Implementation of sheet-pipe subsurface drainage system in Indonesia: Enhancing soil aeration and water management

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Abstract. Since 2017, the installation of the Sheet-pipe system in Indonesia has marked a significant development. This initiative, a collaboration between the Ministry of Agriculture and a Japanese construction company, aims to improve water management in rice paddies. The system was specifically installed at the Sukamandi Rice Research Center in West Java, covering an area of 3600m². Seven parallel sheet-pipe lines, each 100 meters in length and 40 cm deep, were laid out. These lines were consolidated into three drainage outlets regulated by valves. The primary goal was to evaluate the drainage capacity and land drainage modulus using the sheet-pipe system. Measurements of the drainage water exiting each pipe were taken using gravimetric methods at specific time intervals under saturated soil conditions. The results indicated a total drainage rate ranging from 0.396 l/s to 1.431 l/s. The maximum drainage rate per sheet-pipe lane was 0.20 l/s, and the drainage modulus was 275 m^3 day^{-1} ha^{-1}. These findings illustrate the efficiency of the sheet-pipe system in facilitating water reduction to the sheet-pipe depth, thereby enhancing soil aeration.

1 Introduction

The need to increase drainage capacity of waterlogged farmland has driven the development of advanced subsurface drainage technology. This system, known as the sheet-pipe system, has demonstrated significant potential for water saving through its innovative approach to subsurface irrigation. By improving soil drainage capacity, this technology ensures that excess water is efficiently removed, thus preventing waterlogged conditions that can adversely affect crop growth. The implementation of this system not only enhances water management in agricultural settings but also contributes to better soil aeration, fostering healthier and more productive crops.

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Subsurface drainage involves reducing the water level (known as water table) in the ground or the water-saturated layer in the soil to the depth of pipe installation, thereby providing aeration for the zone above. Subsurface drainage improves plant conditions affected by waterlogging [1]. This process establishes a soil layer with pores unoccupied by water, enhancing aeration in the zone above the water table. Such conditions, as well as saturated soil states, can be adjusted based on field requirements to ensure optimal productivity.

The Sheet-pipe system, which consists of long perforated plastic sheets shaped into pipes using special tools, is designed to improve soil drainage capacity. This innovative system is particularly beneficial for draining waterlogged soil and facilitating soil leaching, making it an essential tool in agricultural water management practices. The sheet-pipe system can change the larger pores in soils and encourage cracks to develop, which can ultimately improve soil aeration [2, 3]. Research has shown that subsurface drainage systems can significantly enhance crop yield and soil [4, 5] and multi- purpose land use. As for the multi-purpose land use of paddy field can be realized by using the subsurface for irrigation and control the water table and soil moisture [6].

The installation of the Sheet-pipe system in Indonesia represents a significant advancement since its initiation in 2018. This joint endeavor between the Ministry of Agriculture and a Japanese construction company has aimed to enhance water management in rice paddies substantially. Observations have been made regarding the characteristics of this land, such as its performance in maintaining the uniformity of the groundwater table [7] and its interactions with rainfall. These observations also indirectly relate to the land's interactions with rainfall, as the study investigates how soil macroporosity and hydraulic conductivity are affected by drainage and soil moisture conditions [8]. The land that as modified with sheet-pipe had also been observed for its correlation with productivity, which was slightly higher than the conventional field productivity. This shows the potential benefit of sheet-pipe for improving field water management that leads to production increase.

However, the drainage capacity of the sheet pipe after installation is not yet known, especially for soil and climate conditions in Indonesia. This specification must be determined before this technology can be used in agricultural land development. Therefore, an investigation needs to be conducted with the primary aim of assessing the drainage capacity and drainage modulus of the land using the sheet-pipe system.

2 Methods

The Sheet-pipe Subsurface Drainage system is at the Rice Research Station in Sukamandi, Subang, West Java, Indonesia, now known as *Balai Besar Pengujian Standar Instrumen Padi*. Measurements were taken using gravimetric methods at specific intervals under saturated soil conditions. The analysis focused on the drainage capacity to assess the efficiency of the sheet-pipe system.

