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Research Paper

# Sawah Surjan Environmental Management for Food Crop Diversification in Kulon Progo of Yogyakarta, Indonesia

Sri Nuryani Hidayah Utami[1]*, Pradysta Maya Hermania[2], Benito Heru Purwanto[1]

[1] *Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada*
[2] *Under Graduate Program of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada*
***Corresponding author**: nuryani@ugm.ac.id

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**Abstract**
The Surjan system offers a multi-faceted approach to agricultural land management, particularly effective in dealing with inundation issues while increasing crop diversity. Our research focused on Surjan system lands in the Kulonprogo area, incorporating both observational methods and farmer interviews to glean a comprehensive understanding of the system's impact on soil and gas emissions. The Surjan system comprises two primary features: "mound," which refers to raised beds suitable for horticultural and dryland crops, and "tabukan," sunken beds ideal for rice and rice-fish farming systems (mina padi). One of the most notable environmental benefits of this system is its role in flood prevention, reducing eutrophication and greenhouse gas emissions. Soil analysis showed variations in pH, redox potential, and organic matter, indicating that the system has a distinct impact on soil chemistry. Specifically, the pH ranged from $6.65$ to $7.69$, redox potential varied from $-49$ to $10$ mV, and organic matter spanned $1.28\%$ to $3.59\%$. Perhaps most interestingly, methane gas emissions from land managed through the Surjan system were significantly lower than those from conventional rice fields. Emissions ranged from 4.06 - 45.73 $\mu$g /m$^2$/ minute, presenting a promising avenue for reducing the agricultural sector's environmental footprint.

**Keywords**
*Greenhouse Gas Emissions, Rice Fields, Soil Properties, Surjan, Wetlands*

## 1. INTRODUCTION

Indonesia has enormous wetland resources. The wetlands area in Indonesia reaches 43 million hectares, or 22.51% of the total land resource area in Indonesia (Ritung et al., 2015). The existing wetlands in Indonesia include swamp and non-swamp wetlands. However, the potential of this large wetlands has not been optimally utilized.

Indonesia's enormous wetland resources are still not optimally utilized as agricultural land due to their low productivity levels. The average productivity index (IP) of wetlands that have been used as agricultural land is 0.6-1. The low IP value indicates such low productivity of agricultural land in wetlands that it is still very limited in meeting the food demands.

The low productivity of agricultural land in wetlands is caused by the physical conditions of the existing wetlands. Wetlands in Indonesia tend to be sensitive to climate. They will be inundated during the rainy season and dried out during the dry season (Alwi and Tapakrisnanto, 2017; Amalia and Kusasi, 2017). This condition causes wetlands in Indonesia to be underutilized as agricultural land because they require advanced management.

Surjan system is one of the innovations in managing wetlands as agricultural land. The name 'Surjan' is taken from the Javanese language, which means stripes (Nursyamsi et al., 2014). The stripes pattern depicts a combination of alternating raised and sunken beds planted with different commodities. The raised bed is part of the land that is elevated and planted with dry land commodities (Nursyamsi et al., 2014). The sunken bed is a part of the land that is inundated and planted with rice, kale, and other wetland crops (Nursyamsi et al., 2014). The area of sunken beds also has the potential to be used as mineral oil.

The agricultural land management using the surjan system can be found in Depok Village, Panjatan District, Kulon Progo Regency, Special Region of Indonesia. Surjan system in Kulon Progo was initially applied to overcome inundation and poor drainage problems (Marwasta and Priyono, 2007; Rijanta, 2018; Heryani et al., 2019). Recently, research on the development of agricultural land using Surjan system in other areas has begun (Rijanta, 2018). However, there has not been much discussion about the potential of Surjan system and its implication on the environment. Thus, this study aimed to collect data on agricultural land management using the Surjan system in Kulon Progo and examine its impacts on the environment

## 2. EXPERIMENTAL SECTION

### 2.1 Research Location

The research was conducted in the rice fields with Surjan and conventional farming systems located in Depok Village, Panjatan District, Kulonprogo Regency, Yogyakarta Special Region (Fig 1). Sampling was carried out in two rice fields with Surjan system, which were planted with rice - corn and rice - shallot, and one conventional rice field. Interviews were conducted with farmers to find out more detailed soil treatment and land management (Table 1). The rice fields observed are located in alluvial plains, which are on the southern side of the Sentolo hills (Husein and Srijono, 2010). The material characteristics of the fields are gravel, sand, and clay from the eroded hilly material deposits. The Sentolo hills consist of limestone and marl (Rahardjo and Rosidi, 2012). Surjan and non-Surjan fields in Depok Village are located in the downstream Serang River Watershed (Sartohadi and Wisyatmanti, 2021). As the downstream part of the Serang watershed, Depok Village is a flood-prone area (Sartohadi and Wisyatmanti, 2021).

