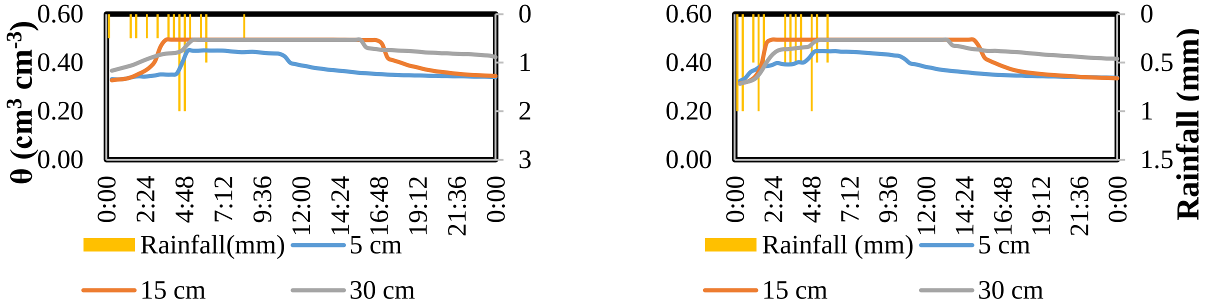
28.11.2019
(e)

Figure 1. 8 Soil moisture changes (θ, cm^3 cm^{-3}) at three depths of 5 rainfall events (a, b, c, d, e) in Isashi-Hishikarimode, Kagoshima



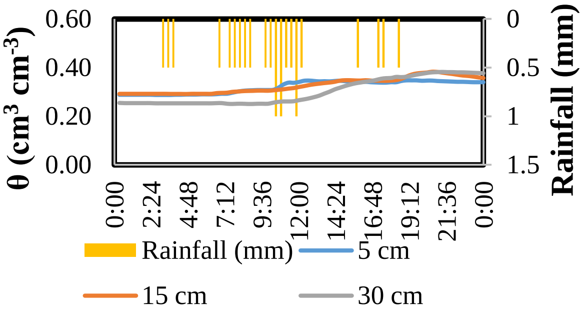
12.11.2018
(a)

16.11.2018
(b)



19.11.2018
(c)

22.11.2018
(d)



28.11.2018
(e)

Figure 1.9 Soil moisture changes (θ, cm^3 cm^{-3}) at three depths of 5 rainfall events (a, b, c, d, e) in Kitakata, Kagoshima

rainfall. When the saturated moisture content of the upper layer reached around 14:20 in S1 and S2. Thus, the clear drainage photos of event-1 were recorded at 14:25 in S1 (Figure 1.6 a) and 16:43 (Figure1.7 a) on 12th November 2018. From these pictures, the installed sheet-pipe in different soils was functioning well and the beginning of drainage in these soils was different. Figures 1.8 a and 1.9 a showed the drainage event-1, wherein the resulted daily soil moisture changes matched with the resulted drainage photos indicating clear time information.

At drainage event-2, all soil moisture contents of different soil depth reached the maximum at 21:36 pm in S1 and after 24:00 in S2 (Figures 1.8 b and 1.9 b) on the 16th of November 2018. However, the saturation point of the lowest layer, 30 cm soil depth reached around 19:12 on both sides. It could predict that draining time began at that time but the photos on that day of both cameras did not function well at night time. Thus, the clear pictures could record in the morning of the next day (Figures 1.6 b and 1.7 b).

According to drainage events 3, 4, and 5, it could be estimated at the beginning of the drain time. When the lowest soil layer reached the maximum soil moisture storage, it began to drain on both study sites. Thus different drainage photos of both sides (Figures 1. 6, 1.7 c, d, and e) were matched with different drained time-records (Figures 1.8, 1.9 c, d, and e). Generally, the uppermost soil layer of both sites showed less soil moisture content while it was draining under the installed sheet-pipe. It indicated the success of the perforated sheet-pipe installing in these fields when compared to without ones under continuous rainfall. Increasing, decreasing, and stagnating patterns of soil moisture were related to rainfall conditions and drainage. Swarowsky, *et al*. (2011) also discussed that water dynamics in soil were governed by many factors that change vertically with depth, laterally across landforms, and temporally in response to climate.

1.2.3.3 Comparison of Water-logged Days in Two Selected Sites

Table 1.2 Comparison of water logged days in the selected two sites

soil depths	Isashi-Hishikarimode (S1)		Kitakata (S2)	
	with SP (N=3)	0 SP (N=3)	with SP(N=3)	0 SP(N=3)
5 cm	1	6	0	4
15 cm	2	17	1	5
30 cm	4	21	4	10

With SP means field with perforated sheet-pipe and 0SP means field without perforated sheet-pipe

Installing sheet-pipe as a shallow subsurface drain significantly reduced water-logged days in both sites (Table 1.2). Under without sheet-pipe, a prolonged waterlogging observed during a study period. Mostly, it occurred at 15 cm and 30 cm of the root zone. There were six days for waterlogging at 5 cm of S1 and four days in S2. For 15 cm soil depth, those were seventeen days in S1 and five days in S2. The maximum number of water-logged days observed at 30 cm soil depths for twenty-one days in S1 and ten days in S2. There was no consecutive waterlogging under the sheet-pipe installed condition in both places. Likewise, other conventional drains, such as mole and tiles, were reported as a reduction of the water table and a control waterlogging (MacEwan et al., 1992; Muirhead *et al.*, 1996).

1.2.4 Conclusion

This study investigated the performance of the installed perforated sheet-pipe as a shallow subsurface drain on water-logging in the paddy soils. We compared the performance of the drainage condition between the soils with and without an installed drain. Results of soil moisture changes under two conditions were completely different. When the rain started, the upper layer moisture showed higher than the other two layers. When the drainage began, moisture contents of the lower layers were almost high. Although there were seven rainfall events greater and equal ten mm day^{-1}, only five drainage events could record with the camera. Under the installed sheet-pipe condition, there was no consecutive waterlogged day, whereas a prolonged water-logging occurred at 15 cm and 30 cm depths of uninstalled soils in both sites. During a study period, installed perforated sheet-pipe as a subsurface drain saved waterlogging at rooting zones of 15 cm and 30 cm in two regions of Japan.

1.3 Objectives of the Present Study

The main objective of this study is to investigate the impacts of the installation of perforated sheet pipe as shallow subsurface drain on some soil properties. To approach the main objective, three specific objectives were laid out for each research. They were:

- To observe the soil moisture changes as drainage characteristics and functions of the newly installed sheet-pipe
- To identify the changes of some paddy soil properties by the newly installed sheet-pipe in paddy soils as a short term effect
- To investigate the changes of some soil properties under long term installation of sheet pipe effect

1.4 Structure of the Present Study

Regarding the objectives laid out, our preliminary study for evaluation of drainage function states in the Chapter 1. In this study, we determine the performance of the installed perforated sheet-pipe with soil moisture changes. The results compared to those of without ones. This study highlights the nature of soil moisture changes and how long it takes between rainfall and drainage events under different soils. Also, we characterize the duration and frequency of waterlogging during the study period. In this study, soil moisture sensors and motion-activated cameras were utilized together with weather data to identify the drainage events. From this study, the identification of drainage characteristics is necessary for the first step of research purposes in field conditions. Besides, the basic requirements learned from the preliminary trials are listed, and some improvements for further research could propose.

To understand the perforated sheet-pipe as shallow subsurface drain in paddy soils, the Chapter 2 states as reviews. This chapter describes in two sections, namely the role of agricultural drainage under climate change and impacts of subsurface drainage on paddy soils**.** In the first section, we review challenges, some considerations of agricultural field drainage, different drainage systems, and the importance of subsurface drainage. Furthermore, logical discussion on soil function and subsurface drainage also states in this section. Then, we discuss why subsurface drains are installed as the first step in land reclamation. How and where it can install for different purposes explains in the second section. Also, the impacts of subsurface drainage describe in that part in terms of crop production, soil properties, and environmental aspects.

Chapter 3 illustrates the **s**hort-term impacts of the perforated sheet pipe as a shallow subsurface drain on paddy soil properties. In this chapter, changes and differences in soil properties are presented comparing with before and after installed states. This study emphasizes on the same soil under the short-term. The reasons for changes in soil properties and some impacts are proposed as short-term effects.

Chapter 4 clarifies the long-term impacts of the installed perforated sheet-pipe on some paddy soil properties. Under different installed durations, this study reports the most significant changes in soil properties. From these changes, why we observed some impacts by the installed perforated sheet-pipe explains in this section.

Chapter 5 summarizes the observations and states the results as conclusions. Besides, lessons learned, some suggestions, and recommendations based on our studies show in this chapter.

Chapter 2

Reviews of the Literature

2.1 Role of Agricultural Drainage under Climate Change

World population would approach 9 billion by 2050. Coupling with the rising population, global water demand would also increase to meet food demand. In global food demand, the required agricultural water use would compete with other water withdrawals such as uses of urban, industry, recreation, and environmental protection (de Fraiture and Wichelns, 2010). Current findings warned that global climate change also stressed water security through changing temperatures, long-term variations in precipitation, and regional rainfall distribution patterns (UN-WFP, 2018).

Ayars and Evans (2015) verified that the water requirement for crop production was significantly low in places with effective utilization of water practiced. Besides, the application of modern irrigation and drainage techniques could maintain sustainable crop production and control some environmental impacts (Smedema *et al.*, 2004). There was some significant evidence due to the application of such modern management practices. These helped to improve crop yields, assisted a solution to the rapidly emerging food demands, decreased total freshwater diversions for agriculture, and conserved environment (Ayars and Evans, 2015).

Globally, around 18% of the cultivated area was under irrigation, and its production contributed 40% of all food. Over the decades, an increase in irrigated crop production played a significant role in successes during the Green Revolution and the eradication of famines in Asia (Schultz *et al.*, 2005). Recently, irrigation was responsible for water shortages, severe environmental damage, and crop failures. The consequences were an increase in social inequality (WCD, 2000; FAO *et al.*, 2020). On the other hand, drainage was highlighted as one of the integrating manners to invest in sustainable agriculture, land management, and rural development (Tayagi, 2012).

Thus, future agricultural drainage is challenging to meet world food demand under climate change with severe environmental concerns. On the other hand, it is necessary to increase crop production both from irrigated & non-irrigated areas using the modern irrigation practices and improved drainage systems. Regarding the past citations, it could predict that food production from the improved drainage for the 2025-time horizon would increase by 1.0–1.5% in irrigated area and 0.5–1.0% in the rain-fed area (Wrachien and Feddes, 2004; Ritzema *et al.*, 2007; Gopalakrishnano, 2009).

Concerns with the controlled drainage, Ayars and Evans (2015) proposed that combined subsurface irrigation & subsurface drainage system was one of the critical future components for sustainable water management in humid and arid areas. They believed that such a system could maintain much available water for crops, and active management of the drainage operation absolutely required in those areas. The benefits of controlled drainage included reducing groundwater pollution, maintaining water use efficiency, and promoting higher quality crop & its yield (Phene *et al.*, 1992; Alam *et al*., 2002; Lindenmayer *et al.*, 2007).

Recent publications suggested that agricultural water management should aim to achieve the triple goals of increased food production, equitable access, and environmentally friendly practices. Furthermore, it is necessary not to neglect field drainage as well as to equip the developed drainage infrastructures. This improvement should be adaptable under climate change for the future (ICID, 2014).

2.1.1 Challenges of Agricultural Field Drainage

ICID (2018) expected that future global food demand would rely on food production from both irrigated & non-irrigated areas. Modern irrigation practices and improved drainage systems would also take part in food production. Recent papers highlighted to consider the outlook of future drainage. Schultz *et al.* (2007) reported an evaluation of past & current drainage management options as the first step to find the solutions for the improvement of future agricultural drainage techniques. Secondly, poor understanding of beneficial and non-beneficial effects of drainage on some areas of agriculture was one of the disturbances. Little investment was one of the problems in the maintenance of drainage systems. Under government funds, little interest in providing and maintaining drainage services as well as the training for operations were other problems. Finally, a huge expense of renovating and improving these systems were other reasons to ignore the drainage development (Ayars and Evans, 2015). Thus, the future of agricultural drainage will face several significant obstacles. For example, the design and service life of drainage infrastructure has been generally neglected. Many drainage systems have also failed or are failing with no plans. There are no resources to replace them. For these reasons, Scheumann and Freisem (2002) identified drainage as the forgotten issue in sustaining irrigated agriculture.

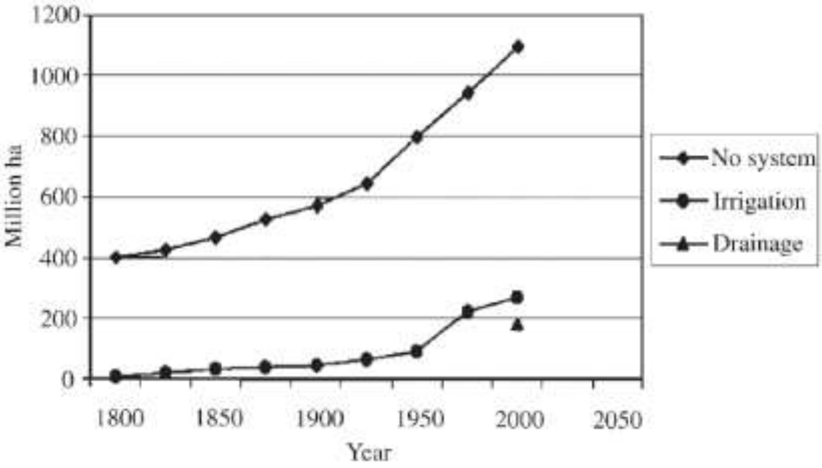
Ayars and Soppe (2014) proposed that improving or modifying the current drainage management, proper design, criteria, and practices should be considered. ICID (2018) also suggested that this developed drainage technique should also be adaptable to climate change. Besides, environmental safeguarding was necessary. Creating an affordable price was one of the requirements. While installing the drainage infrastructure, efficient management skill for labor and time is also necessary.

Currently, most developed countries have been developed in agricultural field drainage. In contrast, developing countries are in little interest. On a global scale, open drains & surface drainage, subsurface drains, and vertical drainage systems are currently applied. These represented 55%, 38%, and 7% of the drained areas, respectively (Schultz *et al.*, 2007). Recent papers stated less than 16% of global irrigated areas are as salt-affected. These salt-affected areas also required to reclaim with drainage (Zimmer *et al.*, 2005). Also, rain-fed cropland and irrigated land equipped with some improved drainage due to uncertain rainfall. Many successes were observed by the installation of subsurface tile or mole drains in agricultural fields (Strock *et al.*, 2011). In paddy soils, Ogino and Ota (2007) also applied shallow subsurface drains for wetland paddy cultivation and converted upland crops or orchards, in Japan.

In the selection of proper design for field drainage systems, determinations of drain depth, drain spacing, and the required transport capacity of the drains were some considerations. For effective drainage of different crops, characterization of soil moisture regimes from saturated to unsaturated conditions, infiltration, porosity to water supply, and critical water requirements were necessary at first. Evapotranspiration and climatic parameters would also support decision making. However, knowledge regarding drainage development was limited. Thus, further researches based on these limitations would support better planning and management of an improved agricultural drainage system (Smedema and Ochs, 1998; Smedema *et al.*, 2000; Smedema *et al.*, 2004; Ritzemaa *et al.*, 2006).

2.1.2 Considerations for Drainage Development under Climate Change

In most of the world's irrigated and rain-fed lands, drainage facilities developed on a step-by-step basis over the centuries. In many facilities, structures were aged or deteriorating. This fact pointed out why drainage development was necessary. In such a case, to renew or even replace as well as redesign and rebuilt should consider (Smedema, 2000; Schultz *et al.*, 2007). For example, drainage systems in past designed for long life (50 years or more) based on the assumption that climatic conditions would not change in the future. These drainage designs would be inappropriate in the future due to global warming and the greenhouse effect. Therefore, it was recommended for the planners and designers to examine planning principles, design criteria, operating rules, and management policies for new infrastructures (Wrachien and Feddes, 2004; WWC, 2018).



(Source; Schultz, 2001)

Figure 2.1 Expansion of current world's cultivated area with no water management system and under irrigation and currently drained land

From Figure 2.1, it was recognized that out of a total cultivated area of around 1500 million ha, 1100 million ha were agriculturally exploited without water management systems. It meant, "Without drainage, there was no completion of water management" (Schultz, 2001). Basically, he gave a piece of advice to develop drainage management with some divisions of global agricultural drainage zone. According to agro-climatic conditions, there are three global agricultural drainage zones (Bouarfa *et al.*, 1996; Smedema and Ochs, 1998; Schultz, 2001; Smedema *et al.*, 2000; 2004). They are the temperate (humid) zone, the arid & semi-arid zone, and the humid & semi-humid zone (Figure 2.2).

In the temperate (humid) zone, the purpose of drainage is to prevent waterlogging and to provide good traffic-ability conditions for farm machinery. The drainage systems mostly applied in this area are surface and subsurface. During recent decades, some drainage problems in this area were arising due to salinization, leaching of fertilizers & pesticides, pollution from municipal and industrial sources. In additions, transboundary water quality problems in some river basins were observed (Schultz *et al.*, 2007).

(Smedema *et al*., 2004)

Figure 2.2 Agroclimatic zones

In the arid and semi-arid zone, the major role of drainage is to prevent irrigation-induced waterlogging and salinization of the fields. In this region, drainage has usually installed in combination with irrigation. The problem of this zone is to achieve self-sufficiency in food production with the effective use of water. Improved and or controlled drainage may be seen there as another way to conserve precious water resources. Subsurface drainage systems are also applied to control groundwater tables (Schultz *et al.*, 2013).