Fig 1 shows the stages of the sheet-pipe system installation, starting from rolled-up sheets to being embedded in the ground. Initially, the sheet-pipe consists of rolls of perforated plastic sheets, which are formed into pipes using specific tools. The agricultural bulldozer equipped with a mole-plough and a tightening device attached at the back is typically used for this process. As the machine advances, the mole-plough creates a tunnel and simultaneously pulls the sheet-pipe into it. Once installed, the sheet-pipe is fitted with air inlets which are pipes leading to the open air, and outlets on the side of the drainage channels available.

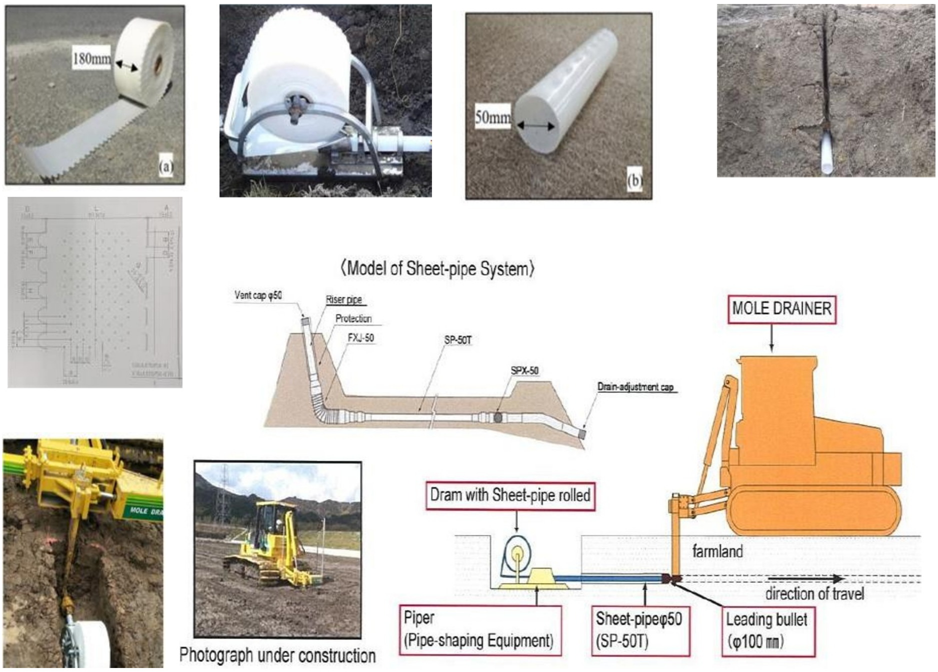


Fig. 1. Sheetpipe installation [9]

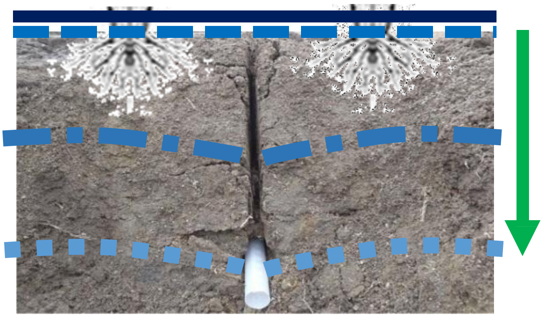


Fig. 2. Water level reduction: flooded (solid line), saturated without flooding (dashed line), middle depth (dotted-dashed line), and maximum depth at drainage pipe level (dotted line)

Fig 2 illustrates the decrease of water levels under various conditions: flooding, saturation without flooding, intermediate depth, and maximum depth at the drainage pipe (dashed line), indicating the effectiveness of the drainage system at different depths. The depth of the pipe determines the maximum water boundary and can be adjusted according to the needs of plants and water management in the field. As water decreases, air enters and migrates between soil pores, enhancing soil aeration.

