The effect of sheet-pipe technology application on soil properties, rice growth, yield and prospect to increase planting index

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Abstract. Sheet pipe technology is a drainage and irrigation underground system. This study aimed to understand the effect of sheet pipe technology on growth, yield and prospect to increase planting index (PI) on irrigated rice field. The research conducted in Sukamandi Experimental Station, West Java on 2019 to 2020. It used nested design with five replications. First was water management as nested factor, i.e.: Sheet pipe and (2) no sheet pipe. Second was cropping system, i.e.: (1) paddy–paddy, (2) paddy–paddy–soybean, (3) paddy–paddy–paddy, using Inpari 43 GSR Agritan. The result shown that (1) The effect of sheet pipe was strongly influenced by the season, especially in the dry season. (2) Sheet pipe supported better tiller ability, leaf area index, biomass, plant height, root volume, number of panicle per hill, number of grains per panicle and yield. (3) Increasing PI from two to three using sheet pipe technology could increase the total yield by 11.54% (paddy-paddy-soybean) and 26.94% (paddy-paddy-paddy) compared with no sheet pipe. Meanwhile, the paddy-paddy also provided total yield of 10.86% compared with no sheet pipe, and (4) Sheet pipe increased soil pH, bacterial aerobic, rhizobium and nitrogen fixing bacteria, and soil respiration.

1. Introduction
Water-saving irrigation still a serious issue which linear with increasing rice consumption and water scarcity. In 2025 was predicted that the availability of water resource per capita in many Asian countries decline around 15 to 54% compare to 1990 [1]. Rice cultivation in lowland area need 1,000 to 2,000 mm water irrigation per season [2]. Technologies should play role to increase water use efficiency [2, 3]. Alternate wetting and drying and aerobic rice system reported low water input but increase the efficiency compare to flooding system [2–6]. However, water use efficiency not only about irrigation system but also how to drainage so plant get water as well as the needs and maintain field from lodging problem, optimum humidity, methan gas production, etc [7]. Continuously flooded conditions was no longer a good recommendation because it became preferred conditions for pests and diseases [8,9] and stimulate the development of methanogenic bacteria for the production of methane gas that damages the environment [10]. One alternative instrument to overcome the problem of poor land drainage is the application of underground drainage systems in the form of porous pipes embedded in the soil called as sheet-pipe system. Sheet pipe system is a shallow underground drainage system using a 50 mm diameter porous pipe embedded in the soil at a depth of 50 cm. Besides being able to function as a drainage system, this technology can also play a role in storing water in the ground when water input is limited.
Before being pulled and immersed into the ground using a mole drainer, the sheet pipe has a rolled sheet shape (figure 1), and when pulled by itself the sheet will fold and form a 50 mm diameter pipe [11]. Subsurface drainage system was reported could increase yield and water productivity, nutrient efficiency, and reduce environmental effects [7]. This study aimed to understand the effect of sheet-pipe technology installation on growth, yield and prospect to increase planting index on irrigated rice field.

![Figure 1](image)

**Figure 1.** Sheet pipe sheet (left) and after being pulled by the mole drainer to fold and form a 50 mm diameter pipe (right).

2. **Materials and methods**
Research was conducted in Sukamandi Experimental Station, Indonesia Center for Rice Research Institute, Subang, West Java in the three planting seasons of the wet season, dry season 1, and dry season 2 in 2019 to 2020. It was arranged using nested design with five (5) replications. First factors was water management as nested factor with two levels, i.e.: (1) Sheet-pipe installation (±3,600 m²) and (2) Without sheet-pipe installation (farmer practice (±5,400 m²). Second factor was cropping system with three levels, i.e.: (1) paddy–paddy, (2) paddy–paddy–soybean, (3) paddy–paddy–paddy. Rice variety was Inpari 43 GSR Agritan. Before land preparation, a composite soil sample was taken, to determine the nutrient status of N, P, K and the pH using soil test kit for irrigated paddy field, as well as to determine the dose of N, P and K fertilizer needed. Seeds planted by direct sowing or transplanting on the field. N fertilizer applied in three different times i.e 7 to 10 days after transplanting (DAT) or 30 days after sowing (DAS), maximum tillering, and panicle initiation. P fertilizer was applied entirely at first application, while 50% K fertilizer was applied at first and third application. Observation parameters include:
1. Soil analysis. The analysis carried out for both before and after trial for chemical and biological analysis.
2. Plant growth. Tillering ability, Leaf area index (LAI), biomass, roots volume, and plant height. Tiller numbers of soybean was approximated by counting the number of branches per hills.
3. Yield components. Consist of: panicle number per hill, grain number per panicle, filled grain percentage, and 1,000 grains weight on 14% MC (moisture content) from 12 hills per plot.
4. Yield. Harvesting for each plot taken from size of ± (2.5 x 2.5) m² per plot on 14% MC. Data was analysis using varian analysis continued with Least Significant Different (LSD) 5% to understand the differences between treatments.