In the humid and semi-humid zone, the role of drainage encompasses waterlogging control, salinization prevention, and flood protection in various proportions. Mainly drainage is applied according to crop season. During the wet season, rain-fed (rice and dry food) crops are chiefly cultivated in large areas according to the relatively abundant rainfall. Generally, open drainage systems are applied there. While rainfall intensities are so high, extra pipe drainage requires solving insufficient capacity, and thereby it becomes very expensive. In many areas of this zone, drainage systems apply without irrigation. When systems are improved to enable the cultivation of crops during the wet and the dry seasons, drainage systems in combination with irrigation systems are generally applied (Schultz *et al.*, 2007). Especially in Japan, there was also experienced with the combination of open and pipe drainage systems in order to get good control of surface water and groundwater for mixed crops – rice followed by dry crops (Ogino and Ota, 2007).

Large lowland areas along the coasts and river floodplains in semiarid and arid zones are still reclaiming. Reclamation of these lowlands requires the application of a drainage system also. Depending on the local conditions, combined with flood protection and or irrigation requires. An increase in impermeable areas in coastal lowlands resulted from an enormous expansion of urban and industrial areas that were observed there (Schultz, 2001). Thus, there was more flooding than before. Another increasing problem was the pollution of drainage systems. Its source originated from an uncontrolled wastewater discharge from urban and industries as well as from the uncontrolled application of fertilizers and pesticides in agriculture (Schultz *et al.*, 2005).

Global warming due to the greenhouse effect varied with the hydrological process such as water regimes, water resource systems, and then on the drainage planning & design process (Leavesley *et al.*, 1992). Under considerations of the drainage system, it is necessary to cope with all of the uncertainties of how climate change and how drainage systems have to adapt to such climate change. To solve long-term such issues by climate change, the identification of short-term strategies in detail also requires. The development of a comprehensive approach requires to integrate all reliable issues into the drainage project selection. Furthermore, further research based on the effect of climate variables on water demand for irrigation, and the impacts of climate on infrastructure performance on drainage would support drainage development (Schultz *et al.*, 2007).

2.1.3 Drainage Systems: Surface, Subsurface, and Shallow Subsurface

USDA-NRCS (2001) provided the drainage system and functions in water management like that; there are three functions in a drainage system. They are creating well-drained arable land, preventing salinization of the soil, and lowering the groundwater table. The last function has the removal of accumulated salts and or toxic elements. One or all of these functions can accomplish the drainage. However, the success of drainage depends on the soil, meteorological, and hydrological conditions.

A drainage system can consist of a field drainage system, the main drainage system, and an outlet. A field drainage system can be surface drainage, subsurface drainage, and or both. Main drains are collectors of water from the field drains, and convey it to the outlet of the area. An outlet is an open connection, discharge sluice, or pumping station to evacuate the drainage water to a receiving water body.

A surface drainage system is the removal of excess water from the surface of the land by means of improved natural channels or constructed drains. There are two purposes for the improvements in design. The first one is to minimize crop damage resulting from water ponding on the soil surface following a rainfall event, particularly in ground slopes less than 2%. The second one is to control runoff without causing erosion for steeper land slopes.

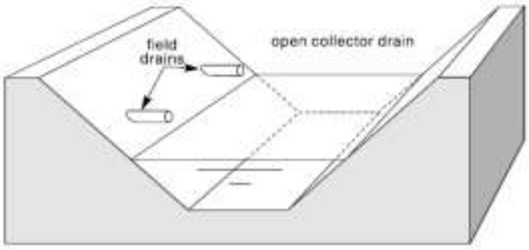
Surface drainage systems can apply in relative flatlands that have soils with a low or medium infiltration capacity. In lands with high-intensity rainfalls that exceed normal infiltration capacity, surface drainage can reduce frequent waterlogging on the soil surface. In this situation, some improvement structures are necessary to build for the prevention of flooding, such as land leveling, smoothing the construction of surface water inlets to subsurface drains, and the construction of shallow ditches & grass waterways.

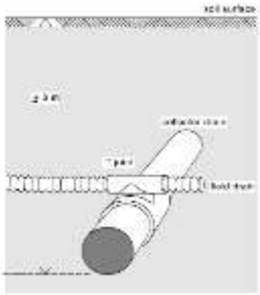
Surface drainage systems can be classified into two: namely “Regular Surface Drainage System” and “Controlled Surface Drainage System”. The regular surface drainage systems which start functioning as soon as there is an excess of rainfall or irrigation operate entirely by gravity. They consist of reshaped or reformed land surfaces and can be divided into bedded systems. These are the systems, used in flatlands and graded systems, used in sloping lands. The bedded and graded systems may have ridges and furrows. The checked or controlled surface drainage systems consist of check gates placed in the embankments surrounding flat basins such as those used for rice fields in flatlands. These fields are usually submerged and only need to be drained on certain occasions (e.g. at harvest time). Checked surface drainage systems are also found in terraced lands used for rice.

Surface drainage can affect the water-table by reducing the volume of water entering the soil profile. Surface drainage improvements require annual maintenance, and careful designs required to ensure soil erosion control. At the same time, earthmoving activities are extensive, and these make it expensive. Land grading might expose less fertile and less productive subsoils. Such earthmoving and land grading activities create an agricultural area to waste. Further open ditches may interfere with moving farm equipment across a field (ICID, 2018).

A subsurface drainage system is a man-made system that reduces excess water and dissolved salts to flow across the soil to the pipe or open drains. Open drains have some advantages that they can receive overland flow and thus can also be used for surface drainage. The disadvantages of open drains are the loss of land, the interference with the irrigation system, the splitting-up of the land into small farm blocks, which delays farming operations, and a maintenance burden. To overcome these disadvantages, pipe drains can be installed. The choice between open or pipe drains has to be made at two levels. The first one is for field drains, and another one is for collector drains. If the field drains are to be pipes, there are two options for the collectors. These are;

- Open collector drains with a singular pipe drainage system (Figure 2.3)
- Pipe collector drains with a composite pipe drainage system (Figure 2.4)





(Source: Oosterbaan, 2014)

Figure 2.3 In a singular pipe drainage system, each drained pipe discharges in to an open collector drain.

Figure 2.4 In a composite system, the collector drained pipe is buried.

Thus, open drains, pipe drains, mole drains, or a combination of these can be installed in a subsurface drainage system. Subsurface drain pipes are usually made of earthen, porcelain, pipe, polyvinyl chloride, and polyethylene plastic. These pipes can be installed with 7 - 50 m spacing at 1.5 - 2 m soil depth (FAO, 1995). In the conventional subsurface drainage of most Japanese paddy fields, pipe drains are installed with a spacing of 7-12 m at 1 m soil depth by using the filter envelope with straw, gravels, or others (Tabuchi, 1985).

This combined system is mostly applied in irrigated areas of arid and semi-arid regions. Especially, in the fields practicing with the rotational cropping pattern (rice-soybean), subsurface drainage is usually applied for salinity control of the dry-foot crops. Surface drainage is needed to evacuate standing water from rice fields. Subsurface drainage is usually practiced before fertilizer applications or to dry crops before harvest. In areas with occasional high-intensity rainfall (more than 50 mm/day) that causes water ponding at the soil surface, this combined system is also practiced (Ritzema, 2006).

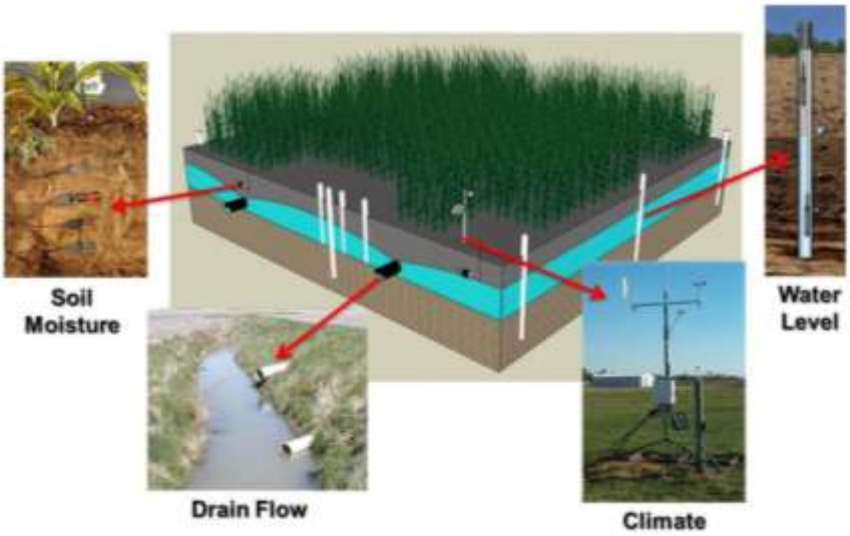
"Shallow Subsurface Drainage System"; Soils with much clay content (40-60%) are difficult to drain due to the formation of the impermeable soil layer. Soils with loamy silt are vulnerable to erosion by intense rainfall (USDA-NRCS, 1999). In those cases, installation of the perforated pipe as a shallow subsurface drain helps to favor much water infiltration and conserve soils. Generally, the installation depth of a shallow subsurface drain can vary from 60 to 90 cm according to the planning & construction method, the appropriate soil conditions (i.e., suitable soil texture and soil moisture), and problems (e.g., the collapse of cut-drain). This system is mostly applied in paddy fields. Mole drains with high-performance perforated plastic sheet-pipe are widely installed at a shallower soil layer with closer spacing of 4 m. In Japan, sheet pipe as a shallow subsurface drain can perform in preventing flooded land combined with surface drainage. It can control the groundwater table and salinity (JASPiP, 2014; Okuda *et al.*, 2017).

2.1.4 Subsurface Drainage in Land Reclamation

Land reclamation with surface and or subsurface drainage has many functions with land shaping, bedding, and filtering (Skaggs, 1980). Also, several considerations for land drainage are necessary to minimize the risks such as flooding, destroying lives & farmland, and its consequences. In developed countries, most land reclamation projects have been installing subsurface drainage (Schultz, 2001). Wherein, these countries challenged with some constraints on field drainage such as cost of maintenance, considerations on cost-benefit, policy improvements on water-related issues, and the role of private-public partnerships (Daniele, 2003; Schutz *et al.*, 2013). Regional wide challenges are also developed. In most irrigated areas (semi-arid & arid conditions), an increase in water logging with salt-affected problems are arising. In humid areas, such problems plus flooding and lack of subsurface drainage in farmland are encountered.

Installing drainage has been practiced as a long-term solution for such challenges. Understanding & investing in the development of drainage infrastructure, human capacity, research, and technology are major requirements (Ritzema *et al.*, 2017). Schutz *et al.* (2013) advised modifying the current drainage systems in the developed countries where it was required. They also recommended installing a proper drainage system in developing countries with the deficient drainage system. These countries need an introduction of drainage systems, including both surface and subsurface drains in farmland for increasing crop production and preventing floods.

Besides, countries in arid and semi-arid conditions require to reduce the high groundwater table, to drain salt, and to utilize water effectively. Thus, Wrachien and Feddes (2004) suggested that installing the dual purposes drainage with sub-irrigation in fields probably had some potential to save water. In this system, irrigation began when the soil dried, and drainage functioned when it flooded. Such controlled drainage had already been practiced in the USA since 1992. Especially, this practice was successful in the years with frequent rains and short droughts (Reinhart *et al.*, 2016). Thus, Fraser and Fleming (2001) encouraged to development of agricultural drainage systems with land reclamation.



Source: https://www.usgs.gov/media/images/illustration-subsurface-drained-agricultural-field
(Credit: Erik Smith, Upper Midwest Water Science Center. Public domain.)

Figure 2.5 Expected reclaimed land with subsurface drains

Figure 2.5 shows an expected reclaimed land with subsurface drains. In which, the drained field with a weather station showed for measuring climate data. There was also a piezometer network for continuous water level measurements. At that field, soil moisture probes were fixing, and subsurface drainage flow was illustrating. Such a complete land reclamation project helped to support the agricultural water management including field drainage and water balance for several crop seasons (Margane *et al*., 2013).

Historically, civilizations of Greek and Egypt relied on surface drainage to preserve cropland from being damaged by floodwaters. Since then, agricultural drainage including subsurface drainage has continued to change and developed throughout the years to now (Donnan, 1976). In Japan, land reclamation projects have been equipped with surface and subsurface drainage in coastal land and lowland rice fields from 1954 to 1970. New methods of utilizing subsurface drainage facilities for irrigation (SPIDI) has been introduced in these paddy fields since the middle of the 1990s. This method also considered harmony with the environment (Ogino and Ota, 2007).

Installing drainage structure in land reclamation project is determined with cost impacts. Most developed countries counted the charges based on monitoring and evaluation on benefits from land use, agro-climate, water table, salinity and soil conditions.

2.2 Impacts of Subsurface Drainage on Paddy Soils

2.2.1 Environmental Impacts of Sub-Surface Drainage in Paddy Field

Subsurface drainage systems have direct and indirect impacts on the environment. These impacts could be positive and negative. Pollution of drainage water was a major concern, in which salts, nutrients, organic components, and heavy metals contaminated downstream sites (Sallam and Ismail, 2012; Abd-Elaty *et al.*, 2017). In the case of Egypt, the results of the EIA matrix application for subsurface drainage projects showed the benefits of positive as 85.50%, zero as 6.5%, and negative as 5%. This calculation was based on environmental feasibility and the existing situation. In another study conducted in the Yamaska river basin, the total amount of herbicide and atrazine was lost with runoff. In which, 51 to 62% of those were removed from fields through surface runoff, and 16 to 24% was through subsurface drainage (Muir and Baker, 1976).

In terms of soil conservation, Skaggs *et al.* (1982) discovered that amount of soil lost by erosion under the subsurface drainage reduced a factor of ten on a Goldsboro sandy loam, with a 2% slope in North Carolina. Liquid manure flow was also reduced with subsurface tile drains, and it made less pollution downstream. The reason was that spreading liquid manure when the soil was dried, reduced the risk of macro-pore flow in subsurface drainage (Geohring *et al.,* 2005).

Under waterlogged paddy soils, uptake of many nutrients by rice plants, such as N, P, Mn, and Fe increased but uptake of other cat-ions reduced (FAO, 2006 b). With proper drainage, some extra elements uptake by rice were reduced, and uptake of required cations was increased. An example was observed at wetland maintenance. Woltemade (2000) reported that constructed wetlands with subsurface drainage were effective at removing nutrients, sediments, and chemicals from agricultural wastewater. For salinity and waterlogging management, subsurface drainage with proper drain depth and spacing were an effective solution (Christen and Ayars, 2001; Tiwari and Goel, 2017).

To reduce GHGs from paddy fields, proper irrigation and drainage management is an important option to mitigate global warming. In literature, both environmental conditions and paddy management practices control CH_4 and N_2O emissions. Such management practices changed soil properties such as pH, soil organic & inorganic carbon content, and drainage capacity. These variations helped to control GHGs emissions. In some reports, incorporation of organic matter such as straw, manure, compost, phosphorous, and seasonal water management accelerated to reduce such gases emission (Yan *et al.,* 2005; Mikawa and Sakai, 2010; Itoh *et al.*, 2011; Malyan *et al.*, 2016; Tariq *et al.*, 2017; Bertora *et al*., 2018). Similar enactments were noticed by application of different N-inputs in paddy soils followed by different water management systems (Toriyama, 2002; Cassman *et al.*, 2002; Cheng *et al.*, 2007; Liu *et al*., 2010). Besides, AWD (alternate wetting and drying), early-season drainage, midseason drainage, wherein single or multiple drainages during rice growth period were explained as promising options for mitigating CH_4 emissions from paddy soils (Wassmann et al., 1993; Zheng *et al.*, 2000; Tyagi et al., 2010; Pandey *et al.*, 2014; Tariq *et al.*, 2017a; 2017 b). Empirically, single drainage in the middle of rice season reduces CH_4 emissions by 36%–50% (Gupta *et al.*, 2002; Tyagi *et al.*, 2010). As a result, integrated subsurface drainage management practices significantly decreased water pollution, water-mediated social problems including health, economics, and an increase in water treatment costs (de Hean,1987; Wanninger, 1999).

2.2.2 Impacts on Crop Production by Sub-Surface Drainage in Paddy Field

Improved drainage and flood protection allow farmers to diversify cropping systems. Thereby, farmers can achieve higher and more secure yields. In paddy fields, the installed subsurface drainage system serves to hasten surface drainage of excess rainfall during crop establishment. Also, it helps to prevent total seedling submergence. Additionally, removing excess water within the soil layer by subsurface drainage hastened crop harvesting (Murashima and Ogino, 1994; Okwany *et al.*, 2016). In converted or reclaimed paddy fields with subsurface drainage, cultivation of some crops such as wheat, corn, soybeans, sugar beets, sunflowers, sugar cane, citrus, and forages increased yields & profits (Fraser and Fleming, 2001). The main reason was that most cultivated crops after rice did not like waterlogging. Timely drainage and farm machinery operations were necessary (Neigashi, 1970; Ransom and Mattern, 2011; Oosteerban, 2017; Johnson, 2018). Plamenac (1988) discovered that subsurface drainage had more efficient in machinery works on drier soil, reduced labor hours, and helped to minimize fossil fuel consumption & associated costs. Mid-season drainage in paddy field generally improved rice plant growth, and increased crop yield subsequently (Matsushima, 1970). Okamoto (1997) mentioned that the implementation of a subsurface drainage system extended the root zone soil layer and kept this as aerobic conditions. There were some results of higher yields from changing soil layer with aerobic conditions by subsurface drainage. These significant effects showed not only on rice yields but also on successive crop yields (Kenawey *et al.*, 1997; Chan and Cheong, 2001). Besides, different drain performance with spacing, depths, size, and applied drain-envelop, showed many positive impacts on rice yields (Murashima and Ogino, 1994; Jorjani and Vuuren, 1991). With controlled drainage, intermittent irrigation, dry seedbed preparation, and floating seedbed preparation could practice in paddy fields (FAO, 1995; Keiser *et al.*, 2002; Siaga *et al.*, 2019).

