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Effects of Different Biomass Waste Applications on Carbon Dioxide (CO_2) Emission Rates in Clay Loam Soil

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Abstract. *Organic materials begin to decompose when residues are added to the soil, resulting in the emission of different gases, mainly CO_2, depending on microbial activities associated with soil moisture and temperature. A laboratory experiment was conducted to determine the C release from the decomposition of biomass often utilized for organic fertilizer production by measuring the evolution of CO_2. The treatments of the CO_2 incubation were: T1-Control (Soil alone), T2-rice straw (RS), T3-carbonized rice hull (CRH), T4-RS + CRH, T5- air-dried poultry manure (APM), T6-APM + CRH, T7-synthetic fertilizer (SF) and T8-SF + CRH. Results show that the cumulative CO_2 emissions from different treatments were higher than the control. A faster rate of CO_2 release was observed in the first seven days, with a peak at Day 2, and decreased after that in all treatments during the five-week incubation period. The cumulative CO_2 emissions of all treatments in descending order are as follows: T2, T4, T6, T5, T8, T7, T3, and T1. The lowest CO_2 emissions were noted in the control and CRH, while the highest was from RS and PM. Findings such as these can be assumed that the slower release of CO_2 from CRH can be considered a climate-smart soil management strategy for reducing CO_2 emission from the soil.*

Keywords: carbon dioxide, CO_2 emission, organic materials, biomass wastes

1. INTRODUCTION

Crop leftovers after harvesting are considered biomass wastes, and when they decompose, they add a sizable amount of organic matter to the soil. Biomass breakdown is a natural process that aids in converting organic source materials into forms that plants can absorb. However, the amounts of agricultural waste generated by more efficient production methods are growing faster than the rate of natural breakdown. In addition to producing 15.2 million tons of rice annually, the Philippines also produces 11.3 million tons of rice straw [1]. Most rice biomass is still discarded carelessly despite its many known applications. The Philippines' yearly rice hull production is estimated to be at 2 million tons. It is mainly underutilized, a poor source of animal feed, and is frequently burned, posing risks to people and the environment. Moreover, poultry manures from broiler and layer chickens are most common in the Philippines [2]. The poultry industry generates enormous amounts of waste. Most wastes generated by poultry are animal manures, which contain feces and urine and contribute to environmental pollution [3]. Excessive agricultural waste poses a serious issue because of its potentially adverse environmental impacts if improperly managed. One of the challenges of dealing with agricultural wastes is the high C/N that take longer to decompose, making them not readily applicable to soil as fertilizers. Consequently, biomass waste deposition proceeds at a higher rate than decomposition, creating problems when not contained and managed [4].

There have been several types of research performed to develop proper management strategies for the utilization of organic raw materials. However, the factors that influence the decomposition pattern require an understanding of how each constituent element interacts. Currently, many existing composting technologies aim to convert raw materials into organic matter that can be used in agriculture effectively. However, in most cases, organic matter production has been restricted at higher C/N ratios of biomass wastes. There should be a proper balance of C and N if decomposition is to proceed rapidly. Worldwide, food production has been pressured by increasing land degradation, high input costs, climate change, etc.[5]. Sustainable production using organic fertilizers can address the increasing fertilizer prices and amend the degraded soils. Organic matter has numerous beneficial effects when added to the soil. They increase soil fertility, provide a balanced supply of nutrients, and build up OM. However, these beneficial effects are dependent on the nature of materials, their nutrient content, and the process of their decomposition in the soil [6]. In this connection, using the advancement of science and technology, and innovation for sustainable development are needed to enhance organic fertilizer production while preserving the environment [7].

