SAINS TANAH – Journal of Soil Science and Agroclimatology

Journal homepage: http://jurnal.uns.ac.id/tanah

Effects of rice husk biochar and raised bed on CO_2 flux and shallot (*Allium cepa* L.) production on peatland

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ARTICLE INFO

Keywords:
Ameliorant
Emission
Greenhouse gases
Histosol
Organic fertilizer

Article history
Submitted: 2021-01-22
Accepted: 2021-12-15
Available online: 2021-12-29
Published regularly: December 2021

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ABSTRACT

This study aims to assess the effect of rice husk biochar, raised beds, and chicken manure on the CO_2 flux and shallot production on peatland. This study adopted a factorial randomized block design with three factors and three replications. The P1 treatment was recommended by the Swamp Land Agricultural Research Institute by adding chicken manure (5 ton ha^{-1}) and rice husk biochar (5 ton ha^{-1}) while the P2 treatment was recommended by the Vegetable Research Institute by adding chicken manure (10 ton ha^{-1}). The raised beds heights were 20 cm (A) and 30 cm (B). Variance analyses were applied to each observation variable and followed by Duncan's Multiple Range Test at a 5% level. The P1A treatment was the best in improving the shallot production up to 10.88 tons and producing the lowest CO_2 cumulative flux up to 0.158 ton ha^{-1} $season^{-1}$.

How to Cite: Kusuma, E.W.W., Maas, A., Utami, S.N.H., & Maftuah, E. (2021). Effects of rice husk biochar and raised bed on CO_2 flux and shallot (*Allium cepa* L.) production on peatland. Sains Tanah Journal of Soil Science and Agroclimatology, 18(2): 159-165. https://dx.doi.org/10.20961/stjssa.v18i2.47974

1. INTRODUCTION

The high conversion of agricultural land to non-agricultural land in Java island has encouraged the government to develop peatlands for agriculture to increase national food needs and world markets. Approximately 30% of the peatlands in Indonesia are located in Kalimantan and the long history of peatlands mention that the peatlands in Kalimantan for agriculture were used as a resource to produce fruit, food, and spices (Osaki et al., 2016), which motivated the government to open peatlands extensively. In any case, peatland management and clearing required a lot of input to at least make the land suitable for plants. Thus, peatland management is very expensive and causes harmful environmental impacts. Indonesian peat swamp forests bring great regional and global benefits, whereas drainage and conversion of these peatlands to agricultural lands causes serious and irreversible environmental damage (Hergoualc'h et al., 2018).

The management and clearing of peatlands will release CO_2 to the atmosphere as a result of oxygen reacting with peat carbon, which causes global warming. Agricultural activities such as land clearing, land management, fertilizing, and liming accelerate the decomposition of organic matter and produce CO_2 emissions. The peatland ecosystems are fragile and peat soils start releasing carbon dioxide gas if the ecosystems are destroyed (Surahman et al., 2018).

Rice is the main food of Indonesian people, the rice production is quite high even on peatland in Kalimantan. Much of the rice husk waste is produced to be used as an ameliorant. Rice husk has a granular structure, chemical stability, insoluble in water, and high mechanical strength (Mohamad et al., 2018). Rice husk biochar is produced from low-temperature pyrolysis of rice hulls. Biomass pyrolysis is a thermal degradation process in the insufficiency of oxygen and produces gas, tar, and char. Rice husk biochar has been considered to increase crop productivity by enhancing soil structure and improving nutrient adsorption. The dominant components of rice husk biochar are carbon and SiO_2 (Ebe & Ano, 2020). The SiO_2 is approximately 76% – 99% of the rice husk's total weight (Menya et al., 2018). The combination of biochar and compost has shown an increasing nutrient, cycling, infiltration, and water retention in peat soil (Kern et al., 2017). A previous study with five rates of rice husk biochar doses, i.e., 0, 2, 4, 8, and 16 ton ha^{-1}, showed that provision of rice husk biochar up to 8 ton ha^{-1} effectively increased the peat soil pH, total N, available P, and available K in peat soil, and it was not significantly different with rice husk biochar doses 16 ton ha^{-1} (Maftu'ah & Nursyamsi, 2019). Hence, this study used rice husk biochar a slightly higher dose of 10 ton ha^{-1}.

