Effects of Biochar Amendment on CO_2 Evolution in Four Ecotypes of Leyte Sab-A Basin Peatland, Philippines

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ARTICLE INFO

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ABSTRACT

Atmospheric carbon cycle criticisms are significant liabilities in existing predictions of future climate. Carbon dioxide (CO_2) discharges caused by climate warming through dense peat stores will frame a stable positive carbon cycle–atmospheric input. An experimental-descriptive analytical method was used to acquire data on quantifying the amount of CO_2 evolved in the four adjacent ecotypes of Leyte Sab-A Basin Peatland (LSBP), Philippines, both with and without biochar incorporation. Results showed that after 120 days of incubation, the CO_2 evolved between ecotypes measured 0.73 mg CO_2/g, 0.31 mg CO_2/g, 0.23 mg CO_2/g, and 0.20 mg CO_2/g for TML (marshland), TPF (peat forest), TAL (agricultural land), and TMV (mixed vegetation), respectively. In comparison, treatments with biochar were 0.81 mg CO_2/g, 0.57 mg CO_2/g, 0.46 mg CO_2/g, and 0.43 mg CO_2/g for TMLB (marshland+biochar), TPFB, TMVB, and TALB, respectively. Results rendered significant differences between ecotypes, and between those with added biochar (p-value: 1.8E-06). This study concludes that TML with and without biochar had the highest evolved CO_2 over time, implying the best ecosystem preservation among the ecotypes. For future studies, these findings establish a scientific basis for adaptive response assessment of peatlands to climate change, and for decisions made in support of policy changes.

1. INTRODUCTION

One of the most significant uncertainties in future climate projections is the interaction between the climate and the terrestrial carbon cycle (Kaur et al., 2022; Lu et al., 2021). The increased decomposition of deep peat deposits that have persisted for centuries to millennia may result in increased carbon dioxide (CO_2) outflow caused by climate change (Humpenöder et al., 2020). Several factors characterize this increased decomposition, including wildfires, human activities, and acidification. The decomposition process accelerated once these occurrences became continuous, releasing carbon dioxide (Jayasekara et al., 2024). As a result, a positive feedback loop may exist between the carbon cycle and the atmosphere. However, due to the limited duration or complementary nature of field discipline and the potential for disturbances during respiration measurements, the long-term climate sensitivity of carbon in peatlands, particularly at depth, remains uncertain.

Moreover, the peatlands are wetland ecosystems characterized by the accumulation of organic matter called "peat", which derives from dead and decaying plant materials under high water saturation conditions (PAWB-DENR, 2013). It plays an essential role as a global carbon sink, and it stores up to 30% of the world's soil organic carbon (SOC) pool despite covering only 3% of the Earth's surface (Yao et al., 2022). Unfortunately, over half of Europe's former peatland area has been damaged due

to peat quarrying and land use changes such as drainage to make them suitable for agriculture or forestry (Joosten, 2016). Aeration of the soil is necessary for plant growth and makes the soil viable. On the other hand, the transition from anaerobic to aerobic conditions causes the rapid decomposition of peat that has accumulated under waterlogged conditions. As a result, the previous C-sink is now a significant source of atmospheric carbon dioxide (Du et al., 2022), and peatlands are known to be a significant contributor to global climate change issues (Humpenöder et al., 2020).

In the Philippines, there are two sites where peatlands have been confirmed—the Agusan Marsh (Alibo and Lasco, 2012) and the Leyte Sab-A Basin Peatland (LSBP) (Bobon-Carnice et al., 2023). The Leyte Sab-A Basin is located in the three barangays of the municipality of Alang-Alang, Leyte, namely Barangay Langit, Barangay Divisoria, Barangay Tabangohay, and Barangay San Isidro from the municipality of Sta. Fe, Leyte is located along the edges of the Mainit River Irrigation System. The Sab-A Basin is considered the most prominent water catchment area in Leyte. It is an elongated basin aligned northwest-southwest, situated northeast of the island of Leyte, near Tacloban City. The extreme northwest of the basin is somewhat isolated from the central basin by a ridge running south into the basin. Peat (Dolongan peat) is mainly found in the basin's central part, away from the surrounding ridges.

Around the margins of the basin, the Dolongan soil/peat mix is found, presumably since erosion from the surrounding ridges has deposited mineral soil at the foot of the ridges. Peat and mineral soil are interbedded in these areas. In addition, this peatland has been designated as a free zone for the protection, preservation, conservation, and restoration of unique ecosystem management areas due to the government's reclamation efforts. The said free zone has been used to focus on land management, which involves certain activities such as agriculture and settlements that serve the local community's economic needs. The eastern basin's undeveloped peatland is 1,288 ha and consists of marsh woodlands and grass/sedge peat swamp areas. A recent publication indicates that LSBP stores 36.6 Tg of C and could sequester 134.5 Tg of CO_2, representing 0.04% of the total tropical peat C (Bobon-Carnice et al., 2023). It is important to note that since their formation, peatlands have been both absorbing and emitting greenhouse gases (GHGs). As a result, it may take some time before the impact of CO_2

sequestration in peat is observed, but it is believed that the benefits of CO_2 sequestration in peat outweigh the benefits of methane (CH_4) emissions. Peatlands have been studied and found to be CO_2 sinks in some years and sources in others, depending on the climate. As concerns about climate change grow, efforts to assess soil carbon pool capacity and alterations have been reignited (Jackson et al., 2017). Most field studies on soil CO_2 budget measure CO_2 effluxes at the surface and CO_2 concentrations within the soil. Surprisingly, determining CO_2 effluxes provides a clear picture of its production in the land, and its emissions from depleted, carbon-rich soils like peatlands are becoming increasingly recognized as critical to the global carbon cycle (Hermans et al., 2022).

The reaction to climatic warming via CO_2 evolution has been considered worldwide for the most recent decades. In contrast, CO_2 development and soil carbon mineralization have been paid incredible acknowledgment for their massive impact on the global carbon cycle and terrestrial biological systems. Soil respiration is the CO_2 emission from soils, providing insight into soil carbon stocks and inputs. This flux influences the global carbon cycle as a potential regulator of the global greenhouse effect and climate. Temperature is often positively associated with soil respiration rates. As a result, higher temperatures are frequently associated with escalated soil respiration estimations, accelerating carbon cycling via autotrophic respiration and contributing to a potentially substantial positive response to climatic warming via heterotrophic soil carbon respiration (Tang et al., 2019). It has been thought that the recent rise in global temperature due to climate change has caused a higher estimate of soil respiration.