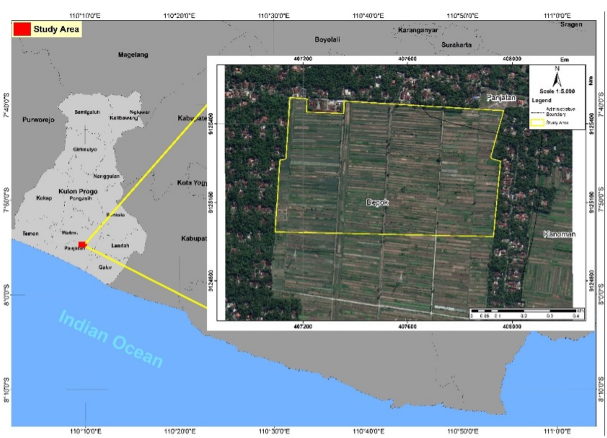



**Figure 1.** Location of rice fields with Surjan system

### 2.2 Research Design and Sampling

The data, including characteristics of rice fields with Surjan system, plant varieties, cropping patterns, fertilizers used, soil cultivation, spacing, planting time, and land dimensions, were collected through observation and interviews. Observations were started from January-April 2018 to October-March 2021. Interviews were conducted with the owners of Surjan and conventional rice fields.

Soil chemical properties and gas emission data were collected during the rice planting period based on the age of the plants, namely 50, 65, and 80 days after planting (DAP). Soil samples were re-observed in the field in December 2020 to confirm that there were no significant changes in physical and chemical properties based on the field observations. The soil sampling technique is composite from three replications. Disturbed soil sampling was used for laboratory analysis, including soil pH, electrical conductivity, redox potential, soil organic C, exchanged bases (K, Na, Ca, Mg), and cation exchange capacity (van Reeuwijk, 2002). The differences between Surjan and conventional rice field designs are presented in Fig. 2.

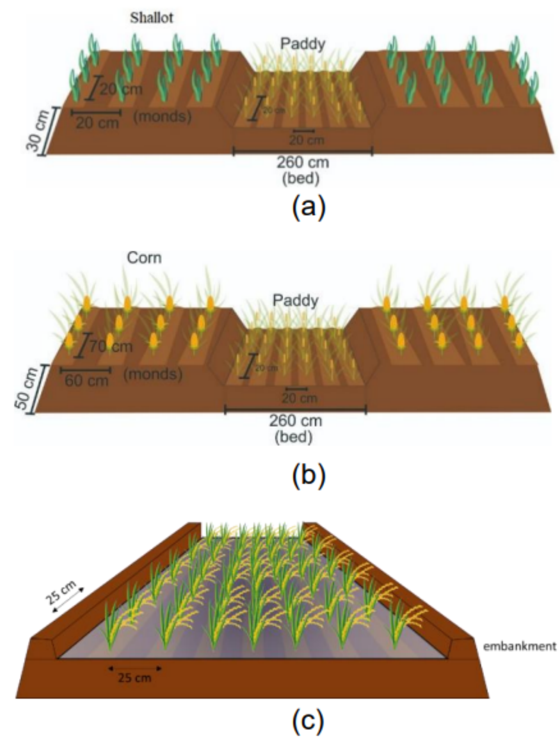



**Figure 2.** Design of (a) Rice-shallot Surjan; (b) Rice-corn Surjan; and (c) conventional rice field

Gas sampling was carried out at 07.00 - 09.00 in the morning. Samples were taken every 10 minutes using a hood planted into the ground (Fig. 3). Five repetitions were made to minimize errors. Measurement of $CH_4$ and $CO_2$ gas emissions was carried out using Gas Chromatography (GC). Calculation of $CH_4$ and $CO_2$ gas emissions was performed using the formula from Khalil et al. (1991) as follows:

$$F = \frac{dc}{dt} \times \frac{V_{\text{ch}}}{A_{\text{ch}}} \times \frac{mW}{mV} \times \frac{273.2}{(273.2 + T)}$$

Where:

- F = $CH_4/CO_2/N_2O$ gas flux ($mg/m^2$/sec)
- $\frac{dc}{dt}$ = delta concentration of $CH_4/CO_2/N_2O$ per time (ppm/minute)
- Vch = volume of the chamber ($m^3$)
- Ach = area of the chamber ($m^2$)

- mW = molecular weight of $CH_4/CO_2/N_2O$ (g)
- mV = molecular volume of $CH_4/CO_2/N_2O$ (22,41 l)
- T = average temperature (°C)

**Figure 3.** Gas sampling on rice-shallot Surjan (left) and conventional rice field (right)

### 3. RESULT

Surjan farming system has advantages over conventional rice fields in terms of the diversity of plants cultivated. Observations were made in one conventional rice field and two Surjan fields planted with rice - maize and rice - onions. The rice variety planted is IR 64, while the maize variety used was a hybrid one, and the shallot variety used was Srikayang. The dose of organic fertilizer used in the conventional rice field was higher than that in Surjan fields (Table 1). the doses and types of inorganic fertilizers used in the conventional and Surjan rice fields also varied according to the farmers' needs.