3. **Results and discussion**
3.1. **Response on plant growth**
Since the first (wet season) and second (dry season 1) planting season basically were the same crop (Inpari 43), it was no difference in cropping treatment. The third season (dry season 2), it found
significant difference between cropping patterns due to different crop (rice and soybean) (data not shown). Furthermore, there was a significant difference between sheet pipe and no sheet pipe on growth variables. Sheet pipe was shown better response especially in dry season (figures 2 and 3). Water management was one of the cultivation techniques that affect plant development, especially on tiller ability [12]. It was due to differences in water depth which affect soil aeration and nutrient availability including the dynamics of nitrogen in the soil until it becomes a form that can be absorbed by plants for growth and initiation of panicle formation [13]. Sheet pipe treatment in the three cropping patterns was also shown a slightly higher posture at dry season. Agronomic characteristics especially age and plant height had significant influence on assimilation translocation. Higher assimilate could be stored in biomass accumulation as well as in higher plant height [14]. The accumulation of root, leaf and stem biomass in sheet pipe treatment was also higher than no sheet pipe, but not in panicle biomass accumulation (figure 3). The accumulation of biomass in panicle parts was strongly influenced by the filling ability which was very vulnerable to insufficient water [15]. The roots volume observed in the sheet pipe treatment was showed 60 ml per hill while in the no sheet pipe approached 50 ml lower than the sheet pipe treatment (figure 5). Differences in water saturation conditions greatly affected root development [16]. Optimal growth could not be obtained if the plant was not supported by healthy and optimal root development [17]. However, LAI on sheet pipe treatment was shown lower value compared to control (no sheet pipe) on soybean but higher on paddy (figure 4). The plants response to water also influenced by plant density that will determine the actual and maximum yield that related in relative evapotranspiration [18].

![Tillering Ability](image)

**Figure 2.** Tillering ability under different water management across seasons. Error bar indicated standard deviation on each treatment, Sukamandi (2019).
3.2. Response on yield and yield components

The yield showed that sheet pipe treatment significantly increased production especially in the dry season 1, while in the wet season and the second dry season even the production was increased but not statistically significant (data not shown). This was presumably because in Sukamandi field station surface water was quite abundant in wet season and the ability of sheet pipe to store water especially during the dry season was more effective than its drainage ability in the wet season. Drainage was not equivalent to the precipitation volume. The differences in water depth would affect the soil and increase nutrients including nitrogen in the soil into a form that plants could absorb for growth and panicle initiation formation [13]. Meanwhile, paddy-paddy-soybean (C3) cropping pattern provides the highest total yield than two other cropping patterns. Paddy-paddy-soybean (C2) cropping pattern showed equivalent yield to paddy-paddy (C1) because on the dry season 2 there had been a lot of rain thus
soybean was not optimal. In Figure 8, it was agreed even not significantly different, sheet pipe treatment showed higher yield. Increasing crop yield by sheet pipe installation on each C1; C2; and C3 cropping pattern were 10.86%; 26.94% and 11.54% than no sheet pipe (figure 6).

Figure 6. Yield comparation on three seasons trial under different water management and cropping system, Sukamandi 2019.

The effectiveness of sheet pipe installation on increasing rice production in the dry season was assumed due to its effect on the formation of grain per panicle (figure 7). Among other yield component variables, number of grains per panicle was significantly different between sheet pipe and no sheet pipe treatments in both dry season 1 and dry season 2, whereas in the wet season showed the opposite response. Three factors affect the yield were the number of panicles per unit area, the average number of grains per panicle, and the average of grain weight units [19]. The number of panicles per hill also showed same response in the dry season. However, it should be noted that on sheet pipe treatment showed slightly lower grain filling percentage. Water stress, especially during the flowering and ripening have very significant impact on plant stress due to lack of water, incomplete filling and can result in a 34-36% decrease in yield, both in the dry and wet seasons [15].