Consequently, it has led to a more significant greenhouse effect and a positive reaction loop for climate change. On the other hand, most field investigations of soil CO_2 budgets only assess CO_2 effluxes at the surface and its concentrations within the soil, providing only a limited view of CO_2 production in the soil. CO_2 evolution rates can be used to assess the effects of inorganic and organic matter on soil and its use. Several factors influence the mineralization of organic materials, including deposit quality or composition, soil temperature, water availability, and soil properties (Weber and Quicker, 2018).

Therefore, reducing greenhouse gas emissions and extracting CO_2 from the atmosphere are essential to minimizing climate change's adverse effects. A comprehensive examination is required before

investing in and executing these techniques to make educated decisions. One possible option for removing CO_2 from the environment is biochar production, which involves roasting biomass without oxygen to create a stable, carbon-rich material. Initial research on using biochar as a soil amendment is still in its infancy, but preliminary findings indicate that it may reduce the requirement for supplementary fertilizers and water. Through enhancing soil carbon sequestration, biochar has the potential to significantly contribute to climate change mitigation (Chagas et al., 2022). According to Söderqvist (2019), the pyrolysis process reforms the fast degradable carbon compounds in the biomass into more stable structures in the biochar. These carbon structures are more resistant to degradation than the original carbon compounds in the biomass. From this, the amount of carbon in the atmosphere circulating in the fast cycle can be reduced when carbon is introduced into a slower carbon cycle. This can be seen in contrast to burning fossil fuels, which release carbon from long-term storage into the atmosphere (Qambrani et al., 2017).

Biochar is increasingly recognized as a good soil amendment for nutrient retention and water-holding capacity (Rubin et al., 2022). Its peat incorporation could help mitigate nutrient leaching, enhance plant growth, and support restoration efforts (Cai et al., 2021). Soil acidity is a common problem for denuded peatlands, and adding biochar could buffer it, creating a more favorable environment for microbial activity and vegetation recovery (Wang et al., 2024). It has also been found to restrain GHG emissions, improving soil carbon sinks (Mosa et al., 2023) and peat stabilization (Ritter et al., 2022). Nevertheless, this study has yet to test the performance of biochar with peat if its decomposition dynamics are the same with mineral soils.

In this light, the researchers pursue the conduct of this study with the primary purpose of quantifying the CO_2 evolution rates of distinct peatland ecotypes and assessing the possibility of biochar to mitigate climate change by inhibiting carbon dioxide evolution in peatland ecosystems. This study's findings are expected to substantially impact understanding the biochar's effectiveness in mitigating climate change and on future land use and carbon sequestration plans. By studying the impacts of biochar on CO_2 evolution rates in several peatland ecotypes, this work gives essential insights into the feasibility and potential benefits of employing biochar as a strategy for carbon sequestration in peatland ecosystems.

2. METHODOLOGY

2.1 The study site

The study was conducted in Leyte Sab-A Basin Peatland (LSBP). Samples were taken from the three barangays of the municipality of Alang-Alang, Leyte, Philippines, namely Barangay Langit, Barangay Divisoria, Barangay Tabangohay, and Barangay San Isidro in the municipality of Sta. Fe, Leyte, Philippines. The site presented in Figure 1 is located along the edges of the Mainit River Irrigation System. It has 3,088.00 ha, of which over half has been reclaimed for agriculture (Bobon-Carnice et al., 2023). The remaining unutilized peatland of 1,288 ha in the basin's eastern part consists of a small swamp forest and sedge/grass peat swamp (PAWB-DENR, 2013).

2.2 Sampling procedure

Four ecosystem types were identified in Sab-A Basin, Leyte: marshland (ML), peat forest (PF), agricultural land (AL), and mixed vegetation (MV). Topsoil (0-20 cm) from these ecosystem types was collected using core samples: three for soil incubation and one for bulk density, moisture content, and oven-dried weight (ODW) measurement. One-time sampling was done to collect the peat substrate after a day of site visit and ecosystem re-assessment.

2.3 Biochar preparation

The study used an improvised pyrolyzer to produce pyrolysis from poultry litter. This improvised pyrolyzer comprises a cylindrical tin can (with lid), which is 10 inches high and 3 inches radius, and a rectangular tin can, whose capacity is 15 kg with a complete measurement of 24×15×15 inches. To produce the pyrolysis, the researchers poured one kilogram of feedstock inside a cylindrical tin sealed with its lid. Then, the said tin was placed inside a rectangular tin can with fire at about 400-600°C heat temperature. The procedure lasted approximately 6-8 h until the poultry litter turned into biochar. After eight hours, the biochar was removed from the pyrolyzer and cooled for 5 to 10 min until the biochar's temperature moved to 40°C. After the cooling process, it was crushed, pulverized, and homogenized to its desired size, 1-2 mm in range, using a wooden mallet. This crushed poultry litter biochar was set aside and prepared for the next experiment.
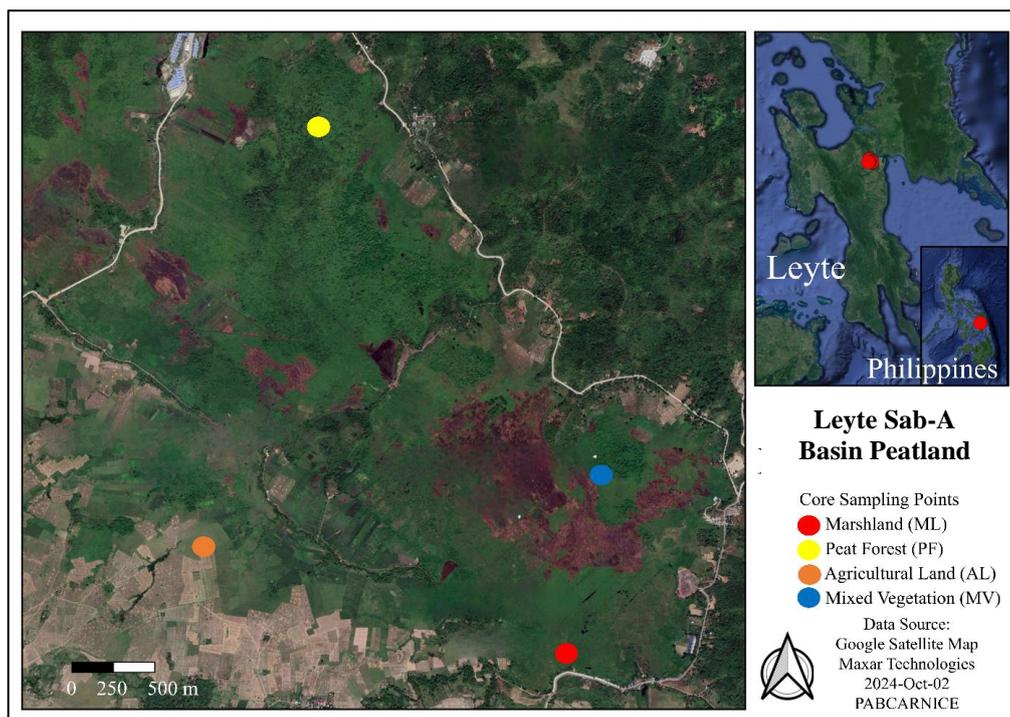
Figure 1. Map of sampling sites in Sab-A Basin, Leyte, Philippines.