The beds prevented puddles that cause tubers to rot so that the shallot bulbs can grow well. A previous study (Maftu'ah et al., 2019) has used beds of 30 cm in peatlands whereas farmers typically use beds of 20 cm. Therefore, this study compared the effect of raised beds on the chemical properties of peatlands, CO_2 flux, and crop yields.

Shallots are one of the leading commodities with high economic value. The prospect of Indonesian shallots on the world stage is quite good considering Indonesia is one of the world's largest shallot exporters. Shallot is a lowland vegetable that is used by the consumers as a seasoning, raw materials of the food industry, and medicine (Setyadjit & Sukasih, 2015). The improvement of soil properties is needed to increase soil fertility and to support the growth and yield of shallot. The increasing growth and yield of shallot are shown by enhancing the percentage of leaf length, number of leaves, number of tillers, and production of bulbs per hectare (Sulakhudin et al., 2019).

This study aims to assess the effect of rice husk biochar, chicken manure, and raised bed on the chemical properties, CO_2 flux, and shallot production on peatland. The expected benefit of this study is to formulate a plant cultivation technology that will increase the productivity of shallots by taking into the sustainability of peatland and the environment.

2. MATERIALS AND METHODS

The research location was determined purposively. The research was conducted in the middle of July 2019 to September 2019 in Kalampangan Village, Sebangau, Palangkaraya, Central Kalimantan Province. The land slope was 0% or flat. The peatland type in this research location is tidal swamp type D, which is the driest land on the upper slope and peak of the peat dome, never overflowed by large and small tides with a groundwater depth of more than 50 cm from the ground. Peat thickness reaches 2.5–3.0 m and it is ombrogen peat type due to most of it formed in the environment affected by rainwater. The research was conducted during the dry season whereas the source of peat groundwater in Kalampangan Village is rainwater. The research location was agricultural land and also a periodically experiment land, which is developed by local farmers for farming vegetables, chili, and shallot whereas the previous researches were focused on corn and red chili.

Table 1. Chemical properties of peat soils

Parameters	Value
pH (H_2O)	3.36
pH (KCl)	2.31
Electrical Conductivity (mS cm^{-1})	0.12
Available P (ppm)	26.06
Organic Carbon (%)	54.0
Organic Matter (%)	93.10
Ash Content (%)	6.90
Total N (%)	0.89
Exchangeable-K ($cmol^{(+)}kg^{-1}$)	0.55
Exchangeable-Na ($cmol^{(+)}kg^{-1}$)	0.16
Exchangeable-Ca ($cmol^{(+)}kg^{-1}$)	3.29
Exchangeable-Mg ($cmol^{(+)}kg^{-1}$)	6.63
Cation Exchange Capacity ($cmol^{(+)}kg^{-1}$)	54.55
Base Saturation (%)	19.48

The shallots were planted in plot areas of 5.0 m × 1.2 m each, with a Polyvinyl chloride pipe was set on each bed as a piezometer. This study adopted a factorial randomized block design with three factors and three replications. The first factor was fertilizer recommendation with added ameliorants (P) consisting of the following: P1 was recommended by the Swamp Land Agricultural Research Institute by adding chicken manure (5 ton ha^{-1}) and rice husk biochar (5 ton ha^{-1}) and P2 was recommended by the Vegetable Research Institute by adding chicken manure (10 ton ha^{-1}). The second factor was raised bed height consisting of: (A) 20 cm and (B) 30 cm. The treatments are:

