IOP Conference Series: Earth and Environmental Science

Influence of biochar application on carbon dioxide (CO_2) emission under soybean crop

To cite this article: D Darusman *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1356** 012053

13TH-AIC-ELS IOP Publishing
IOP Conf. Series: Earth and Environmental Science **1356** (2024) 012053 doi:10.1088/1755-1315/1356/1/012053

Influence of biochar application on carbon dioxide (CO_2) emission under soybean crop

D Darusman[1,3], S Syakur[1,3*], Z Zaitun[2,3], C D Vonna[1]
[1]Soil Science Department, Faculty of Agriculture, Universitas Syiah Kuala, Indonesia
[2]Agrotechnology Department, Faculty of Agriculture, Universitas Syiah Kuala, Indonesia
[3]Research Center for Biochar and Sustainable Tropical Forests, Universitas Syiah Kuala, Indonesia

*E-mail: syakur@usk.ac.id

Abstract. Biochar, an organic solid produced through pyrolysis, exhibits promising potential as a soil amendment. The utilization of biochar as a soil amendment is geared towards the reduction of CO_2 emissions and the sequestration of carbon in soil, thus playing a pivotal role in addressing climate change. This research was undertaken to quantify the extent of carbon emissions resulting from various biochar application treatments in soybean cultivation. The field study was structured in a randomized non-factorial design, encompassing five distinct biochar types: rice husk at application rates of 20 and 30 ton ha^{-1}, *pulai* wood (*Alstonia scholaris*) at rates of 20 and 30 ton ha^{-1}, and a control group serving as a reference. Each treatment was replicated three times. The quantification of greenhouse gas emissions involved the utilization of a CO_2 gas detector (Digital type HT-2000) placed within a chamber measuring 66 cm x 46 cm x 78 cm. The findings elucidated that the application of biochar had a discernible influence on the levels of CO_2 gas emissions. Specifically, the application of 30 ton ha^{-1} of rice husk and 20 ton ha^{-1} of *pulai* wood yielded higher emissions in comparison to the control group. This phenomenon is attributed to the favorable environment created by biochar within wetter soil conditions, fostering the proliferation of microorganisms, and subsequently contributing to increased emissions through microbial respiration.

1. Introduction

Soil serves as the largest and most effective reservoir of greenhouse gases (GHGs), specifically carbon storage. The dominant GHGs influencing climate change are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The concentration of GHG emissions in the atmosphere continues to rise uncontrollably, potentially leading to climate change. The impacts of these changes have caused alterations in the activities of surface-dwelling organisms. Therefore, it is imperative to make efforts to reduce emissions/mitigate them to anticipate changes in climate-related elements.

Biochar is a solid organic product rich in carbon obtained through pyrolysis in the absence or with limited oxygen [1]. The pyrolysis process yields biochar along with gases and other liquids. Biochar possesses a complex pore structure and a large specific surface area. Consequently, biochar is a material capable of capturing carbon from the air and storing it in the soil. Biochar is also recognized as an inexpensive adsorbent capable of absorbing contaminants present in rhizosphere soil. Biochar or char produced through recent pyrolysis methods is acknowledged as a potential solution to agricultural challenges such as climate change, soil degradation, low crop yields, and water pollution.

As a soil conditioner, biochar can sequester carbon, enhance soil water retention capacity, increase soil pH, improve soil structure, suppress the development of specific plant diseases, and create a favorable habitat for symbiotic microorganisms [2]. It is essential to thoroughly understand the characteristics of biochar to optimize its applications. In-depth scientific studies and field experiments continue to explore the potential of biochar in addressing environmental and agricultural challenges. However, limited research is available on how biochar can reduce or mitigate carbon emissions in soybean *(Glycine max* L. Merill) croplands. This research aims to investigate the influence of biochar types on the reduction of carbon dioxide (CO_2) greenhouse gas emissions in soybean croplands.

2. Material and Method

The materials employed in this study included *pulai* woods (*Alstonia scholaris*), rice husk (*Oryza sativa*), edamame soybean seeds (*Glycine max.* L), and related substances. The apparatus utilized consisted of a CO_2 gas detector (Digital type HT-2000) for biochar greenhouse gas measurement, a greenhouse chamber (66 x 46 x 78 cm), a biochar grinder, a chamber muffler furnace (Thermo Scientific Thermolyne F4820-33) with temperature control, an oven, a camera, and other related laboratory equipment.

Figure 1. *Pulai* wood (left) and rice husk (right) used for feedstocks.