2.4 Incubation

This process used fresh, top peat samples as the primary substrate. This experiment formulated nine treatments (TML (marshland), TPF (peat forest), TAL (agricultural land), TMV (mixed vegetation), BIOCHAR (biochar, no peat samples), TPFB (peat forest+biochar), TMLB (marshland+biochar), TALB (agricultural land+biochar), and TMVB (mixed vegetation+biochar)) with three replications each. All the ecosystem peat samples were put inside a glass jar measuring 8" in height × 2.5" in diameter, with a total capacity of 400 g. Each glass jar contains 25 g of peat substrate, and treatments with biochar were incorporated with 5 g. Then, biochar was evenly spread. Subsequently, the samples were then transferred to the laboratory facility of Eastern Visayas State University, Tacloban City, where the experimental set-up was located. The samples were stored in a closed room with a controlled temperature not exceeding 35°C and no exposure to direct sunlight. As a controlled experiment, three additional glass jars containing only 15 mL of NaOH were labeled TO1, TO2, and TO3. The experimental design employed a randomized complete block design (RCBD), and various treatments were analyzed over 120 days. The indicated number of incubation days under controlled conditions has been validated to be enough to detect short – to medium-term decomposition experiments

(Nikonova et al., 2023; de Jong et al., 2020; Jian et al., 2020; Hogg et al., 1992).

2.5 Carbon dioxide evolution determination

The evolved carbon dioxide was measured using a standard method (Anderson, 1982; Jenkinson and Powlson, 1976). The peat samples were placed in jars with 15 mL of 0.1 sodium hydroxide (NaOH) solution, and the jars were tightly sealed to prevent CO_2 exchange with the atmosphere. After every three days of exposure, the NaOH was collected and titrated with 0.05 N hydrochloric acid (HCl) solution and 0.05 N barium chloride ($BaCl_2$) solution using a phenolphthalein indicator. Each ecotype's moisture content was calculated, and about 3-5 mL of water was added to emulate its natural moisture content, estimated at 50-70%. Water is added every time the substrate's water content is visibly reduced based on the watermark outside the jar. The following formula was used to calculate the milligrams of CO_2 evolved and grams of organic material decomposed for each treatment (Jennings et al., 2010):

$$\text{Milligrams C or } CO_2 = (B - V)\, NE$$

Where; V=volume (mL) of acid to titrate the alkali in the CO_2 collectors from the treatments to the endpoint; B=volume (mL) of acid to titrate the alkali

in the CO_2 collectors from the control to the endpoint; N=normality of acid; E=equivalent weight.

*If data are expressed in terms of carbon, E=6. *If data are expressed in terms of carbon dioxide, E=22. The evolved and cumulative carbon dioxide were expressed as mg CO_2/g peat soil.

2.6 Calculation and data analysis

In order to calculate the percentage weight of the different treatments, the oven-dry weight of each treatment subtracted from the initial weight was determined. The initial weight is calculated by taking the difference between the weight of the different amendments and the moisture content. This calculation is essential to determine the effectiveness of the different treatments for reducing carbon dioxide emissions and increasing carbon sequestration.

A one-way analysis of variance (ANOVA) was performed, following the Duncan Multiple Range Test (DMRT), at a significance level of 0.05 to identify whether there were statistically notable differences between the treatments. In addition, linear regression was employed to evaluate the correlations between the impacts of biochar on CO_2 evolution, between temperature and the number of days of decomposition, and between CO_2 evolution and the number of days of decomposition.

3. RESULTS AND DISCUSSION

3.1 Biochar effect on the degree of decomposition

During the first seven days of peat ecotypes' decomposition, the CO_2 evolved in the process was low, with values of 0.17 mg CO_2/g (ML), 0 mg CO_2/g (PF), 0 mg CO_2/g (MV), and 0.10 mg CO_2/g (AL). This is attributed to the commencement of the decomposition process in the initial stage, with the rate expected to increase gradually over time (Abro et al., 2011). Moreover, the CO_2 evolution of TPF, TMV, and TAL was also low in the first seven weeks and gradually increased through the following weeks until the last day of incubation, as shown in Figure 2.

The results were consistent in that the rate of evolved carbon dioxide was low (1.43 g/kg) in the first week of incubation and continuously increased until the last day. Conversely, TML showed a significant increase on the fourth day, contradicting the results of Abro et al. (2011). Nevertheless, some results may be consistent with the results that TML showed. The previous studies of Hossain et al. (2017) and Rahman et al. (2014) showed that the maximum carbon dioxide

emission was found and recorded during the first week of incubation.