Research shows that the application of OM improves the rhizosphere ecosystem, suppresses soil-borne pathogens, and promotes plant growth [8]. Furthermore, organic fertilizers such as composts have a considerable effects on the soil's physical properties, such as structure, bulk

density, porosity, and others [9]. Composting is also a good approach to attaining improved and sustainable agricultural productivity because retrieval of nutrients from plant biomass and animal manure through composting enhances crop yields [5]. Organic matter content is one of the indices of soil fertility. It increases the nutrient retention capacity of the soil, thus increasing the supply and availability of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and other nutrients. These are the soil nutrients needed by plants in large quantities to maintain their metabolic processes and overall good state [10].

Despite the known benefits of OM and the growing body of research on composting and biomass waste utilization, there remains a limited understanding of how different biomass wastes particularly those with varying carbon-to-nitrogen (C/N) ratios affect decomposition rates and CO_2 emissions when applied in the soil. Most existing composting technologies do not adequately address the imbalance in C/N ratios, which impede efficient decomposition and organic fertilizer production. Furthermore, while organic amendments are known to influence soil health and crop productivity, their role in greenhouse gas emissions, particularly CO_2, has not been fully quantified or compared across different biomass types. This study addresses this gap by examining the chemical properties of biomass wastes and measuring soil CO_2 emissions following their application.

Soil microorganisms decompose organic matter, releasing CO_2 through respiration. Also, different organic amendments can result in varying levels of CO_2 emissions while higher application rates of organic amendments can lead to increased CO_2 emissions from the soil [11]. There is a worldwide consensus on the use of biological technology for the treatment of organic wastes. Composting, for instance, is utilized for aerobic biological stabilization of different increasing organic wastes. Composting, on the other hand, is inherently generating CO_2 and other greenhouse gases [12]. Therefore, it is essential to investigate the C released from the biomass to determine the magnitude of CO_2 emitted from the soil with different biomass waste applications. The objectives of this study were as follows: 1) determine the chemical properties of biomass wastes and 2) measure CO_2 emissions from the soil applied with the different biomass wastes.

2. MATERIALS AND METHODS

2.1. Soil Collection

The clay loam soil from the uncultivated area inside Scheide Farm, Silliman University College of Agriculture was used in the experiment. The topsoil (up to 30 cm depth) was collected and air-dried. After it was air-dried, it was cleaned, and all organic debris and stones were removed and sieved (2 mm).

2.2. CO_2 Emission Measurement Setup

The mason jar (500mL) with a 10 cm height and 8 cm diameter dimension was used in the incubation of samples. Fifty (50) g of soil was placed in the mason jar, and soil moisture was preserved at 45% field capacity water-soil (w/w) throughout the incubation time. The opening of each jar was covered with plastic and squeezed with a rubber band before the glass jar cap was tightly covered. The glass jar was sealed to prevent leaking gasses from the decomposing materials (Figure 1). All the treatments were replicated thrice per titration at 2, 5, 7, 21, 28, and 35 days [13].

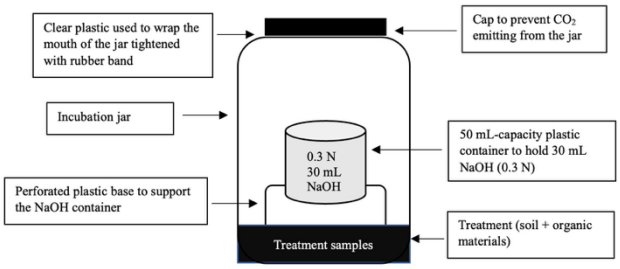

Figure 1. CO_2 incubation setup.

2.3. CO_2 Emission Determination by Titration

During the incubation period, the NaOH contents of incubation jar samples were transferred from a 50 mL plastic container to a 125 mL Erlenmeyer flask and two to three drops of phenolphthalein and 1.0 mL of 50% $BaCl_2$ were added. The CO_2 that evolved was calculated using the data gathered through titration on Days 2, 5, 7, 14, 21, 28, and 35, and the results were reported as mg CO_2 produced per 100 g soil. The CO_2 evolved was calculated using the following formula:

$$mg\ of\ CO2 = \frac{[(B-V)xN/2]xM}{T}\ x\ 2 \qquad (1)$$

where mg of CO_2 is the amount of CO_2 emitted per 100 grams of soil, B/V is the volume of HCl (mL), N is the HCl concentration (eq L^{-1}), and M is the molecular mass of CO_2 (44 g mol^{-1}), T is time in days, and 2 is the coefficient.