A non-factorial randomized complete block design with five treatments replicated three times was employed in this experiment. Each plot measured 2 by 3 m. The five treatments, including one control, were designated as follows: P0 (control), P1 (biochar from *pulai* wood at 20 ton ha^{-1}), P2 (biochar from *pulai* wood at 30 ton ha^{-1}), P3 (biochar from rice husk at 20 ton ha^{-1}), and P4 (biochar from rice husk at 30 ton ha^{-1}).

Biochar production was conducted using the Kon-tiki model and the conventional Drum method. The biochar production guidelines were adapted from the Ithaka Institute for Carbon Intelligence [3]. The Drum method represents a traditional/local approach commonly practiced by the local community. The biochar production procedure followed the guidelines provided by [3]. Land preparation involved soil cultivation using hoes and rakes. Fifteen plots, each measuring 2 × 3 m, were established. Biochar was evenly distributed and incorporated into the soil to a depth of 20 cm. Biochar was applied at rates of 20 ton ha^{-1} and 30 ton ha^{-1} (according to treatments), equivalent to 12 and 18 kg $plot^{-1}$, respectively. The biochar was then incubated for three weeks.

Soybean seeds were planted with a spacing of 0.20 × 0.20 m. Edamame soybean seeds obtained from the private soybean seed producer ANAK Pohon, Sleman, Yogyakarta, were used. Planting was conducted in rows, with two soybean seeds placed in each hole at a depth of approximately 0.2 m. Fertilizer application occurred twice at 0 and 14 days after planting (DAP), with the following doses: Urea (50 kg ha^{-1}), SP36 (75 kg ha^{-1}), and KCl (75 kg ha^{-1}). Fertilizers were applied in bands, followed by irrigation. Sampled plants were randomly selected, with 10% of the population per plot, resulting in 12 plants per plot. Bamboo sticks with numbering were placed alongside selected plants.

Field CO_2 gas sampling adhered to the [4] procedure, utilizing a chamber designed to capture external air, constructed from acrylic glass measuring 66 cm x 46 cm x 78 cm. The chamber featured (1) a thermometer for measuring internal temperature, (2) dry batteries for operating a fan, (3) a fan to homogenize the air inside, and (4) soil to seal the chamber bottom to prevent air from escaping. Sampling occurred over one month, resulting in 24 greenhouse gas samples. The first sample was taken before planting, with subsequent samples collected weekly, starting one week after fertilizer application.

To assess the influence of soil moisture on emissions, approximately 100 g of soil samples were taken from each plot at a depth of 0-20 cm. CO_2 emissions were measured using a Digital Gas Detector (type HT-2000), placed inside the chamber. The displayed values were recorded as CO_2 emissions at 10-minute intervals for 30 minutes per observation. Subsequently, the CO_2 greenhouse gas emission flux was calculated using the formula reported by [5] :

$$F = dc/dt \times Vch/Ach \times mW/mV \times 273.2/((273.2 + T))$$

Where:
- F represents gas flux ($mg/m^2/day$).
- dc/dt denotes the rate of gas concentration change over time (ppm/minute).
- Vch represents chamber volume (m^3).
- Ach represents chamber area (m^2).
- mW is the molecular weight of the gas (g).
- mV is the gas molecular volume (22.41 L).
- T is the average temperature during gas sampling (°C).

3. Result and discussion

The average greenhouse gas CO_2 emissions over three gas sampling periods due to biochar application are presented in Figure 2.

