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Carbon Dioxide (CO_2) emissions and ecological effects of biomass composts

Arsenio D. Bulfa Jr.[1,2*] and Jose Edwin C. Cubelo[1]

[1]Silliman University College of Agriculture, Bantayan, Dumaguete City Negros Oriental 6200, Philippines
[2]Graduate School, University of the Philippines Los Baños, College, Laguna, 4031, Philippines
[*]Corresponding author: arseniodbulfa@su.edu.ph

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Abstract

Composts from biomass wastes are a source of plant nutrients and help improve soil quality. An experiment laid out in a split-plot in a completely randomized design was conducted to determine the chemical properties of composts produced from the decomposition of biomass wastes mixtures such as poultry manure + rice straw (PMRS) and poultry manure + carbonized rice hull (PMCRH) with different C:N ratios and their application effects on corn growth, soil chemical properties, earthworm behavior, and CO_2 emissions. Results show that the chemical properties of composts were relatively high; however, increasing the C:N ratio led to reductions in pH, organic carbon (OC), total P, total K, and total NPK. Compost application significantly enhanced corn growth and improved soil chemical properties. Root weight, root length and plant height were significantly increased in both PMRS and PMCRH-treated soils. No significant avoidance behavior was observed among earthworms in compost-treated soils indicating suitability for soil fauna. In the incubation setup, a significant amount of CO_2 was captured in the soil treated with PMCRH. The application of both compost types is recommended as it improved soil health, enhanced plant growth, and was safe for soil organisms. PMCRH compost application is a potential carbon capture and storage strategy that may help reduce CO_2 emissions. This approach supports a sustainable food production system with net carbon sequestration and provides an optimal, localized, and environmentally sustainable biomass waste management solution.

Keywords: composts, CO_2 emission, amendment, carbon sequestration, biomass, wastes

1. Introduction

Biomass wastes are crop residues after harvest that contribute a significant amount of organic matter (OM) in the soil after decomposition. Every year, the Philippines produces 15.2 million tons of rice, leaving behind 11.3 million tons of rice straw [1]. Despite its several documented uses, the majority of rice biomass is still discarded indiscriminately [2]. The Philippines' yearly rice hull production is estimated to be at 2 million tons [3]. 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 [4].

The issue of excessive agricultural waste poses a significant environmental challenge due to its potential adverse impacts if not appropriately managed. The problem in addressing this lies in the high C:N ratios of biomass wastes, which significantly lengthen their decomposition process, rendering them less readily applicable as fertilizers in soil. This imbalance results in the accumulation of biomass at a faster rate than it can decompose, leading to complications when the waste is not effectively contained and managed. Numerous composting technologies aim to convert raw materials into organic matter suitable for agricultural use. Despite these efforts, organic matter production often faces limitations, mainly when dealing with higher C:N ratios in agricultural wastes [5]. Achieving a proper balance between carbon and nitrogen is essential for promoting rapid decomposition. By addressing the challenges posed by high C:N ratios in biomass wastes, decomposition efficiency can be enhanced and contribute to sustainable agricultural practices.

Research shows that the application of OM improves the rhizosphere ecosystem, suppresses soil-borne pathogens, and promotes plant growth (6). 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 (4). These are the soil nutrients needed by plants in large quantities to maintain their metabolic processes and overall good state which can be sourced from composting biomass. Compost application can improve various soil chemical properties that benefit plant growth. Vermicompost has been found to not have negative impacts on the environment, soil, or plants. Composting and vermicomposting processes can reduce the bioavailability of potentially toxic elements in sewage sludge digestate [7].

On the other hand, earthworms play a key role in composting and can significantly impact the soil microbial community. Studies have shown that established earthworm populations can induce shifts in soil microbial diversity. Earthworms also directly impact plant growth and nutrient cycling, largely mediated through changes in the microbial community [8]. Their feeding behavior can further influence soil microbial communities. Indeed, composts from biomass wastes can enhance corn growth, improve soil chemical properties, and influence the behavior and diversity of earthworms, which are important indicators of soil health and fertility [8,9].

However, composting, is inherently generating CO_2 and other greenhouse gases. Hence, it is necessary to investigate the ecological effects of compost produced from biomass wastes with different carbon-nitrogen C:N ratios as decomposition liberates the C from the biomass. It is essential to determine the magnitude of CO_2 emitted from the soil with compost applications. Specifically, this study sought to determine the chemical properties of compost derived from biomass wastes with different C:N ratios, their application effects on CO_2 emissions, corn growth, soil chemical properties, and earthworm behavior.

2. Materials and Methods

2.1 Biomass Waste Mixtures Carbon-Nitrogen (C:N) Ratio Preparations

The preparation of different C:N ratios of poultry manure mixed with shredded rice straw and poultry manure mixed with carbonized rice hull was based on the moisture content, organic carbon, and total nitrogen analyses. In attaining the 15:1, 20:1, 25:1, 30:1, and 35:1 C:N ratios of the mixtures of two materials, the determination of organic carbon, total nitrogen through chemical analysis, and moisture contents were conducted. The organic C, total N, and moisture content data were plugged into the formula adopted from Cornell Waste Management Institute, Cornell University written below [10]. The derived formula was used to determine the volume of another material (kg) Q2 to be mixed to attain the desired C:N.

$$R = \frac{Q1(C1 * (100 - M1) + Q2(C2 * (100 - M2)}{Q1(N1 * (100 - M1 + Q2(N2 * (100 - M2)} \qquad Q2 = \frac{Q1 \ x \ N1 \ x \left(R - \frac{C1}{N1}\right) x \ (100 - M1)}{N2 \ x \left(\frac{C2}{N2} - R\right) x \ (100 - M2)}$$

where *R* is the C:N ratio, *Qn* is the mass of material n ("as is "or "wet weight"), *Cn* is the carbon (%), *Nn* is the nitrogen (%), and *Mn* is moisture content (%) of material n.