2.4. Chemical Analyses

The clay loam soil was analyzed for pH at a soil-water mixture ratio of 1:1 (w/v) using a glass electrode pH meter [14], OC by the Walkley and Black method [15] [16], available P using the Olsen method [17], and exchangeable K using a flame photometer [18] [19]. The chemical properties of biomass wastes were analyzed for moisture, OC by the Walkley and Black method [15] [16], total N by the Kjeldahl method [20], total phosphorus (P) by the Vanadomolydate method [21], total K by flame

Photometer [20]. The analyses of all samples were conducted at the ASI, Analytical Service Laboratory, UPLB, Laguna, Philippines.

2.5. Data Analysis

The data gathered in this study that was laid out in a completely randomized design (CRD) was analyzed using one-way analysis of variance and honest significant difference (HSD) to determine the differences between treatment means at a 5% level of significance by HSD uisng the Statistical Tool for Agricultural Research (STAR) 2.0 software developed by the International Rice Research Institute.

3. RESULTS & DISCUSSIONS

3.1. Soil Chemical Properties

The soil used in the study exhibited a nearly neutral pH of 6.9, which is favorable for plant growth and microbial activity. The organic carbon (OC) content was 2.17%, suggesting a moderate level of organic matter, which plays a crucial role in soil fertility and nutrient retention. The available phosphorus (P) was notably high at 115 mg/kg, indicating sufficient nutrient supply for plant uptake. Similarly, the available potassium (K) was also elevated at 0.83 cmolc/kg, contributing to soil fertility and plant health (Table 1).

Furthermore, the soil demonstrated a high cation exchange capacity (CEC) of 27.96 cmolc/kg, which is beneficial for nutrient retention and availability. The dark color of the clay loam soil suggests a high organic matter content, which likely contributed to its elevated CEC. These characteristics indicate that the soil provides a nutrient-rich environment for microorganisms in the CO_2 emission incubation experiment (Table 1).

Table 1: Chemical properties of the clay loam soil used in the CO_2 emission from the incubation experiment.

Properties	Chemical Analysis
pH	6.9
Organic Carbon (OC) (%)	2.17
Available Phosphorus (P) (mg/kg soil, Olsen)	115
Available Potassium (K) (cmolc/kg soil)	0.83
Cation Exchange Capacity (CEC) (cmolc/kg soil)	27.96

total nitrogen (N), total phosphorus (P), total potassium (K), total NPK, and the C/N ratio. For moisture content (%), PM has the highest moisture content (60.00%), indicating a wet material that can enhance microbial decomposition. CRH (13.06%) and RS (7.69%) have significantly lower moisture contents, making them drier materials with slower decomposition rates.

CRH has the highest organic carbon content (44.28%), followed by RS (33.22%), while PM has the lowest (6.64%). This suggests that CRH and RS contribute more to soil organic C, whereas PM is more nitrogen-rich. PM has the highest N content (0.83%), making it a strong N source for plant growth. For total N, CRH (0.74%) and RS (0.65%) contain lower N levels, meaning they primarily function as C sources rather than direct nitrogen fertilizers. However, PM has the highest phosphorus content (1.08%), essential for plant root development while CRH (0.16%) and RS (0.11%) have lower phosphorus content. Potassium (K) content is highest in CRH (0.19%), followed by PM (0.15%) and RS (0.14%), with CRH providing a small but stable potassium contribution to the soil. PM has the highest total NPK content (2.06%), making it the most nutrient-dense material. CRH (1.09%) and RS (0.90%) have lower total NPK values, meaning they contribute mainly to soil organic matter rather than immediate plant nutrition (Table 2).