Alternate wetting and drying (shallow subsurface drainage plus surface drainage) provided uniform rice seedling establishment (Bouman and Tuong, 2001; Singh *et al.*, 2008). Ease of weed control was observed under this practice (Jabran and Chauhan, 2015). An improvement of rice morphological characters was also found (Yang *et al*., 2017). Maximum in grain yield was obtained with this practice (Avil Kumar *et al.* 2006). Water productivity of rice was also maximized by minimizing the use of freshwater under such conditions (Rezaei *et al*., 2009; Kumar and Rajitha, 2019). In terms of grain quality, AWD helped to reduce arsenic (As) content in rice grain (Yang *et al.*, 2017).

Subsurface drainage practice can integrate with other management practices or field operations and received some positive impacts. Examples were nutrient management practices such as 4 R (right source, right dosage, right application method, right time), timely weeding, and pest management (Fausey, 2005; Ibrahin *et al.*, 2008).

2.2.3 Impacts on Soil Properties by Subsurface Drainage

Facilitating subsurface drainage accentuates the soil hydraulic properties through soil pores. Generally, the soil has a major component of solids & pores (comprising both air & water), and soil pore space varies with soil type, structure, and land management (Hillel, 1998; Scott, 2000). All pores in soil took part in several roles for soil aeration, soil water storage, soil nutrient transformation, and presence of biota, which are essential sources for soil physical, chemical, and biological functions (Hamblin, 1985; Horn *et al.*, 1995;

Dorner & Horn, 2006). Macro-pores with greater than 50 µm in diameter developed from good aggregates, and these are important for air movement and drainage for excess water. Meso-pores with 30 -50 µm size were important for soil water storage and water and nutrient movement in soils (Greenland, 1977; Kay, 1990; 1998; Hillel, 1998; Robertson and Groffman, 2007). Nevertheless, both macro and mesopores were essential for soil water movements (Eusufzai and Fujii, 2012). As a result, water, salt, nutrients, pollutants, oxygen, carbon dioxide, heat, and electric charges occurred in these pores with drainage (transport processes) (Hillel, 2004). Weather and biota also enhance the transport process directly, and involvement of soil-biota interaction in soil pores also modifies soil functions (Lal and Shukla, 2004).

Soil water retention was greatly influenced by pore shape, size, distribution, & continuity, and above applied management practices such as AWD, tillage operations, manuring, and addition of organic matter. (USDA-NRCS, 1990; Sands, 2001; Hillel, 2004; Lal and Shukla, 2004). When the soil begins to dry, the proportion of air-filled pores increases inversely, while water-filled pores decrease. As a result, evapotranspiration (ET) and storage water changed. Skaggs *et al.* (1994) proved that lowering seasonal water tables by subsurface drained fields offered temporary storage space for water in the soil profile. This effect depended on antecedent soil moisture conditions (Sands, 2001). Improved temporary storage space allowed much water to infiltrate easily in the soil profile and consequently reduced surface runoff volume (Konyha *et al.*, 1992; Stillman *et al.*, 2006). As a result, there could be either an attenuating or increasing downstream peak flows (Robinson, 1990; Fraser and Fleming, 2001).

Impacts of subsurface drainage on peak flows also depend on soil type, precipitation characteristics, drainage design, and topography. Regarding different soil types, peak flow by subsurface drainage to tiles was reduced in clay and silty soils, but those in sandy soils were increased. Although subsurface drainage in coarse-textured soils helped to improve soil permeability, water retained in such soils depended on precipitation events (Robinson, 1990).

Some results showed that installation of subsurface drainage had increasing saturated hydraulic conductivity, preventing waterlogging, and it should be invested as a long term solution (Skagg, 1996; Christen *et al*., 2001; Hopkins, 2002; Ritzema, 2006; Huffman *et al.*, 2013; Gibson, 2014; Xian *et al.*, 2017). The main reason was surface cracks development in clayey paddy soils (Tabuchi, 1968). These cracks induced macro-pores near the tiles, and their formations by drainage depend on time (Robinson, 1990; Stillman, *et al*., 2006; Tuohy et al., 2015; 2016). In some cases, it took several years, and frequent drying and wetting were necessary (Eigendbrod, 2003).

As soil hydraulic properties changed, other soil physical and chemical properties also varied with reducing water table, sodicity, salinity, and harmful elements in root zone through leaching (Moharram *et al.*, 1999; Christen and Skehan, 2001; Sands, 2001). In a case study, groundwater table reduction from -66 cm to -85 cm and from - 4 cm to -7 cm of the soil surface was observed in dry and wet seasons, respectively. Soil salinity also reduced in that case (Bakri *et al.*, 2015).

In the case of India, the installation of subsurface drains reduced soil pH, EC, and ESP after four years' study of silty clay and clay soils (Okuda *et al.*, 2017; Mallika *et al*., 2018). They explained that saturated hydraulic conductivity took part as a key role of changes in such soil properties. Also, integrated performance of changing soil properties was related to each other. In soils with high organic matter content such as peat soils, the absence of drainage caused the formation and accumulation of large quantities of toxic substances such as hydrogen sulfide, soluble manganese, iron, or aluminum. In these soils, subsurface drainage helped to create more aeration and convert to less toxic substances with much oxidation (FAO, 1995). With subsurface tile drain, changes in soil temperature were observed in Minnesota. An average of 4°C increments in soil temperature was detected at both coarser and finer texture-soils (Jin *et al*., 2008). Furthermore, subsurface tile drainage also changed soil structures and other properties. However, their changes were not constant and time-dependent, especially, if the stable aggregates were destroyed during installation (Madramootoo *et al*., 2007).

In terms of discharge, subsurface drainage increased total annual outflow from fields, and it was 10% (40 mm/year) higher than from surface drainage (Robinson, 1990; Konyha *et al.*, 1992). Khand *et al.* (2014) explained that evapotranspiration, ET, was another important component of field water balance. Cumulative daily ET from subsurface drained fields was generally higher than ET in undrained fields (Rijal *et al.*, 2012; Yang *et al*., 2017). However, some studies gave the opposite results (Rijal *et al.*, 2012).

Most researchers confirmed that tile drainage had several benefits in improving traffic-ability and reducing soil erosion. In the case of shallow subsurface drainage, increasing permeability, and changing soil properties were accompanied in subsurface soil layers (Oosterbaan, 2002; Wesström and Joel, 2008; Welage *et al*., 2019). Under the long-term study, tile drains in paddy fields had some positive impacts on improving soil physical properties such as soil bulk density, water retention, hydraulic conductivity, and compaction of silty loam soils (Daniel *et al*., 2019). In contrast, some negative impacts were observed with poor drainage. These depend on the installed conditions, planning, and management of the soil environment (Skaggs *et al.*, 1982b; Osunbitan *et al*., 2005; FAO, 2007; Pandey *et al*., 2014).

Chapter 3

Short-term Impacts of Perforated Sheet-Pipe as Shallow Subsurface Drain on Paddy Soil Properties

Abstract

Some soil properties are expected to change under shallow subsurface drainage. In this study, sheet-pipe was used which has been developed and has been introducing in Japan for about 40 years. However, research on the sheet pipe is limited and it is necessary to extend these studies. To investigate changes in soil properties at the field where sheet-pipe has been installed, soil samples were collected, with drainage stream sites at the fields (upstream, midstream, downstream), distances from the sheet-pipe (0 m, 1 m, 2 m), and soil depths (10 cm, 25 cm, 45 cm) before and after a rice cultivation.

As a result, during only one rice cropping, we could not find significant impacts on some soil properties by the sheet-pipe except larger pores. We observed larger meso-pore portion at 0 m and 1 m distance from the sheet-pipe at deeper soil layers (both 25 cm and 45 cm depth). Although difference in macro-pores in this study was not so significant, the meso-pores supposed to lead to develop macro-pores and cracks. And they would improve drainage characteristics in the future.

3.1 Introduction

Global agricultural production has been aiming at adapting climate change and producing more crops with effective water management under sustainability. Agricultural drainage, including surface and subsurface drainages, removes excess water from flooded land and provides better environments for crops. Parsinejadi & Akram (2018) proposed that drainage is one of the main elements of integrated water management for climate-adaptive solutions.

Improvements in soil water storage and increases in percolation or permeability with conventional tiles or mole drains have been reported (Blann *et al.* 2009; Fausey 2005; Skaggs *et al.,* 1994). However, few papers have showed that conventional drainage impacts such soil characteristics as soil bulk density, aggregation, compaction, macro-porosity, soil salinity, pH and CEC (Vopravil *et al.,* 2017; Wealge *et al.,* 2019). Moreover, water table reduction and increases in air-filled capacity, saturated hydraulic conductivity, and water holding capacity were studied using such drainage technologies (Tiwari & Goel, 2017; Schwab *et al.,* 1985). Most studies have focused on topsoil with a heavy texture and the spacing of deep drains, and mainly compared adjacent soils with non-mole or tile treatment. Limited literature has thus explained the long- term effects of such drainage on crop yield and soil physical properties (Wesström *et al.,* 2008).

In one deep drainage study, Francis & Morton (1991) claimed that subsurface gravel mole drainage did not affect drainage through less surface infiltration and soil water content, but also observed more root extension from upper layers to near the drainage. Subsurface-shallow drainage is expected to offer more benefits in accelerating drainage as compared with deep drainage (Oosterbaan, 2017). Therefore, more research must be conducted on subsurface-shallow drainage such as sheet-pipe.

Sheet-pipe was developed about 40 years ago and is mainly installed in the western part of Japan. It was typically installed at soil depths of 40-50 cm with a close spacing (4-8 m). These setting have been settled with empirical ways. One significant advantage of sheet-pipe compared with other conventional drains is no need for such transitional materials as gravel or straw. Because sheet-pipe does not require such transitional materials (JASPiP, 2014), it is considered a cost-effective and environmentally friendly technique. The limited previous studies on paddy fields with heavy texture soils found that installing sheet-pipe had some benefits in reducing waterlogging and the EC of drained water (Setiawan *et al.,* 2019).

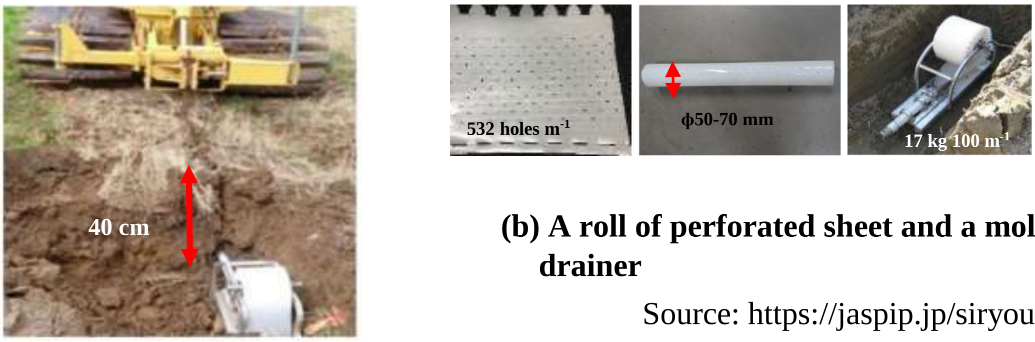
Research remains inadequate, however, on the drainage function of sheet-pipe and its impact on soil properties. For instance, it remains unclear where the drainage water passes through, while the why & how aspects of the sheet pipe function have yet to be clarified. And when do these impacts appear after installation? Hence, this study investigated the changes in some paddy soil properties as a short-term impact under newly installed sheet-pipe during a single rice cropping. For that purpose, we studied soil properties collected from stream sites with sheet-pipe installed (upstream, midstream, downstream) in the field, and at specific distances from the sheet-pipe (0 m, 1 m, 2 m) and soil depths or layers (10 cm, 25 cm, 45 cm), both before and after rice cultivation.

3.2 Materials and Methods

3.2.1 Experimental Set up

The polyethylene plastic perforated sheet-pipe with distinct tiny pores (approx. 1 mm in diameter, 532 holes m^{-1}) and weighing 17 kg per 100 m was installed in a paddy field at Takedatsu, Kunisaki city, Oita prefecture, Japan on

April 3, 2018. The experimental field (measuring 0.32 ha) is located 0.36 m above sea level in a closed embankment to prevent the intrusion of seawater. This land was reclaimed about 40 years ago and has recently been used for the cultivation of rice as fodder. Prior to cultivation in 2018, 20 tons of gypsum and 200 kg of manure per hectare were applied. Table 3.1 summarizes the time schedule.



(a)Installing the sheet-pipe in the field

(b) A roll of perforated sheet and a mole drainer

Source: https://jaspip.jp/siryou/

Figure 3.1 General features of perforated sheet-pipe and its installation in the field

Table 3.1 Time schedule

Activity	Timing (2018)
Installation of sheet-pipe	April3rd
Soil sampling (Before)	April 4th
Land Preparation	April 12th
Rice planting	April 15th
Closure of drainage	July 18th
Harvesting	November 10
Soil Sampling (After)	November 25

There was space of 4 m on average for installing sheet-pipe along a 0.1% slope in the field. The installation process entailed first cutting up the land with a ripper mounted on a bulldozer, and then installing perforated sheet-pipe at a depth of 40 cm (Figure 3.1 a). This flat plastic sheet could be transformed into a pipe measuring 70 mm in diameter when installed in the field using a mole drainer (Figure 3.1 b**)**. The drain outlet was opened at the end of July in 2018 (closed during the growth period).

3.2.2 Soil Sampling and Analyses

The first soil sampling was performed on April 4, 2018, one day after the installation of sheet-pipe. A second sampling was later performed after rice harvesting on November 25, 2018.

A total of 27 soil samples representing the stream sites with the sheet-pipe (upstream, midstream, and downstream) was collected at three soil depths (10 cm, 25 cm, and 45 cm) with three replications. A visual and soil hardness investigation revealed a compacted plough layer at a depth of 15-20 cm. We collected soil samples from different soil layers as follows: 10 cm as disturbed topsoil, 25 cm as undisturbed topsoil, and 45 cm as undisturbed subsoil, with 100 cm^3 sampling cores for undisturbed soil and about 500 g of disturbed soil. For the second sets, 81 soil samples representing the same state as the first sampling plus three additional distances from the sheet pipe (0 m, 1 m, and 2 m) were collected after harvesting. Both disturbed soil (≈ 500 g**)** and undisturbed soil with 100 cm^3 cores were collected. The average temperatures during soil sampling were 17.1°C (1st sampling) and 12.1°C (2nd sampling), respectively.

Field infiltration was analyzed with a DIK-4201-cylinder intake rate meter at distances of 10 m and 30 m from the drain outlet after sheet-pipe installation (at the 1st soil sampling) and after one rice cropping (at the 2nd soil sampling). In the laboratory, the soil texture (% sand, silt, and clay) was analyzed using the pipette method and classified as per the US Department of Agriculture (USDA) procedure. Soil moisture content was measured using the gravimetric method. Saturated hydraulic conductivity was measured with a Daiki permeameter (DIK-4050) using the falling head method. In this study, *K*s (cm s^{-1}) value was converted to a logarithmic value (-log *K*s). The soil organic carbon (SOC, %) was determined using the ignition loss method with a muffle furnace (ADVANTEC KL-160) and was calculated from the difference of dried weight of 105°C and 550°C divided by dried weight at 105°C x 100. Soil bulk density (BD) was analyzed using the dry core method (Rowell, 1994). Soil-water characteristic curves were drawn using the hanging column method for lower suction values (-10 cm to -150 cm) and the centrifuge method (KOKUSAN 2750) for high suction values (pF=2.4 to 4.2). The soil-water characteristic curves were used to formulate three prediction trends at lower suction values, S-shape, and higher suction values. The Young–Laplace equation was then applied together with these three prediction trends to calculate the pore size distribution. In this study, > 50 µm of pore size was classified as a macro-pore (MaP), and 50 to 0.5 µm as a meso-pore (MeP) (Lal & Shukla 2004). Plant available moisture (PAM) was calculated for a difference between pF 2.0 and pF 4.2 (Lal & Shukla, 2004). The units of all pores were $cm^3\ cm^{-3}$. The HORIBA HM-20p pH meter and HORIBA ES-14 conductivity meter were used to measure soil pH and electrical conductivity (EC, $\mu S\ m^{-1}$) in 1:5 deionized water, respectively. Total carbonate (total CO_3) was measured using volumetric analysis (Rowell 1994). Disturbed soil samples were used to determine soil texture and analyze SOC, pH, and EC.

3.2.3 Statistical Analyses

Statistical analyses such as Pearson's correlation, linear regression analysis, analysis of variance F-test, a multi-collinearity test, and formulating with an adjusted R^2 test were analyzed with SPSS-15. Firstly, ANOVA (analysis of variance) for factorial design was carried out for three factors. Herein, rice cropping was analyzed with paired t-test. Distances, streamlines and soil depths (N=27) were main effects and checked their interactions with two & three ways. After that, combined analysis was carried out for the same stream site due to different distances and soil depths. All means were compared to identify the changes under the installed sheet-pipe before and after rice cropping at the stream sites with installed pipe, and at specific distances from the sheet-pipe at all soil depths, with a least significant difference of 5%.