1. P1A: chicken manure (5 ton ha^{-1}), rice husk biochar (5 ton ha^{-1}), lime (5 ton ha^{-1}), NPK (350 kg ha^{-1}), SP 36 (150 kg ha^{-1}), KCl (200 kg ha^{-1}) with raised beds of 20 cm;
2. P1B: chicken manure (5 ton ha^{-1}), rice husk biochar (5 ton ha^{-1}), lime (5 ton ha^{-1}), NPK (350 kg ha^{-1}), SP 36 (150 kg ha^{-1}), KCl (200 kg ha^{-1}) with raised beds of 30 cm;
3. P2A: chicken manure (10 ton ha^{-1}), lime (5 ton ha^{-1}), Urea (300 kg ha^{-1}), SP 36 (150 kg ha^{-1}), KCl (200 kg ha^{-1}) with raised beds of 20 cm;
4. P2B: chicken manure (10 ton ha^{-1}), lime (5 ton ha^{-1}), Urea (300 kg ha^{-1}), SP 36 (150 kg ha^{-1}), KCl (200 kg ha^{-1}) with raised beds of 30 cm.

The fertilizers and ameliorants were given during land preparation before planting, namely rice husk biochar (5 ton ha^{-1}), lime (5 ton ha^{-1}), chicken manure (5 ton ha^{-1} and 10 ton ha^{-1}), NPK (150 kg ha^{-1}), urea (100 kg ha^{-1}), SP36 (50 kg ha^{-1}), and KCl (100 kg ha^{-1}). The first follow-up fertilizer at 2 weeks after planting (WAP) included NPK (100 kg ha^{-1}), urea (100 kg ha^{-1}), SP36 (50 kg ha^{-1}), and KCl (100 kg ha^{-1}). The second follow-up fertilizer at 4 WAP included NPK (100 kg ha^{-1}), urea (100 kg ha^{-1}), and SP36 (50 kg ha^{-1}).

The initial and further chemical properties were analyzed by taking soil samples at the depth of 0–20 cm of each bed. The initial peat soil analyses were as follows: pH H_2O and KCl were measured using a pH meter, electrical conductivity was measured using electrical conductivity meter, organic carbon was measured using the gravimetric method, total N was measured using the Kjeldahl method, cation exchange capacity and bases saturation (exchangeable-K, exchangeable-Na, exchangeable-Ca, exchangeable-Mg) used

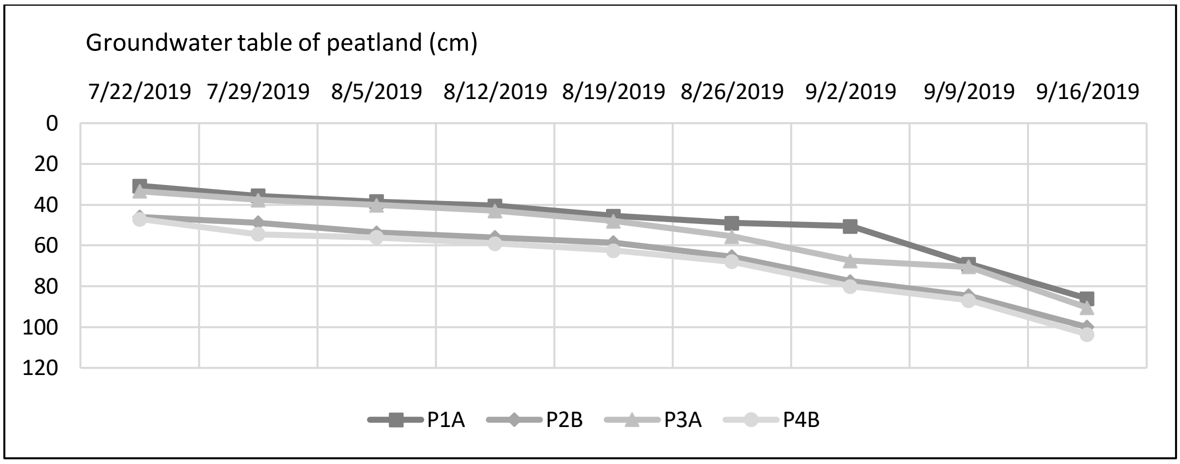

Figure 1. Groundwater Table of Peatland (**Note:** P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

NH_4OAc extraction and measured using the AGILENT 240FS atomic absorption spectrometer (manufactured by Agilent Company in California, the United States of America), available P was measured using the Bray method, and the CO_2 flux was measured using the LI-820 CGA 1632 CO_2 Gas Analyzer (manufactured by Li-Cor in Nebraska, the United States of America). The analyses of soil samples were carried out at the soil analysis laboratory in the Indonesian Swampland Agriculture Research Institute (ISARI), Banjar Baru, South Kalimantan.