Table 1 Rice straw, carbonized rice hull (CRH), and poultry manure (PM) chemical properties.

Biomass wastes	Moisture (%)	Chemical Properties (%)					
		OC	Total N	Total P	Total K	Total NPK	C:N
Rice Straw	7.69	33.22	0.65	0.11	0.14	0.90	51:1
CRH	13.06	44.28	0.74	0.16	0.19	1.09	60:1
Poultry manure	60.00	6.64	0.83	1.08	0.15	2.06	8:1

2.2 Seedling Emergence, Seedling Growth and Earthworm Avoidance Test

The seeds were placed in pots in contact with soil treated with compost produced from biomass wastes with different C:N ratios. The effects were evaluated for 21 days after seedling emergence in the control group and all treated media. The endpoints determined were visual assessment of seedling emergence, biomass measurements, shoot height, and the visibly damaging effects on different plant parts [11].

The two-section avoidance test was performed to determine the C:N ratios of compost on earthworm activity. The test containers were made of a 750 mL black rectangular polypropylene box (120 mm x 175 mm x 55 mm). Removable cardboard divider wall was used to divide the contents of the container into two equal portions. One of the sections was filled with 250 g of uncontaminated soil (control section), and the other with soil added with compost at a specific C:N ratio with the amount based on the standard application rate. Five replicates were prepared for each treatment. In each container, ten adult *Eudrilus eugeniae* (250-600 mg) were placed on the middle line of the soil surface after removing the cardboard divider. Containers were sealed with transparent lids with perforations covered with wire gauze to prevent earthworms from escaping. The media with earthworms were incubated at room temperature for 48 hours. The avoidance rate (AR) was computed as: AR = (CS-TS/N) * 100; where C is the number of earthworms in the control section, T is the number of earthworms in the test section and N is the number of earthworms per replicate [12].

2.3 CO_2 Emission Measurement Setup

The Mason jar (500 mL) 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 organic materials [13]. All the treatments were replicated thrice per titration at 2, 5, 7, 21, 28, and 35 days. During the incubation period, the NaOH contents of incubation jar samples were transferred from the 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 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:

$$mg\ of\ CO_2 = \frac{\left[(B - V)x\frac{N}{2}\right] x\ M}{T}\ x\ 2$$

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/mL), and M is the molecular mass of CO_2 (44 g mol), T is time in days, and 2 is the coefficient [13].

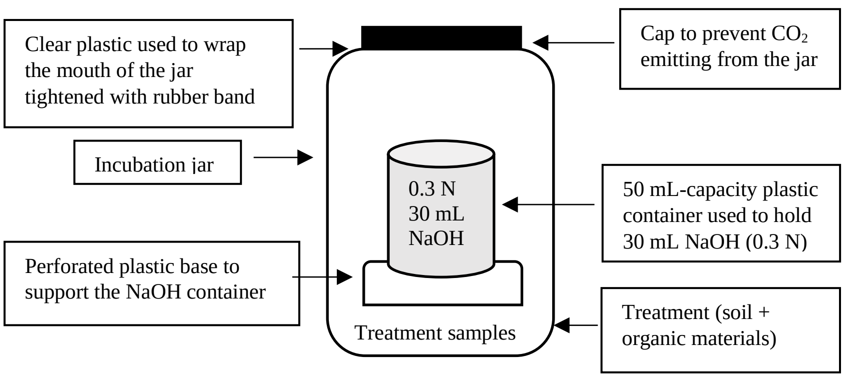

Figure 1 CO_2 incubation setup.

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 (PHS-3C PH METER, model: 2 in 1 Benchtop pH/thermometer by RCYAGO®, China) [14], OC by the Walkley and Black method [15], available P using the Olsen method (UV Spectrophotometer, model: UV-1800 by Shimadzu Corporation, Japan) [16,17], and exchangeable K using a flame photometer [18]. The organic fertilizer was analyzed for pH at a soil-water mixture ratio of 1:1 (w/v) using a glass electrode pH meter, OC by the Walkley and Black method [19], total N by the Kjeldahl method (VELP® Kjeldahl Systems by Scientifica Srl, Italy) [19,20], total phosphorus (P) by the Vanadomolydate method (UV Spectrophotometer, model: UV-1800 by Shimadzu Corporation, Japan) [21], total K by flame photometer (Sherwood Model 410 Flame Photometer by Sherwood Scientific Ltd, United Kingdom) [21]. All analyses of samples were conducted at the ASI, Analytical Service Laboratory, UPLB, Laguna, Philippines.

2.5 Experimental Design

The experiment was laid out in a split-plot in a completely randomized design (CRD). There were five treatments with three replicates for the two compost types, the poultry manure + rice straw (PMRS) and poultry manure + carbonized rice hull (PMCRH) mixtures. Each compost from PMRS and PMCRH with different C:N ratios (15:1, 20:1, 25:1, 30:1, and 35:1) was tested for corn seedling growth at 5 T/ha application rate and earthworm behavior (avoidance test) and carbon dioxide emission at 1:10 (v/v). The amounts of treatments applied are shown in Table 2.

Table 2 Treatments for different composts produced from biomass wastes with different carbon-nitrogen (C:N) ratios at 5 T/ha application rates for growth test, 1:10 v/v for earthworm avoidance test, and CO_2 emission test.