3.3 Results and Discussion

3.3.1 General Properties of Soils

Table 3.2 General characteristics of soils

Soil Depth	Sand (%)	Silt (%)	Clay (%)	Soil Texture (USDA, 1994)	pH (H_2O 1:5)	EC (μS cm^{-1})	$CaCO_3$ (%)
10 cm	75.5(±1.3)	15.2(±2.1)	13.3(±1.7)	Sandy loam	6.7 (±0.2)	58.9 (±9.9)	5.2 (±1.5)
25 cm	74.2(±4.6)	13.2(±4.5)	12.6(±1.4)	Sandy loam	6.6 (±0.3)	76.6 (±16.7)	5.9 (±1.1)
45 cm	81.6(±1.4)	9.7(±1.6)	8.7(±1.0)	Loamy sand	6.7 (±0.2)	79.7 (±15.5)	6.5 (±2.3)

* Numbers in parentheses denote standard deviations.
Number of disturbed samples = 108 (27 before +81 after rice cropping).

As shown in Table 3.2, the soil texture in the study field was sandy loam in the upper two layers (10 cm, 25 cm) and loamy sand in the deeper layer (45 cm). Although soil pH at a soil depth of 10 cm was not different from that at 45 cm, the EC and total CO_3 (%) values at a soil depth of 45 cm were higher than those in the upper two layers.

The basic intake rate at a 2-m distance from the sheet-pipe after rice cropping showed a slightly higher trend than that at a 2-m distance before rice cropping (Table 3.3).

Table 3.3 Comparison of Infiltration test before and after rice cropping

Expression	2-m JAISP (before)			2-m ISP (after)		
	10 m from outlet	**30 m from outlet**	**Average**	**10 m from outlet**	**30 m from outlet**	**Average**
Basic Intake rate (mm h^{-1})	2.9	5.9	4.4	4.9	12.0	8.5

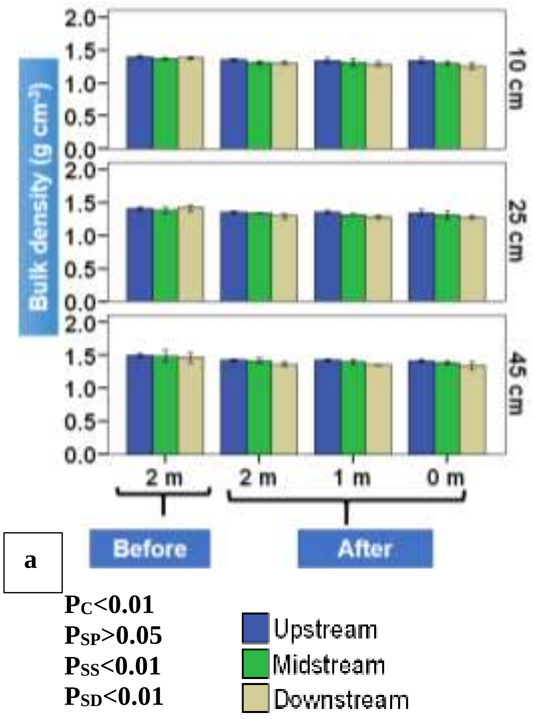
2-m JAISP denotes testing at a 2-m distance from the sheet-pipe just after installation before rice (fodder) cultivation.

2-m ISP denotes testing at a 2-m distance from the installed sheet-pipe after rice (fodder) harvesting.

3.3.2 Changes and Difference in Soil Physical Properties

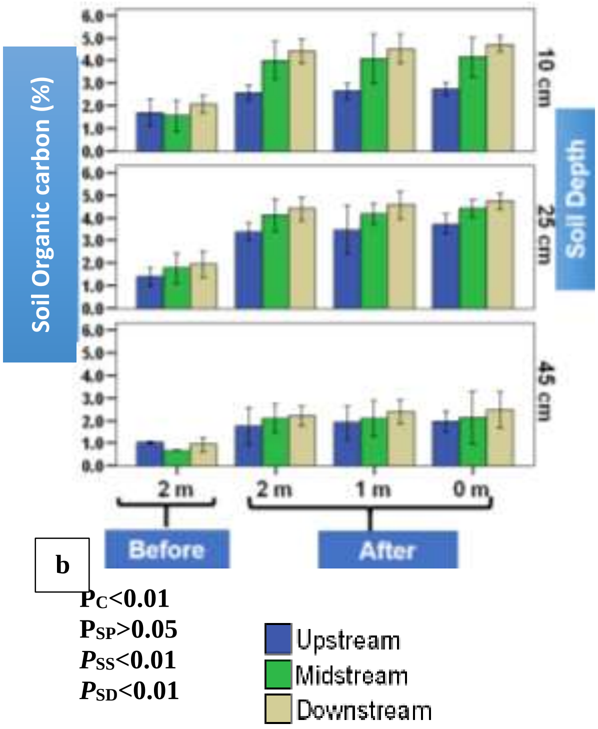
Figure 3.2 shows differences and changes of some soil properties (N=27 =3x3x3). In this study, "change" refers to changes due to a rice cropping (before & After, Figure 3.2); "difference" refers to the differences among stream lines, distance and soil depths (Figure 3.2 & Table 3.4).

There is a significant difference for the average according to a rice cropping ($P<0.01$). For the streamline, there is a significant difference of the average for BD (Bulk Density), SOC (Soil organic Carbon), - log *K*s (Saturated hydraulic conductivity) and MaP (Macropores). And for the soil depth, there is a significant difference of the average for BD, SOC and MeP (Mesopores). Regarding for MeP, there is a significant difference among a rice cropping, distance and soil depth.



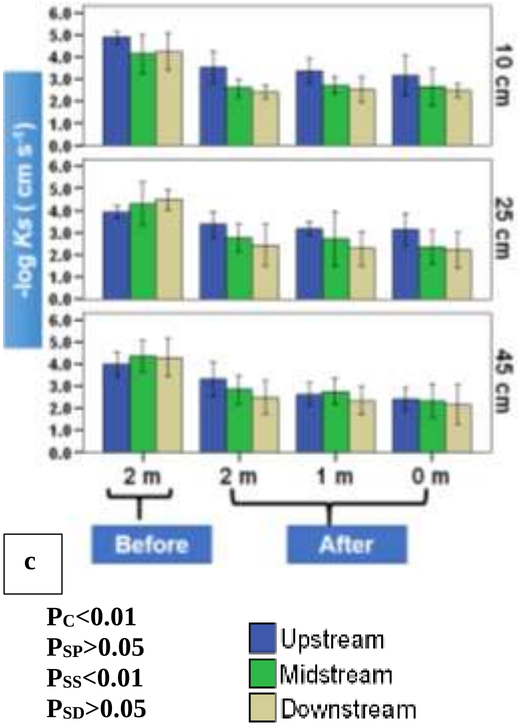
a

$P_C<0.01$
$P_{SP}>0.05$
$P_{SS}<0.01$
$P_{SD}<0.01$



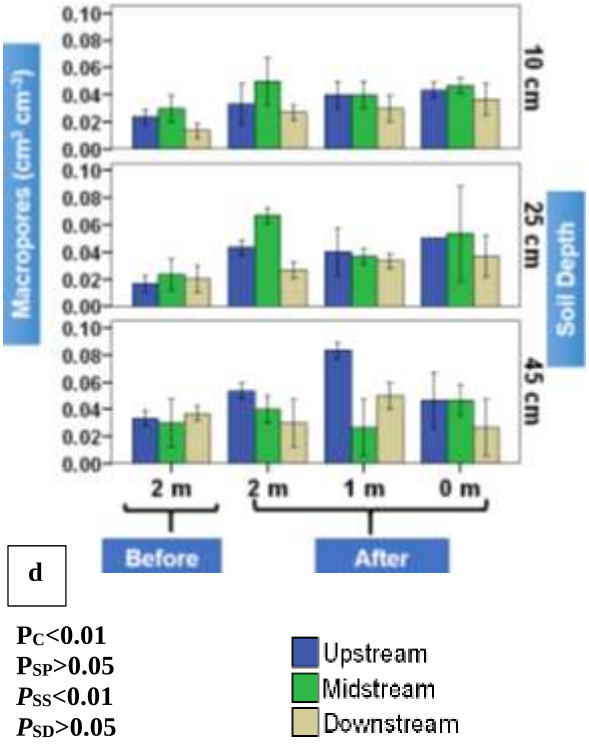
b

$P_C<0.01$
$P_{SP}>0.05$
$P_{SS}<0.01$
$P_{SD}<0.01$



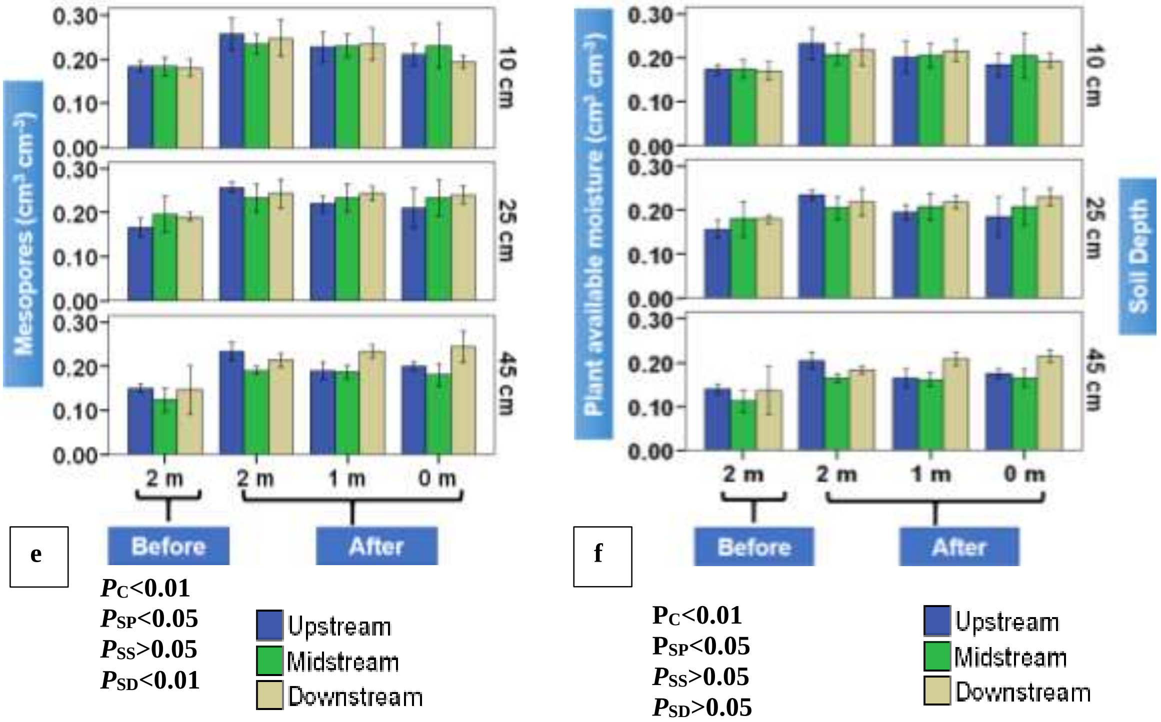
c

$P_C<0.01$
$P_{SP}>0.05$
$P_{SS}<0.01$
$P_{SD}>0.05$



d

$P_C<0.01$
$P_{SP}>0.05$
$P_{SS}<0.01$
$P_{SD}>0.05$



e

$P_{C}<0.01$
$P_{SP}<0.05$
$P_{SS}>0.05$
$P_{SD}<0.01$

f

$P_{C}<0.01$
$P_{SP}<0.05$
$P_{SS}>0.05$
$P_{SD}>0.05$

Figure 3.2 Changes and difference in a) soil bulk density (g cm^{-3}), b) soil organic carbon (%), c) saturated hydraulic conductivity (-log *K*s), d) macropores (cm^{3} cm^{-3}), e) mesopores (cm^{3} cm^{-3}), and f) plant available moisture (PAM, cm^{3} cm^{-3}) at different soil depths, stream sites, and sheet pipe distances during a rice cropping.

Before= before rice cultivation After=after rice cultivation
Error bars express as standard deviations.
Pc<0.01 means that changes in soil properties during a rice cropping are statistically highly significant at P<0.01.
Psp<0.05 means that changes in soil properties regarding distances from the sheet-pipe are statistically significant at P<0.05.
Pss<0.01means that changes in soil properties under different stream sites are highly statistically significant at P<0.01.
Psd<0.01means that changes in soil properties at different soil depths shows highly statistically significant at P<0.01.

Figure 3.2 a and b show the changes and differences in average BD and SOC. At all soil depths, average BD basically became smaller and average SOC became larger after a rice cropping compared with those before a rice cropping. Average BD at 2-m distance from the sheet-pipe through the soil layers was reduced from 1.42 g cm^{-3} (before rice cropping) to 1.35 g cm^{-3} (after rice cropping). In contrast, average SOC through the soil layers increased from 1.5% (before) to 3.2 % (after).

Regarding the streamline after a rice cropping, average BD (1.39 g cm^{-3}) of upstream was slightly larger than those of downstream (1.33 g cm^{-3}). After a rice cropping, SOC content at depth of 25 cm was larger than that of 10 cm depth.

Figure 3.2 c to f show change and difference of - log *K*s, MaP, MeP and PAM (Plant Available Moisture) at each distance, stream-line and soil depth before and after a rice cropping.

Although -log *K*s generally became smaller after a rice cropping, MaP, MeP, and PAM became almost larger than those before cropping at all depths. After a rice cropping, average - log *K*s became smaller from upstream to downstream. Regarding the soil depths, the average value of -log *Ks* at depth of 45 cm was the minimum.

A large portion of MeP increased near the sheet-pipe downstream. Average MeP was 0.23 cm^3 cm^{-3} at 25 cm depth, and 0.21 cm^3 cm^{-3} at 45 cm depth.

Increases in (MaP+ MeP) at 2-m distance at 25 cm & 45 cm soil depth after a rice cropping were different from those at 2-m distance before a rice cropping. And an average (MaP + MeP) at 45 cm depth downstream rose from 0.03 + 0.14 cm^3 cm^{-3} (2-m distance before rice cropping) to 0.03+ 0.24 cm^3 cm^{-3} (0-m distance after rice cropping).

With the conventional subsurface drainage used in paddy fields, saturated hydraulic conductivity and macro-pores mostly increased (Talukolaee *et al.* 2018).

3.3.3 Relations between soil properties and saturated hydraulic conductivity

Figure 3.3 shows the relations between saturated hydraulic conductivity (-log *K*s) and some soil properties before and after a rice cropping for each depth (N=36=9(before) +27(after)). The regression lines were also put.

The larger - log *K*s, the larger for BD but the smaller for SOC, MaP, MeP and PAM for all depths. According to a rice cropping, BD decreased, while SOC, MaP, MeP and PAM increased for all soil depths. There are the largest R^2 between -log *K*s and SOC (0.74-0.81), and BD (0.65-0.78) follows.

3.3.4. Average soil properties according to each factor

Table 3.4 shows the comparison of each soil property (average, N=3) at the different soil depths due to the same stream sites and distances from the sheet-pipe after a rice cropping. Statistical grouping was analyzed and some soil properties profiles were shown. Basically, there was clear difference among the soil depths and each soil characteristic of deeper depth is different from those of shallow ones. For example, BD of 45 cm depth were different from those of 10 cm and 25 cm depth under the same stream site and distance. However, only MeP at 0-m distance, at 45 cm depth downstream was larger in deeper depth than other places. Large average value of MeP were found in deeper depth especially downstream.

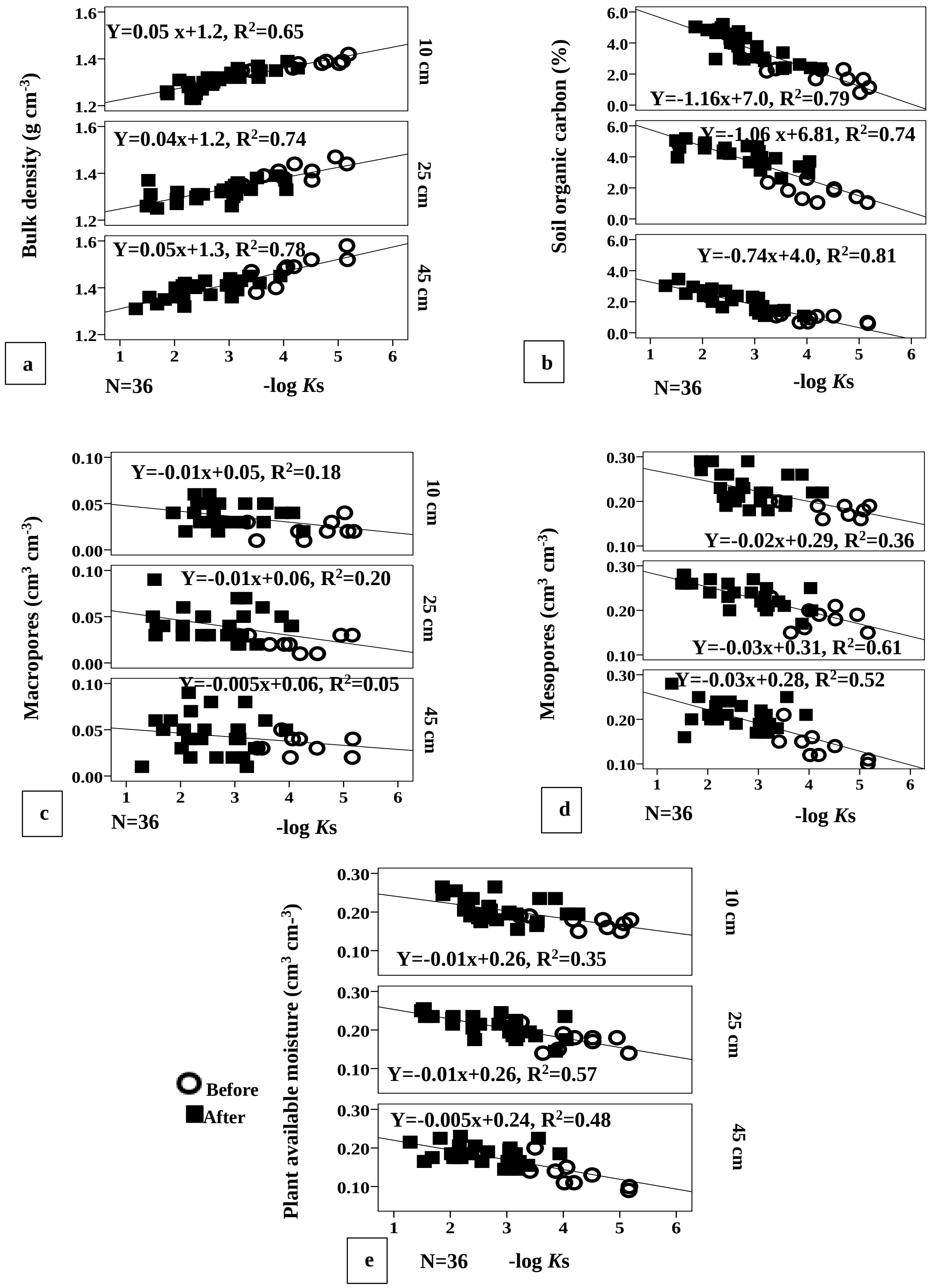


Figure 3.3 Relationships between saturated hydraulic conductivity (–log *K*s) and a) bulk density, b) soil organic carbon (%), c) macropores (cm^3 cm^{-3}), d) mesopores (cm^3 cm^{-3}), and e) plant available moisture (cm^3 cm^{-3}).