Figure 7. Yield components on three seasons trial under different water management and cropping system, Sukamandi (2019).
3.3. Response on soil chemical and biological properties

The cropping pattern affected the soil acidity after treatment. Paddy-paddy-soybean had strong acidic pH level while the cropping pattern of paddy-paddy had moderate acidic pH level in both water management treatments. Furthermore, in paddy-paddy-paddy cropping pattern, it was seen that water management using sheet pipe could maintain pH in the moderate acidic level, while no sheet pipe treatment was in strong acidic level (figure 8). Soil pH was one of the important soil factors in supporting plant growth because rice plants will grow optimally at a minimum pH of 5.5. Higher amount of crop residue reported increase soil pH specific based on commodity and soil type, especially on acid and moderately acid soils [20]. Other soil chemical characteristics of the experimental field were presented in table 1.

![Figure 8. Soil pH between sheet pipe and no sheet pipe treatment, Sukamandi (2019).](image)

The presence of aerobic, rhizobium and nitrogen fixing bacteria were higher on sheet pipe field treatment. Likewise, soil respiration in sheet pipe treatment was better than the no sheet pipe (figure 9). Soil biological characteristics or soil microorganisms are important factors in soil ecosystems, because they affect the cycle and availability of plant nutrients and stability of soil structure [21]. High population of microorganisms and the diversity of microorganisms only be found in the soil that allows these microorganisms to be developed and be activated which are availability of sufficient nutrients, suitable soil pH, good aeration and drainage, adequate water and sufficient energy sources, etc [22].

The cropping pattern treatment using legume (C2) with water management support using sheet pipe provided a greater amount of rhizobium than no sheet pipe (figure 10). Besides the presence of rhizobium, cropping patterns involving legumes in this case paddy-paddy-soybeans could provide a greater number of aerobic bacteria, nitrogen fixing bacteria and phosphate-soluble bacteria than paddy-paddy-paddy cropping pattern. Sheet pipe treatment was also shown higher bacteria anaerobic value and more phosphate solvents than no sheet pipe (table 2). Based on cropping pattern treatment, with the discovery of rhizobium which was a group of bacteria with the ability on nitrogen uptake showed that planting legumes in the cultivated land was needed as an effort to increase/restore soil fertility. The importance of rotating plants with legumes was to support increasing rhizobium which only found in the roots of legume plants but not found in paddy [23].
Table 1. Soil chemical properties after treatment under different water management and cropping system, Sukamandi (2019).

| No. | Parameter                  | Sheet Pipe          | No Sheet Pipe       |
|-----|----------------------------|---------------------|---------------------|
|     |                            | Paddy-Paddy-Paddy  | Paddy-Paddy-Soybean| Paddy-Paddy | Paddy-Paddy-Paddy | Paddy-Paddy-Soybean | Paddy-Paddy |
| 1.  | pH                         |                     |                     |             | 5.4               | 5.4                 | 5.6       |
|     | Actual                     | 5.8                 | 5.4                 | 5.5         | 5.4               | 5.4                 | 5.6       |
|     | Potential                  | 4.6                 | 4.3                 | 4.3         | 4.3               | 4.4                 | 4.4       |
| 2.  | Organic Carbon (%)         | 0.96                | 0.90                | 0.89        | 0.95              | 0.99                | 0.74      |
| 3.  | Total N (%)                | 0.10                | 0.09                | 0.09        | 0.09              | 0.10                | 0.08      |
| 4.  | P Available (ppm)          | 23 (Olsen)          | 4.1 (Bray)          | 21 (Olsen) | 2.4 (Bray)        | 2.8 (Bray)          | 23 (Olsen) |
|     | Potential (mg 100g⁻¹)      | 43                  | 34                  | 42          | 31                | 39                  | 32        |
| 5.  | K Available (ppm)          | 31                  | 31                  | 32          | 28                | 44                  | 17        |
|     | Potential (mg 100g⁻¹)      | 3                   | 3                   | 3           | 2                 | 7                   | 2         |
| 6.  | CEC (cmol, kg⁻¹)           | 13.58               | 14.43               | 14.93       | 18.54             | 15.24               | 13.41     |
| 7.  | Na (cmol, kg⁻¹)            | 0.69                | 0.75                | 0.7         | 1.07              | 0.7                 | 0.55      |
| 8.  | Ca (cmol, kg⁻¹)            | 8.35                | 8.05                | 8.35        | 10.55             | 8.48                | 8.08      |
| 9.  | Mg (cmol, kg⁻¹)            | 2.28                | 2.35                | 2.37        | 2.86              | 2.37                | 2.24      |
| 10. | Base saturation            | 84                  | 78                  | 77          | 78                | 76                  | 81        |