Compost Type	Treatments	C:N Ratios of biomass waste mixtures	Compost applied per incubation jar v/v (1:10) (g)	Compost applied per soil & earthworm medium v/v (1:10) (g)	Compost applied per plant at 5 t/ha. (g)
PMRS	Control	-	-	-	-
	T1	15:1	5	25	94
	T2	20:1	5	25	94
	T3	25:1	5	25	94
	T4	30:1	5	25	94
	T5	35:1	5	25	94
PMCRH	Control	-	-	-	-
	T1	15:1	5	25	94
	T2	20:1	5	25	94
	T3	25:1	5	25	94
	T4	30:1	5	25	94
	T5	35:1	5	25	94

2.6 Data Analysis

The data gathered in this study that was laid out in split plot in a CRD were analyzed using a two-way analysis of variance for composts and treatments within compost types and composts x treatments interaction and honest significant difference (HSD) to determine the differences between treatment means at a 5% level of significance by HSD using the statistical tool for agricultural research (STAR) 2.0 software developed by the International Rice Research Institute.

3. Results and discussion

3.1 Soil Chemical Properties

The soil had a pH of 6.9 which was close to neutral. Corn plants generally prefer slightly acidic soil. The available phosphorus (P) was very high at 115 mg/kg soil. Similarly, the available potassium (K) was high at 0.3 cmol/kg soil. The soil cation exchange capacity (CEC) was very high at 27.96 cmol/kg soil, indicated by its dark color due to the rich organic matter, which likely increased the CEC.

Table 3 Chemical properties of clay loam soil used in growth test, earthworm avoidance, and CO_2 emission incubation.

Properties	pH	OC (%)	Avail. P mg/kg soil (Olsen)	Avail. K cmolc/kg soil	CEC cmolc/kg soil
Clay loam Soil	6.9	2.17	115	0.83	27.96

3.2 Compost Chemical Properties

The chemical properties of composts from PMRS and PMCRH, such as pH, OC, total P, total K, and total NPK, were significantly different. The PMCRH produced from biomass wastes containing the lowest C:N (15:1) ratio had the highest pH and declined as the C:N ratios increased. The same trend was observed in PMRS, where the highest pH was observed in T1 with a mixture containing the lowest C:N ratio and declined as the C:N ratios increased. All treatments in PMRS were significantly different except for T3 and T4, which were not significantly different from each other. All treatments within PMRCH were significantly different from each other.

The organic carbon (OC) from the two compost types (PMRS & PMCRH) was very high and significantly different. In PMRS, T1 and T2 were significantly different from each other but not different compared to T3, T4, and T5. The same observation was noted from compost types in which the highest OC was recorded from composts produced from treatments with the lowest C:N ratios. In PMCRH, T1 was significantly different compared to all treatments, while only T2 and T4 were not significantly different from each other. The average OC in PMCRH treatments was generally significantly higher compared to the PMRS treatments. A significant difference in total N was observed in PMRS treatments but not in PMCRH treatments. In PMRS, T1 was significantly different from all treatments except for T4. However, the total N in PMCRH treatments was significantly higher than in PMRS treatments (Table 4).

The total P for both PMRS and PMCRH was very high and highly significant. A distinct inverse relationship was observed from all treatments in both compost types. The highest total P was noted in the composts produced from treatments with the lowest C:N ratios and decreased as the C:N ratios increased. All treatments within PMRS and PMCRH were significantly different from each other except for T4 and T5 in PMCRH, which were not significantly different. The average total P of all treatments in PMCRH was significantly higher than PMRS (Table 4). A high concentration of total K was observed from PMRS and PMCRH, which was highly significant. All treatments within PMRS and PMCRH were significantly different from each other except for T4 and T5 in PMCRH, which were not significantly different. Although all treatments within compost types had high total K, a decreasing trend of total P was observed from low to high C:N ratios of treatments. Generally, the average total P of all treatments in PMCRH was significantly higher than PMRS (Table 4). The total N, P, and K from PMRS and PMCRH were significantly different. A decreasing trend as the C:N ratio increased was observed from all treatments in both compost types. Specifically, PMCRH, with the lowest C:N (15:1), showed the highest total NPK, similar to PMRS. However, the PMCRH treatments were significantly higher than the PMRS treatments. On the other hand, PMRS had a total NPK ranging from 3.28 to 7.20, with treatments having C:N ratios of 15:1, 20:1, and 25:1 that produced at least 5% total NPK. Notably, all composts produced from PMCRH had a total NPK ranging from 5.65 to 10.33, which the Philippine National Standards for Organic Soil Amendments considered organic fertilizers (Table 4). The final C:N ratios were significantly different. In PMRS, T1 was significantly different compared to T3, T4, and T5, and T4 vs. T5. In PMCRH, T1 was significantly different compared to T2, T3, and T4. Generally, the final C:N of all treatments from the two compost types was lower than 15, ranging from 4:1 to 10:1, with the treatments with the lowest C:N ratio (15:1) in PMRS and PMCRH noted the highest C:N ratio compared to other treatments within compost types. The lower C:N indicates that microorganisms used C for growth and energy during decomposition (Table 4).

Table 4 Chemical properties of composts produced from poultry manure and rice straw mixture (PMRS) and poultry manure and carbonized rice hull mixture (PMCRH) with different C:N ratios.