Before= before rice cultivation After=after rice cultivation

Regression equations are shown for each soil property. There, x means –log *K*s and Y means each soil property such as soil bulk density (g cm^{-3}), soil organic carbon (%), macropores (cm^3 cm^{-3}), mesopores (cm^3 cm^{-3}), and plant available moisture (cm^3 cm^{-3}).

Table 3.4 Comparison of average of some soil characteristics at different soil depths due to the same stream site and distance

stream site	distances (m)	soil depths (cm)	BD	-log Ks	SOC	MeP	MaP	PAM
up	0	10	1.3367 B	3.1700 A	2.7367 B	0.2097 A	0.0433 A	0.2036 B
		25	1.3467 B	3.1400 A	3.7267 A	0.2100 A	0.0500 A	0.2187 B
		45	1.4200 A	2.4100 B	1.9500 C	0.1993 A	0.0467 A	0.2516 A
	1	10	1.3400 b	3.3667 a	2.6600 b	0.2267 a	0.0400 b	0.2645 a
		25	1.3500 b	3.1600 a	3.4800 a	0.2200 a	0.0400 b	0.1793 b
		45	1.4233 a	2.6333 b	1.9033 c	0.1900 b	0.0833 a	0.1559 c
	2	10	1.3433 β	3.5433 α	2.5733 β	0.2567 α	0.0333 ϒ	0.2530 β
		25	1.3533 β	3.3633 α	3.3900 α	0.2567 α	0.0433 β	0.2840 α
		45	1.4267 α	3.3133 β	1.7467 ϒ	0.2333 β	0.0533 α	0.2302 ϒ
mid	0	10	1.2933 H	2.6467 G	4.1467 G	0.2300 G	0.0467 H	0.2325 H
		25	1.3133 H	2.3333 G	4.4033 G	0.2333 G	0.0533 G	0.2205 H
		45	1.3900 G	2.3333 G	2.1200 H	0.1800 H	0.0467 H	0.2580 G
	1	10	1.3100 Y	2.7200 X	4.0767 X	0.2300 X	0.0400 X	0.2048 Y
		25	1.3167 Y	2.7100 X	4.1733 X	0.2333 X	0.0367 X	0.2266 X
		45	1.4000 X	2.7467 X	2.0800 Y	0.1867 Y	0.0267 Y	0.2345 X
	2	10	1.3067 z	2.6100 x	4.0100 x	0.2333 x	0.0500 y	0.2046 z
		25	1.3333 y	2.7633 x	4.1467 x	0.2333 x	0.0667 x	0.2267 y
		45	1.4167 x	2.8600 x	2.1033 y	0.1900 y	0.0400 z	0.2570 x
down	0	10	1.2567 q	2.4967 p	4.7267 p	0.1927 q	0.0367 p	0.2353 p
		25	1.2767 q	2.2033 p	4.7400 p	0.2400 p	0.0367 p	0.2236 pq
		45	1.3467 p	2.1767 p	2.4767 q	0.2433 p	0.0267 q	0.2138 q
	1	10	1.2867 e	2.5333 d	4.5167 d	0.2333 d	0.0300 e	0.2468 d
		25	1.2833 e	2.2833 d	4.5700 d	0.2433 d	0.0333 e	0.2335 d
		45	1.3567 d	2.3433 d	2.3800 e	0.2333 d	0.0500 d	0.2109 e
	2	10	1.3000 E	2.4233 D	4.4067 D	0.2467 D	0.0267 D	0.2279 E
		25	1.2967 E	2.4467 D	4.4133 D	0.2433 D	0.0267 D	0.2485 D
		45	1.3633 D	2.4967 D	2.2000 E	0.2133 E	0.0300 E	0.1893 F

BD; soil bulk density (g cm^{-3}), *K*s; hydraulic conductivity (cm s^{-1}), SOC: soil organic carbon (%), MaP; macro-pores (cm^{3} cm^{-3}), MeP; meso-pores (cm cm^{-3}) and PAM (plant available moisture, cm^{3} cm^{-3}), respectively.

3.4 Discussion

After a single rice cropping, the change & difference of BD, SOC, and -log *K*s (Figure 3.2 a, b, c) were observed. Smaller BD and larger SOC were found even at deeper layers (25 cm & 45 cm) and downstream after a rice cropping. At the shallow depths, the intrusion of rice roots basically induced a reduction in BD. But these change were induced not only rice roots & sheet-pipe installation but also by many management practices, including rice cropping management practices such as manuring, land cultivation, and water management, etc. BD and SOC were also associated with -log *K*s (Figure 3.3 a and b). Ultimately, we could identify no significant impacts caused by the use of sheet-pipe.

This study also found a large portion of larger pores (MaP + MeP). Despite the clear increases in MeP at soil depths of 25 cm and 45 cm, there were no clear increase in MaP (Figure 3.2 d and e). In particular, a large portion of MeP was found at the downstream site of 0-m distance and a depth of 45 cm (Table 3.4).

Larger pores normally develop from the soil surface due to natural drying. However, this study found increases in MeP at deeper layers, with MaP development not being clear. This is not normal. It seems feasible to understand that under the opening conditions of the sheet-pipe end (outlet), the air was ventilated or moved into the sheet-pipe, especially near the drainage outlet (i.e. downstream). We could expect air intrusion and drying near the drainage outlet to induce MeP development.

In our long-term study, increases in both MaP & MeP were clear (Soe *et al.,* 2019), but in this study an increase in only MeP was distinct. The sheet-pipe used in this study lasted only seven months, whereas those used in our previous long-term study were installed for 7 and 12 years, respectively.

These larger pores are responsible for water movement (Eusufzai & Fujii, 2012). The sheet-pipe was apparently responsible for MeP development, which is a sign regarding the transition of MaP development. It is widely known that the development of MaP required several years (Eigendbrod, 2003). Tabuchi (1968) also referred to the generation of cracks in paddy soils under traditional drainage as a function of dryness that takes several years.

3.5 Conclusion

This study investigated the changes in some soil properties under installed sheet-pipe, one of the subsurface drainage technologies, in a paddy field with regard to the stream sites of drainage, distance from the sheet-pipe, and soil depths (layers) during a rice cropping. As a result, during only one rice cropping, we could find no significant impacts caused by the sheet-pipe on some soil properties, except for larger pores. We observed larger MeP (meso-pores) portions at distances of 0 m and 1 m from the sheet-pipe at deeper soil layers (at depths of 25 and 45 cm), especially downstream.

Although the differences in macro-pores in this study were not significant, meso-pores are supposed to lead to the development of macro-pores and cracks, as well as improved drainage characteristics in the future. An increase in meso-pores in this study was assumed to be a transition state of small cracks or macro-pores. Therefore, the spatial distribution of cracks or MaP under installed sheet-pipe must be clarified, and these developing rates and periods should be investigated as part of future studies.

Chapter 4

Long-term Impacts of Perforated Sheet-pipe as Shallow Subsurface Drain on Some Paddy Soils Properties

Abstract

Recent studies suggested not to neglect drainage as a proper water management option for sustainable agricultural production and to upgrade shallow subsurface drainage system for integrated use. As shallow subsurface drains can accelerate water flow by gravity and improve soil aeration, the installation of perforated sheet-pipes in Japanese paddy fields probably influence on soil functions and properties for a long-term. This study focuses on some changes in soil properties around the sheet-pipes at a depth of 40 cm in paddy soils after a long-term installation. Using (3 × 3 × 2) factorial design with three replications, we collected soil samples on farmland in Hisayama, Fukuoka, and Usa, Oita, in Japan in 2017. Three factors in this experiment were three-stream sites (upstream, midstream, and downstream), three distances from the sheet-pipe (0 m = center, 1 m, and 2 m), and two soil layers at 10 cm and 25 cm, respectively. We measured thirteen potentially changeable soil properties and analyzed the data statistically by F test. We compared all means at least the 5% significantly different level. As a result, there was a major improvement in air-filled capacity and infiltration at the center of sheet-pipe. Moreover, changes in soil bulk density were significant near the sheet-pipe, with an increase in soil organic carbon and total carbonate content. These promoted changes in soil aggregation and an increase in macro-pores & porosity that allowed more water & air to pass through. In sum, changes in soil properties after a long-term installation of the sheet-pipe were more distinct according to the distances than those of the stream sites (from irrigation point to drainage outlet).

4.1 Introduction

The perspective for future drainage highlights to improve crop production with a climate-smart drainage. According to the 2025s timeline prediction, it requires to develop and supply the world food demands targeting an increase from 1 to 1.5% under irrigated and from 0.5 to 1% under rain-fed agriculture. To achieve these marks, field drainage is necessary in both irrigated and rain-fed conditions (Smedema, 2000; Wrachien and Feddes, 2004). Furthermore, development of future agricultural field drainage techniques also stresses integrated use of water, cost & labor savings, and environmental safeguarding (UNEP, 2016). Recent studies suggested not to neglect the agricultural drainage and to upgrade or modify drainage technology (Wrachien and Fasso, 2002; Nijland *et al*., 2005; Schultz *et al.*, 2015). Especially, subsurface drainage has been proposed as one of the possible solutions to meet the above mentioned. The main reason is that subsurface drainage can protect crops from moisture-related issues, reduce the negative environmental impacts on agriculture such as pollution, salinity, acidity, and a decrease in peak flow of downstream flooding (Simundsson *et al*., 2016).

Using a subsurface drain helps to improve soil aeration, remove salts near root zone. As a result, plant can develop well and crop production can increase (Ritzema *et al.*, 2008). In addition, he suggested that application of modern drainage management practice such as dual purposed drains for subsurface irrigation and drainage could approach to future agricultural sustainability. This practice must meet required food production, save water resources, and sustain our ecosystems (Madramootoo *et al*., 2007). As subsurface drain with combined irrigation techniques can adjust soil moisture regime to store much available water, it is considered one of the effective water management for crop production as well as the only solution for providing land reclamation on a long-term basis (Tiwari and Goel, 2017).

Subsurface drains with tiles are mostly installed in agricultural land. These are made from clay or plastic as conventional drains and perforated plastic sheet-pipes as modified ones. Using tile drains helped to enhance gravity flow in soil profile. Besides, soil structure under tile drains was better with improving soil porosity, tilth, and the trafficability of soil (Geohring and Steenhuis 1987; Madramootoo *et al.*, 1997; Hillel 1998; Josa *et al.*, 2013). Thereby, soil chemical properties varied together with soil physical and hydraulic changes, but their impacts were different due to different regions (Mallika *et al*., 2018; Daniel *et al.*, 2019). In terms of agronomic benefits, installing tile drains made soils warmer than undrained soils. This drained land lead to earlier spring sowing & germination of seeds, much developing crop growth, and more increase in crop yields (Singh *et al.*, 2008; Yang and Zhang, 2010). Thus, Colwell (1978) reported that yield from tile drainage increased 35, 32, 48, 47, 27% for grain corn, soybeans, wheat, oats, hay, respectively.

Subsurface drainage has some positive and negative impacts on environmental greenhouse gas emissions. Installing tile drains in paddy fields reduced methane gas and nitrous oxide emission (Kimura *et al*., 2004; Wang *et al*., 2011; Skinner *et al*. 2014; Smith *et al.* 2014). It greatly reduced nitrogen and phosphate pollution at the downstream site of paddy fields (FAO, 2007). Sug (2007) reported that subsurface drainage affected wildlife ecosystems for wetland habitats as a negative impact. As subsurface drainage is a long term installation, it is necessary to understand its effects on soil properties over time for improvement of soil and water management (Schultz *et al.,* 2007). Thus, future research should address the impact of subsurface drainage on soils and its ecosystems (UNEP *et al.*, 2014). Kumar *et al.* (2014) observed that an integrating with tillage, impacts of the long-term subsurface drainage (tile) significantly improved soil organic carbon content, soil aggregation, and porosity in the corn-corn cropping system. However, their observations showed at the upper soil layer of 10 cm depth. Some impacts near the installed pipe for long term solutions were still unknown.

Recently, the perforated sheet-pipe has been extensively installed at paddy fields in Japan (JASPiP, 2014). Installing shallow subsurface drain has some benefits of controlling the flooded lowlands as well as the groundwater table. Besides, it helps to facilitate operation of farm machineries and to convert lowland paddy soil to upland. However, research on long term impacts of the installed sheet-pipe in paddy soils is still limited. To develop the future drainage system especially in Japan for sustainable production, Ogino and Ota, (2007) suggested to understand the impacts on paddy soil properties of current water management practice.

Therefore, the main objective of this study is to investigate a long-term impacts of perforated sheet pipe installation on paddy soil properties. Changes in such soil properties should vary with three-stream sites (upstream-near irrigation inlet, midstream- between irrigation inlet and drainage outlet, downstream- near drainage outlet, three-distances from the sheet-pipe (0 m=center, 1 m and 2 m), and two-soil depths (layers at 10 cm, 25 cm).

4.2 Materials and methods

4.2.1 Study Sites and Experimental Design

The study site of the soil sampling area in Hisayama (Figure 4.1a), Fukuoka Prefecture was located at the geographic coordinates of north latitude 33° 38′ and east longitude 130° 30′. Its area was 1282 m^2. The paddy had cultivated for many years under the management of a farmer. However, at the time of soil sampling, it was fallow. In this field, the perforated sheet pipe had

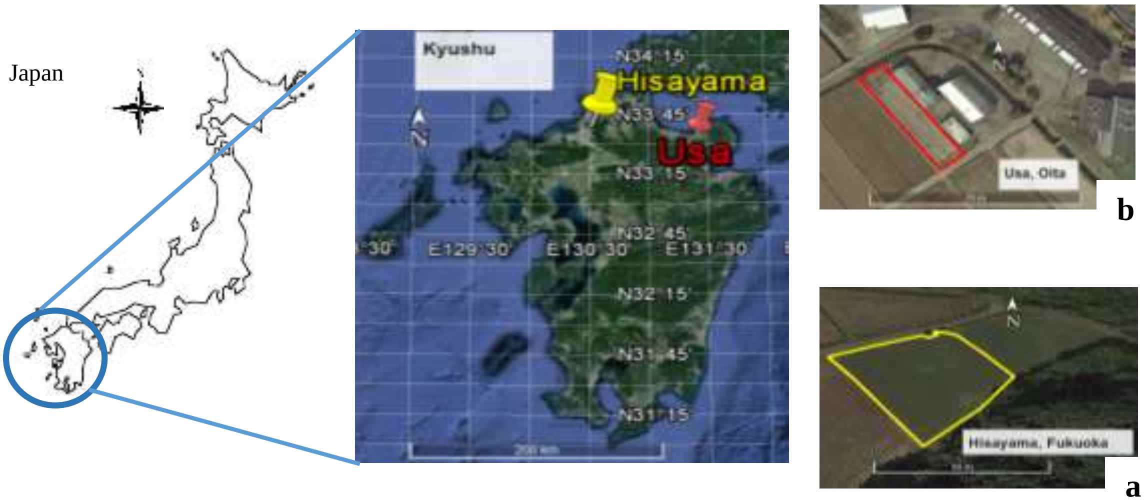


Figure 4.1 Geographic position of study sites, a) Hisayama and b) Usa

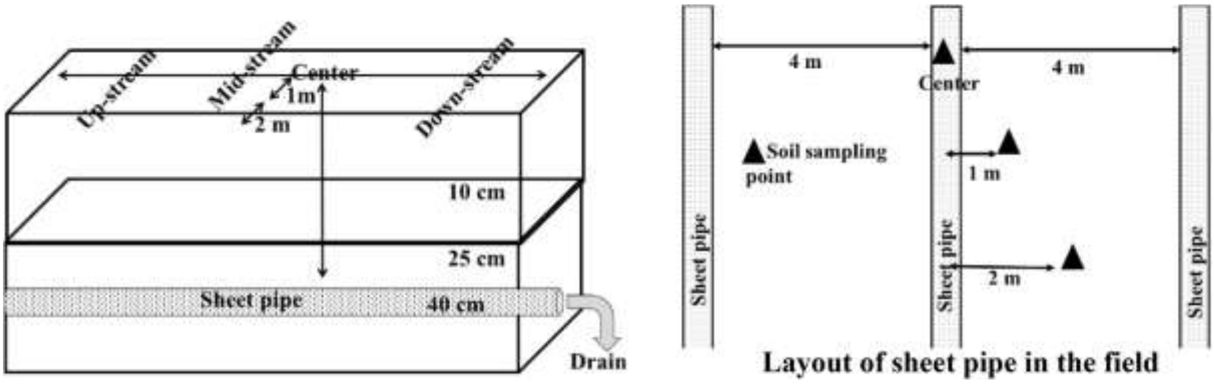


Figure 4.2 Soil sampling layout in the study sites

installed at 40 cm of the soil depth 15 years before. The second study site at Usa (Figure 4.1b), Oita Prefecture was located at the geographic coordinates of north latitude 33° 32′ and east longitude 131° 23′. Its area was 516 m^2. Paddy rice and soybeans were cultivated alternately under the management of an institute of agricultural research. Soil sampling was carried out after the harvest of soybeans in this field. In this study site, the perforated sheet pipe was installed 7 years ago at a depth of 40 cm. In both study fields, perforated sheet pipes were laid out as 4 m spacing between each.