Agricultural mechanization in the three types of rice fields was carried out using tractors (Table 1). The use of a tractor can cause the soil to be mixed intensively. The spacing used in the conventional rice fields was 25 x 25 cm, while in the Surjan rice - corn and rice - shallot fields were 20 x 20 cm - 20 x 70 cm and 25 x 25 cm - 20 x 20 cm, respectively (Table 1). The three fields have different planting calendars. The conventional rice field was planted with rice from January to April and June to September. The first rice field with Surjan system was planted with rice and corn from January to April and October to January and with rice and peanuts from June to September. The second rice field with Surjan system was planted with rice and shallots from January to April and with rice and corn from June to September. Meanwhile, in other months, the rice fields were not planted with anything (bero) (Table 1).

The productivity index (IP) in wetlands can be increased by changing the shape of the land surface using a Surjan system. Multiple cropping patterns can be applied to the Surjan farming system to diversify the yield of agricultural products obtained in one harvest period. The selection of plant types is based on the differences in the degree of water saturation and soil moisture in each part of the field. The tabukan (sunken bed) in the Surjan system tends to have a high degree of water saturation and soil moisture so that it has the potential to be planted with rice (Das et al., 2015). The relief of the land surface in the Surjan system has a height difference of ± 30-50 cm so that water from the mounds (raised beds) is easily drained to the tabukan (sunken beds) area. The mound (raised bed) has low water saturation and soil moisture so that it is suitable for planting several types of dryland crops such as corn, beans, chilies, and shallots (Das et al., 2015).

Inundation can affect the amount of redox potential in the soil. Redox potential is negative in reductive/ anaerobic conditions, while redox potential is positive in oxidative/aerobic conditions (Fiedler et al., 2007). The conventional rice field showed a redox potential of -56 mV at 50 days after planting (dap), which gradually increased to 39 mV at 80 dap (Fig. 4c). Similarly, the Surjan rice-shallot field also showed a pattern of increasing redox potential from 50 to 80 dap, which was -13 mV to 11 mV (Fig. 4c). The increase in redox potential is possible due to water raining at different age ranges according to the plant needs (Minamikawa et al., 2006; Sutton-Grier et al., 2011). The redox potential of the Surjan rice-corn field at all ages showed a negative value (- 18 mV to - 40 mV) (Fig. 4c).

The electrical conductivity in conventional and surjan rice fields showed a different pattern. The electrical conductivity in the conventional ricefield tended to fluctuate at various planting ages (Fig. 4b). Meanwhile, in the Surjan rice fields (rice - corn and rice - shallot), it gradually decreased at 50, 65, and 80 days after planting (Fig. 4b). The electrical conductivity in the conventional and Surjan (rice-corn) rice fields was higher than 70 dS / m (Fig. 4b), while the electrical conductivity in Surjan rice-shallot field was between 8 dS / m to 10 dS / m (Fig. 4b). The Surjan rice - shallot field was at a high salinity level, while the conventional and surjan rice - corn fields were at an extreme salinity level. The limit of salinity is based on the response to plants (Gopalakrishnan and Kumar, 2020).

Soil pH is related to the number of exchanged bases in the soil, such as Exc. K, Exc. Na, Exc. Ca, and Exc. Mg. The characteristics of soil material derived from limestone material deposits may be the main cause of soil pH in all land types ranging from 6.6 to 7.9 (neutral to alkaline). The Exc. K in conventional and Surjan rice fields showed a value of <0.5 cmol (+) / Kg (moderate) (Fig. 4e). The Exc. Na in all land types and planting ages tended to vary from very high (> 1 cmol (+) / Kg) to very low (<0.1 cmol (+) / Kg) (Fig. 4f). The increasing plant age (50, 65, and 80 days after planting) decreased the Exc. K and Exc. Na (Fig. 4e and Fig. 4f). The Exc. Mg in all land types was very low (<0.3 cmol (+) / Kg) (Fig. 4h). Meanwhile, the Exc. Ca in all land types was high (> 11 cmol (+) / Kg) (Fig. 4g). The soil cation exchange capacity in all land types and planting ages showed a value of 35 cmol (+) / Kg to 46 (cmol (+) /