Composts	Treatment C:N	Chemical Properties						
		pH	OC (%)	Total N (%)	Total P (%)	Total K (%)	Total NPK (%)	Final C:N
PMRS	T1 (15:1)	8.96^{a}	7.61^{a}	1.02^{a}	3.13^{a}	3.05^{a}	7.20^{a}	$8:1^{a}$
	T2 (20:1)	8.03^{b}	6.73^{b}	0.88^{b}	2.62^{b}	2.74^{b}	6.24^{b}	$8:1^{a}$
	T3 (25:1)	$7.31c^{d}$	4.38^{c}	0.82^{b}	1.94^{c}	2.21^{c}	4.97^{c}	$5:1^{bc}$
	T4 (30:1)	7.46^{c}	4.48^{c}	1.05^{a}	1.63^{d}	1.46^{d}	4.14^{d}	$4:1^{c}$
	T5 (35:1)	7.11^{d}	4.57^{c}	0.84^{b}	1.34^{e}	1.10^{e}	3.28^{e}	$5:1^{b}$
PMCRH	T1 (15:1)	9.24^{a}	12.41^{a}	1.19^{a}	3.98^{a}	5.16^{a}	10.33^{a}	$10:1^{a}$
	T2 (20:1)	9.14^{b}	10.02^{c}	1.23^{a}	3.15^{b}	3.95^{b}	8.33^{b}	$8:1^{bc}$
	T3 (25:1)	7.11^{c}	9.30^{d}	1.20^{a}	2.28^{c}	3.16^{c}	6.64^{c}	$8:1^{bc}$
	T4 (30:1)	6.80^{d}	9.87^{c}	1.34^{a}	1.85^{d}	2.59^{d}	5.78^{d}	$7:1^{c}$
	T5 (35:1)	6.31^{e}	11.81^{b}	1.31^{a}	1.79^{d}	2.55^{d}	5.65^{d}	$9:1^{ab}$
Composts x Treatments								
PMRS		a	a	a	a	a	a	a
PMCRH		b	b	b	b	b	b	b
Significance								
Composts		ns	***	**	***	***	***	***
Treatments		***	***	**	***	***	***	***
Composts x Treatments		***	***	ns	***	***	***	***

Values are means (n=3). Different letters indicate significant differences among treatments within compost types ($p \leq 0.05$; HSD Test); * F test significant at ($p \leq 0.05$); ** F test significant at ($p \leq 0.01$); ***F test significant at ($p \leq 0.001$)

3.3 Soil Chemical Properties

There was no distinct trend observed in the soil pH after compost applications; however, some treatments were significantly different. In PMRS treatments, T2 was significantly different compared to T4 and T5. Although T2 was not significantly different from the control, it had the highest soil pH compared to all treatments in PMRS. In PMCRH, T1 and T2 had the highest soil pH, which was significantly different compared to T4 and T5. T2 was slightly higher than the control but not significantly different (Table 5).

The % OC of the test soil was moderate at 2.17. The applications of the two compost types significantly affected the % OC. A decrease of % OC was observed in the control, and a significant increase across all treatments with PMRS and PMCRH additions was noted. In PMRS, T4 and T5 were significantly higher than the control, T1, T2, and T3. In PMCRH, T1 had the highest % OC, which was also significantly higher compared to the Control, T3, T4 and T5. The treatments with the highest % OC increase in PMRS were T4 and T5 at 3.17 and 3.15, respectively. However, in PMCRH, an increase in % OC was observed in compost additions produced with lower C:N ratios, such as T1 and T2, at 3.09 and 2.99, respectively. The highest % OC increase in T4 in PMRS was 46% compared to T1 in PMCRH, which was 41%. Generally, PMCRH treatments increased % OC over the control compared to PMRS treatments (Table 5).

The available phosphorus of the initial test soil was high at 115 ppm. Although the available P was reduced in the control, all other treatments were significantly increased by PMRS and PMCRH applications. A distinct trend was observed in both PMRS and PMCRH applications, in which compost produced from biomass wastes with lower C:N ratios raised the available P the highest and declined as the C:N ratio increased. The treatment with the highest available P in PMRS is at 452 mg/kg soil, a 393% increase compared to the initial test soil and a 402 % increase compared to the control. In PMCRH, the highest is at 329 mg/kg soil, a 186 % increase compared to the initial soil and 265 % compared to the control. Overall, PMRS treatments significantly increased the soil available P more compared to PMCRH treatments. Results such as these suggest that composts produced from lower C:N ratios effectively increase the availability of P in the soil (Table 5).

The exchangeable K of the initial test soil was high at 0.83 cmol/kg soil and decreased in the control. A significant increase in K concentrations was observed in all treatments with PMRS and PMCRH applications. Similar to available P, a distinct trend was observed in both PMRS and PMCRH applications, where compost produced from biomass wastes with lower C:N ratios increased the exchangeable K the highest and declined as the biomass wastes increased. The highest increase in exchangeable K in PMRS treatment was in T1 at 3.87 cmol/kg soil, equivalent to a 366 % increase compared to the initial test soil and 644% compared to the control. In PMCRH, T1 had 3.08 cmol/kg soil, equivalent to a 271% increase compared to the initial test soil and a 492 % increase compared to the control. Overall, PMRS treatments significantly increased the available K more compared to PMCRH treatments (Table 5).

Table 5 Chemical properties of soil after treatment of composts produced from poultry manure and rice straw mixture (PMRS) and poultry manure and carbonized rice hull mixture (PMCRH) with different C:N ratios.