The lowest CO_2 evolved rates were recorded from Day 1 to Day 54 for treatments PF (0 mg CO_2/g), MV (0 mg CO_2/g), and AL (0.05 mg CO_2/g), but ML's lowest CO_2 evolved rates of 0.17 mg CO_2/g were recorded from Day 3.

Moreover, Figure 2 demonstrated that after 120 days of decomposition, TML (0.51 mg CO_2/g) obtained the highest degree of decomposition due to the highest evolved CO_2, seconded by TPF (0.34 mg CO_2/g), TAL (0.24 mg CO_2/g), and TMV (0.01 mg CO_2/g), which attained the lowest degree of decomposition.

TML, attaining the highest evolved CO_2, in which its decomposition patterns show rapid decomposition from Day 3 to Day 111. It was observed that on the 111th day, TML had its highest decomposition peak due to its anoxic wet condition. Moreover, there was a decrease in CO_2 from Day 111 to Day 120 due to the remaining organic materials that are slowly decomposable. The implication of this result may vary on the peat-soil carbon storage mechanisms of ML that influence the destabilization/stabilization of the SOC; it relates to the peat ecotype biotic components that impact the ecotype decomposition. In this study, marshland dominated by herbaceous floras and its wet characteristics may implicate the rapid decomposition resulting in evolved carbon dioxide ascending.

Figure 3 revealed that after 120 days of decomposition, BIOCHAR (4.04 mg CO_2/g) attained the highest degree of decomposition due to the highest evolved CO_2, seconded by TMLB (1.53 mg CO_2/g), then TPFB (1.21 mg CO_2/g), followed by TMVB (1.17 mg CO_2/g), and TALB (1.09 mg CO_2/g) is the lowest.

Compared to the unamended peat soil, peat respiration was significantly higher in the peat ecotypes with biochar incorporation. The results are the same as the study of Cheng et al. (2018), in which incorporating biochar into the peat soil increased its respiration with the increasing incubation time and high temperature. All the treatments with biochar incorporation (Figure 3) increased the CO_2 evolution relative to the control (BIOCHAR), which ranges from 0-4 CO_2 mg/g compared to the unamended treatments (Figure 2), which only ranges from 0-1.5 CO_2 mg/g. Biochar attains the highest evolved CO_2, and its decomposition patterns show a steady decomposition rate from Day 60 to Day 120. Further, it was observed that on the 15th day, biochar had its highest

decomposition peak. This response could be attributed to the loss of C from the biochar itself and the abiotic release of CO_2 from biochar minerals formed during pyrolysis (Amalina et al., 2022; Jones et al., 2012). It also implies that the maximum carbon dioxide emission on the 15th day was recorded due to a high temperature (27.6°C) (Zhao et al., 2017). The said results contrast with other articles that experimented on sandy loam soil (Lu et al., 2014), which suppressed decomposition, also with biochar as a soil amendment (Hua et al., 2014), and with biochar and straw incorporation (Hou et al., 2020). Further, straw composting experiments inhibit CO_2 release (Lin et al., 2022), and the same is true with the soils amended with cornstalk biochar with different rations (Zhou et al., 2023).
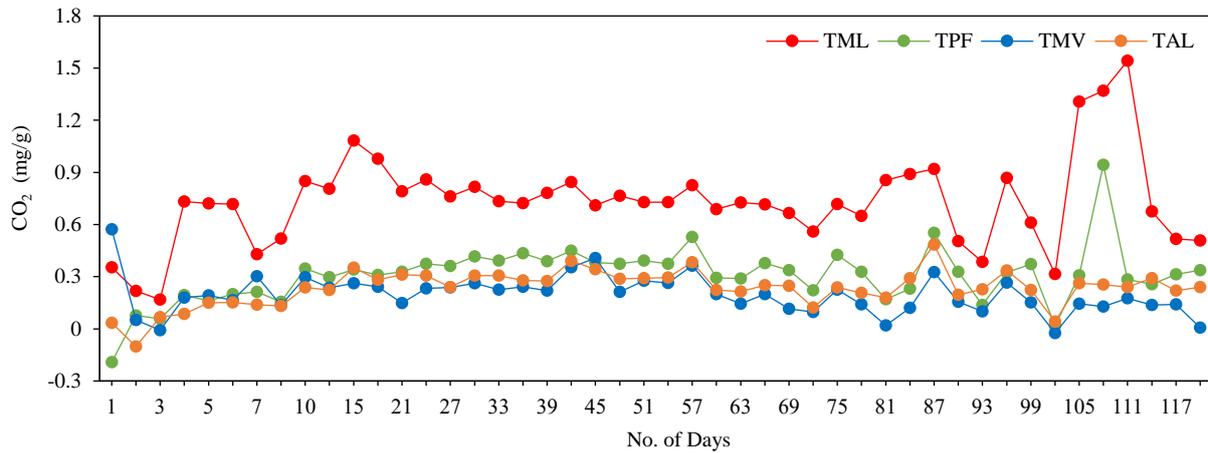

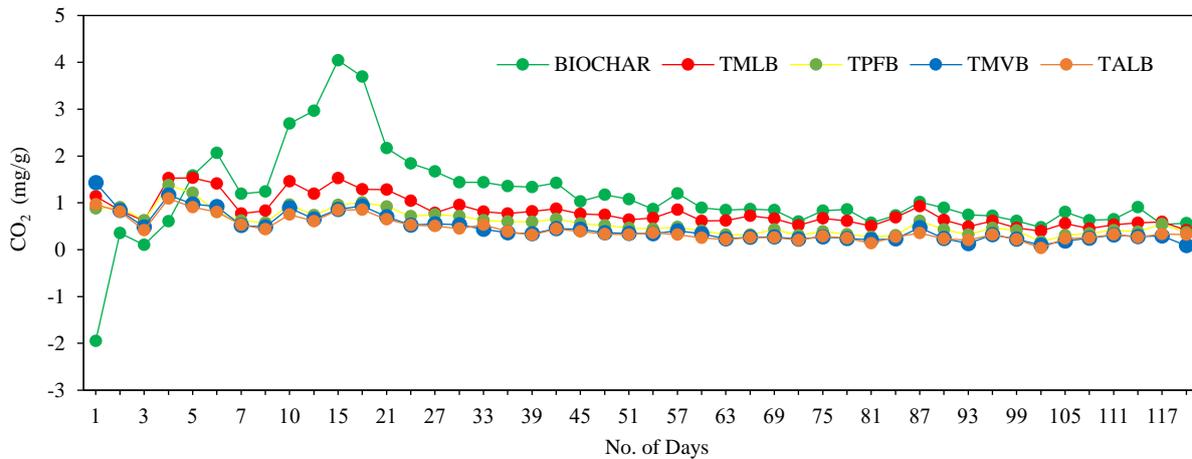**Figure 2.** CO_2 (mg/g) evolved of peat ecotypes after 120 Days of decomposition

Figure 3. CO_2 (mg/g) evolved of peat ecotypes with biochar incorporation after 120 Days of decomposition.