**Table 1.** Land management of Surjan and non-Surjan (conventional) farming systems

| No. | Observation | Conventional, Rice | Surjan, Rice-Corn | Surjan, Rice-Shallot |
|---|---|---|---|---|
| 1 | Variety | IR 64 | Rice: IR 64, Corn: Hybrid | Rice: IR 64, Shallot: Srikayang |
| 2 | Cropping pattern | Monoculture | Polyculture | Polyculture |
| 3 | Fertilizers | 3000 kg.ha$^{-1}$ manure<br>930 kg.ha-1 containing active materials of N 15%, P2O5 15%, K 15 (three weeks after planting) | Rice: 2000 kg.ha$^{-1}$ manure<br>Rice: 650 kg.ha$^{-1}$ containing active materials of N 15%, P2O5 15%, K 15, S 10% (five weeks after planting)<br>Corn: 300 kg.ha$^{-1}$ containing active materials of N 15%, P2O5 15%, K 15, S 10%<br>Corn: 250 kg.ha$^{-1}$ containing active materials of N 46% | Rice: 2600 kg.ha$^{-1}$ manure<br>Rice: 100 kg.ha$^{-1}$ containing active materials of N 46%<br>Shallot: 100 kg.ha$^{-1}$ containing active materials of P2O5 36%, S 5%<br>Shallot: 60 kg.ha$^{-1}$ containing active materials of K 60%, Cl 46% |
| 4 | Soil tillage | Plowed by tractor | Plowed by tractor | Plowed by tractor |
| 5 | Plant spacing | Rice: Tiles (25 cm x 25 cm) | Rice: Tiles (20 cm x 20 cm)<br>Corn: 20 cm x 70 cm | Rice: Tiles (25 cm x 25 cm)<br>Shallot: 20 cm x 20 cm |
| 6 | Planting calendar | Rice (Jan-Apr), Bero/not planted (Apr-May), Rice (Jun-Sep), Bero/ not planted (Sep-Oct) | Rice-corn (Jan-Apr), Bero/not planted (Apr-May), Rice-peanut (Jun-Sep), Bero/not planted (Sep-Oct), Rice-corn (Oct-Jan) | Rice-shallot (Jan-Apr), Bero/not planted (Apr-May), Rice-peanut (Jun-Sep), Bero/not planted (Sep-Oct) |
| 7 | Raised bed | 0 cm | 50 cm | 30 cm |

Kg) (high to very high) (Fig. 4).

$CH_4$ gas emissions in the conventional and Surjan rice fields showed a significant difference. The conventional rice field had a greater $CH_4$ flux (135.17 $\mu g/m^2$/minute), compared to the Surjan fields, producing an average $CH_4$ flux of 45.73 $\mu g/m^2$/minute (rice-corn) and 4.06 $\mu g/m^2$/minute (rice-shallot) (Fig. 5a). The difference in $CH_4$ flux values between the conventional and Surjan rice fields was 110.27 $\mu g/m^2$/minute. Conversely, the $CO_2$ gas emission in Surjan fields was greater than in the conventional rice field. The Surjan rice - corn and rice - shallot fields produced an average $CO_2$ flux of 6,889 $\mu g/m^2$/minute and 14,193.47 $\mu g/m^2$/minute, respectively. Meanwhile, the conventional rice field produced a $CO_2$ flux of 6,430.46 $\mu g/m^2$/minute (Fig. 5b). The difference in the $CO_2$ flux values between the Surjan and conventional rice fields was 4,110.77 $\mu g/m^2$/minute. The difference between inundated sunken beds and dry raised beds conditions led to (Das et al., 2015). The increasing planting age of rice in the conventional rice field, rice - corn in Surjan field, and rice - shallot in Surjan field could not reduce the $CH_4$ and $CO_2$ emissions produced (Fig. 5).

## 4. DISCUSSION

The use of wetlands for the agricultural field has not been optimal due to the high costs. The construction of mobile embankments, the construction of water gates, the regulation of macro-micro water systems, and the provision of high ameliorants result in a high cost that is not affordable for farmers. Surjan farming system is an innovation in agricultural land management at minimal costs that is easily affordable. The Surjan system allows the land to be modified according to the dimensions and size desired. Determination of the dimensions and size of the Surjan field also needs to consider agricultural mechanization systems such as deep plow tractors and shallow plow tractors. Land modifications that are easy for farmers at affordable costs make the Surjan farming system a local-scale wetland utilization solution.

The Surjan farming system allows land to be modified into two parts, namely tabukan (sunken beds) and mounds (raised beds) (Nursyamsi et al., 2014). The area of sunken beds is inundated so that it can be planted with rice and has the potential to be used together for fish farming (mina padi). The raised beds have dry conditions so that they can be planted with vegetables, tubers, and fruits. The utilization of different parts of land causes the Surjan field