Parameters	Initial C:N of biomass waste mixtures	pH	OC (%)	Avail. P mg/kg soil (Olsen)	Avail. K Cmol/kg soil
Control	-	7.3 ^{ab}	1.99 ^{c}	90 ^{d}	0.52 ^{e}
Soil + PMRS	T1 (15:1)	7.0 ^{bc}	2.38 ^{b}	452 ^{a}	3.87 ^{a}
	T2 (20:1)	7.5 ^{a}	2.32 ^{b}	442 ^{a}	3.14 ^{b}
	T3 (25:1)	7.3 ^{ab}	2.24 ^{b}	332 ^{b}	2.41 ^{c}
	T4 (30:1)	7.2 ^{bc}	3.17 ^{a}	250 ^{c}	2.08 ^{d}
	T5 (35:1)	7.1 ^{bc}	3.15 ^{a}	238 ^{c}	2.15 ^{d}
Control	-	7.3 ^{ab}	1.99 ^{d}	90 ^{d}	0.52 ^{e}
Soil + PMCRH	T1 (15:1)	7.5 ^{a}	3.05 ^{a}	329 ^{a}	3.08 ^{a}
	T2 (20:1)	7.5 ^{a}	2.99 ^{a}	288 ^{b}	2.88 ^{b}
	T3 (25:1)	7.4 ^{ab}	2.58 ^{b}	176 ^{c}	2.28 ^{c}
	T4 (30:1)	7.1 ^{bc}	2.43 ^{c}	79 ^{d}	1.82 ^{d}
	T5 (35:1)	7.0 ^{bc}	2.68 ^{b}	71 ^{d}	1.75 ^{d}
Compost x Treatments					
PMRS		a	a	a	a
PMCRH		a	b	b	b
Significance					
Composts		ns	*	***	***
Treatments (C:N ratios)		*	***	***	***
Composts x Treatments		ns	***	***	***

Values are means (n=3). Different letters indicate significant differences among treatments within compost types ($p \leq 0.05$; HSD Test); * F test significant at ($p \leq 0.05$); ** F test significant at ($p \leq 0.01$); ***F test significant at ($p \leq 0.001$)

3.4 Effect of PMRS and PMCRH on seedling emergence and seedling growth

A significant difference was observed in plant biomass in both PMRS and PMCRH. All the treatments with compost applications yielded higher biomass than the control. In PMRS, T3 had the highest plant biomass, followed by T4, T5, T2, and T1, respectively. T1 was significantly different compared to all treatments except for the control. In PMCRH, T1 and T4 produced the same biomass, followed by T2, T3, and T5, respectively. T1 was significantly higher than the control, and significantly different compared to T2, T3, and T5. Overall, PMRS treatments significantly increased the biomass more than PMCRH treatments (Figure 2(A)).

The root weight was significantly different in both PMRS and PMCRH-treated soils. In PMRS treatments, T4 had the highest root weight, followed by T3, T5, T2, T1, and the control (Figure 2(B)). T4 was significantly different compared to all the treatments. In PMCRH, T1 had the highest root weight, followed by T4, T3, T5, and T2, respectively. T1 was significantly different compared to T5, T2, and the Control. All treatments treated with composts produced a high root weight over the control. Overall, the PMRS treatments were significantly higher than PMCRH treatments. The root length significantly differed in both PMRS and PMCRH treatments (Figure 2(C)). In PMRS, T1, and T4 had the highest root lengths compared to other treatments and the control. T1 was significantly different compared to the Control and T2. In PMCRH, T2 had the highest root length, significantly different from the control. Collectively, PMCRH treatments had longer lengths compared to PMRS. All treatments in PMRS and PMCRH increased the plant height compared to the control. In PMRS, T2, T3, T4, and T5 had comparable plant heights, significantly higher than T2 and the control, respectively. In PMCRH, T2, T3, T4, and T5 had comparable plant heights, significantly higher than T2, and the control. Overall, PMCRH treatments were significantly higher than PMRS treatments (Figure 2(D)).