Fifty-four units of soil samples were collected in each field according to the pre-layout experimental design (Figure 4.2), as factorials with three replications. Treatment factors were three different stream sites, three sheet pipe distances and two soil depths. Different stream sites refer to upstream, midstream and downstream, and three sheet pipe distances characterize as center (0 m), 1 m and 2 m apart from the sheet pipes installed. According to soil heterogeneity at two distinct soil layers, soil sampling was carried out at two soil depths, 10 cm and 25 cm, respectively. Based on the soil texture, three replications at least 1 m distant were done. Undisturbed core samples were collected to determine the saturated hydraulic conductivity, soil water characteristic curves and soil bulk density in the laboratory. Composite soil samples (disturbed) were brought for the determination of selected soil properties. Soil sampling was carried out in September 2017 at Hisayama and October 2017 at Usa.

4.2.2 Soil Analysis

Table 4.1 Textural classification at different soil depths of paddy soils

Region	**Soil depths**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural classification**
Hisayama	10 cm	45.5 ± 3.8	20.7 ± 5.3	33.8 ± 6.3	Sandy Clay loam
	25 cm	44.9 ± 3.9	22.3 ± 7.2	32.8 ± 7.7	Clay
Usa	10 cm	53.6 ± 6.9	12.0 ±2.2	34.4 ± 6.7	Sandy Clay Loam
	25 cm	51.1 ± 5.2	6.4 ±3.2	42.5 ± 4.0	Sandy Clay

Numbers in front of ± are means and behind ± are standard deviations

Classification of soil texture is an important characteristic for installing a specific drain, and soil textural proportions could vary by different soil depths, different landscapes, different causes of soil erosion, etc. In this study, the USDA textural classification was determined using the pipette method. The mean proportion of sand, silt and clay at different soil depths with standard deviations are shown in Table 4.1. Soil bulk density (BD) was calculated by using undisturbed core samples based on the ratio of dry soil weight (g) to core sample volume (cm^3) (Rowell, 1994). Soil organic carbon (SOC, %) was determined using the loss of ignition method (Rowell, 1994) in a muffle furnace (FM 48) at 500 °C for 5 h to get the constant weight. This determination method was only for total carbon as an organic source (Schumacher, 2002). Soil porosity (f) is an important soil physical characteristic of being porous that permits air or water to pass through, and it was calculated using a theoretical formula (Lal and Shukla, 2004). Saturated hydraulic conductivity (Ks) is a property of soil water movement within the saturated soil profile, and its unit can be expressed as cm day^{-1}. Using its negative logarithmic values, it can be predicted that lower values mean greater intensity. Generally, measurement of saturated hydraulic conductivity was based on Darcy’s law. In this study, a DK-4050 instrument with the falling head method was used to predict its property. The soil water characteristic curve (pF) in this study was developed to estimate the soil hydraulic properties as the plant available moisture (PAM), soil moisture content at field capacity (FC), permanent wilting point (PWP) and air-filled capacity (AC). In this study, the hanging column method was utilized for the determination of lower soil suction values and the centrifuged method (KOKUSAN 2750) for higher suction values. AC was calculated using the difference of water content at saturated condition ($m^3\ m^{-3}$) and FC ($m^3\ m^{-3}$). Plant available moisture was determined from the difference between soil water content at the FC (pF = 2.0) and PWP (pF = 4.2) (Lal and Shukla, 2004). Using pF curves, three prediction trends at lower suction values, S-shape and higher suction values were formulated in Microsoft Excel

2010. The Young–Laplace equation (1983) was then applied together with these three prediction trends to calculate the macropores (MaP) (> 50 µm), mesopores (MeP) (0.2 to 30 µm) and storage pores (StoP) (0.5 to 50 µm) based on the Kay (1990, 1998) and Greenland (1977) classifications. Based on the best estimation of soil structural index (Kemper and Rosenau, 1987), the water stable micro-aggregates (< 0.25 mm) were found to be insensitive to soil management (Tisdall and Oades, 1982). Thus, water-dispersed aggregate of 0.25 mm in diameter was assumed as the boundary between micro-aggregates and macro-aggregates and fraction size distribution was determined by CIMMYT (2003). Soil pH was measured at the 1:5 deionized water using the pH meter HM-20p, HORIBA (Rowell 1994). Electrical conductivity (EC, µS m^{-1}), an indicator for soil salinity and predictor for accumulated salt load in soil, was measured using the extracted 1:5 soil suspensions with the conductivity meter ES-14, HORIBA (Rowell 1994). Total carbonates (total CO_3), an indicator for inorganic carbon stands for sources of calcium and magnesium carbonates in soils, were measured using volumetric analysis (Rowell, 1994).

4.2.3 Statistical Analyses

All collected data were stored in Microsoft Excel 2010 and analyzed with the Stata-15 (2017) program. First, a descriptive statistic was performed. Then, an ANOVA table was constructed to identify the significance of the treatments using the F test. All means were then compared to a least significant difference level of 0.05. Relationships between the measured soil properties were determined using Spearman’s rank correlation analysis. Based on the progress or decline of the measured soil properties (mean), positive or negative impacts were predicted in this study.

4.3 Results and discussion

4.3.1 Impacts of Perforated Sheet Pipe Distances on Soil Physical Properties

Changes in soil physical properties are shown in Figure 4.3 for Hisayama and Figure 4.4 for Usa. Changes in soil bulk densities in the two regions were highly significantly different at the 1% level due to sheet pipe distances and soil depths (Figures 4a, 5a). Average soil bulk density ranged from 1.41 to 1.47 g cm^{-3} in Hisayama and from 1.35 to 1.46 g cm^{-3} in Usa. In both regions, soil bulk density was reduced from 2 m of sheet pipe distance to the center of the sheet pipe installed at both layers.

A decline in soil bulk density was counted to 0.03 in the lower layer and 0.01 in the upper layer at Hisayama. At Usa, the decrements for both layers from 2 m to the center of sheet pipe distances were 0.03. In this study, decrease in soil bulk density from 2 m distance to the center of the installed sheet pipe was related to accumulation of soil organic carbon and evolution of soil porosity because of the negative correlations among BD versus SOC and BD versus f (r = -0.78, -0.88) in Hisayama and (r = -0.68, r = -0.71) in Usa (see Tables 4.3 and 4.4). Similarly, Chaudhari *et al.* (2013) explained that there were significant relationships among soil textures, organic matter content and total nutrients of Coimbatore soil. In this study, the nearer the sheet pipe, the lower the soil bulk density. This improvement indicated a positive impact of the installation of the sheet pipe. A significant accumulation of soil organic carbon (SOC) in two regions, as well as both layers, was observed (Figures 4.3 b and 4.4 b). More OM accumulated above the center of the sheet pipe than other places. It was more pronounced in Usa than those in Hisayama. Upper layer increments of SOC from 2 m to 0 m of the sheet pipe were from 7.13 to 7.48% in Hisayama and 9.75 to 10.77% in Usa. Greater SOC accumulation above the center of the sheet pipe in

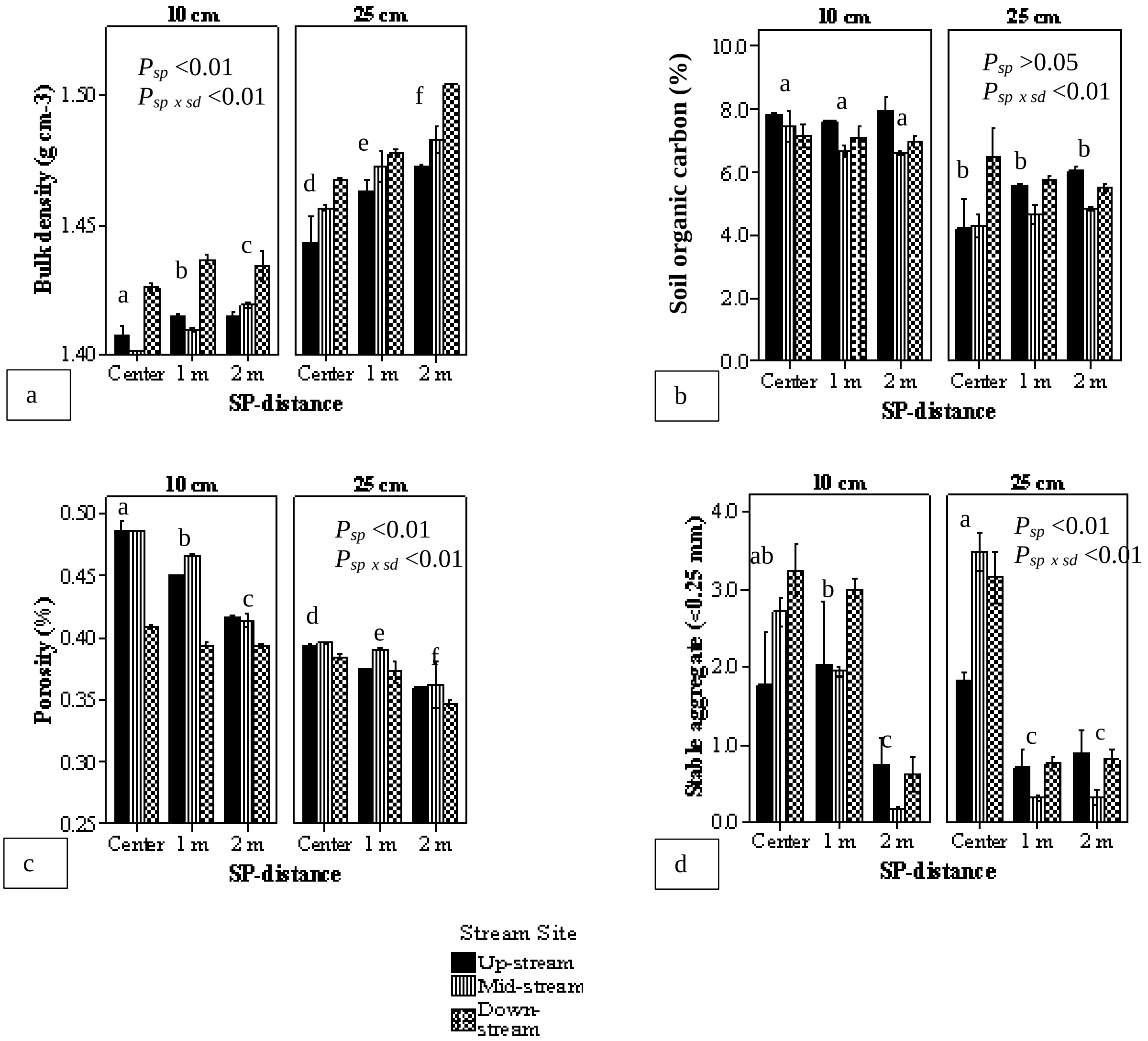


Figure 4.3 Changes in soil physical properties in Hisayama due to perforated sheet pipe distances at different soil depths: a) soil bulk density; b) soil organic carbon; c) porosity; and d) stable aggregates

*The same letters shown on the bars are not significantly different at 5% by LSD and calculations based on 9 data of upstream, midstream, downstream,
*sp means sheet pipe

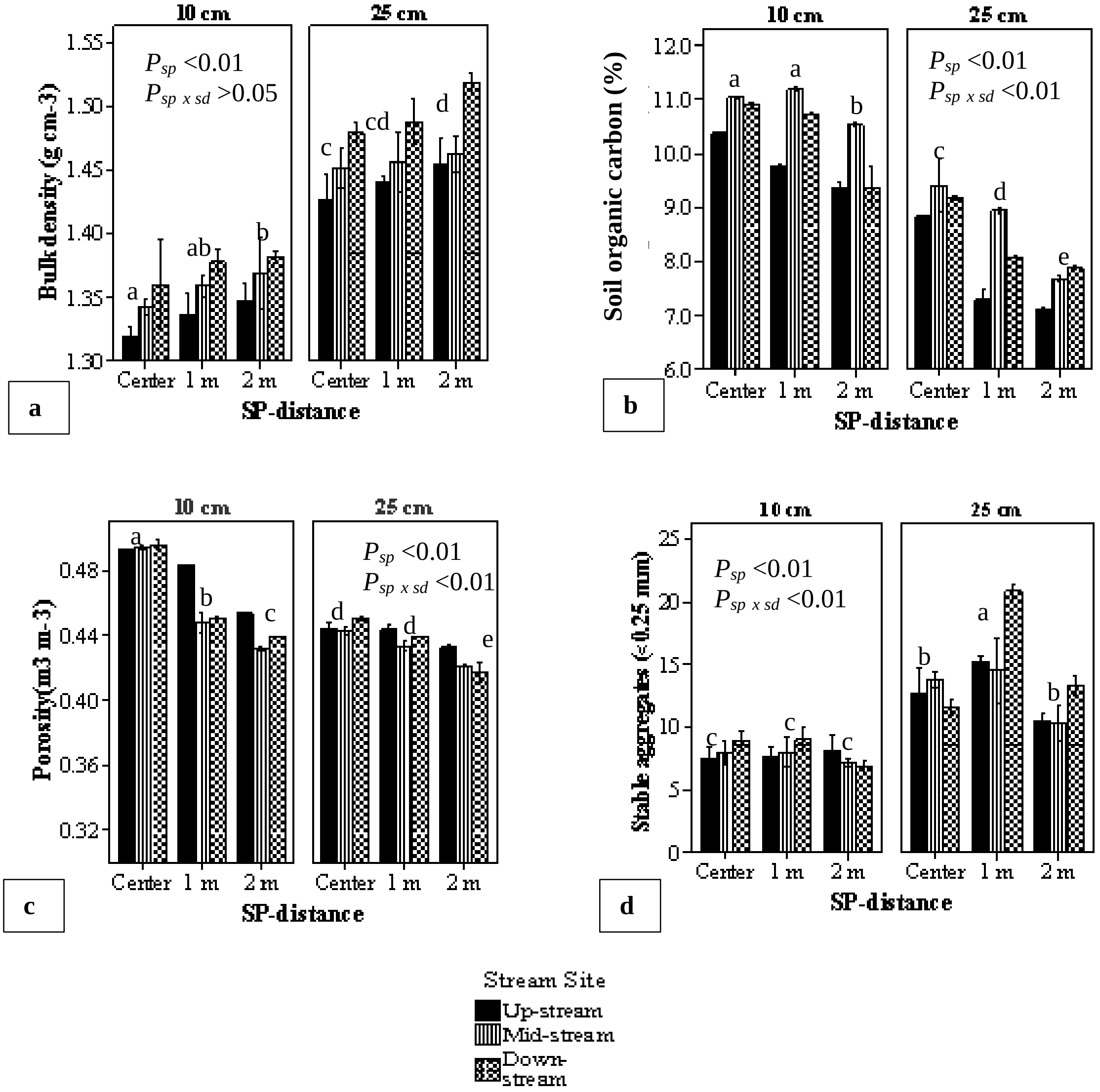


Figure 4.4 Changes in soil physical properties in Usa due to sheet pipe distances at different soil depths: a) soil bulk density; b) soil organic carbon; c) porosity; and d) stable aggregates.

*The same letters shown on the bars are not significantly different at 5% by LSD and calculations based on 9 data of upstream, midstream, downstream.
*sp means sheet pipe

this study was related to negative correlations of -log Ks (r = -0.55 in Hisayama and r = -0.34 in Usa). In this study, one of the possible reasons why much SOC content occurred at this distance was the different plant root distribution. Much research showed that the addition of organic matter was related to an increase in SOC, hydraulic conductivity, and that it contributed to improvement in infiltration capacity (Haynes and Naidu, 1998). In this study, changes of SOC from 2 m to center of the sheet pipe presented as a positive impact.