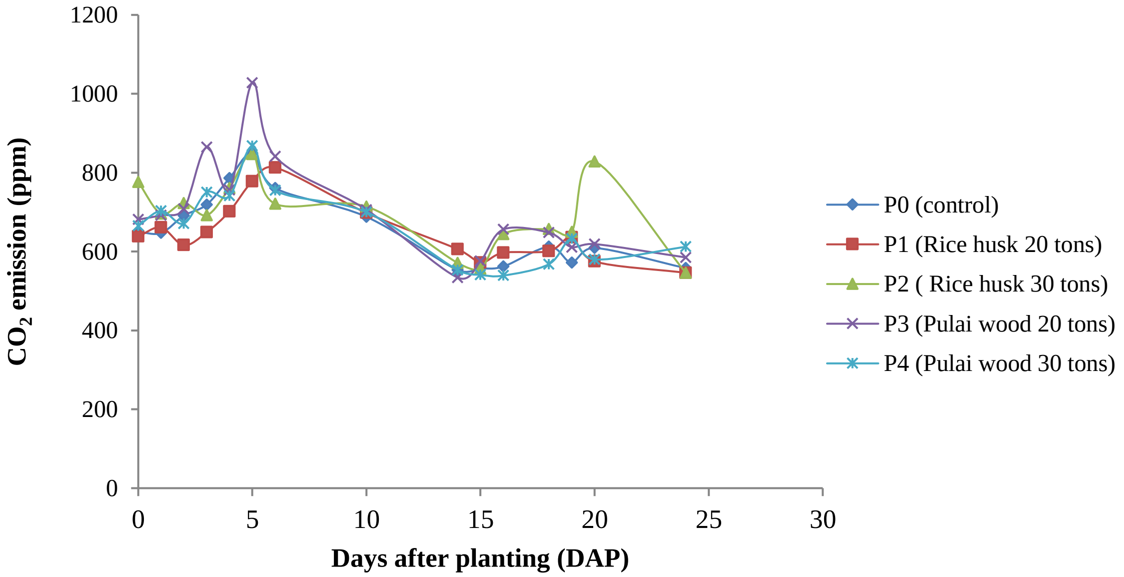

Figure 2. Combined mean CO_2 emission treatment due to the application of various type of biochar.

The research findings indicate that the total average amount and flux of CO_2 emissions due to rice husk and *pulai* wood biochar treatments did not have a significant effect compared to the control group without treatment (Figures 2 and 3). The average emissions were lower compared to the treatment application. However, after 7 days following planting and fertilization, all treatments showed an increase in carbon emissions followed by a decrease until the plants reached 15 days after planting, after which they tended to stabilize until the end of the observation period. The increase in CO_2 emissions at the 7-day mark after planting is believed to be associated with the soil microorganism response to decompose organic matter as a result of additional nutrient input from fertilization. However, there were interesting results concerning the treatment group receiving biochar as an additive. Biochar, although having the potential to reduce CO_2 emissions, may not be effective enough in counteracting the impact of fertilizers on emissions. This study indicates that the application of fertilizers during planting can increase CO_2 emissions within 7 days after planting, despite the addition of biochar in an attempt to reduce emissions.

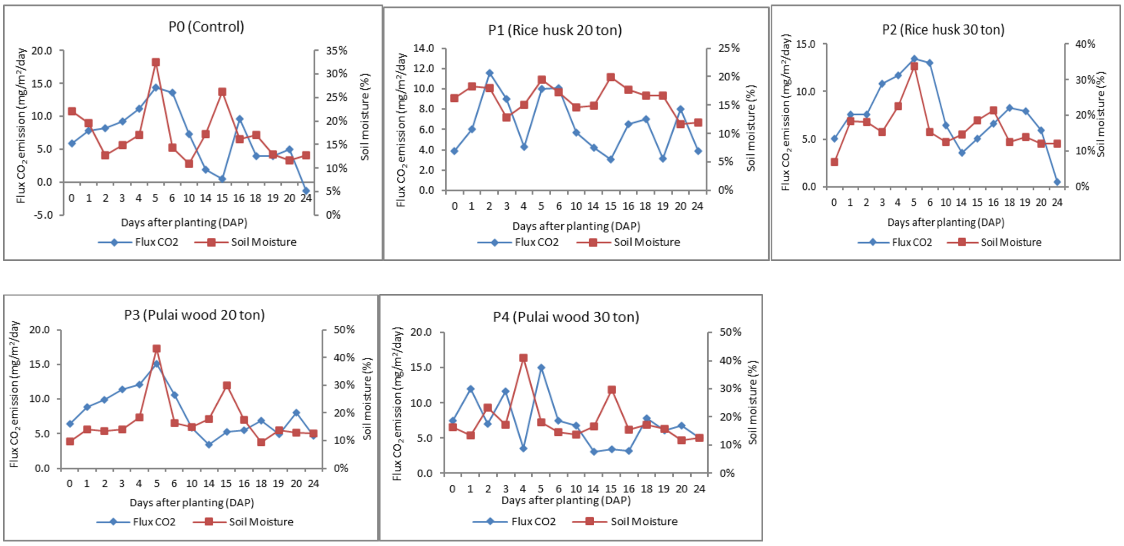

Figure 3. Mean CO_2 emission flux due to the application of various type of biochar.