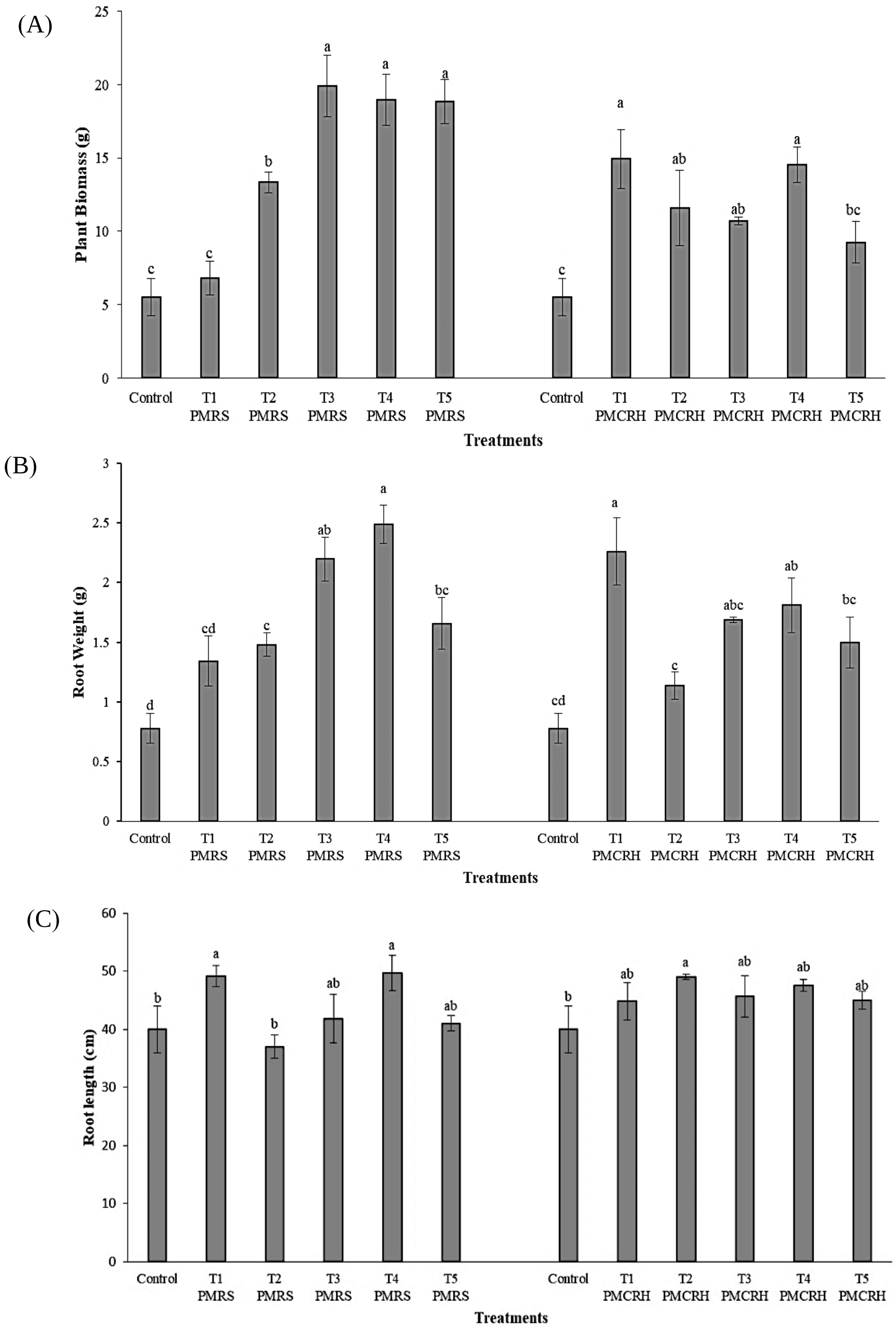

Figure 2 Corn seedling biomass (A); root weight (g) (B); root length (cm) (C); plant height (cm) (D) after PMRS and PMCRH applications. Values are means (n=3) ± standard errors. Different letters above histograms indicate significant differences among treatments within compost types ($p \leq 0.05$; HSD Test); F test significant at $p \leq 0.01$.

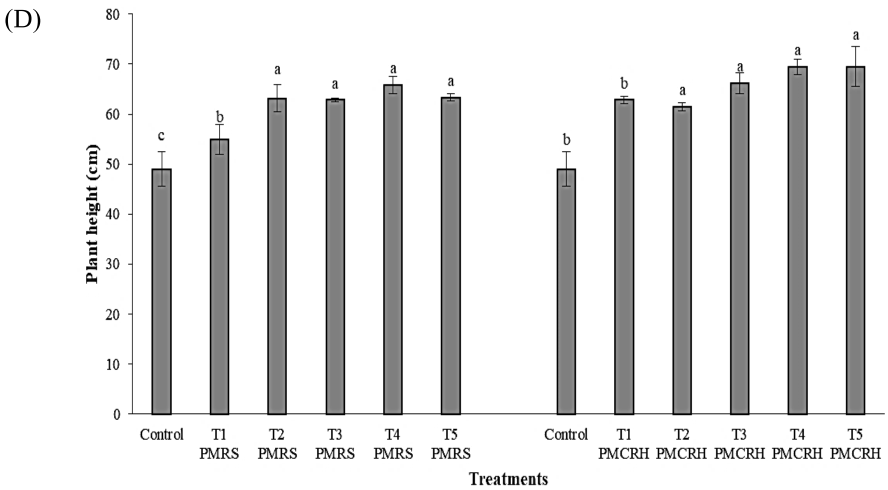

Figure 2 (Cont.) Corn seedling biomass (A); root weight (g) (B); root length (cm) (C); plant height (cm) (D) after PMRS and PMCRH applications. Values are means (n=3) ± standard errors. Different letters above histograms indicate significant differences among treatments within compost types ($p \leq 0.05$; HSD Test); F test significant at $p \leq 0.01$.

In the present study, based on qualitative observations corn produced healthier root with more root hairs when treated with PMRS and PMCRH composts. Treated soils had corn root hairs with white colorations showing active water absorption Also, the corn plants from all treated soils show lush green color compared to the untreated, which were lanky and yellowish.

3.5 Effects of PMRS and PMCRH on earthworm avoidance

The earthworm avoidance test was performed to determine the tendency of *Eudrilus eugeniae* to avoid the applied compost at 10% of the media (v/v) compared to the untreated soil. This is an important indicator to provide information concerning the corresponding response of the test organism to the application of compost. The application rate of 10% (25 g/250 g soil) did not significantly stimulate avoidance in *Eudrilus eugeniae,* while no avoidance was observed in the untreated soil (Figure 3). The average avoidance of earthworms in PMRS-treated soil was 50%, while in PMCRH was 61%. The effective concentration of compost at EC_{10}, did not cause a significant behavioral response in 50 % of the test earthworms. However, PMCRH treatments had relatively higher avoidance compared to PMRS treatments which can be attributed to sudden changes in pH as the treatments had higher pH analyses that also increased the soil pH. Earthworms are considered bioindicators of soil quality as they influence OM decomposition, C:N cycling in the soil, soil porosity, water infiltration, and soil structure [22].