The measured parameter at 2 weeks after planting (WAP) was pH (H_2O and KCl). The measured parameters at 4 and 8 WAP were pH (H_2O and KCl), electrical conductivity, organic carbon, cation exchange capacity, and available P. The CO_2 flux was measured at initial, after raised beds, after ameliorant application, and 4 WAP. The shallot variety was Bauji. Postharvest analysis samples at 8 WAP included weight per hectare and weight of tuber per clump.

The collected data were analyzed by using IBM SPSS (Statistical Package for the Social Sciences) Statistics 23 software, the F-test was applied for each observation variable and followed by Duncan's Multiple Range test of 5% level.

3. RESULTS

Based on Table 1, the peat soil pH (H_2O) was very acidic, which is a particular characteristic of peat soil. Very low pH is a result of the further decomposition of peat material and releasing organic acids. The peat soil electrical conductivity was low due to there is no salinity impact of seawater, the electrical conductivity (EC) value limit for plant tolerance is 4 mS cm^{-1}. The peat soil organic carbon reached 54.0% due to the carbon is the main constituent of peat soil with hydrogen and oxygen to form negatively charged aromatic colloidal groups. The peat soil total N is typically high at a depth of 0–20 cm, however, the peat soil available N is normally low, analysis of total N was relatively high as it comes from organic N. The high of exchangeable-Mg concentration came from the mineral ash from peat soil or residue of giving dolomite in the previous planting. The presence of the mineral ash content can be evidence that the ombrogen peatland was originally a topogen peatland, which obtained mineral runoff from a nearby river.

The peat soil available P reached 26.06 ppm, it could be influenced by the presence of the high Mg levels, because Mg^{2+} is able to replace the position of H^+ and organic acids in the peat soil so the availability of P and other nutrient elements in the peat soil will increase and will be easily taken up by plant roots. The peat soil cation exchange capacity reaches 54.55 cmol.kg^{-1}, because of the high content of aliphatic, aromatic compounds, and rich in oxygen-containing functional groups, such as COOH, -OH, and C-O, which are reactive sites for binding cations. The peat soil bases saturation increased to 19.48% because the common peat type in Indonesia is oligotropic. The oligotropic peatland is infertile considering it has poor nutrients from minerals and low base saturation (such as P, K, Na, Ca, Mg) as a result of its organic compounds are dominated by lignin originating from wood and making it difficult to decompose.

The groundwater tables of peatland (Figure 1) were closely related to the research location which is a type D tidal swamp that is not affected by sea waves. The peat soil actual pH (Figure 2) and peat soil potential pH (Figure 3) at 2 WAP in P1A and P2B treatments were different, it showed that the effect of giving chicken manure up to 10 tons ha^{-1} increased the peat soil pH.

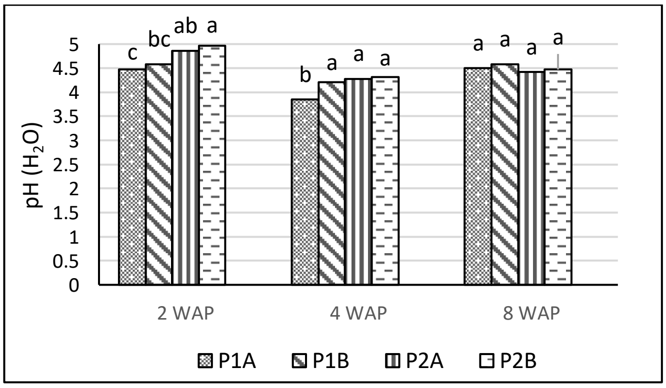

Figure 2. Effects of treatment, time, and raised beds on pH (H_2O) of peat soils (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