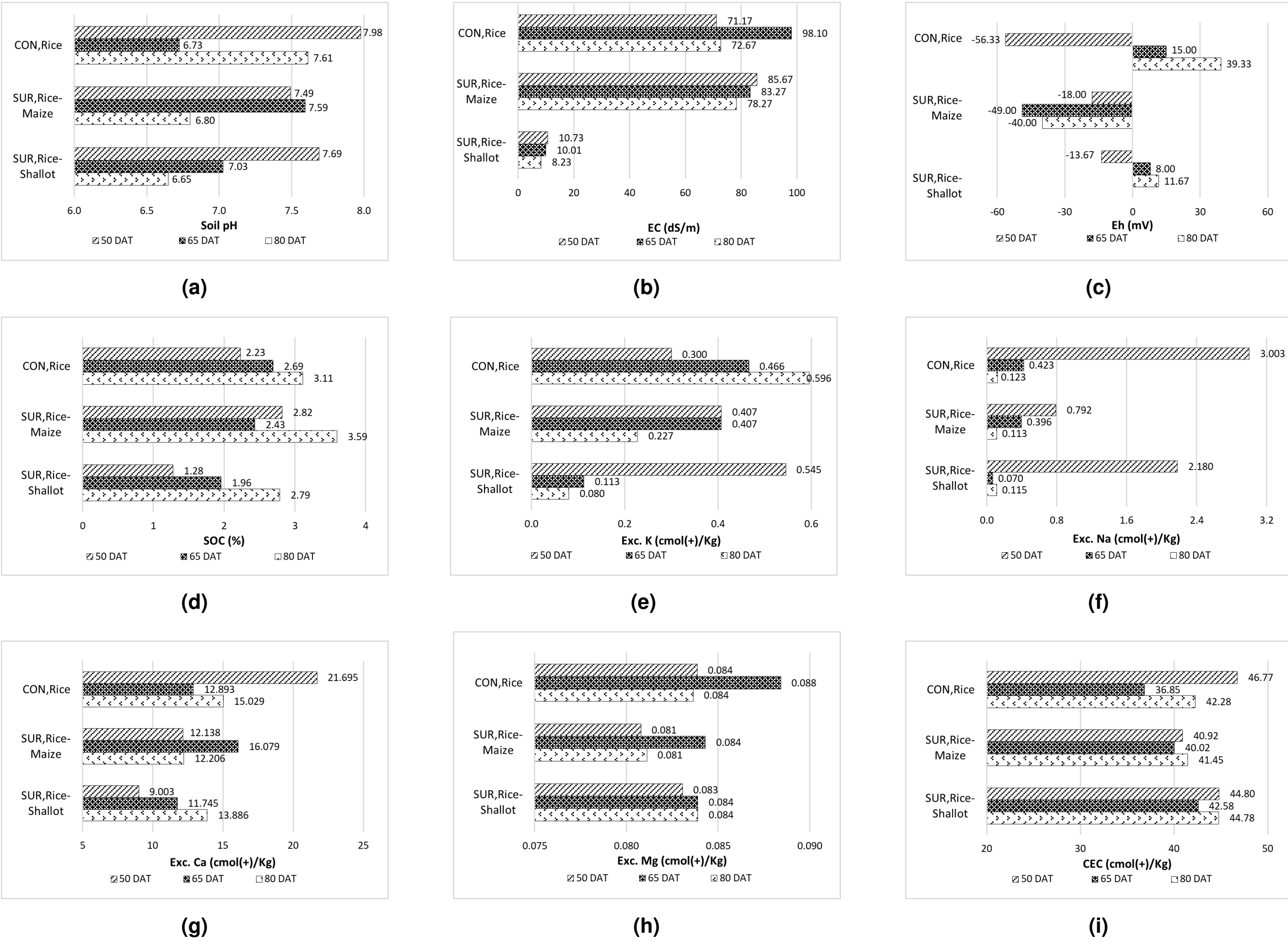


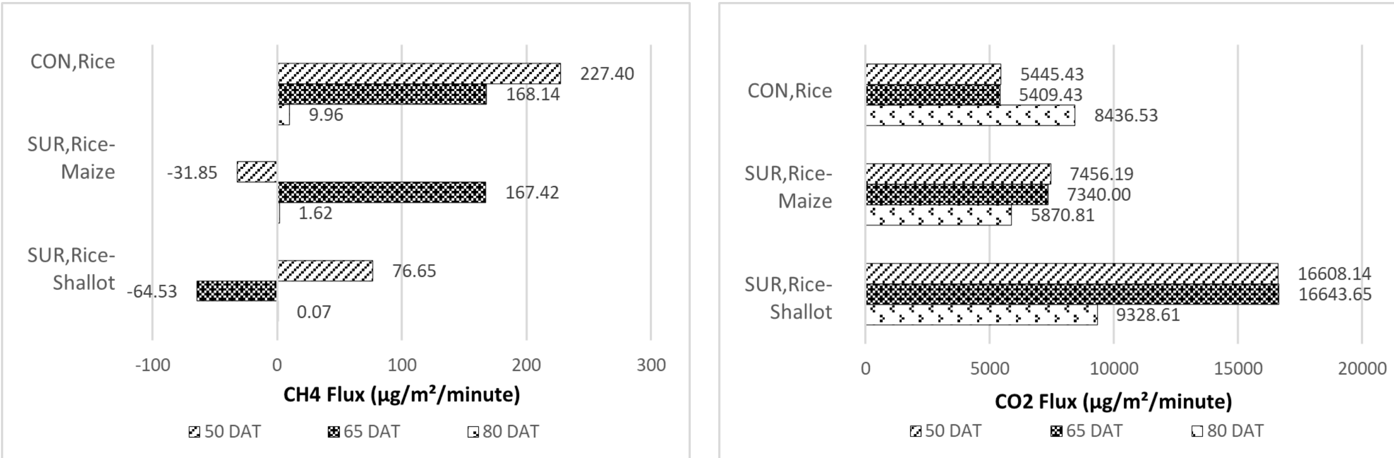

**Figure 4.** Soil chemical properties: (a) soil pH; (b) EC; (c)Eh; (d) SOC; (e) Exc. K; (f) Exc. Na; (g) Exc. Ca; (h) Exc. Mg; (i) CEC

to have a higher diversity of yields than conventional rice or dry fields. The Surjan system also allows harvest in every season (dry and rainy) due to proper water management. Various agricultural commodities in the Surjan field that can be harvested every season can increase farmers' income.

