Soil rewetting to mitigate CO2 emissions of shallot cultivation in tropical peatland

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Abstract. CO2 emissions are agriculture-related problems in peatlands, requiring mitigation. Irrigation and mulching are needed to reduce CO2 emissions in peatlands. This research aimed to study the effect of irrigation system and type of mulch for soil properties and CO2 emissions at shallot cultivation in peatlands. This research was carried out on degraded peatland in the Kalampangan village, Sebangau District, Palangkaraya, from April to December 2017. A split-plot design repeated at 4 times was employed. The main plot was type of rewetting, including manual watering (P) and sprinkler methods (S), the subplot was type of mulches, comprising TM = without mulch, G = weed in situ (Stenochlaena palustris) mulch, J = straw mulch (Oryza sativa). Observed variables included soil pH, Eh, EC, organic C, water contents, and CO2 emissions, performed twice within two months. The results showed that the sprinkler irrigation system and mulch did not affect significantly on pH, Eh and soil moisture content, but significantly influence EC and organic C. The sprinkler irrigation system reduced CO2 emissions up to 10% (2916 kg/ha/season) compared to conventional methods (3250 kg/ha/season). Compared to no mulch (6175 kg/ha/season), Kalakai mulch (Stenochlaena palustris) reduced CO2 emissions up to 33% (4119 kg/ha/season) and rice straw increased CO2 emissions up to 32% (8207 kg/ha/season).

1. Introduction
Peatland covers 14.91 million ha in Indonesia, spreading over four major islands, i.e. Sumatra 6.44 million ha, Kalimantan 4.78 million ha, Papua 3.69 million ha, and Sulawesi <0.10 million ha [1]. Naturally, the peat swamp ecosystem is fragile, requiring appropriate and integrated land management technology to optimize and sustain land productivity. The development of peat land for agriculture faces problems, including high soil acidity, low availability of nutrients in the soil, high organic acids content, carbon emissions and high attack of plant disturbing organisms, and greenhouse gas emissions.

Shallot are potential to be cultivated on peatlands. Technically shallot could be planted in the lowlands, both on wet or dry land. Shallot in West Kalimantan peatlands produced 11-12 t/ha of dried tubers [2]. In addition to the use of suitable varieties, to increase shallot production on peatlands needs appropriate soil management.

Suitable water management was needed for agricultural cultivation on peatlands, to mitigate the degradation of peatlands and low crop production. Water management in peatlands has two main objectives, i.e. (1) to provide sufficient water for plant growth, and (2) to maintain the sustainability of peat by avoiding damage due to drainage or drying. Water has an important role for peat soil to prevent the irreversible drying due to mismanagement. Previous study on oligotrophic peat in Central
Kalimantan showed that non-reverse dryness appeared in 73% moisture content for hemic peat and 55% for saprist peat from its dry weight [3]. Shallot needs sufficient water during their growth, however they didn't need much rain. Watering in dry season is needed, usually once a day in the morning or evening, started from planting to preceding harvesting. Meanwhile rewetting is required in the rainy season to rinse the leaves of the plant, reducing the splash of soil attached to the shallot leaves. In the critical period due to lack of water during tubers development, water deficit can reduce production. It is necessary to regulate soil moisture and frequency of water supply to overcome this problem.

The previous study showed that water sprinkled with a height of 7.5-15 mm supplied once day generated the highest shallot tuber weight [4]. Mulch applied on the soil surface could minimize water loss through evaporation and suppress weed growth [5]. The total irrigation water needed for shallots in sand soil was about 123.8 mm equivalent to 1238 m³/ha/season. The water could be irrigated by using Impact Sprinkler with solar power of 103.5 mm or 1035 m³/ha/ season [6]. This research aims to study the effect of rewetting by sprinkler irrigation system and mulching to the properties of soil and CO₂ emissions in shallot planting on peatlands.

2. Materials and methods

Materials and tools in this research included straw, kalakai (Stenochlaena palutris) leaves, sprinklers, chemicals for soil analysis, syringe needles, hoods, piezometers, office stationery, and laboratory equipment for analysis of soil and gas.

This research was located on peatland in Kalampangan village, Palangkaraya Municipality, Central Kalimantan, conducted in February - December 2017. The study was arranged with a split plot design and four replications, with the following treatments: Main plot: type of watering, namely: P = Manual Watering and S = Sprinkler watering. Whereas subplots are types of mulch, namely: TM = without mulch, G = kalakai (Stenochlaena palutris) mulch and J = Straw mulch. The dose of mulches was 5 t/ha.

The plot size of each treatment was 1.2 m x 10 m. A leveling of the peatland was performed prior to preparing beds and ditches sized of 1.2 m width and 10 m length. The spaces of 20 x 15 cm was holed on the bed and one shallot seed was placed for each hole.