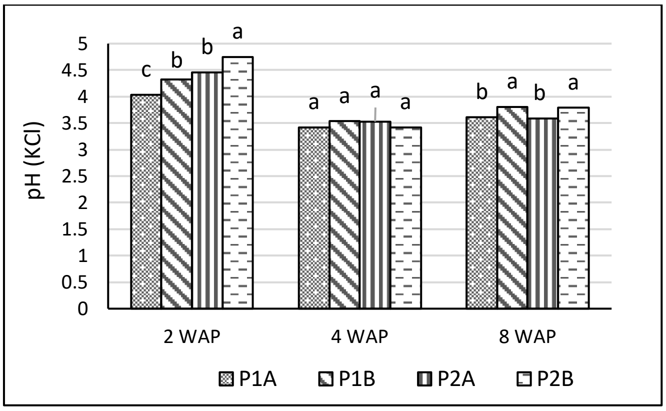

Figure 3. Effects of treatment, time, and raised beds on pH (KCl) of peat soils (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

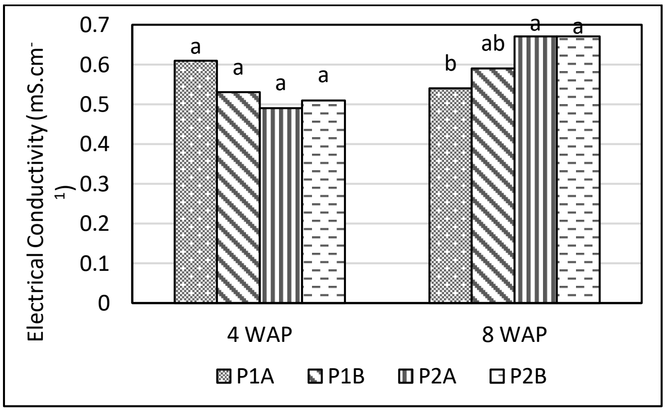

Figure 4. Effects of treatment, time, and raised beds on EC of peat soils (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

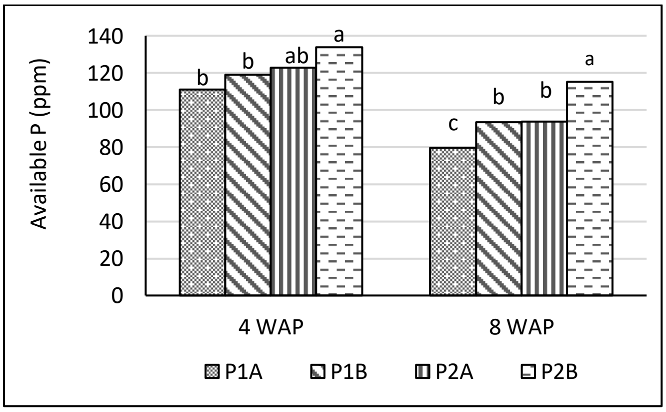

Figure 5. Effects of treatment, time, and raised beds on available P of peat soils (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

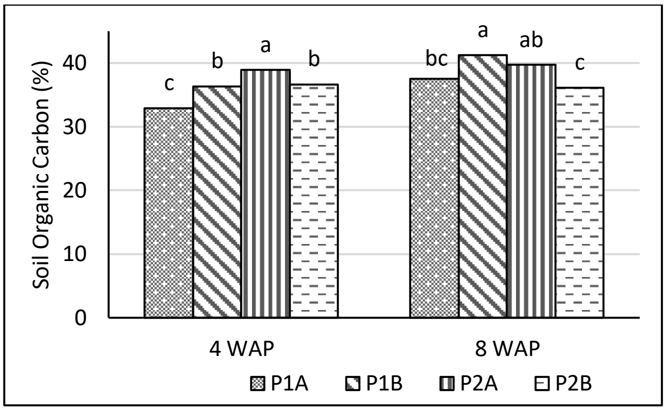

Figure 6. Effects of treatment, time, and raised beds on soil organic carbon of peat soils (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