Surjan system can be a solution to the problems of inundation or poor drainage. The part of the tabukan (sunken beds) in the Surjan field can be used as a place to accommodate excess water (Das et al., 2015). By storing water in the tabukan (sunken beds), the mounds (raised beds) will dry out, thereby being able to be planted with other commodities for agricultural diversification.

Surjan system can also reduce eutrophication in water bodies around the agricultural field. Eutrophication is caused by the accumulation of dissolved nutrients in water bodies (Biagini and Lazaroni, 2018). Nutrients that cause eutrophication from the raised beds can be accommodated in the sunken beds. Hence, those nutrients from the raised beds can be absorbed by rice plants, resulting in no nutrients dissolved and flowing into the water bodies around the agricultural field.

Surjan system also plays a role in reducing greenhouse gas emissions in the atmosphere. Land management with the Surjan system affects the dynamics of soil chemical properties (Velmurugan et al., 2015). The dynamics of soil chemical properties in the agricultural field directly affect the emission of greenhouse gases, especially $CH_4$ and $CO_2$. Soil chemical properties in inundated land are more dynamic and easier to change at any time, while soil chemical properties in non-flooded land are relatively constant. Dynamic changes in soil chemical properties are possible due to the irrigation system so that water circulation continues to change (Katoh et al., 2004). Water retention also results in the release of cations from soil micelles and slows down the rate of decomposition of soil organic matter (Shah et al., 2016; Nakajima et al., 2015). High electrical conductivity




**(a)** **(b)**

**Figure 5.** Gas emission: (a) CH4 Flux; (b) CO2 Flux

in inundated land is a result of salt cations dissolved by water (Shirokova et al., 2000). The salt dissolving process is also followed by an abundant supply of electron donors in the soil, resulting in a more reductive soil atmosphere. Soil atmosphere that becomes more reductive is characterized by negative redox potential values (Wang et al., 1993).

The sunken beds in the Surjan system can be an abundant source of carbon. The abundance of soil organic matter in inundated land is possible due to the presence of rice biomass residues in the soil (Biagini and Lazaroni, 2018; Wang et al., 2021). Soil management by farmers by plowing the soil and burying the remaining rice plants from the roots to the rootstock results in an increase in soil organic matter content (Wang et al., 2015). Soil plowing allows the mixing of soil material with the residual biomass of rice plants. Rice biomass that has not completely decomposed on inundated land has an impact on increasing $CH_4$ gas emissions (Inubushi et al., 1997).

Land change in the Surjan field cannot change the inherent characteristics of the soil material so that the soil pH is still in the range of neutral to alkaline. Provision of mature soil organic matter can also increase soil pH even though it is only temporary (Rukshana et al., 2011). The inherent properties of the soil are derived from the characteristics of the alluvial sediment material, influenced by hills with bedrock in the form of limestone on the north side of the study area. The influence of limestone causes the soil pH to become neutral to alkaline with relatively high solubility of alkaline cations. The high cation exchange capacity in the soil can facilitate the availability of nutrients for plant growth. Plant roots will absorb cations from adsorbed soil micelles and exchanged for H+ coming out of plant roots (Custos et al., 2020). Soil properties that affect the amount of $CH_4$ and $CO_2$ emissions produced in agricultural land are organic C, soil pH, and redox potential. The organic C and soil pH and redox potential are negatively correlated (Fig. 6a).

$CH_4$ gas emissions in Surjan and conventional rice fields are controlled by the level of carbon substrate availability in the soil. The presence of methanogenic microorganisms such as methanosarcina bacteria and methanobacterium plays an important role in increasing $CH_4$ gas emissions through the decomposition of organic matter in an anaerobic atmosphere (Nazaries et al., 2013). The methanogenesis process in the rhizosphere optimally occurs since it is controlled by several factors such as redox potential (Eh) of less than -150 mV, soil pH of 6-8, soil temperature of 30-400 0C, and available organic matter derived from root exudates (Johnson et al., 2007). Liu et al. (2016) add that the type of vegetation, inundation water level, temperature, and soil organic carbon content are the controlling factors for $CH_4$ gas emissions.

There was a close relationship between $CH_4$ gas emissions and the management of irrigation water. Wetland and sunken beds filled with water will create tight anaerobic conditions, and when the redox potential becomes negative, it will facilitate the production of higher $CH_4$ gas emissions (Fiedler and Sommer, 2000). Redox potential values in the conventional rice field (- 56 mV to 39 mV) and Surjan fields with two different types of crop commodities (- 49 mV to 10 mV) have not been able to form $CH_4$ optimally. Abduh et al. (2020) state that the redox potential between -42 mV to 2 mV is not able to form CH4 optimally. Wang et al. (1993) explain that the redox potential will optimally form $CH_4$ in the range - 200 mV to - 300 mV. The redox potential and $CH_4$ flux are negatively correlated (Fig. 6c), meaning that the lower the redox potential, the higher the $CH_4$ flux value (Minamikawa et al., 2006).