Table 2. Soil biological activity after treatment under different water management and cropping system, Sukamandi (2019).

| No. | Parameter                        | Sheet Pipe          | No Sheet Pipe       |
|-----|----------------------------------|---------------------|---------------------|
|     |                                  | Paddy-Paddy-Paddy  | Paddy-Paddy-Soybean| Paddy-Paddy | Paddy-Paddy-Paddy | Paddy-Paddy-Soybean | Paddy-Paddy |
| 1.  | Total Aerob Bacterium           | 4.53 x 10⁶          | 7.35 x 10⁶          | 2.33 x 10⁶  | 4.56 x 10⁶        | 1.79 x 10⁷          | 3.47 x 10⁶  |
| 2.  | Total Anaerob Bacterium         | 5.70 x 10⁶          | 1.87 x 10⁶          | 1.41 x 10⁶  | 4.03 x 10⁶        | 4.87 x 10⁶          | 9.06 x 10⁶  |
| 3.  | Rhizobium                        | 8.89 x 10⁶          | 3.87 x 10⁶          | 1.43 x 10⁶  | 7.37 x 10⁵        | 7.98 x 10⁵          | 4.09 x 10⁶  |
| 4.  | Nitrogen Fixation Bacteria      | 6.90 x 10⁶          | 8.60 x 10⁶          | 1.64 x 10⁶  | 8.64 x 10⁵        | 3.01 x 10⁶          | 3.28 x 10⁵  |
| 5.  | Phosphorus Solvent Bacteria     | 1.00 x 10²          | 6.00 x 10²          | nd          | 2.00 x 10²        | 4.00 x 10²          | 4.00 x 10³  |
| 6.  | Soil Respiration                | 100.66              | 100.92              | 113.26      | 32.87             | 33.89               | 87.86      |
| 7.  | Nitrogen Fixation Activity      | Positive            | Positive            | Positive    | Positive          | Positive            | Positive    |
| 8.  | Phosphorus Solvent Activity     | Positive            | Positive            | Negative    | Positive          | Positive            | Positive    |
| 9.  | Organic Matter-Decomposing Activity | Negative         | Positive            | Negative    | Positive          | Positive            | Positive    |
4. Conclusions
The result shown that the effect of sheet pipe was strongly influenced by the season, especially in the dry season. Almost all those variables were shown better results in the dry season with sheet pipe installation. Therefore, it was estimated that the ability of sheet pipe to store water, especially during the dry season, was more effective than its drainage function in the wet season in the Sukamandi experimental area. Sheet pipe supported better tiller ability, leaf area index, biomass, plant height, root volume, number of panicle per hill, number of grains per panicle and yield. Increasing planting index from two to three using sheet pipe technology could increase the total yield by 11.54% (paddy-paddy-soybean) and 26.94% (paddy-paddy-paddy) compared to no sheet pipe. Meanwhile, the paddy-paddy also provided total yield of 10.86% compared with no sheet pipe. Moreover, sheet pipe increased soil pH, bacterial aerobic, rhizobium and nitrogen fixing bacteria, and soil respiration.

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References
[1] Guera L C, Bhuiyan S I, Tuong T P and Barker R 1998 Producing more rice with less water from irrigated systems Discussion paper series no 29 p 22

Figure 9. Soil biological activity between sheet pipe and no sheet pipe treatment, Sukamandi (2019).