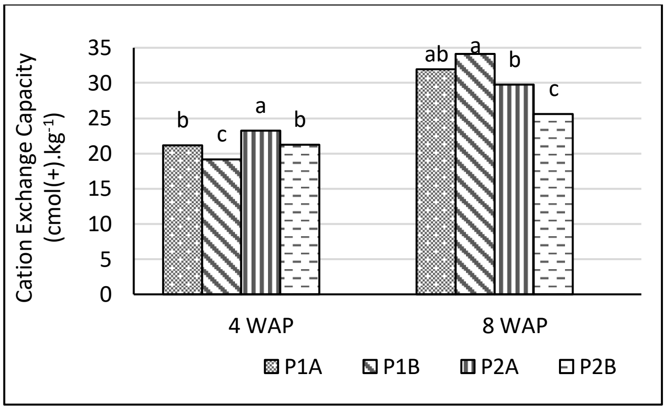

Figure 7. Effects of treatment, time, and raised beds on CEC of peat soils (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

The residue of applying inorganic fertilizers at 4 WAP might appear to increase the actual and potential peat soil pH at 8 WAP up to 4.0–4.5 (pH of H_2O) and up to ≥3.5 (pH of KCl). The low peat soil pH is an inherent trait.

The peat soil EC (Figure 4) of all treatments was very low due to no influence of seawater intrusion. The peat soil available P (Figure 5) of the P2B treatment was the highest, and the raised bed of 30 cm with 10 ton ha^{-1} of chicken manure was increasing the available P. The peat soil organic carbon (Figure 6) and the cation exchangeable capacity (CEC; Figure 7) of the P2A treatment at 4 WAP were significantly different from other treatments. Yet, the P1B treatment at 8 WAP was different from other treatments.

The peatland CO_2 fluxes (Figure 8) of all treatments increased because of the organic matter decomposition by microbes and soil organic carbon oxidation by oxygen in aerobic or dry conditions. The CO_2 fluxes of the P1B and P2B treatments increased dramatically after the ameliorant was applied, while the higher beds increased ameliorant and peat

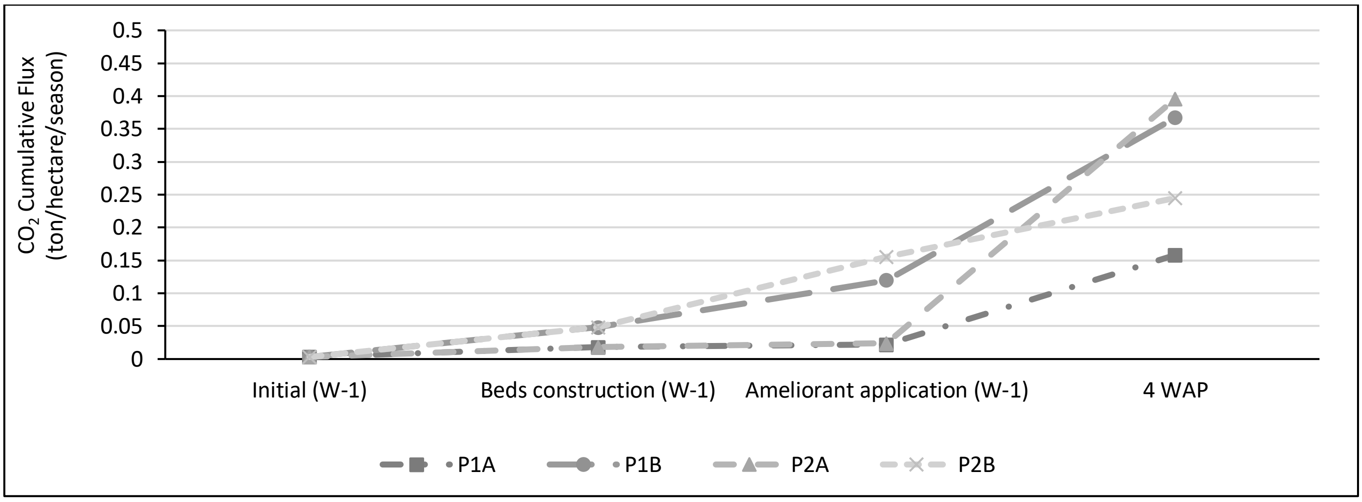

Figure 8. The CO_2 cumulative flux of beds (**Note**: WAP: weeks after planting; W-1: first week before planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