3.2 Carbon dioxide evolution

Figure 4 shows that TML ($R^2=0.0602$), TPF ($R^2=0.0961$), TMV ($R^2=0.1115$), and TAL ($R^2=0.0812$), which means that only 6.02% (TML), 9.61% (TPF), 11.15% (TMV), and 8.12% (TAL) of the CO_2 evolved variation are explained by the number of days of. These low values imply that the number of days is not a strong predictor of CO_2 evolution. The majority of the variation could be due to other factors that affect CO_2 evolution, such as peat moisture, peat temperature, organic matter availability, and microbial activity, which may fluctuate independently of time (Vandecasteele, 2023; Rankin et al., 2022).

On the other hand, adding biochar to the different ecotype substrates rendered contrasting results. Figure 5 shows that for Biochar ($R^2=0.1219$), TMLB ($R^2=0.5686$), TPFB ($R^2=0.6039$), TMVB ($R^2=0.5923$), and TALB ($R^2=0.5734$), which implies that 56.86% (TMLB), 60.39% (TPFB), 59.23% (TMVB), and 57.34% (TALB) that number of days progresses, there is a significant and predictable change in CO_2 evolution rates. This potentially means that adding biochar to the

different ecotypes of peat substrates increases microbial activity and decomposition of organic matter (Deshoux et al., 2023; Xiang et al., 2023; Bobon-Carnice, 2014). Nevertheless, even with such results, the model leaves the remaining variation unexplained; it cannot be neglected as CO_2 evolution can be affected by other variables such as temperature (a by-product of decomposition) and moisture content of the different ecotypes (Jiang et al., 2024). On the other hand, it is expected that biochar ($R^2=0.1219$) treatment alone would render a weak linear relationship with time as it does not contain any peat substrate, and biochar alone has high recalcitrance to decomposition (Azzi et al., 2024) and is interestingly comparable to the results of the peat ecotypes without biochar.

It has been reported that when biochar is used as a soil amendment, it stimulates soil fertility and improves soil quality by increasing soil pH, increasing the ability to retain moisture, attracting more useful fungi and other microbes, improving the ability of cation exchange, and preserving the nutrients in the soil (Ajema, 2018). Additionally, the study of Sovova et al. (2021) discovered that biochar's efficacy differed between peat soil ecotypes. This may imply the reason for the difference in the relationship between the treatments and biochar application.

In contrast, Cheng et al. (2018) argue that abiotic CO_2 release is unlikely to explain the observed increase, as contributions from this source would typically increase with higher biochar production temperatures due to decreased colloidal mineral content and an increase in metal oxide formation (Angın, 2013). The additional CO_2 could, therefore, originate from the microbial-induced solubilization and breakdown of the biochar (Jiang et al., 2016). Overall, the results imply that treatments with biochar incorporation were significantly higher than those without.

Peat ecotypes with and without biochar amendment exhibited a linear inclination with significant differences during incubation, as shown in Figure 4 and Figure 5. Moreover, ecotypes with 5 g biochar addition significantly increased the evolved CO_2 between the 15th and 20th day. These outcomes were dependable with the study of Rahman et al. (2014), who stated that organic deposits significantly increased when biochar was added compared to treatments without biochar.

3.3 Cumulative value of CO_2 (mg) evolved and percentage weight loss

Cumulative CO_2 (mg/g peat soil) value on peat ecotypes without biochar varied slightly in all four treatments after 120 days of incubation. From Day 1 to Day 120, ML (33.64 mg/g peat soil) tends to have the highest cumulative CO_2 value (Figure 6). On the 10th day and onwards, the decomposition of the four treatments significantly increased.

The overall cumulative value of CO_2 (mg/g peat soil) evolved of TML, TPF, TAL, and TMV (mixed vegetation) is 33.64, 14.20, 10.76, and 9.04, respectively, which implies that TML has the highest degree of decomposition, and TMV has the lowest (Figure 6). TML (marshland) accumulated the highest carbon dioxide evolved compared to the other treatments because of their anoxic wet conditions. Marshland ecosystems provide an optimum natural environment for the sequestration and long-term storage of carbon dioxide (CO_2) from the atmosphere (Mitsch et al., 2013), possibly due to TML accumulating the highest carbon dioxide evolution.
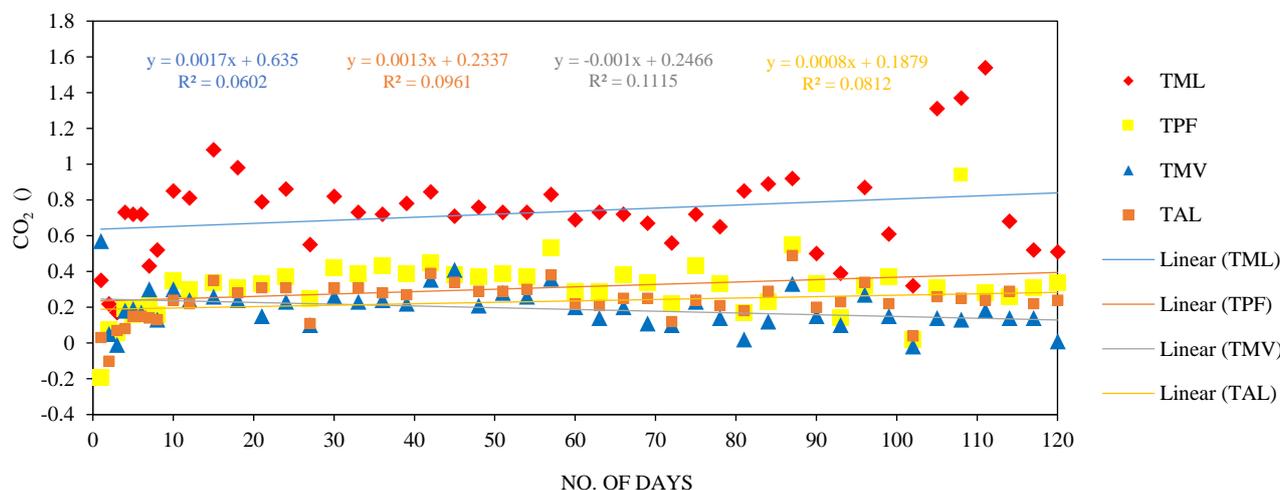