The research results demonstrate that CO_2 emission flux fluctuated due to biochar application. The overlaid flux of CO_2 versus soil water content, as shown in Figure 3, revealed an increase in soil moisture content at 5 and 15 days after planting. High soil moisture is favorable for microorganisms, leading to an increase in population and respiration. In this study, it is shown that the effect of fertilization on CO_2 emissions is not consistent (Figure 3). The measured CO_2 concentration actually represents a balance between CO_2 emissions from respiration and CO_2 absorption by leaves. Based on the research by [6], it is demonstrated that N fertilization generally increases total CO_2 emissions in barley plants. This is due to increased root respiration as a result of enhanced plant growth due to N fertilization. Another study conducted by [7] resulted that urea and biochar-based urea increased soil CO_2 emission. The addition of urea can also trigger an increase in CO_2 emissions due to increased soil microbial activity, soil microbial respiration is the mainly path by which CO_2 is released to the atmosphere. Additionally, the hydrolysis of urea also generates CO_2.

The average flux of greenhouse gas CO_2 emissions in relation to soil moisture content due to the application of various types of biochar is presented in Figure 3. Based on Figure 3, the highest average soil moisture content was observed at 5 and 15 days after planting (DAP). This occurrence can be attributed to rainfall events before the CO_2 gas measurements were taken. The magnitude of CO_2 emissions is dependent on soil moisture content, and adequate soil moisture creates an optimal root environment, promoting vigorous plant growth. Vigorous plants take up carbon dioxide (CO_2) for respiration and use it for photosynthesis process. The cumulative respiratory output from both root respiration and microbial respiration within the soil ecosystem is contingent upon a sustained imbalance of soil organic matter levels in relation to soil moisture content. Notably, the increase intensity in root respiration rates observed in wetter soil conditions was found to be only fifty percent of the concurrent increase in respiration attributed to decomposition activities [8].

The issue of soil moisture availability is closely related to the decomposition of organic matter and soil microorganism activities. Decomposition of organic matter carried out by soil microorganisms thrives when there is sufficient water and air in the soil. Higher soil microbial activity accelerates the decomposition process, leading to rapid mineralization of elements, including the release of CO_2 emissions into the air. Conversely, in minimum tillage practices where soil is minimally disturbed, oxygen penetration into the soil is limited, resulting in reduced soil respiration.

4. Conclusion

1. Fertilization influences the rate and amount of greenhouse gas CO_2 emissions at the 7-day after planting. This suggests that the application of fertilizers has a notable impact on early-stage plant emissions.
2. Soil moisture content plays a pivotal role in determining the magnitude of fluctuation in CO_2 emissions. Adequate soil moisture levels create an optimal root environment, facilitating vigorous plant growth. Such thriving plants efficiently absorb CO_2 for respiration and engage in photosynthesis optimally, contributing to the observed effects on CO_2 emissions.
3. These conclusions emphasize the complex interplay between fertilization, soil moisture, and plant growth on CO_2 emissions, shedding light on the dynamic processes influencing greenhouse gas emissions in agricultural systems. Further research in this field may provide insights into strategies for mitigating greenhouse gas emissions in agricultural practices.

Acknowledgments:

We thank the Institute for Research and Community Services (LPPM) Universitas Syiah Kuala for funding this research with scheme of Professor Research grant, year 2022.

References

[1] Lehmann J 2007 A handful of carbon *Nature* **447** 143–4
[2] Tanah B P 2009 Analisis Kimia Tanah, Tanaman, Air dan Pupuk
[3] Draper K 2018 The potential for Biochar to improve sustainability in Coffee cultivation and processing: A White Paper *Ithaka Inst. Carbon Intell.*
[4] Minamikawa K, Tokida T, Sudo S, Padre A and Yagi K 2015 Guidelines for measuring CH4 and N2O emissions from rice paddies by a manually operated closed chamber method *Natl. Inst. Agro-Environmental Sci. Tsukuba, Japan* **76**
[5] Yang L and Cai Z 2005 The effect of growing soybean (Glycine max. L.) on N2O emission from soil *Soil Biol. Biochem.* **37** 1205–9
[6] Chu H, Hosen Y and Yagi K 2007 NO, N2O, CH4 and CO2 fluxes in winter barley field of Japanese Andisol as affected by N fertilizer management *Soil Biol. Biochem.* **39** 330–9
[7] Zhang S, Zhou J, Chen J, Ge T, Cai Y, Yu B, Wang H, White J C and Li Y 2023 Changes in soil CO2 and N2O emissions in response to urea and biochar-based urea in a subtropical Moso bamboo forest *Soil Tillage Res.* **228** 105625
[8] Kotroczó Z, Makádi M, Kocsis T, Béni Á, Várbíró G and Fekete I 2023 Long-term changes in organic matter content and soil moisture determine the degree of root and soil respiration *Plants* **12** 251