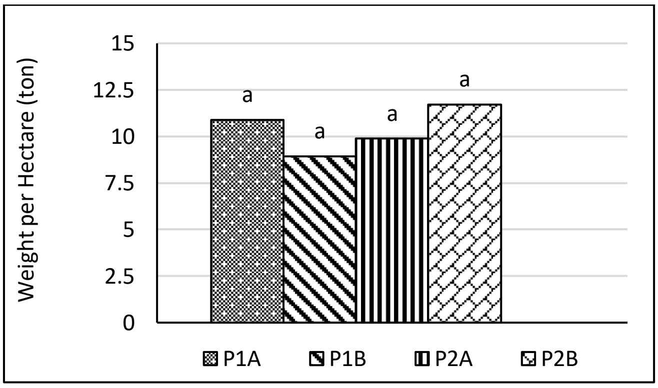

Figure 9. Shallots weight per hectare (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

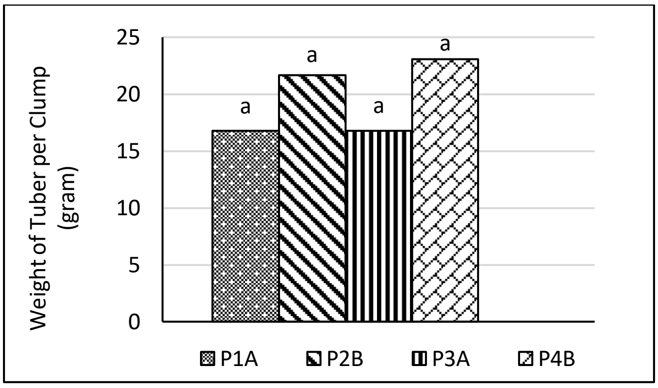

Figure 10. Shallots weight of tuber per clump (**Note**: Different letters on the graph are significantly different values in the 5% level of DMRT. WAP: weeks after planting; P1: chicken manure 5 ton ha^{-1} and rice husk biochar 5 ton ha^{-1}; P2: adding chicken manure 10 ton ha^{-1}; A: raised bed 20 cm; B: raised bed 30 cm)

decomposition by microorganisms and oxidation by oxygen. The lowest CO_2 flux was produced by the P1A treatment might appear to the addition of rice husk biochar 5 ton ha^{-1} with lower bed reduced CO_2 fluxes.

The weight per hectare (Figure 9) and weight per tuber (Figure 10) of all treatments were not significantly different, implying that all treatments were effective in increasing yields. However, the P2B treatment produced a higher weight per hectare and followed by the P1A treatment.

4. DISCUSSION

The groundwater tables of peatland fluctuations affect the transformation and transportation of nutrients in peatlands. The lowest groundwater level in Central Kalimantan occurred in October (Hirano et al., 2016). Decreasing groundwater levels afford to lead to high CO_2 emissions, the groundwater level decreased with the peak of the dry season.

The chicken manure has high alkaline saturations which was considered to increase the peat soil pH. Chicken manure contains specific elements such as macronutrients and micronutrients in higher amounts than other organic fertilizers. The cation exchange capacity is low, but the alkali saturation is high. Chicken manure in a gradual and long-lasting release of nutrients suggests that the provision of chicken manure allows for improved physical and chemical properties of peat soils (Harsono, 2020).

Rice husk biochar is considered to increase pH, CEC, ash content, and exchanged bases. Rice husk biochar is potentially ameliorating the moderate level of acidity and the CEC increased significantly by adding rice husk biochar (Ghorbani et al., 2019). A combination of rice husk biochar and lime showed an increase in soil pH, available P, and alkaline cations (Mosharrof et al., 2021). The SEM-EDX analysis appeared that the microstructure of the rice husk biochar was highly heterogeneous, rice husk biochar contains minor nutrients such as P, Ca, Mg, Na, K, Al, Fe, Mn, and Ti (Varela Milla et al., 2013) that increased the peat soil pH, CEC, ash content, and exchanged bases. The peat soil pH depression followed by dropped in CEC at 4 WAP, was caused by a lowering in the rate of decomposition due to the addition of organic matter. Chemically, carbon chains, such as carbohydrates and polysaccharides, in peat soil have an effect on CEC, which is a characteristic of functional groups, such as hydroxyl, carbonyl, and carboxyl (COOH) and can also affect some anion exchange capacity. According to Maftu'ah et al.