Prior to planting, the outer skin of dried shallot were cleaned. The tuber ends of seed tubers with shelf life less than 2 months were cut along approximately ¼ part to accelerate shoot growth and stimulate the growth of side bulbs [7]. Besides, the tubers should be mixed with fungicide for 10 grams/1 kg of tubers, then plant for 12 hours. The shallot bulbs were placed into the planting holes by keeping the tip of the tubers rose on the surface. Watering was done twice in the morning and evening.

Cow manure was soil ameliorant which is applied 2 weeks before planting at 15 t/ha. Basic fertilizers comprised of Urea, SP 36 and KCl were mixed and distributed evenly with the soil 2-3 days before planting with a dose of 100 kg N, 120 kg P2O5, and 150 kg K2O per hectare. First fertilization composed of N and K fertilizers was applied at 10-15 days after planting and secondly a month after planting, at ½ dose of each application.

The initial soil chemical characteristics to be analyzed included pH H2O (4.65), pH KCl (3.38), EC (0.062 mS/cm), total N (0.495%), organic C (56.5%) and available P (22.18 mg/kg). Soil samples for the analyses were collected every month along with gas collection. The gas emissions were measured by placing closed chamber (width 17 cm, length 50 cm, height 35 cm) above ground to cover shallot plant, equipped with a thermometer and fan wind inside the chambers. Gas was taken by using syringes needles with retrieval intervals every 5 minutes. Gas was taken in the morning from 6:00 - 8:00 am. Gas is analyzed using Micro-GC. Calculation of gas emissions using the equation below:

\[ E = \frac{Bm}{V_m} \times \frac{S_{ap}}{S} \times \frac{V}{A} \times \frac{273.2}{T+273.2} \]

Where:

- \( E \) = flux CO₂ (mg/m²/day)
- \( V \) = cover volume (m³)
- \( A \) = cover base area (m²)
- \( T \) = average air temperature in the containment (°C)
\[ \frac{\Delta C_{\text{sp}}}{\Delta t} = \text{change rate of gas CO}_2 \text{ concentration (ppm/minute)} \]
\[ B_m = \text{CO}_2 \text{ gas molecule weight in standard condition} \]
\[ V_m = \text{gas volume in stp (standard temperature and pressure) condition} \]
i.e. 22.41 liter at 23oK

Analysis of variance was performed on the observed variables followed by Duncan test for \( \alpha=5\% \). Correlation and regression analyses were used to determine the relationship between variables. Moreover, regression analysis was employed to relate chemical properties and CO\(_2\) emissions.

3. Results and discussion

3.1. Soil characteristics

Soil properties observed at 4 weeks after planting (WAP) and 8 WAP include pH H\(_2\)O, pH KCl, EC, Eh, organic C and water content. The analysis of variance showed that irrigation types and mulch types had no significant effect on the pH H\(_2\)O, pH KCl, EC (Figure 1. Soil pH when plants were 4 and 8 weeks after planting.), Eh and soil moisture content (Figure 3), but EC and organic C had significant effects (Figure 2).

In general, there was an increase in pH at 8 WAP. However, based on the data, rewetting by sprinkle irrigation without mulching generated a higher increasing pH than other treatments. The use of sprinkle on peatlands generated higher efficiency of watering compares to manual system because of peat porosity, rapid soil infiltration, and high surface flow.

![Figure 1. Soil pH when plants were 4 and 8 weeks after planting.](image)

Increasing soil pH in 8 WAP compared to 4 WAP was due to the applications of dolomite lime at 4t/ha and cow manure at 15 t/ha before planting. Liming aims to reduce soil acidity while improve nutrient balance in order to increase nutrients absorption [8]. Lime provides an OH\(^-\) supply which combines with H\(^+\) to form water, causing the H\(^+\) level decreases and the soil pH increases.

The value of electrical conductivity at observation 4 WAP and 8 WAP is presented in Figure 2a. There was significant effects of watering and mulching to soil EC. However, soil Eh showed an insignificant effect (Figure 2b). The highest value of electrical conductivity (EC) was found in manual methods + without mulch treatment, while the lowest was in sprinkle + straw mulch treatment. In sprinkle + straw mulch treatment, it is suspected that there was dilution of soil solution that decreased the ion concentration. This condition was parallel with soil moisture content in sprinkle + straw mulch treatment that was higher than other treatments (Figure 3b).
Figure 2. Effect sprinkle and mulch types on soil EC (2a), and soil organic C (2b).

The effect of Electrical conductivity (EC) to the plants described by the availability of water and osmotic pressure. EC represents the composition of cations and anions present in soil solutions. Increasing EC was within the safe limits for plant growth, i.e. <2 mS/cm. According to Sipayung [9] the value of EC ranging between 0-2 mS/cm was safe for plants.

Watering and mulching had a significant effect on soil organic C. Increasing soil organic C was observed on manual watering + weed (Kalakai) mulch. Both mulching types, either in-situ weeds (Kalakai) or straws, significantly increased soil organic C levels (Figure 2b).

Figure 3. Effect of sprinkle and mulch type on soil Eh (3a), and soil moisture content (3b).