Figure 4. Linear regression analysis of peat ecotypes with biochar CO_2 evolved and the number of days of decomposition
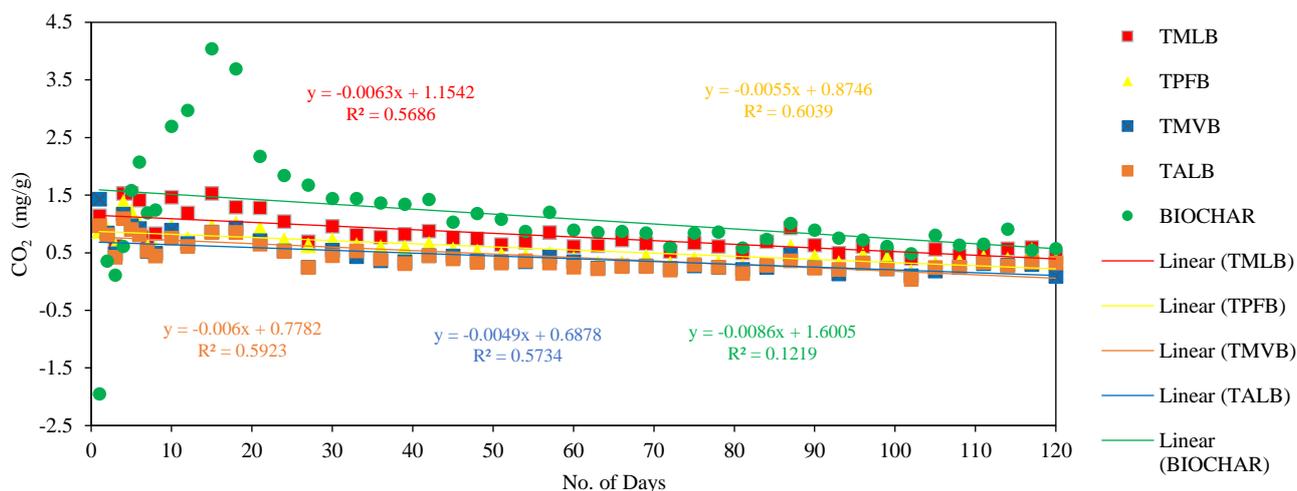
Figure 5. Linear regression analysis of peat ecotypes without biochar CO_2 evolved and the number of days of decomposition

The implication of this result varies on the ecotype characteristics and components (abiotic and biotic) that influence the mechanism of the peat soil on rapid decomposition. The effect of ecotypes on the cumulative emission of CO_2 at the end of 120 days of incubation was significant (F=65.55, p<0.05).

TPF lost about 79.83% of its total ODW for 120 days, while TML, TAL, and TMV attained 77.51%, 51.73%, and 51.35%, respectively. This could be due to TPF vegetation being dominated by forest trees that have not been degraded yet, with the probability of a high percentage of bioavailable carbon in its substrate that could be easily decomposed (Jayasekara et al., 2024). TML evolved the highest carbon dioxide (Figure 7), which is directly proportional to weight loss, as in the case of the other three treatments. Such high CO_2 evolution compared to other ecotypes could be due to the fine root systems of the marshland (Dargie et al., 2024), which are dominated by macrophytes (Bobon-Carnice et al., 2023). On the other hand, treatment TMV attained the lowest carbon dioxide evolution (Figure 6) and the lowest percentage of weight loss (Figure 7). This could be due to peat compaction due to anthropological intervention where different trees and a mix of agricultural tillage are being practiced.

Cumulative CO_2 (mg/g peat soil) value on peat ecotypes with added biochar varied slightly in all five treatments after 120 days of incubation. From Day 1 to Day 120, BIOCHAR (biochar alone) tends to have the highest cumulative CO_2 value. Subsequently, on the 10th day and onwards, the five treatments significantly increased the degree of decomposition (Figure 8). The reason BIOCHAR alone accumulated the highest carbon dioxide evolved compared to the

other four treatments is that BIOCHAR could be due to the process of pyrolyzing it; the pyrolysis process seriously affects the quality of biochar and its potential value in carbon sequestration (Rawat et al., 2019). Furthermore, it has been reported that when biochar is used as a soil amendment, it stimulates soil fertility and improves soil quality by increasing soil pH, increasing the ability to retain moisture, attracting more useful fungi and other microbes, improving the ability of cation exchange, and preserving the nutrients in the soil (Ajema, 2018). Moreover, it can be further analyzed in the study of Sovova et al. (2021) on the impacts of biochar application on soil characteristics and plant growth across several peat soil ecotypes. The study concluded that biochar application enhanced plant growth by enhancing soil parameters like pH, cation exchange capacity, and water-holding capacity. Therefore, it may imply the reason for the exponential increase of evolved carbon in all the peat ecotypes with added biochar as an amendment.

Treatment MLB lost about 67.19% of its total ODW for 120 days, while TPFB, BIOCHAR, TALB, and TMVB attained 62.89%, 59.62%, 48.67%, and 45.07%, respectively (Figure 9). As with the other treatments, BIOCHAR and TMLB evolved the highest carbon dioxide, directly proportional to weight loss. Conversely, treatment ALB attained the lowest carbon dioxide evolved, which should supposedly have the lowest weight loss. Despite this, results (Figure 9) revealed that TMVB recorded the lowest weight loss of its total ODW for 120 days.