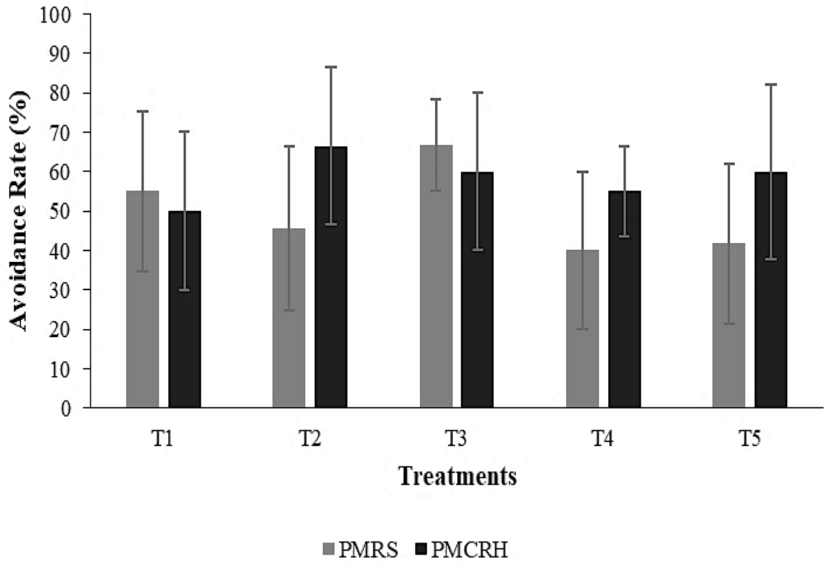

Figure 3 Earthworm avoidance rate on the application of PMRS and PMCRH treatments produced from biomass wastes with different carbon-nitrogen C:N ratios at 1:10 v/v.

3.6 CO_2 emissions from different treatments

Figure 4 shows the cumulative carbon dioxide emissions from different treatments. Results show that a faster rate of CO_2 release was observed in the first seven days, with a peak at Day 2 and reduced after that in all treatments during the five weeks incubation period. The CO_2 emissions of all treatments from the two compost types in descending order are as follows: T1 PMRS (35.15 mg CO_2), T2 PMRS (34.56 mg CO_2), T3 PMRS (27.19 mg CO_2), control (19.62 mg CO_2), T4 PMRS (18.64 mg CO_2), T3 PMCRH (13.59 mg CO_2), T5 PMRS (12.92 mg CO_2), T5 PMCRH (12.76 mg CO_2), T4 PMCRH (9.63 mg CO_2), T1 PMCRH (8.97 mg CO_2), T2 PMCRH (8.24 mg CO_2). In PMRS, T1 had the highest CO_2 evolution, followed by T2, T3, Control, T4, and T5. T1 was significantly higher than the Control, T3, T4, and T5 but not significantly different compared to T2, while T4 and T5 were significantly lower than the control and significantly different from each other. A decreasing emission trend was noted in PMRS as the C:N ratios of biomass wastes increased. In PMCRH, all treatments were significantly lower than the control. The CO_2 emissions of T3 and T5 were comparable and significantly higher than T1, T2, and T4. Overall, PMRS treatments had significantly higher CO_2 emissions than PMCRH treatments. The PMCRH composts show a constant decrease in CO_2 emissions compared to PMRS treatments, which can be related to the carbonized rice hull mixed with poultry manure, which had undergone substantial decomposition that lowered the CO_2 emissions.

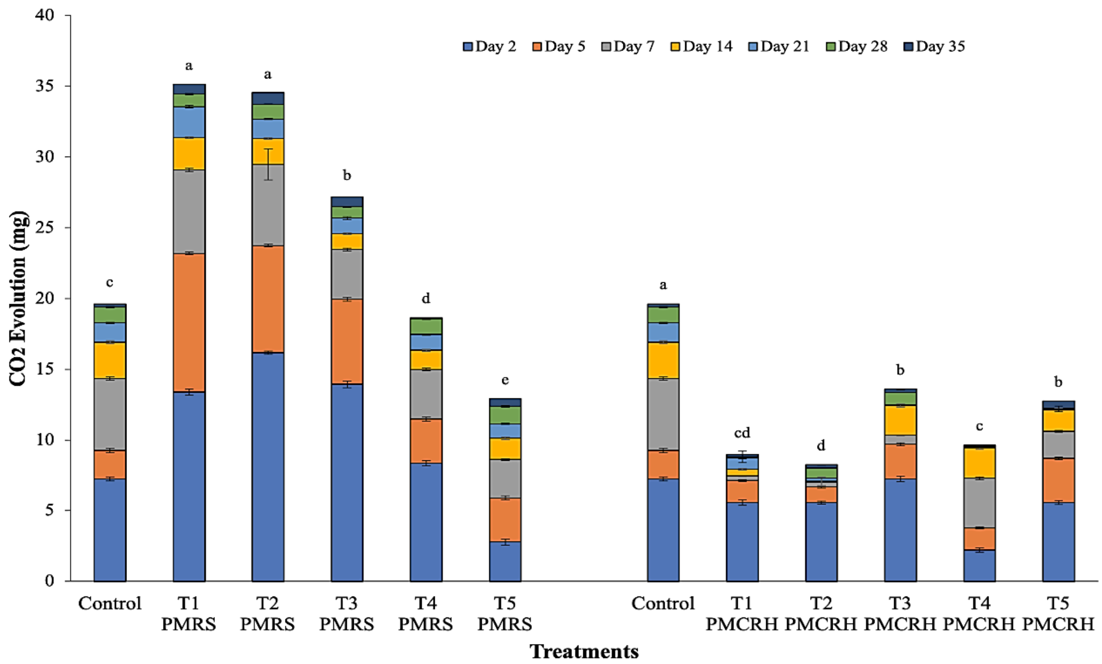

Figure 4 Cumulative CO_2 emission during the 35d incubation period of PMRS and PMCRH compost applications produced from biomass wastes with different carbon-nitrogen C:N ratios.