Changes in soil porosity (f) in two regions were significantly different at the 1% level due to the sheet pipe distances and soil layers (Figures 4.3 c and 4.4 c). The pattern of its changes showed an increasing order from 2 m of the sheet pipe distance to the center. Both layers of two regions showed the same patterns. The maximum f (0.46 m^3 m^{-3} in Hisayama and 0.49 m^3 m^{-3} in Usa) occurred at the center of the sheet pipe and the minimums (0.37 m^3 m^{-3} in Hisayama and 0.42 m^3 m^{-3} in Usa) were at 2 m. The reason for increase in f above the sheet pipe was related to many soil properties in this study (Tables 4.2 and 4.3). Improvement in soil aggregation, accumulation of soil organic matter and evolution of soil bulk density above the sheet pipe probably contributed to the progress of f. This result showed formation of soil fractures or cracks in the soils. Similarly, the impact of the sheet pipe installation on f from 2 m to the center of the sheet pipe could be assumed positive. Changes in soil aggregation patterns in two regions were presented differently at two layers due to the sheet pipe distances (Figures. 4.3 d and 4.4 d). Significant changes in stable aggregate (< 0.25 mm) were observed at 1 m of the lower layer in Usa. More stable aggregates were observed in Usa (10.54%, n = 54) than in Hisayama (1.54%, n = 54). Stable soil aggregation was favored by lime application (Ca^{2+}) (Roth and Pavan, 1991), the presence of ionic strength and soil pH (6.0 to 6.6) (Castro and Logan, 1991).

Table 4.2 Matrix of correlation coefficients for all measured soil properties in Hisayama, Fukuoka (n=54)

Soil properties	(<0.25 mm)	BD (g cm^{-3})	*f*(%)	MaP	-log *Ks*	PAM (% vol)	FC (%vol)	AC (% vol)	SOC(%)	pH(1:5)	EC (1:5) µS m^{-1}	Total CO_3	MeP	StoP
(<0.25 mm)	1													
BD (g cm^{-3})	-.31(*)	1												
***f*(%)**	.33(*)	-.88(**)	1											
MacP	.42(**)	0.12	-0.09	1										
-log *Ks*	-0.16	.83(**)	-.73(**)	0.08	1									
PAM (% v0l)	0.10	-.69(**)	.58(**)	-.38(**)	-.50(**)	1								
FC (%vol)	-0.11	-.61(**)	.54(**)	-.74(**)	-.43(**)	.72(**)	1							
AC (% vol)	.50(**)	-0.22	.38(**)	.75(**)	-0.25	-0.21	-.53(**)	1						
SOC(%)	0.16	-.68(**)	.60(**)	0.20	-.55(**)	.41(**)	0.13	.45(**)	1					
pH(1:5)	-.27(*)	.46(**)	-.30(*)	-0.18	.30(*)	-0.25	-0.09	-0.22	-.36(**)	1				
EC(1:5) µSm^{-1}	0.15	.39(**)	-.33(*)	0.09	.32(*)	-.38(**)	-0.19	-0.12	-.64(**)	0.21	1			
Total CO_3	0.22	.47(**)	-.35(*)	0.17	.39(**)	-.49(**)	-0.25	-0.07	-.62(**)	0.17	.82(**)	1		
MeP	0.21	-.74(**)	.79(**)	-0.09	-.60(**)	.45(**)	.31(*)	.46(**)	.73(**)	-.28(*)	-.52(**)	-.62(**)	1	
StoP	0.21	-.74(**)	.79(**)	-0.09	-.60(**)	.45(**)	.31(*)	.46(**)	.73(**)	-.28(*)	-.52(**)	-.62(**)	1.00(**)	1

* and ** stand for significant at P = 0.05 and P = 0.01, respectively

< 0.25 stable aggregates;
MaP macropores;
FC field capacity;
pH soil pH (1:5 water);
MeP mesopores

BD soil bulk density;
-log *K*s saturated hydraulic conductivity (logarithmic value);
AC air-filled capacity;
EC electrical conductivity (1:5 water);
StoP storage pores

***f* porosity;**
PAM plant available moisture;
SOC soil organic carbon;
Total CO3 soil inorganic carbon;

Table 4.3 Matrix of correlation coefficients for all measured soil properties in Usa, Oita (n=54)

Soil properties	(>0.25 mm)	BD (g cm^{-3})	*f* (%)	MaP (%)	-log *Ks*	PAM (%)	FC (%)	AC (%)	SOC(%)	pH	EC (µSm-1)	Total CO3	MeP	StoP
(>0.25 mm)	1													
BD (g cm-3)	.74(**)	1												
***f*(%)**	-.41(**)	-.71(**)	1											
MaP(%)	0.03	0.20	-0.16	1										
-log *Ks*	.34(*)	.66(**)	-.63(**)	0.17	1									
PAM (%)	0.14	.43(**)	-.57(**)	0.14	.46(**)	1								
FC(%)	-0.24	-.48(**)	.92(**)	-0.02	-.48(**)	-.39(**)	1							
AC (%)	-.54(**)	-.85(**)	.82(**)	-.32(*)	-.67(**)	-.68(**)	.54(**)	1						
SOC(%)	-.59(**)	-.74(**)	.63(**)	-0.05	-.34(*)	-.43(**)	.40(**)	.79(**)	1					
pH	0.06	0.16	-0.22	0.08	-0.06	0.23	-0.21	-0.17	-.32(*)	1				
EC (µSm^{-1})	0.25	.41(**)	-.28(*)	.36(**)	.70(**)	.30(*)	-0.14	-.41(**)	-0.11	-0.20	1			
Total CO$_3$	.33(*)	.46(**)	-0.22	-0.03	.44(**)	.29(*)	-0.04	-.42(**)	-.38(**)	0.01	.30(*)	1		
MeP	.30(*)	.41(**)	-.44(**)	.42(**)	.38(**)	.47(**)	-0.25	-.60(**)	-.34(*)	-0.23	.34(*)	0.19	1	.29(*)
StoP	-0.12	-0.13	.39(**)	.40(**)	-0.04	-0.18	.49(**)	0.13	.27(*)	-0.26	0.07	0.01	.29(*)	1

* and ** stand for significant at P = 0.05 and P = 0.01, respectively

< 0.25 stable aggregates;
MaP macropores;
FC field capacity;
pH soil pH (1:5 water);
MeP mesopores

BD soil bulk density;
-log *Ks* saturated hydraulic conductivity (logarithmic value);
AC air-filled capacity;
EC electrical conductivity (1:5 water);
StoP storage pores

***f* porosity;**
PAM plant available moisture;
SOC soil organic carbon;
Total CO3 soil inorganic carbon;

The presence of stable aggregates in Usa was highly related to BD, *f*, AC and SOC ($r = 0.74$, -0.41, -0.54 and -0.59 in Table 4.3). The presence of more stable aggregate in Hisayama was highly related to MaP and AC ($r = 0.42$ and $r = 0.50$ in Table 4.2). In this study, the presence of more stable aggregates probably accelerated to preferential water flow of soils as well as the air passing through by macropores or cracks. Based on the changes in stable aggregates in two regions, impact due to the installation of sheet pipe from 2 m and above assumed as neither positive nor negative.

4.3.2 Impacts of Perforated Sheet Pipe Distances on Soil Hydraulic Properties

The results in Figures 4.5 and 4.6 showed that there were significant changes in hydraulic properties in soils such as saturated hydraulic conductivity (-log *Ks*), plant available moisture (PAM), field capacity (FC), macropore volume (MaP), air-filled capacity (AC) and mesopore volume (MeP) according to the sheet pipe distances with different layers in two regions. The pattern of changes in these properties presented differently. Although there was no significant change in -log *Ks* within a layer, some increasing trends of -log *Ks* observed within a short distance in both regions (Figures 4.5 a and 4.6 a). It meant that the more adjacent a region was to the sheet pipe, the greater the *K*s. Minimum -log *Ks* (3.2 in Hisayama and 2.3 in Usa) was observed at the center of the sheet pipe installed. As there were high correlations among -log *Ks*, soil bulk density, soil organic carbon content, and total carbonate in two regions (Tables 4.2 and 4.3), it could be one of the reasons of faster infiltration occurred. Thus, installation of sheet pipe in the study sites had a positive impact on *K*s. Changes in PAM, FC, MaP and MeP content at every sheet pipe distances in the two regions are shown in Figures 4.5 and 4.6 b, c, e and f, respectively. Generally, PAM at the center of the sheet pipe was lower than in other places. The decrease in PAM from 2 m

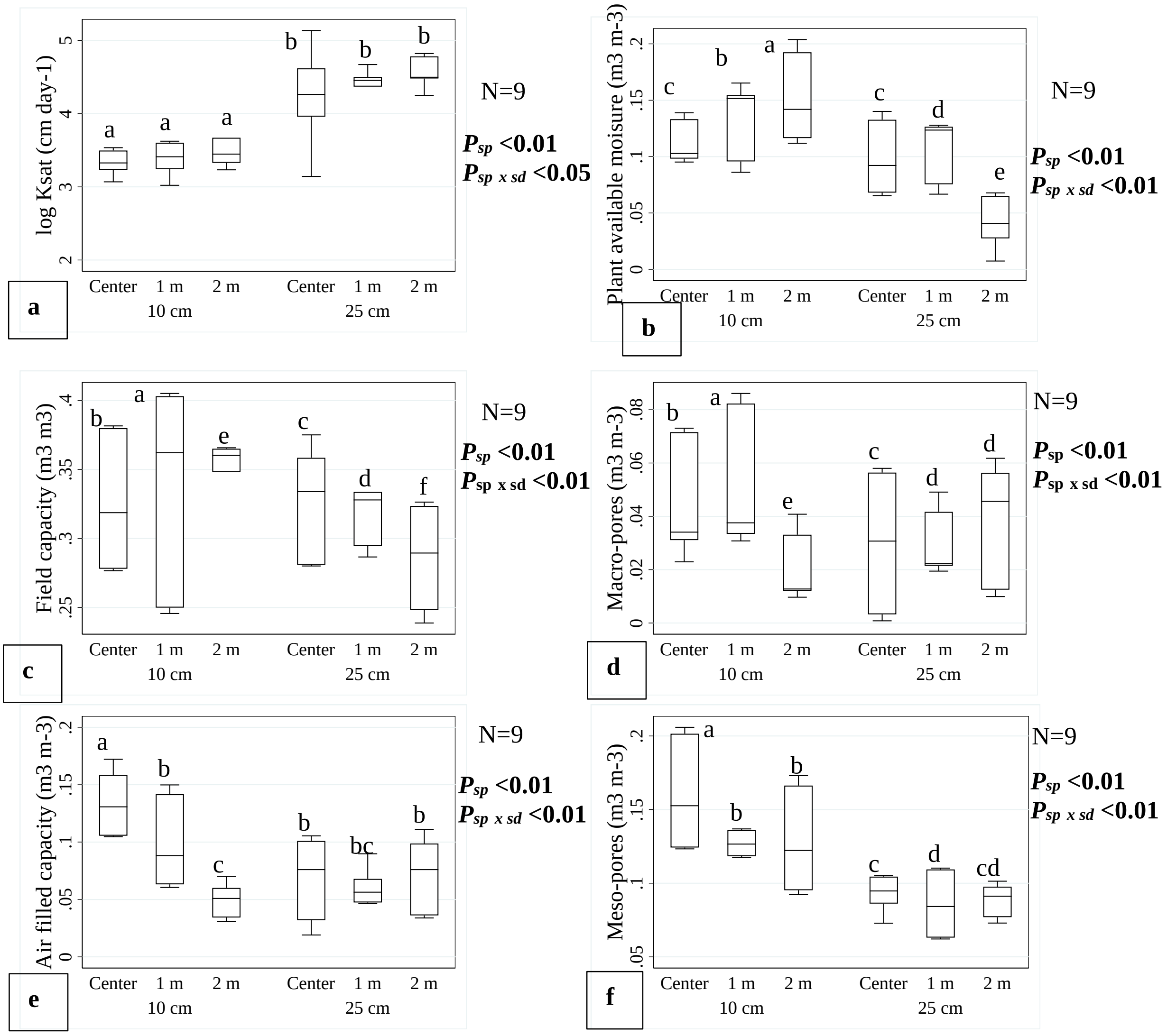


Figure 4.5 Changes in soil hydraulic properties in Hisayama: a) saturated hydraulic conductivity (-log Ks); b) plant available moisture (PAM); c) field capacity (FC); d) macropores (MaP); e) air-filled capacity (AC); and f) mesopores (MeP).

*The same letters shown on the bars are not significantly different at 5% by LSD and calculations based on 9 data of upstream, midstream and downstream,

*sp means sheet pipe

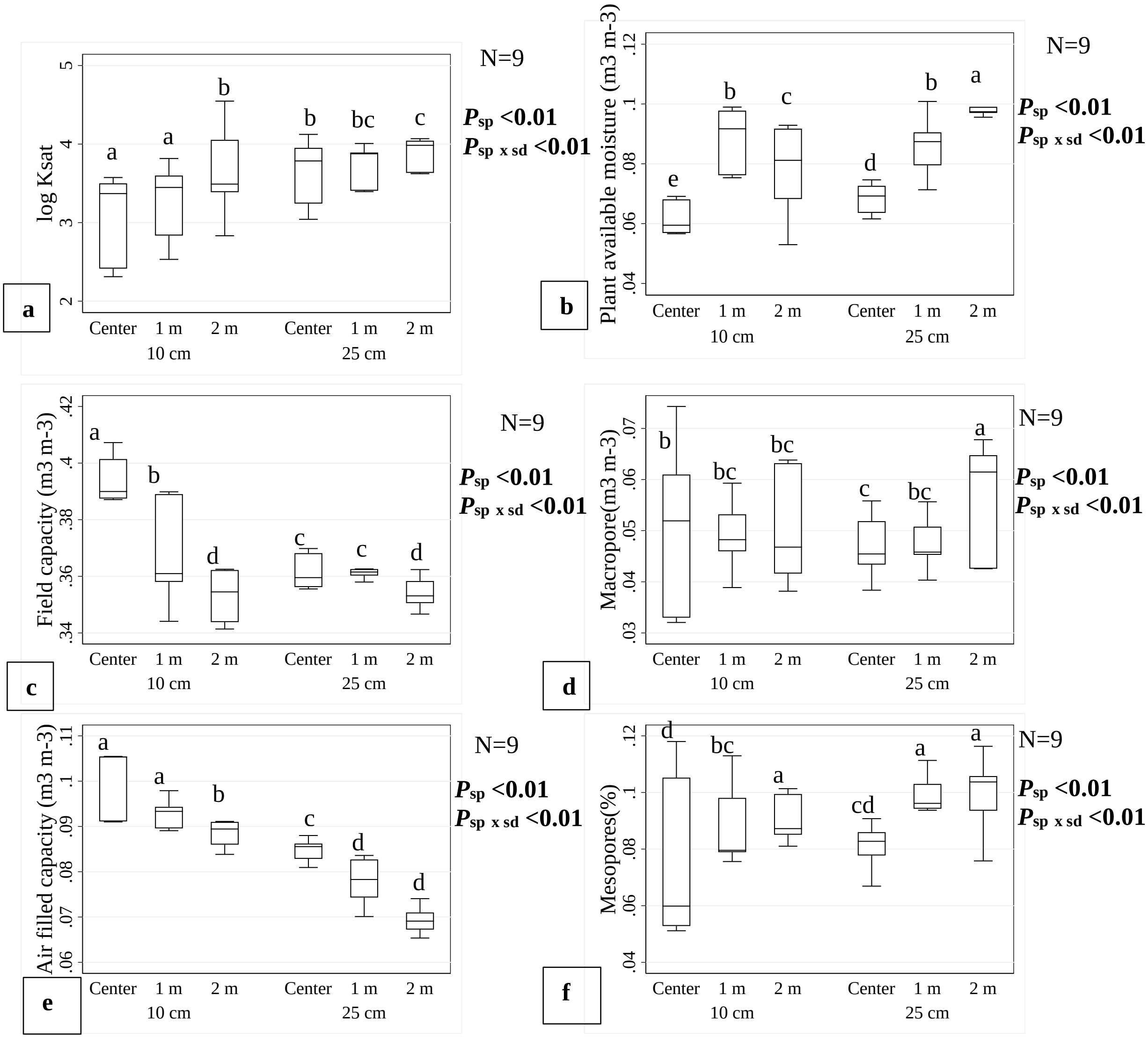


Figure 4.6 Changes in soil hydraulic properties in Usa: a) saturated hydraulic conductivity (-log *K*s); b) plant available water moisture (PAM); c) field capacity (FC); d) macropores (MaP); e) air-filled capacity (AC); and f) mesopores (MeP).