Carbon-to-nitrogen (C/N) ratio is an important parameter in decomposition. The C/N ratio controls the speed of decomposition, nitrogen availability, and microbial activity. A balanced ratio (20–30:1) is ideal for efficient decomposition, ensuring that both C and N are available for microbial and plant needs [21]. CRH (60:1) and RS (51:1) have very high C/N ratios, meaning they decompose slowly and can temporarily immobilize nitrogen in the soil. PM has a low C/N ratio (8:1), indicating a rapid decomposition and high nitrogen availability for plants and microbes. PM is a fast-releasing nutrient source due to its low C/N ratio and high N, P, and total NPK contents. RS and CRH are primarily organic matter sources, with CRH being the most stable due to its high carbon content and slow decomposition rate. CRH contributes to long-term soil health and structure, while PM is better for immediate nutrient supply (Table 2).

Table 2. Chemical properties of RS, CRH, and PM used in the CO_2 emission from the incubation experiment.

Property	RS	CRH	PM
Moisture (%)	7.69	13.06	60.00
OC (%)	33.22	44.28	6.64
Total N (%)	0.65	0.74	0.83
Total P (%)	0.11	0.16	1.08
Total K (%)	0.14	0.19	0.15
Total NPK (%)	0.90	1.09	2.06
C/N	51:1	60:1	8:1

3.2. CO_2 Emissions

Figure 2 presents the cumulative CO_2 emissions from different treatments over a five-week incubation period. The emissions were measured at multiple time points (Day 2, Day 5, Day 7, Day 14, Day 21, Day 28, and Day 35), with different shades representing each

sampling day. The CO_2 emissions increased rapidly in the first seven days, peaking at Day 2, followed by a gradual decline. All treatments resulted in higher cumulative CO_2 emissions than the control (T1), showing that OM contribute to CO_2 release due to microbial decomposition. The cumulative CO_2 concentrations of the treatments were the following: T6 (APM + CRH) – 256.88 mg (highest emissions); T5 (Air-Dried Poultry Manure - APM) – 255.13 mg; T4 (RS + CRH) – 250.59 mg; T2 (RS) – 249.37 mg; T8 (SF + CRH) – 149.36 mg; T3 (CRH) – 145.36 mg; T7 (Synthetic Fertilizer - SF) – 144.07 mg; T1 (Control - Soil alone) – 89.58 mg (lowest emissions). T2, T4, T5, and T6 showed the highest emissions, which were not statistically significant. This indicates that RS and PM promote significant microbial activity, leading to rapid decomposition while T7 and T8 showed intermediate emissions, statistically different from the highest group but still greater than the control. T3 had significantly lower emissions, such as the control (T1). This suggests that CRH decomposes slowly, thereby reducing CO_2 release.

The treatments without CRH are T1, T2, T5, T7, these treatments include soil alone (T1), (RS, T2), (APM, T5), and synthetic fertilizer (SF, T7). T2 and T5 exhibited high cumulative CO_2 emissions (249.37 mg and 255.13 mg, respectively), indicating that biomass such as RS and PM enhance microbial decomposition and CO_2 release. Intermediate emissions were observed in T7 (SF) (144.07 mg), higher than the control (T1, 89.58 mg) but lower than T2 and T5. T1 had the lowest CO_2 emissions, showing that the absence of organic amendments limits microbial activity and decomposition. The treatments with CRH are T3, T4, T6, T8, these include CRH alone (T3), RS + CRH (T4), PM + CRH (T6), and SF + CRH (T8). T4 (250.59 mg) and T6 (256.88 mg) had emissions comparable to their non-CRH counterparts (T2 and T5), indicating that the presence of CRH did not significantly reduce microbial decomposition when mixed with RS or PM. T8 (SF + CRH, 149.36 mg) had slightly higher emissions than T7 (SF, 144.07 mg), suggesting CRH had minimal effect when paired with synthetic fertilizer. T3 (CRH alone, 145.36 mg) had emissions almost similar to T1 (control), indicating that CRH decomposes slowly and does not contribute significantly to CO_2 release.