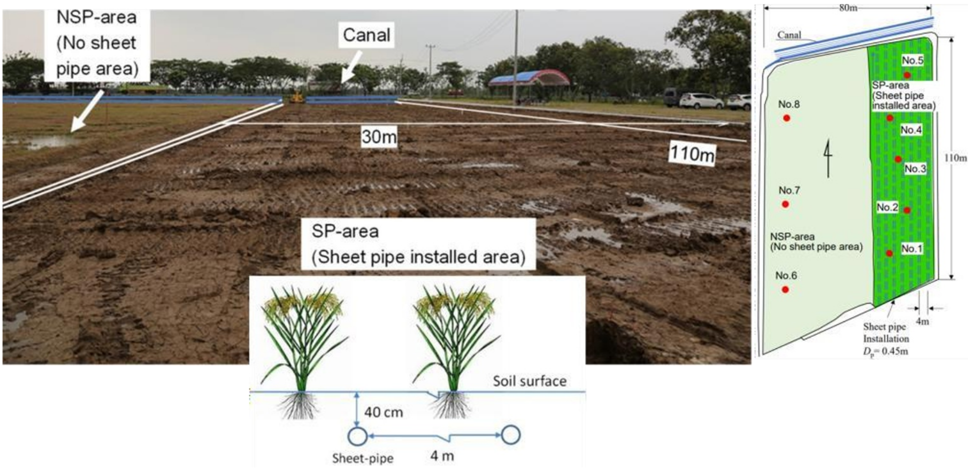
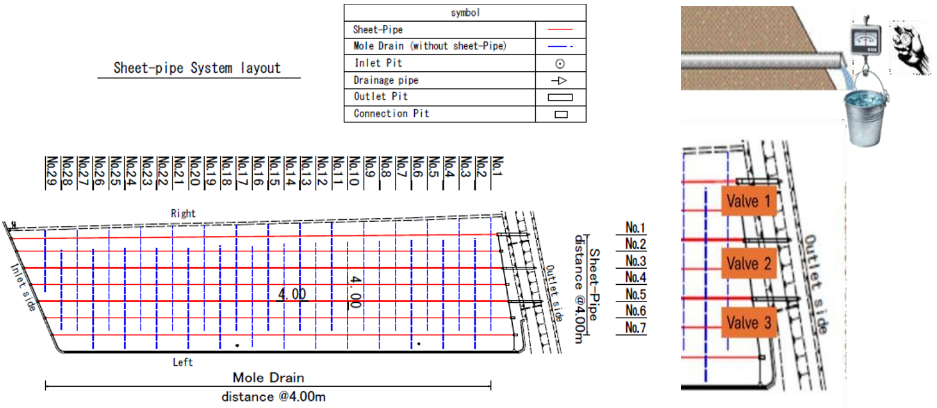


Fig. 3. Sheet-pipe Subsurface Drainage system at Rice Research Station, Sukamandi, Subang, West Java, Indonesia

The system was implemented at a paddy field experimental field covering 3600m² (Fig 3). Fig 4, a and b show the design of sheet-pipe system and it's drainage capacity measurements. Seven parallel sheet-pipe lines, each 100 meters long and installed at a depth of 40 cm, were carefully laid out. These lines were merged into three drainage outlets, which were regulated by valves to control water flow effectively (Fig 4.a).



(a) (b)

Fig. 4. a. Layout of Sheet-pipe Subsurface Drainage system. **b.** Measurement of Sheet-pipe Drainage Rate

Fig 4.b. depicts the process of measuring the sheetpipe drainage rate at the Rice Research Station in Sukamandi, Subang, West Java, Indonesia. The flow rate measurements were conducted at each of the sheetpipe drainage outlets—V1, V2, and V3—starting with the initial water level set at ground level. These measurements were taken over a 24-hour period, between 7 AM and 6 PM, using the gravimetric method to measure the weight of stored drainage water. This systematic approach ensures accurate assessment of the drainage efficiency across different outlets.