*The same letters shown on the bars are not significantly different at 5% by LSD and calculations based on 9 data of upstream, midstream and downstream

*sp means sheet pipe

to center of the installed sheet pipe at upper layer could count as 4% in Hisayama and 3% in Usa. The lower PAM above the center of the sheet pipe correlated with the high soil water infiltration and other soil chemical properties (Tables 4.2 and 4.3). The presence of storage pores contributed less to this property. In addition, potentially drought-prone could be observed above the center of sheet pipe because the PAM results were less than optimum content of 0.10 to 0.15 $m^3 m^{-3}$ (Cockroft and Olsson, 1997). Therefore, the impact of the sheet pipe on this property assumed as negative. In two regions, the maximum water content at field capacity (FC) or upper limit of the soil water storage showed differently at 0.33 $m^3 m^{-3}$ at 2 m distance of the sheet pipe in Hisayama and 0.37 $m^3 m^{-3}$ above the sheet pipe in Usa. These differences were related to different soil textures, land management practices including tillage operation, cultivated crops, and manure applications. The reasons why strong correlations observed between FC and -log *K*s, MaP, and SOC in both soils (Tables 4.2 and 4. 3) were due to the presence of organic matter in soils and the retained water against the gravity of water flow due to macropores (Lopez and Barclay, 2017; Oliveira *et al.*, 2015). Although the similar increasing trends of FC were noticed in the lower layers of both soils, those of upper layers were irregular. Thus, the impact produced by the sheet-pipe installation on FC could be recognized as neither positive nor negative. Non-uniform patterns of MaP ($m^3 m^{-3}$) contributions were seen in both soil layers of Hisayama and Usa (Figures 4.4 d and 4.5 d). Surface macropores could vary temporarily due to farm management including tillage, weeding (Josa *et al.*, 2013) and root distribution (Dohnal *et al.*, 2009). In this study, non-uniform changes in MaP due to the installation of sheet pipe were related to the presence of stable aggregate in Hisayama and enhancement of air-filled capacity in both regions. As the studied soils were in fine-textured soils, this situation would probably contribute to the formation of macropores under wet and dry conditions together with the presence of organic matter and transport of water & air flow

(White, 1985). In summary, the impact of the sheet pipe installation on this soil could not identify clearly as positive or negative. The trends of AC (m^3 m^{-3}) produced by the installation of sheet pipe in the two regions (Figures 4.5 and 4.6 e) tend to be in increasing order from 2 m to 0 m, and it was more advanced in the upper layers. The reason for the greater AC near the sheet pipe was highly related to BD, *f*, -log *Ks* and many other soil properties (Tables 4.2 and 4.3). For the surface soils, AC should be as at least 0.10 to 0.15 m^3 m^{-3} for adequate root growth (Cockroft and Olsson, 1997). In this study, AC above the sheet pipe was 0.10 m^3 m^{-3} in Hisayama and 0.09 m^3 m^{-3} in Usa. Although these values were optimum for the adjacent sheet pipe, those from further distances were below optimum. Thus, progress of the AC occurred above the sheet pipe and was considered as a positive impact.

MeP (m^3 m^{-3}) of both soil layers in the two regions showed differently (Figures 4.5 f and 4.6 f). However, their changes due to the sheet pipe distances and soil depths were statistically different at 1% level. In Hisayama, their patterns at both layers were in increasing order but the opposite occurred in Usa. Maximum MeP content (0.16 m^3 m^{-3}) was found above the center of the upper layer in Hisayama, and that content (0.10 m^3 m^{-3}) occurred at the lower layer of the 2 m distance in Usa. These patterns were shown in two regions because there was a link between the presence of MeP and soil textural conditions, especially in silt content (Table 4.1), the presence of soil organic carbon in two regions and water flows in the soil profile, -log *Ks* (Tables 4.2 and 4.3). Beck *et al.* (2003) discussed the water retention and its transfer properties as the pore space characteristics determined by a function of relative humidity. In this study, changes in this soil property form 2 m to center was probably due to the accumulation of water transport materials such as organic carbon, soluble carbonates, salts, and moisture retained there (Moret and Arrue, 2007; Reynolds *et al.*, 2003; Mordhorst *et al.*, 2017). As changes in MeP due to the sheet pipe distances in two regions showed differently, its impact assumed as neither positive nor negative.

4.3.3 Impacts of Perforated Sheet Pipe Distances on Soil Chemical Properties

Table 4.4 Changes in soil chemical properties by sheet pipe distances in two regions and its impact

Region	**Soil chemical properties**								
	pH(1:5)			**EC(1:5)µS m^{-1}**			**Total CO_3**		
	Center	1 m	2 m	Center	1 m	2 m	Center	1 m	2 m
Hisayama	6.50b ± 0.32	6.62a ± 0.25	6.47b ± 0.12	13.47a ± 3.17	12.88b ± 3.42	10.06c ± 3.49	8.80a ± 2.18	8.39a ± 1.72	6.25b ± 3.45
Usa	6.73a ± 0.12	6.71a ± 0.11	6.77a ±0.23	29.05a ± 15.63	31.72a ± 13.23	34.54a ± 14.28	7.96a ± 4.9	8.29a ± 3.86	8.49a ± 4.71
Impacts (Positive/ Negative)	Neither			Neither			Neither		

Numbers in parentheses are standard deviations

*Same letters within the rows of each property are not significantly different at $p < 0.05$

Table 4.4 describes changes in soil chemical properties due to sheet pipe distances such as pH, EC and total $CaCO_3$ in two regions. Statistically, responses of soil pH, EC and total $CaCO_3$ installed by the sheet pipe were significantly different at 1% in Hisayama. However, the opposite results observed in Usa. Based on the uneven responses of pH, EC and total $CaCO_3$ due to sheet pipe installation in two regions, it was difficult to state as positive or negative impact. 0.003unit increment in soil pH produced by Hisayama, while that of 0.004unit decrease in USA from 2 m to center of the sheet pipe installed. Generally, the soil pH of the two regions showed 6.4 in Hisayama and 6.7 in Usa. These values of ionic strength indicated optimum conditions for crop growth (USDA-NRC, 2017). For the salt load indicator, the patterns of EC were not similar in two regions. An increasing order of EC occurred in Hisayama from 2 m to above the center of the sheet pipe installed. The opposite pattern occurred in Usa. The presence of total carbonate was maximum at 2 m of the sheet pipe distance in paddy soil of Usa and center of that in Hisayama. The relationships between EC and total $CaCO_3$ in two regions were positively correlated (r = 0.82 and r = 0.30) (in Tables 4.2 and 4.3). In addition, positive correlations of log *Ks* and total CO_3 (r = 0.39, r = 0.44) and a negative correlation log *Ks* and SOC (r = - 0.55, r = - 0.34) occurred in two regions. These relations indicated that there was a dissolved salt and finer OM load due to water flow. Due to uneven responses of chemical soil properties in two regions, it could predict that the impacts of installation of the sheet pipe from 2 m to the center were neither negative nor positive.

4.4 Discussion

In general, changes in soil physical properties from 2 m to the center of the installed perforated sheet pipe interacted with the soil hydraulic properties as well as the chemical soil properties measured in this study. SOC near the perforated sheet pipe accumulated as a nutrient load carried by preferential flow (low in -log *Ks*) in the presence of macropores or cracks (high in AC). Consequently, it resulted in a decrease in soil bulk density above the installed perforated sheet pipe. Under drained (tile) and undrained soils, there were no significant changes in soil bulk density and organic matter content (Jia *et al.*, 2008; Kumar *et al.*, 2014). However, there was an improvement in soil porosity (Kumar *et al.*, 2014). In this study, changes in BD and SOC contributed to increasing the porosity of paddy soils adjacent to the sheet pipe installed.

Enhancement of hydraulic conductivity in paddy soils due to the installation of sheet pipe was not comparable that of conventional (tile) drain because of different tillage management, cropping history and other conditions although similar effects such as improvement of gas diffusivity and air-filled capacity observed (Nakajima and Lal, 2013). In this study, the installation of sheet pipe changed the soil moisture conditions at field capacity, permanent wilting point and plant available moisture based on the sheet pipe distances. However, there were no significant changes in soil moisture under the study of conventional (tile) drained and undrained soils (Jia *et al.*, 2008). Significant changes in MaP ($m^3\ m^{-3}$) were observed in this study as well as in tile-drained soils. Other results of tile drain installation indicated the formation of soil cracks and enhancement of preferential flow (Cooley *et al.*, 2013), conservation of sediment and nutrient loss (Hoorman and Shipitalo, 2006) and pollution for soil and water quality at downstream sites (VCWI, 2017). Consequently, it is suggested to investigate the sediment and nutrient loss and pollution in the drain volume by installing the perforated sheet pipe. The reason for total carbonate accumulation and high EC performance above the sheet pipe was likely to be forward water movement to the perforated sheet pipe. In addition, some of the finer organic matter with dissolved salt could probably be transported to the sheet pipe nearby. There, some soluble salt such as Na can drain easily and some salt such as $CaCO_3$ and $MgCO_3$ can be adsorbed by some soil pores or filtered by the perforated sheet pipe. As a consequence, it created neutral soil pH, much accumulation of SOC and total $CaCO_3$ at the sheet pipe nearby. Finally, greater aggregation of soil together with the progress of f (%) would probably promote soil aeration and water infiltration in turn. Mayer *et al.* (2004) explained one of the mechanisms in which mesopores could protect the loss of organic matter in sediments and soils by water transport throughout the soil profile. Although some literature documented contradictory effects of applying $CaCO_3$ or similar substances on soil water movement and aggregations, some field studies showed the major improvement of soil aeration

(Wagenet and Jury, 1984; Mordhorst *et al*., 2017). Under the conventional (tile) drain, special attention is given because some of the controlled water table by using tile drains affected the adjacent soils as a negative impact due to the accumulation of soluble salts or pollutants (Sug, 2007). In addition, misuse of soil and fertilizer management practices in subsurface tile-drained conditions potentially exaggerated the losses of nutrients in agricultural soils (Chatterjee, 2016). These results alert us the need to investigate the functioning of installed perforated sheet pipe and to consider the intensifying effect of EC in the long-term installation of sheet pipe.

4.5 Conclusion

Installation of the perforated sheet pipe for long term study provides some insights into changes on adjacent soil physical, hydraulic, and chemical properties. After a long-term installation of the sheet-pipe in two regions, there was an increase in soil organic carbon and total carbonate content near the sheet-pipe that contributed to increase soil porosity, air-filled capacity, and reduced soil bulk density. Improvements in soil aggregation and macro-pores also observed above the sheet-pipe. Saturated hydraulic conductivity was high above the sheet-pipe, whereas the plant available moisture was low. However, changes in soil pH and EC were variable at different places under the different wetting and drying cycles of paddy soils. In terms of stream site effect, changes in measured soil properties were not distinct. In sum, changes in soil properties after long-term installation were more significant according to the distance effect (nearness of the sheet-pipe), than according to the stream sites (from irrigation point to drainage out-let).

Chapter 5

General Conclusion and Future Recommendations

5.1 General Conclusions

This study was mostly conducted in paddy fields with different soil textures and locations. Firstly, we investigated the soil moisture characteristics and drainage functions under the installed sheet-pipe compared with the uninstalled ones at two places in Kagoshima. We observed that soil moisture fluctuations under two situations (with & without installed sheet-pipe) were different. Under the uninstalled ones, there was a prolonged water logging at 15 cm and 30 cm soil depths during conducting the field trials. From this study, it was known that the installed perforated-sheet-pipe was well functioned for drainage, and a change in soil water characteristic was a clue for further studies for soil property-changes that impacted by the installed sheet-pipe.

To identify the short-term impacts of the installed sheet-pipe, we conducted the second field experiment in Oita. The significant location of this study was a coastal lowland with sandy loam. When we compared the changes of soil physical and hydraulic properties for one cropping season after cultivation of the fodder rice, we could not identify that the short-term impact on changes in most soil properties, significantly. However, a significant increase in meso-pores near the sheet-pipe at the deeper soil layers was observed (Chapter-3). One of the reasons of an increase in meso-pores in this study seemed to be development of small cracks and under a transition state of macro-pores which required frequent drying and wetting for several years.

To understand the long-term impacts of the installed sheet-pipe, we conducted the third experiment at Fukuoka and Oita. In terms of stream sites, sheet-pipe distances, and soil depths, we investigated the changes in some paddy and converted paddy soils properties. Some improvements in soil bulk density, an increase in soil organic carbon, soil aggregation, macro-pores, soil porosity, and air-filled capacity were observed near the sheet-pipe (0 m distance and 25 cm soil depth). Saturated hydraulic conductivity was high above the sheet-pipe, whereas the plant available moisture was low. One of the reasons why these improvements occurred was the development of some cracks which favored much infiltration to the installed drains. More macro-pore development was a distinct impact by long term and these pores seemed to develop some cracks in clayey soils of this study. This was also a reason why plant available moisture was less at 0 m distance of the sheet-pipe. However, changes in soil chemical properties, such as pH, EC, and total carbonate were unstable regarding different stream sites, sheet-pipe distances, and soil depths (Chapter-4).

5.2 Future Recommendations

This research investigated only on the changes in paddy soil characteristics with the installed sheet-pipe. We studied these impacts with three approaches regarding different stream sites, distances from the sheet-pipe, and soil depths. However, observations of these impacts due to the sheet-pipe only were hard to say clearly because of interaction with some management practices and cropping conditions. As we studied in fields under the installed sheet-pipe, variations of soil characters were accompanied by crop growths. In actual fields, more cracks developed at the up-stream sites than the downstream sites. Plant heights of fodder in the downstream site were more than that of the upstream. However, these developments needed to clarify whether it was only due to the impacts of sheet-pipe or not. Our study is a beginner of agri-environmental scientific research for a drainage development under the shallow subsurface drain of perforated sheet-pipe. Thus, a wide scope of further study concerned with that related information is required to explore. From this research, it can recommend to study for the formation and development of cracks under the installed perforated sheet-pipe in paddy soils. As for the long term, benefits of the installed sheet-pipe on the environment, crop growth, differently managed soils are challenging for the development of drainage.

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Appendix

Index Table 1. Investigating the effect of sheet-pipe installation on changing soil properties using ANOVA (F-test/t-test)

Significance	**Soil properties**					
	BD **(g cm^{-3})**	**OM** **(%)**	**-log Ks** **(cm s^{-1})**	**MeP** **(cm^{3} cm^{-3})**	**MaP** **(cm^{3} cm^{-3})**	**PAM** **(cm^{3} cm^{-3})**
P_C **(Before & After)** *(N=27 &81)*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P_{SP} *(After;N=27)*	>0.05	>0.05	>0.05	<0.05	>0.05	>0.05
P_{SS} *(After;N=27)*	<0.01	<0.01	<0.05	>0.05	<0.01	<0.05
P_{SD} *(After;N=27)*	<0.01	<0.01	>0.05	<0.01	>0.05	<0.05
$P_{(SPXSS)}$	>0.05	>0.05	>0.05	>0.05	<0.05	<0.05
$P_{(SPxSD)}$	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
$P_{(SSx\ SD)}$	>0.05	<0.05	>0.05	>0.05	<0.01	>0.05
$P_{(SPxSSSxSD)}$	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

BD= bulk density; OM=soil organic matter; -log *K*s= saturated hydraulic conductivity; MeP=mesopores; MaP=macropores; PAM=plant available moisture

Before= before rice cultivation After=after rice cultivation

$Pc<0.01$ means that changes in soil properties during a rice cropping are statistically highly significant at P<0.01.

$P_{SP}<0.05$ means that changes in soil properties regarding distances from the sheet-pipe are statistically significant at P<0.05.

$P_{SS}<0.01$means that changes in soil properties under different stream sites are highly statistically significant at P<0.01.

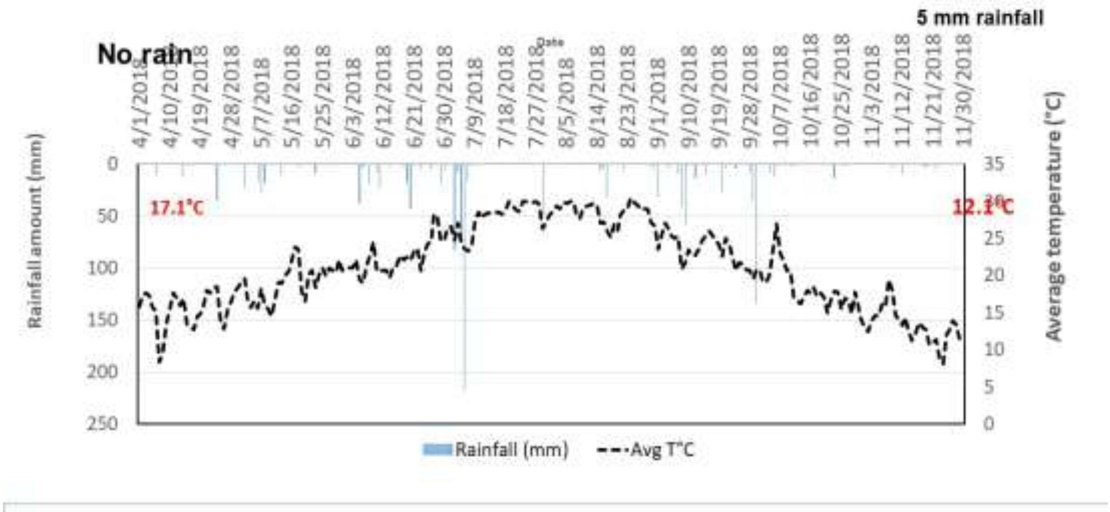
$P_{SD}<0.01$means that changes in soil properties at different soil depths shows highly statistically significant at P<0.01.

$P_{(SPXSS)}>0.05$ means there was not interaction between two factors sheet-pipe distance & stream site.

$P_{(SPXSS)}<0.05$ means there was an interaction effect between two factors sheet-pipe distance & stream site.

$P_{(SPXSSD}>0.05$ means there was no interaction between two factors sheet-pipe distance & soil depth.

$P_{(SPXSSXSD)}>0.05$ means there was no interaction effect between three factors sheet-pipe distance, stream site & soil depth.



Index Figure.1 Meteorological condition from 1st to 2nd soil sampling in Takedatsu, Kunisaki, Oita (MAJ, 2018)

Index Photos Section

Soil Profile at 1st soil sampling

Soil Profile at 2nd soil sampling

Kunisaki, Oita Study

Isashi-Hishikarishimode, Kagoshima

Kitakata, Kagoshima

Soil Sampling at Hisayama, Fukuoka

Infiltration Test at Usa, Oita

A visit to Research Institute, Usa before conducting an experiment

A visit to Hisayama before Conducting an experiment

Determination of surface cracks

Determination of soil water characteristic curve using hanging column method

Determination of soil water characteristic curve using Centrifuge Method

Determination of cracks

Investigation of moisture sensors and Data-logger's function before application in field measurement

1st soil Sampling and field determination at Takedatsu

2nd soil sampling and field determination at Takedatsu