Soil water contents did not show significant differences between the treatments given (Figure 3b). The giving of straw mulch was able to suppress evaporation so that it increased soil moisture content compared to other treatments.

3.2. CO₂ emissions

CO₂ emissions were influenced by the type of watering and mulches. The type of mulches had a greater effect to the amount of CO₂ emissions than watering type. This was seen from the highest CO₂ emissions found in treatments without mulch with manual irrigation (farmer method), while the lowest was in sprinkler treatment mulch with Kalakai (Figure 4).
Watering methods affected CO₂ emissions by changing soil water content which then impacting soil microbial activity. Sprinklers watering could reduce CO₂ emissions compared to the manual method. This could be due to evenly distributed flush water using sprinkler irrigation compared to manual systems. This was different from the results of Lloyd [10] which showed that sprinkler irrigation increasing CO₂ emissions, while CO₂ flux was more affected by plant growth stages. In this study, sprinkler watering could reduce CO₂ emissions up to 10% (2916 kg/ha/season) compared to the manual method (3250 kg/ha/season) on the shallot crop in peatland. Increasing soil moisture content in the sprinkler treatment enhances microbial activity, thus CO₂ emissions could be suppressed.

The effect of mulching differed depending on the type of mulches. The in-situ weeds (Kalakai) could reduce CO₂ emissions by 33% (2059 kg/ha/season) compared to without mulch (4103 kg/ha/season). Rice straw mulches increased CO₂ emissions by 32% (4103 kg/ha/season) compared to no mulch (2933 kg/ha/season). The availability of water and oxygen in the peat soil would trigger soil biological activity that accelerated decomposition process causing an increase of CO₂ emissions. Kirk [11] explained that CO₂ gas produced from decomposition of organic matter on peatlands was controlled by changes in temperature, hydrological conditions, availability and quality of peat material, depending on environmental factors, soil properties and agricultural cultivation techniques. At high temperatures, CO₂ was in form of gas which could be formed immediately in a large number.

Types of organic mulch affected differently to CO₂ emissions in oil palm plantations on peatland [12]. The application of straw-mulch in the top layer of peat briefly could significantly effect on the carbon balance of peatlands, while the decomposition of straw material would increase CO₂ production from peatlands [13]. Straw-mulch potentially increased decomposition of organic matter resulting an increased CO₂ flux [13]. Applying straw-mulch to the ground surface initially causes an increase in soil temperature, thus providing a 'temporary heat place' to increase microbial activity [14].
and therefore, the initial decomposition rate tends to be very fast and labile materials were still available, and over time the decomposition rate tends to decrease [15].

3.3. Correlation between soil characteristics with CO₂ emissions
Figure 6 shows soil properties associated with CO₂ emissions. Organic C shows a negative relationship with CO₂ emissions, in which increasing CO₂ emissions causes the C organic content in the soil to decline. Based on pH data at 4.5 – 5, increasing pH increases CO₂ emissions (Figure 6a). According to Reth et al. [16] CO₂ emissions were positively associated with soil pH. It was observed that CO₂ emissions in pH at 4.8 - 6.0 were strongly related to the respiration activity of soil organisms. According to the results of Fierer and Jackson [17] the community differences and bacterial activity were mostly caused by soil pH; the highest bacterial diversity was in neutral pH, while the lowest was in acidic soils. In extreme acidic and alkaline conditions, proteins is denatured and enzyme activity is inhibited, thereby damaging the metabolic process.

![Figure 6. Correlation between CO₂ flux with pH, organic C, Eh and soil water content.](image)

Based on Figure 6b, there is a negative relationship between soil moisture content and CO₂ emissions. Peat soil water contents greatly affected CO₂ emissions [18,19]. Decomposition will increase when there is a change in soil conditions from wet to dry and moist, or vice-versa from dry to moist. The wet-dry cycle greatly influences the transformation of soil carbon [20]. Dry wet cycles affected soil aeration and create anaerobic conditions into aerobic conditions that increase the diversity of microorganisms [21]. When the soil becomes dry or dried in the laboratory under controlled conditions, then re-watered by rainfall or irrigation, there was an explosion of decomposition, mineralization and release of inorganic nitrogen and CO₂ [22].

4. Conclusion
• Rewetting by sprinkler irrigation and mulch applications did not affect pH, soil moisture and Eh, except on EC and C-organic.
• Sprinkler irrigation could reduce CO₂ emissions by 10% (2916 kg/ha/season) compared to manual irrigation (3250 kg/ha/season).
• Sprinkler irrigation increased soil water content in the surface layer and reduced CO₂ emissions (2916 kg/ha/season) up to 10% compared manual irrigation (3250 kg/ha/season).
• Kalakai mulch reduced CO₂ emissions up to 33% (4119 kg/ha/season) compared to no mulch (6175 kg/ha/season), and rice straw increased CO₂ emissions up to 32% (8207 kg/ha/season).

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