Overall cumulative value of CO_2 (mg/g peat soil) evolved of BIOCHAR (biochar alone), TMLB (marshland+biochar), TPFB (peat forest+biochar), TMVB (mixed vegetation+biochar), and TALB

(agricultural land+biochar) is 52.22, 37.42, 26.58, 21.14, and 19.81, respectively, which implies that BIOCHAR (biochar alone) has the highest degree of decomposition, TMLB (marshland+biochar) is next, and TALB (agricultural land+biochar) has the very slightest degree of decomposition. The results imply that biochar addition to TALB could enhance weight loss during decomposition but not much with carbon dioxide evolution. To this, treatment BIOCHAR has a higher evolved carbon dioxide, which is not much compared to weight loss. It further implies that incorporating biochar into the peat significantly reduced weight loss by 45% with 5 g of biochar application on each peat ecotype.

Current results show that the biochar treatments (Figure 8) exhibited higher cumulative CO_2 evolution than those without biochar (Figure 6). This could be due mainly to the significantly higher emission of CO_2 in the first two weeks. Some studies have reported similar results by Troy et al. (2013), Rogovska et al. (2011), and Keith et al. (2011), which indicated that labile C in biochars could effectively lead to an increase in CO_2 emission. Furthermore, the study of Tomczyk et al. (2020) shows that the biochar produced at lower temperatures induced more cumulative CO_2 emissions. Consequently, Giweta's (2020) review highlights the significant influence of environmental factors such as temperature, moisture, and soil pH on decomposition. In addition, it is worth noting that in real environments, it does not account for natural variability such as temperature and moisture fluctuations, soil microbial diversity, environmental factors (rainfall, erosion), and field heterogeneity (soil texture, pH, varying organic content). However, baseline understanding is essential before conducting field studies and large-scale applications.
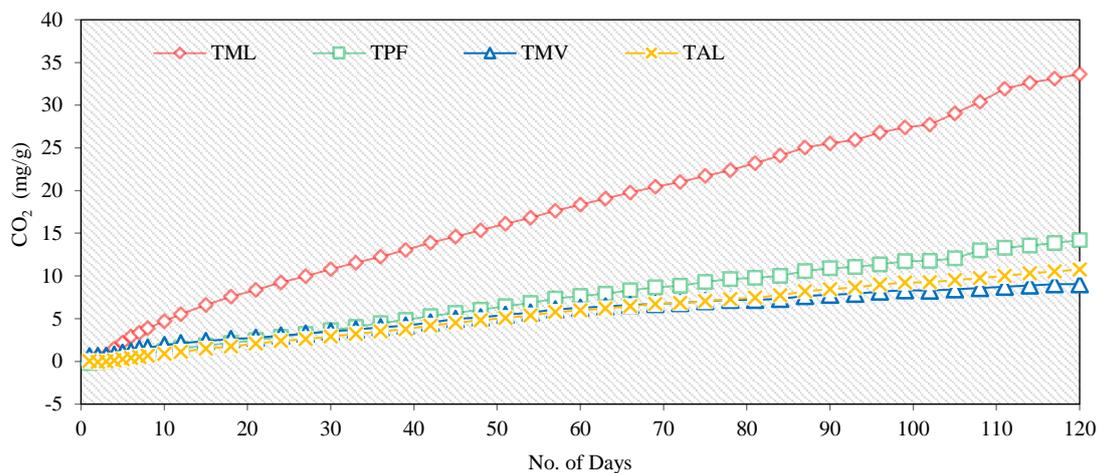

Figure 6. Cumulative value of CO_2 (mg/g) evolved of the peat ecotypes without biochar for 120 days
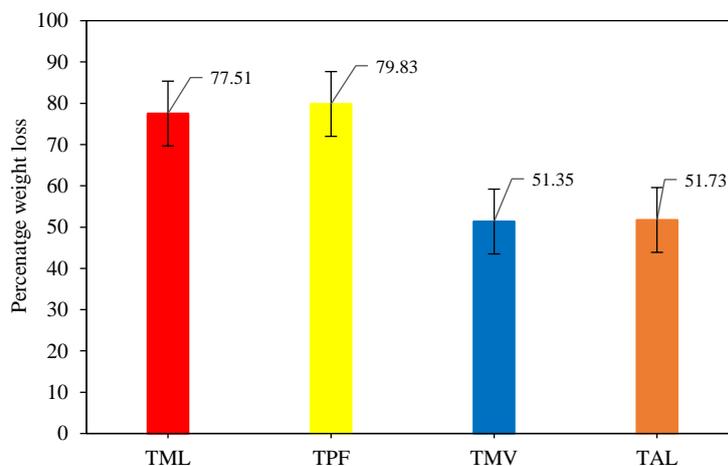

Figure 7. Percent weight loss of the peat ecotypes without biochar after 120 days

Figure 8. Cumulative value of CO_2 (mg/g) evolved of the peat ecotypes with biochar for 120 days