The application of organic matter to Surjan and conventional rice fields needs to pay attention to the level of

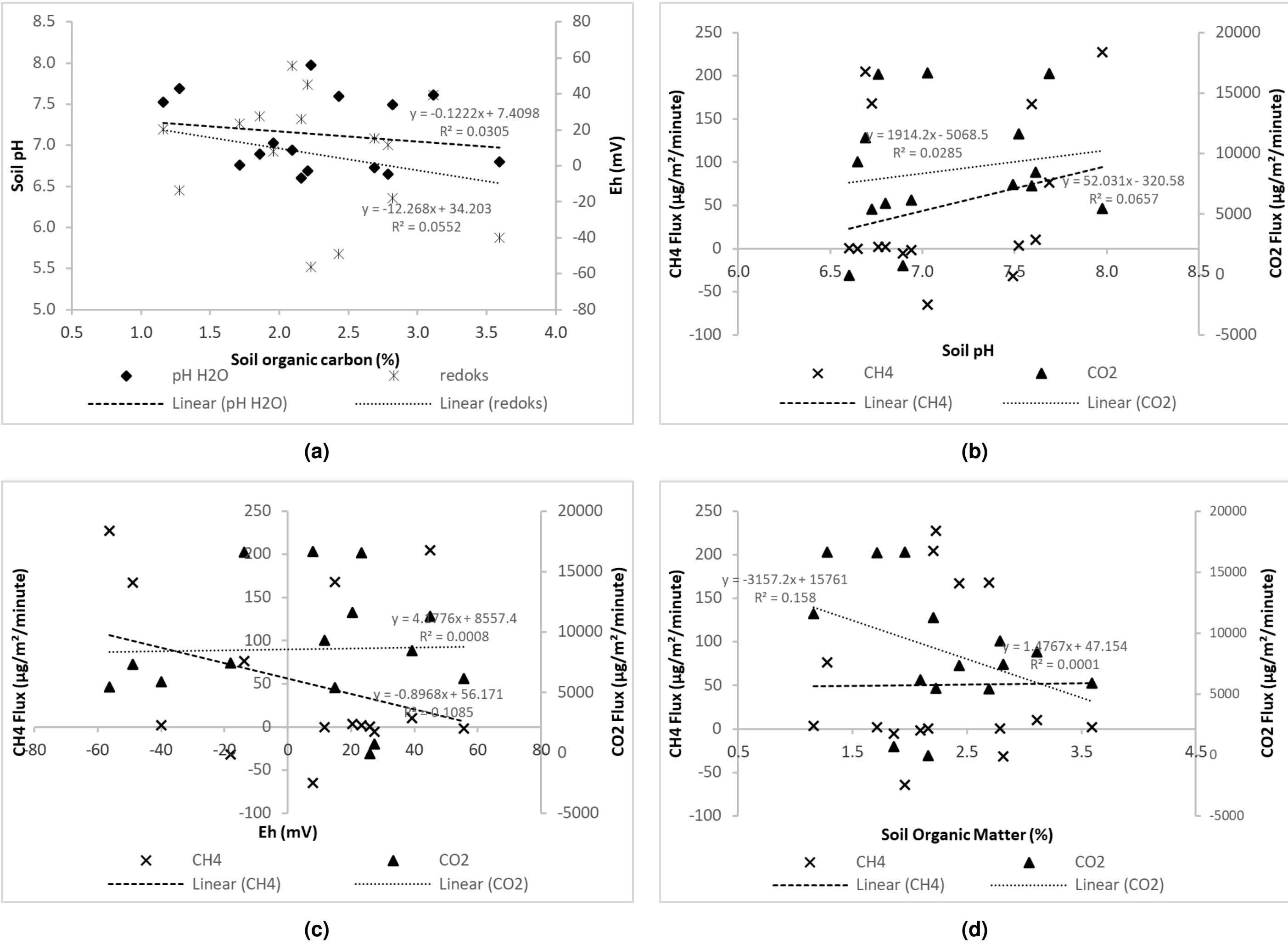



**Figure 6.** Relationship between soil properties and gas emissions: (a) relationship between soil organic C and pH and redox potential; (b) relationship between soil pH and $CH_4$ and $CO_2$ flux; (c) relationship between redox potential and $CH_4$ and $CO_2$; (d) relationship between soil organic C and $CH_4$ and $CO_2$

maturity and the C/N ratio. According to Dendoovenac et al. (2012), rice fields can be the largest source of $CH_4$ emissions because of the inundated land conditions and the maturity level of organic fertilizers applied to the land. Immature organic fertilizers have a high C/N ratio (C/N> 25), but mature organic fertilizers have a low C/N ratio (C/N <15). The provision of immature organic fertilizers allows immobilization by microorganisms that take advantage of the high carbon content (Cheng et al., 2017)). According to Malyan et al. (2016), abundant carbon in the soil will be used by methanogenic microorganisms as a substrate in producing $CH_4$. Kyuma (2004) also explains that immature organic fertilizers have a low nitrogen content, which results in changes in the reductive soil rhizosphere conditions. The soil organic C and $CH_4$ flux are positively correlated (Fig. 6d), in which the addition of organic matter as a carbon source in the soil will increase the $CH_4$ flux.