3 Results and discussion

The sheet-pipe subsurface drainage system effectively managed water levels in the experimental paddy field, offering useful data for future agricultural water management. The measurements involved collecting the drainage water exiting each pipe at specific intervals and converting the results to units of volume. This conversion allowed for a comprehensive analysis of the total and average discharge rates for each of the seven sheet-pipe lines.

Measurement results were converted to volume units for each outlet, with totals and averages calculated for each of the seven pipelines. The system encompassed an area of 3600m² and included three valves, with each of the seven sheet-pipe lanes extending 116 meters in length. Table 1 presents the discharge rates of the drainage system, derived from measurement data.

The table displays discharge rates measured in liters per second (l/sec) at various intervals over two days, October 8th and October 9th, 2019. Each row in the table indicates the date and time of the measurement, followed by the discharge rates recorded at three different points (V1, V2, and V3). Additionally, it includes the average of these three values and the total discharge rate for each time slot.

For instance, on October 8th at 14:24, the discharge rates were 0.375 l/sec, 0.528 l/sec, and 0.528 l/sec for V1, V2, and V3 respectively, resulting in an average discharge rate of 0.477 l/sec and a total discharge rate of 1.431 l/sec. This pattern is maintained across all recorded time slots listed in the table, providing a comprehensive overview of the discharge rates over the specified period.

Table 1. Discharge rates of all valves, their total and averages

Date/Time	Discharge rate (l/sec)				
	V1	V2	V3	Average	Total
10/8/2019 14:24	0.375	0.528	0.528	0.477	1.431
10/8/2019 16:00	0.320	0.476	0.503	0.433	1.299
10/8/2019 17:00	0.337	0.479	0.508	0.441	1.324
10/8/2019 19:48	0.267	0.370	0.392	0.343	1.029
10/9/2019 5:45	0.145	0.232	0.267	0.215	0.645
10/9/2019 7:42	0.140	0.202	0.292	0.211	0.633
10/9/2019 9:31	0.123	0.195	0.250	0.190	0.569
10/9/2019 11:26	0.114	0.171	0.250	0.178	0.535
10/9/2019 14:15	0.093	0.130	0.172	0.132	0.396

Fig 5 depicts drainage rates over a 24-hour period. Both per-pipe and total discharge rates, measured in liters per second, are shown. Starting around 0.2 l/sec (per pipe) and 0.22 l/sec (total), both rates steadily decline. The decrease is initially steeper, becoming more gradual over time. The total discharge rate consistently remains higher than the per-pipe rate, indicating the combined flow from multiple pipes. Overall, the graph illustrates a diminishing drainage flow throughout the measured period

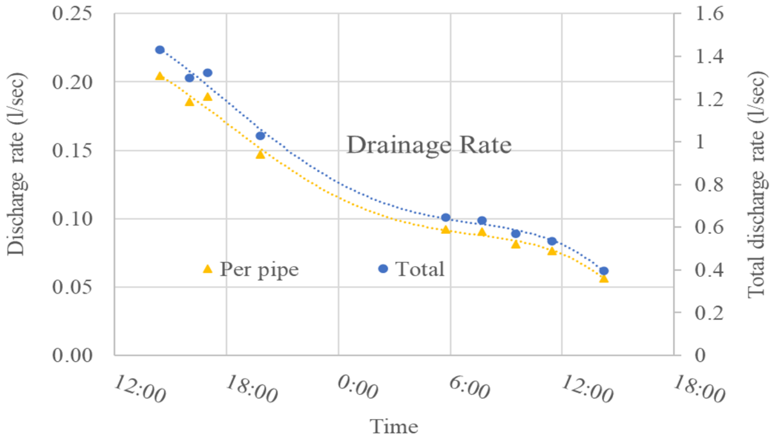


Fig. 5. Sheet-pipe Subsurface Drainage rates, average per pipe and total rate of the land