Figure 9. Percent weight loss of the peat ecotypes with biochar after 120 days
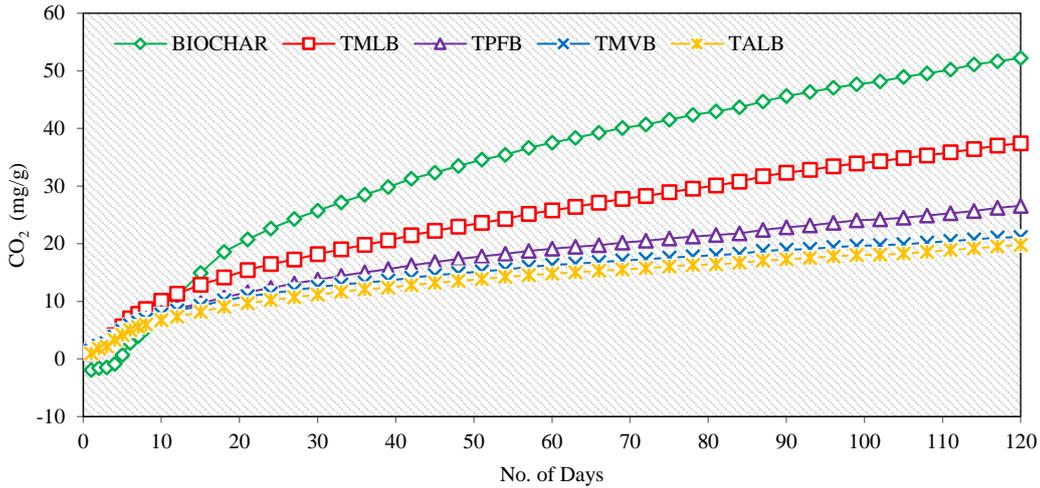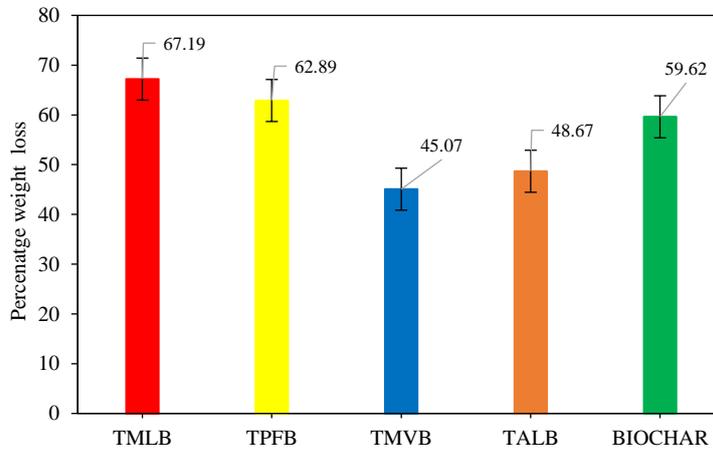
According to the results shown in Table 1, the differences in cumulative CO_2 evolution between the treatments with and without biochar are insignificant (p>0.05) between PF (12.38 CO_2 evolved/g), MV (12.10 CO_2 evolved/g), and AL (9.06 mg CO_2 evolved/g) but significantly different with ML (3.79 CO_2 evolved/g). The highest cumulative CO_2 evolution was observed in ML, both with and without biochar. It may be attributed to its anorexic wet condition compared to other peat ecotypes. It is consistent with Jien et al. (2015) claim that the effects of the initial labile C pool on the cumulative CO_2 emission may vary according to its soil texture and soil pH, which are suggested to be critical control factors in carbon decomposition or CO_2 emission. It was also stated in the study of Shen et al. (2021) that marshlands' carbon sequestration function is critical to slowing climate change and maintaining regional environmental stability. Wetland carbon sequestration capacity is reflected in part by vegetation biomass.

This further coincides with the recent paper of Bobon-Carnice et al. (2023) on the same area where ML rendered the highest C-stocks (15,289.13 mg/ha) among other ecotypes. Therefore, investigating the biomass of marsh vegetation can provide a scientific foundation for estimating marshes' carbon storage and sequestration capacity. It is hypothesized that ML contains organic material that is susceptible to decomposition due to its type of vegetation that is dominated by grasses and sedges, comparing it to PF, which contains trees with higher lignin content, and with MV and AL that is already disturbed and peat is already mixed with mineral soil. The future findings can provide a scientific foundation for accurately evaluating the adaptation actions of wetland ecosystems to climate change and decision support for the adaptive management of wetland ecosystems. In contrast, the lowest cumulative carbon dioxide emission was observed in MV without added biochar.

Table 1. Cumulative value difference of the peat ecotypes with and without biochar

Peat ecotypes	Cumulative value of CO_2 (mg/g) evolved		Cumulative value difference (CO_2 mg/g)
	With biochar	Without biochar	
Marshland (ML)	37.42[a]	33.64[a]	3.79[a]
Peat forest (PF)	26.58[b]	14.20[b]	12.38[b]
Mixed vegetation (MV)	21.14[b]	9.04[b]	12.10[b]
Agricultural land (AL)	19.81[b]	10.76[b]	9.06[b]

*Values with the same letter indicate no significant difference
*Analyzed and evaluated using the 0.05 level Duncan Multiple Range Test (DMRT) ($p < 0.05$)

4. CONCLUSION

The study explored the CO_2 evolution of different peat ecotypes and biochar applications to test if biochar can inhibit the decomposition and release of CO_2. Results revealed that TMLB (37.42 mg/g) rendered the highest cumulative CO_2 evolved, followed by TPFB (26.58 mg/g), TMVB (21.14 mg/g), and TALB (19.81 mg/g), comparing it to treatments without biochar (ML=33.64 mg/g; PF=14.20 mg/g; AL=10.76 mg/g; and MV=9.04 mg/g). This study implies that biochar accelerates CO_2 evolution, and treatments without biochar application render CO_2 less evolved. Moreover, TPF (79.83%) and TML (77.51%) rendered the highest weight loss percentage. The same ecotypes rendered the highest weight loss percentage with biochar application (TMLB=67.19%; TPFB=62.89%). These results are essential in comprehending peatland ecosystems' decomposition and carbon dynamics. Further, one of the novel elements of this research is the emphasis on applying biochar in peat soil. Previous biochar and soil carbon sequestration research has primarily concentrated on agricultural soils or other non-peat ecosystems. It has shown that biochar has the potential to sequester carbon in other ecosystems, but explicitly in peatlands. This study further suggests that long incubation time, field study application, and exploring different biochar compositions should be studied to understand its decomposition dynamics when applied to peat. Thus, its effectiveness in mitigating greenhouse gas emissions and carbon sequestration in peat soils is relatively uncertain.

ACKNOWLEDGEMENTS

AUTHOR CONTRIBUTIONS

Bobon-Carnice, P.A.B.: Supervision, Conceptualization, Investigation, Methodology, Experiment, Validation, Formal Analysis, Visualization, Writing - Revise and Editing. Socias, G.N.: Supervision, Investigation, Methodology, Experiment, Validation, Formal Analysis, Visualization. Corcilles, M.Y.S.: Conceptualization, Investigation, Experiment, Visualization, Formal Analysis, Writing - Original Draft. Abaño, T.K.B.: Conceptualization, Investigation, Methodology, Experiment, Formal Analysis. Espanta, U.M.H.: Conceptualization, Investigation, Methodology, Experiment, Visualization.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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