(2019), organic acids contributed significantly to the low pH in peat soils, pH decreased at 4 WAP as a result of organic acids hydrolysis which was dominated by fulvic acid and humic acid. Nevertheless, the provision of rice husk biochar was able to increase the CEC significantly at 8 WAP, due to the increased activity of organic matter decomposition by microorganisms.

The increase of soil pH followed by available P, organic matter, and EC are also apparently affected by liming. There is a greater biological activity in limed soils (Goulding, 2016), increased activity of microorganisms capable of degrading organic matter. During the maturation stage of organic matter, another part of less degraded organic matter such as lignin serves as new materials to build molecules that lead to humic substances (Ezzariai et al., 2018). The increase of EC came from the high decomposition intensity of peat organic matter by liming, this is a result of the free exchange of ions from peat particles. Additionally, an anion of Cl^- which is the inherent element in KCl fertilizer potentially raised the solubility of the salts in peat soil.

The CO_2 fluxes increased after beds construction up to 0.015–0.045 ton ha^{-1} $season^{-1}$ and after ameliorant application up to 0.004–0.107 ton ha^{-1} $season^{-1}$ because the presence of proper aeration supports soil microorganisms to decompose peat soil. Organic material undergoes decomposition by microbes releases CO_2 and ammonia (Ezzariai et al., 2018). The CO_2 flux of all treatments at 4 WAP increased due to the addition and increase of ameliorant decomposition. The application of higher doses of chicken manure produces a higher CO_2 flux. The chicken manure certainly contributed more emissions, the use of chicken manure is suggested to use sparingly to add necessary nutrients to the peat soil due to lack of specific nutrients (Harsono, 2020). However, the presence of CO_2 in peatland as a dynamic environment can be influenced by several factors, such as groundwater level, liming, and soil management, which encouraged carbon loss in the form of CO_2 and dissolved organic carbon, as well as the addition of ameliorants which increased organic carbon levels. The CO_2 fluxes on the cropland are higher than in the forest probably because of the effect of fertilization (Hirano et al., 2016). The Kalampangan Canal was constructed to lower the groundwater level so it dries up the peatland to cultivate and releases CO_2 (Itakura et al., 2016).

The lowest CO_2 flux was produced by the P1A treatment, this was in line with Maftuah et al. (2016) and Mosharrof et al. (2021) that the use of rice husk biochar may reduce CO_2 flux. The higher biochar application with a longer incubation time is likely to improve soil aggregation, which can increase carbon sequestration in the soil and mitigate CO_2 emissions (Ghorbani et al., 2019). Nonetheless, the P1B treatment produces higher CO_2 flux due to the higher bed.

Application of ameliorant followed by fertilization improved the peat soil properties and potential to produce high shallot productivity (Maswar et al., 2021). The highest potential shallot yield belonged to the P2B treatment, and the higher raised beds increased the aeration of peat soil surface. Additionally, the P2B treatment also showed the higher available P was able to raise the weight of tubers, available P translocates photosynthetic products into the tuber. However, there is no significant difference among treatments.

5. CONCLUSION

The P1A treatment recommendation (raised beds of 20 cm, chicken manure 5 ton ha^{-1} + lime 5 ton ha^{-1} + rice husk biochar 5 ton ha^{-1} + NPK 350 kg ha^{-1} + SP 36 150 kg ha^{-1} + KCl 200 kg ha^{-1}) produced the lowest cumulative CO_2 flux up to 0.158 ton/hectare/season and improved shallot production up to 10.88 ton. The application of rice husk biochar up to 5 ton ha^{-1} was able to reduce CO_2 fluxes and appeared to improve the shallot production though not as high as the application of chicken manure up to 10 ton ha^{-1}.

Acknowledgement

The author would like to thank the Indonesian Swampland Agriculture Research Institute (ISARI) for funding and collaboration project.

Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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