Figure 10. Rhizobium between sheet pipe and no sheet pipe treatment, Sukamandi (2019).
[2] Tuong T P and B A M Bouman 2003 Rice Production in Water-scarce Environments Water Productivity in Agriculture: Limits and opportunities for Improvement CAB International pp 53-67
[3] IAARD 2004 Kebijakan Penelitian dan Pengembangan Pertanian dalam Mendukung Gerakan Hemat Air (in Bahasa) (Jakarta: IAARD press) p 10
[4] Jaffar B S and Sarma A S R 2017 Yield and water use efficiency of rice (Oryza sativa L) relative to scheduling of irrigations Annals of Plant Sciences 6 1559-1565
[5] Abdulrachman S, Setiobudi D, Susanti Z, Widiyantoro, Sudarjah D, Arismani D, Sutaryo U dan Atim 2009 Optimalisasi potensi hasil berbagai varietas padi melalui pengaturan populasi pemupukan N dan pengeolaan air (in Bahasa) Laporan Akhir Tahun (Balai Besar Penelitian Tanaman Padi) p 31
[6] Bouman B A M, Lampayan R M and Tuong T P 2007 Water management in irrigated rice: Coping with water scarcity (Philippines: International Rice Research Institute) p 50
[7] Darzi-Naftchali A and Ritzema H 2018 Integrating irrigation and drainage management to maintain agriculture in Northern Iran Sustainability 10 17
[8] Kadja D H 2015 Pengaruh jenis pupuk dan tinggi genangan air terhadap perkembangan populasi wereng batang padi coklat pada tanaman padi (in Bahasa) Ilmu Pertanian 18 18–23
[9] Nuryanto B 2018 Pengendalian penyakit tanaman padi berwawasan lingkungan melalui pengelolaan komponen epidemi (in Bahasa) Jurnal Litbang Pertanian 37 1–12
[10] Wichelns D 2016 Managing water and soils to achieve adaptation and reduce methane emissions and arsenic contamination in Asian rice production Water 8 2–39
[11] Kyouwa Ketsesu Kogyo 2017 Sheet-pipe system: Subsurface drainage system in shallow strata (http://www.kyouwagrp.jp)
[12] Khalid H M, Mahmod I F, Barakbah S S and Osman N 2018 Impact of water management on fertilizer and tillering dynamic in rice International Journal of Agriculture & Biology 20 37–40
[13] Cassman K G, Peng S, Olk D C, Ladha J K, Reichardt W, Dobermann A, Singh U 1998 Opportunities for increased nitrogen-use efficiency from improved resource management in irrigated rice systems Field Crops Research 56 7–39
[14] Ntanos D A and Koutoubas S D 2002 Dry matter and N accumulation and translocation for indica and japonica rice under Mediterranean conditions Field Crop Research 74 93–101
[15] Dingkuhn M and Pierre Y G 1996 Effect of drainage date on yield and dry matter partitioning in irrigated rice Field Crop Research 46 117–126
[16] Sariam O 2009 Effect of irrigation practices on root growth and yield of rice J. Trop. Agri. and Fd Sc 37 1–8
[17] Yang J, Zhang H and Zhang J 2012 Root morphology and physiology in relation to the yield formation of rice Journal of Integrative Agriculture 11 920–926
[18] Fuadi N A, Purwanto M Y J dan Tarigan S D 2016 Kajian kebutuhan air dan produktivitas air padi sawah dengan sistem pemberian air secara sri dan konvensional menggunakan irigasi pipa (in Bahasa) Jurnal Irrigasi 11 23–32
[19] Beighley D H 2010 Growth and production of rice Soils Plant Growth and Crop Production Vol II www.wolss.net Access on 23 June 2015
[20] Butterfly C R, Baldock J A and Tang C 2013 The contribution of crop residues to changes in soil pH under field conditions Plant and Soil 366 185-198
[21] Paul E A and Clark F E 1989 Soil Microbiology and Biochemistry (London: Academic Press, Inc)
[22] Iswandi A, Santosa D A dan Widijastuti R 1995 Penggunaan ciri mikroorganisme dalam mengevaluasi degradasi tanah (in Bahasa) Kongres Nasional VI HITI 12–15 Desember 1995 Serpong
[23] Anggraini R, Shamdas G B N dan Tangge L 2017 Pengaruh Rhizobium asal tanah bekas tanaman kedelai (Glycine max L.) terhadap pertumbuhan kedelai berikutnya untuk pemanfaatan sebagai media pembelajaran (in Bahasa) E-JIP. BIOL. 5 119–141