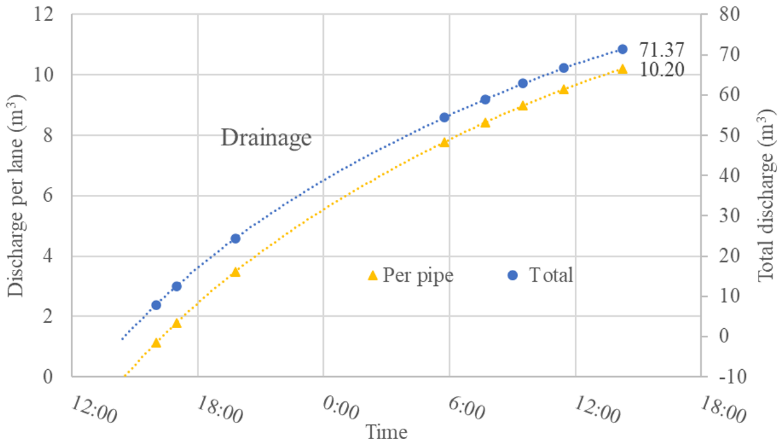


Fig. 6. Sheet-pipe subsurface drainage volume averaged per pipe and total of the land

The chart in Fig 6 illustrates drainage volume over a 24-hour period, showing both per-lane and total discharge in cubic meters. Both measures increase over time, starting near zero. Total discharge increases at a relatively constant, linear rate. Per-lane discharge also increases, but its rate of increase slows down after the initial 12 hours. This suggests that while drainage continues in each lane, the accumulation rate decreases, possibly due to reduced inflow. However, the total drainage volume continues to accumulate steadily, indicating a consistent overall drainage rate from all lanes combined.

Over 24 hours, the drainage can accumulate to 73.1 m^3/day. With this capacity per day, in this area the water level can be decreased by 20 mm per day. The probable time for aeration depends on the soil composition. For soil with 30% drainage pores, the system requires approximately 1.5 days to lower the water table down to 10 cm.

Table 2 provides a summary of the averaged values from all measurements of the sheet-pipe drainage system. The parameters observed include standing water, drain discharge, drain rate, drainage modulus, and drainage spacing. The standing water level was observed to be 40 mm, measured at the level of height. The drain discharge was recorded at 0.48 liters per second, which is the standard plot drainage. The drain rate was found to be 27.5 mm per day, indicating the system's capability to drain water efficiently during periods of high-intensity rain. Finally, the drainage modulus was calculated to be 275 m³ per day per hectare for drainage spacing between the sheet-pipes was set at 4 meters.

Table 2. Drainage system observation parameters for sheet-pipe system

No.	Parameter	Unit	Results	Notes
1	Standing water	mm	40	Levee height
2	Drain Discharge	ltr/s	0.48	Standard plot drainage
3	Drain rate	mm/day	27.5	Able to drain water during high intensity of rain
4	Modulus drainage	m^3/day/ha	275	-
5	Drainage spacing	m	4	-

Sheet-pipes have proven effective in enhancing land management and soil health. However, their application remains limited due to the need for heavy machinery during installation. Additionally, the sheet-pipes are made of imported materials, which contributes to the high overall costs. Further research is required to develop more affordable implementation designs, reduce costs, utilize local materials, and explore non-mechanical options.

4 Conclusions

The results revealed a total drainage rate ranging from 0.396 l/s to 1.431 l/s, with the maximum drainage rate per sheet-pipe lane being 0.20 l/s. The drainage modulus was 275 m^3 day-1 ha-1. These findings highlight the effectiveness of the sheet-pipe system in facilitating water level decrease to the sheet-pipe depth and enhancing soil aeration. Sheet-pipes are effective for improving land management and soil health, but their high costs and installation challenges necessitate further research for more affordable and locally sourced solutions

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