Treatments (T2, T4, T5, and T6) had the highest CO_2 emissions, but their differences were not statistically significant, suggesting that RS and PM (alone or with CRH) promote microbial activity similarly. T7 and T8 had moderate emissions, statistically different from the high-emission group but still significantly greater than the control (T1). T3 and T1 had the lowest emissions and were statistically similar, implying that CRH decomposes at a much slower rate, contributing less to CO_2 release.

The addition of CRH (T4 and T6) did not significantly alter the CO_2 emissions of RS and PM treatments, suggesting that these organic amendments drive microbial decomposition regardless of CRH. However, in the study of Park et al. (2016) CO_2 emission at the 5Mg application of CRH was higher about 18.9% than non-treatment [23]. CRH alone (T3) showed similar trend with the control (T1), confirming its slow decomposition rate and reduced CO_2 emissions. Treatments with synthetic fertilizers (T7, T8) had intermediate emissions, demonstrating a statistically significant difference from both the high-emission and low-emission groups. Overall, while CRH does not significantly reduce CO_2 emissions in treatments with high organic inputs (T4, T6), it does contribute to lower emissions when used alone (T3) or with synthetic fertilizer (T8).

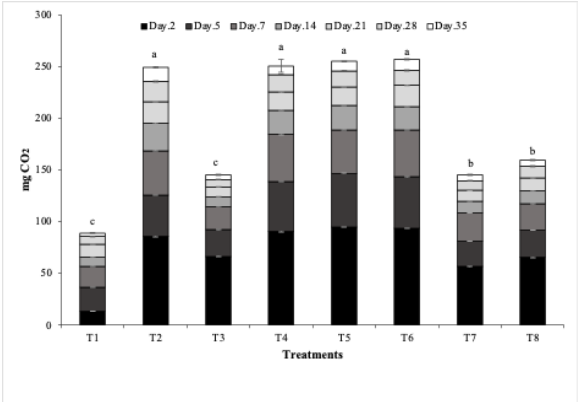

Figure 2. Cumulative CO_2 emissions from different treatments at 2,5,7, 14, 21, 28 and 35 days during theincubation period of biomass waste applications.

4. CONCLUSION

This study highlights the influence biomass wastes applications and organic material composition on CO_2 emissions. The nearly neutral pH, high organic carbon content, and elevated cation exchange capacity of the clay loam soil provide a suitable environment for microbial processes during the incubation. RS and PM demonstrated high decomposition rates due to their OC and N content, resulting in significant CO_2 emissions. The addition of CRH did not significantly alter emissions when combined with high-organic amendments. However, CRH alone exhibited low emissions, like the control, confirming its slow decomposition rate and stabilizing effect on carbon release. Treatments with synthetic fertilizers had moderate emissions, distinct from both high and low-emission groups, indicating a different microbial response compared to organic treatments. The findings suggest that while CRH contributes to long-term soil

health, its role in reducing immediate CO_2 emissions is limited when combined with high-organic inputs.

5. RECOMMENDATION

Based on the findings, it is recommended that future research should prioritize the long-term evaluation of biomass amendments and their effects on soil carbon sequestration, microbial activity, and crop productivity. A more comprehensive understanding also requires investigating non-CO_2 greenhouse gas emissions, nutrient mineralization dynamics, and shifts in microbial community composition. Integrating high C/N ratio materials, such as CRH, with N-rich amendments like PM presents a promising strategy to enhance nutrient availability and improve soil health. Moreover, the adoption of sustainable composting practices, precision nutrient management, and climate-smart agricultural approaches will be essential to optimize carbon sequestration while mitigating greenhouse gas emissions.

6. ACKNOWLEDGEMENT

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