The raised beds in Surjan field tend to produce higher $CO_2$ emissions when compared to the sunken beds and conventional rice field. $CO_2$ emissions may be formed through two respiration processes, namely heterotrophic respiration (organic matter mineralized by soil microorganisms) and autotrophic respiration (plant root respiration) (Bond-Lamberty et al., 2004). According to Luo et al. (2020), decomposition of organic matter followed by increased activity of microorganisms can result in higher $CO_2$ emissions. The contribution of autotrophic and heterotrophic respiration widely varies, controlled by the type of land use and season (Arevalo et al., 2010). The part of the field that is not inundated (the raised beds in Surjan field) has better soil aeration and drainage than the part of the field that is inundated. According to Buragienė et al. (2019), the characteristics of good soil aeration and drainage will facilitate the circulation of oxygen and water to increase the activity of soil microorganisms and can produce higher $CO_2$ emissions compared to the soil with poor aeration and drainage.

$CO_2$ emissions produced in the part of Surjan field planted with shallots were two to three times higher than those planted with corn. According to Zhu et al. (2015), the soil will still produce $CO_2$ flux even without plants, but the density of plants tends to produce a higher $CO_2$ flux. Chen et al. (2016) mention that C4 plants (such as corn and shallots) can produce a higher $CO_2$ flux than C3 plants (rice) because C4 plants produce more root exudate, thereby increasing root respiration. The association between plant roots and microorganisms in the rhizosphere zone can increase soil respiration and $CO_2$ flux (Chen et al., 2019).

$CO_2$ flux in soil respiration can also be influenced by soil pH and C/N ratio. According to Čuhel et al. (2010), the highest soil $CO_2$ flux is in the neutral soil pH range (6.6 - 7.5). The increase in soil pH was also accompanied by an increase in $CO_2$ flux in both conventional and Surjan rice fields, showing a positive correlation (Fig. 6b). Treseder (2008) added that the activity of microorganisms would increase at a pH that is closer to neutral, thereby increasing $CO_2$ production. $CO_2$ flux is also influenced by the relationship between land management, in which the application of mature organic fertilizers and soil cultivation can increase $CO_2$. According to Sylvia et al. (2005), the C/N ratio in the soil illustrates the ease in organic matter decomposition by microorganisms. A decrease in the C/N ratio will increase the $CO_2$ flux. Soil tillage will increase soil pore space and reduce soil bulk density, resulting in gas diffusion and increased $CO_2$ flux (Zhu et al., 2019). $CO_2$ flux tends to decrease in poorly managed soils because the soil pore space is less and reduces gas diffusion between the soil and the atmosphere (Fujikawa and Miyazaki, 2005).

The innovation of Surjan farming system can be applied in any wetland in Indonesia. The Surjan system in Kulonprogo can be a pilot model for local-scale wetland utilization for farmers. The agricultural land ownership in Indonesia is based on individual farmers, meaning that land needs to be modified according to the existing conditions, not based on company scale. Surjan cropping patterns can provide several benefits, including optimizing the use of wetlands, increasing productivity index (IP), increasing food crop diversity, mitigation of greenhouse gas emissions, preventing flood, reducing eutrophication due to agricultural field, and increasing farmer income.

## 5. CONCLUSION

The Surjan system can optimize the use of wetlands as agricultural fields. It can increase the productivity index, reduce the risk of flooding and drought, avoid eutrophication due to agricultural activities increasing food crop diversity, and reduce greenhouse gas emissions. The reduction of greenhouse gas emissions is controlled by soil organic matter content, soil pH, and redox potential, which are influenced by the physical condition and management of the agricultural fields, including tillage, application of fertilizers, and irrigation designs. The agricultural field with Surjan system produces lower $CH_4$ compared to the conventional rice field. However, $CO_2$ production from Surjan fields tended to be high because of the large area of the field that was not inundated. It is necessary to consider appropriate irrigation techniques to help reduce $CO_2$ production in the agricultural field with Surjan system.

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## 7. AUTHOR'S CONTRIBUTION

SNHU Corresponding author, responsible for the processing of budged funding, data analysis, manuscript writing and addressing reviewers' comments, and revising the manuscript, PM coordinated the researchers, accessing data, directly involved in the research design and discussion of results, manuscript writing, BHP guided laboratory measurements for soil characteristics, responding to reviewers' comments, guided field measurements for soil properties and nutrient uptake, provided inputs for revision.

## 8. FUNDING

Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia.

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