3.7 Carbon to Nitrogen (C:N) Ratio

The carbon-to-nitrogen (C:N) ratio of organic materials can vary significantly due to several factors such as environmental conditions, intraspecific variability of biomass, type of organic material, stage of decomposition, moisture content, age of biomass, carbon types, etc. The C:N ratio is influenced by the type of organic matter being composted. For example, plant materials like leaves and grass clippings tend to have higher C:N ratios, typically 20:1 to 40:1, while animal manures and food waste have lower C:N ratios, typically 5:1 to 15:1 [23].
The regional variations in environmental conditions can also influence the C:N ratio. For example, differences in temperature, precipitation, and soil type can affect the decomposition rate and C:N ratio of organic matter [23]. There can be intraspecific variability in the C:N ratio within a single species, which can be influenced by factors such as age, growth conditions, and nutrient availability [23]. Some materials have varying C:N ratios due to differences in their composition and the proportion of carbon and nitrogen they contain such as the type of organic material. Different organic materials, such as plant residues, animal waste, and microorganisms, have distinct C:N ratios. For example, sawdust and paper clippings typically have high C:N ratios, while manures and grass clippings have lower C:N ratios [24].

The stage of decomposition can also change the C:N ratio of organic materials as they decompose. For instance, as organic matter breaks down, the C:N ratio tends to decrease due to the conversion of organic carbon to carbon dioxide [24]. The age of the biomass can influence the varied C:N ratio depending on the stage of growth the biomass source. Young plants tend to have higher C:N ratios than older plants, which have more lignin and less carbohydrates [24]. Additionally**,** the types of carbon present in organic materials can also influence their C:N ratios. For example, lignin, a key component of plant cell walls, can have a higher C:N ratio than other carbon sources [24]. Similarly, the moisture content of organic materials can also impact their C:N ratio. Higher moisture cs can lead to anaerobic conditions, which can slow down decomposition and increase the C:N ratio [10].

3.8 Chemical Properties

Based on the chemical analysis, all three biomass wastes held a very high % OC and % total N. The CRH had the highest % OC (44.28), followed by rice straw (33.22) and poultry manure (6.64). Poultry manure had the highest total N (0.83%), followed by CRH (0.74%) and rice straw (0.65%). For the % total P, poultry manure had the highest content (1.08), followed by CRH (0.16) and rice straw (0.11). As expected, CRH had the highest total K (0.19) due to its ash content, followed by poultry manure (0.15) and rice straw (0.14) (Table 1). The two compost types from PMRS and PMCRH had high OC, total N, total P, and total K. Organic carbon in the soil is believed to play a crucial role in many soil functions and ecosystem services [25]. Furthermore, soil organic carbon plays a dynamic role in the global carbon cycle and climate change. Also, when OC is added and stabilized in the soil, it becomes a significant carbon reservoir in terrestrial ecosystems and regulates soil health and productivity [25]. In the present study, applying composts increased the OC and total N, P, and K contents in the soil and improved the growth of the test plants. Song et al. (2015), noted that organic matter amendments increased corn yield and maintained a sustainable increasing trend in corn yield due to the enhancement of soil fertility and resilience to climate changes [25].

The chemical analyses of composts coming from biomass with different C:N ratios can vary significantly as the C:N ratio of the biomass affects the rate and extent of decomposition. Higher C:N ratios indicate a higher proportion of carbon relative to nitrogen, which can lead to slower decomposition rates. Conversely, lower C:N ratios indicate a higher proportion of nitrogen, which can lead to faster decomposition rates [26,27]. The C:N ratio also affects microbial activity. Microorganisms require a balanced C:N ratio to thrive. Higher C:N ratios can lead to nitrogen limitation, which slows down microbial activity and decomposition. Lower C:N ratios can lead to carbon limitation, which can also slow down decomposition. However, if the C:N ratio is too low, nitrogen may be lost from the system, reducing the overall nutrient availability [26,27].

The influence of C:N ratio on temperature and pH conditions within the compost pile affects the resulting compost. Higher C:N ratios can lead to lower temperatures and higher pH values, which can slow down microbial activity. Lower C:N ratios can lead to higher temperatures and lower pH values, which can enhance microbial activity [27]. These factors collectively influence the chemical analyses of composts coming from biomass with different C:N ratios, resulting in varying stages of decomposition, microbial activity, and nutrient availability.

3.9 Corn Growth

The applications of two compost types significantly improved the plant biomass, root weight, and root length. Root weight is a commonly used parameter for root growth studies in response to the environment [28]. Additionally, root length is a widely used indicator for explaining root systems and predicting their response to environmental changes. In the present study, the root length was significantly different. Root absorption of nutrients and water is related to the root length and surface area. In this relation, the root length is a better parameter of root growth in comparing the absorption of water and nutrients [28].

3.9.1 Earthworm Avoidance

In the present study, there was no earthworm mortality after 48 hours. No significant difference was observed in the earthworm avoidance rate between PMRS and PMCRH treatments. This observation suggests that applications of composts produced from biomass wastes with initial C:N ratios ranging from 15:1–35:1 are safe for earthworms. Earthworms play a critical role in the soil system as they modify the soil environment by changing soil characteristics. They can improve soil physical qualities such as bulk density, infiltrability, hydraulic conductivity, porosity, and aggregate stability. Because of this ability, they are the only species that plays a substantial part in pedoturbation. Similarly, their significance in nutrient cycling and organic matter degradation is crucial [29].

3.9.2 CO_2 Emissions

The co-composting of poultry manure and CRH reduced the CO_2 emissions from PMCRH treatments. The average CO_2 emissions from all PMRCH treatments was 10. 64 mg CO_2, while the average for the PMRS treatments was 25.69 mg CO_2 compared to the control with 19.62 mg CO_2. Based on the PMRS treatments' average emissions compared to the control, the difference of 6.07 mg CO_2 per 100 g soil is estimated to be 121.4 kg of CO_2 emitted per 2,000,000 kg soil or 1-hectare furrow slice soil. On the other hand, a net CO_2 sequestration was observed in PMCRH treatments with 8.98 mg CO_2 per 100 g soil is equivalent to 179.6 kg of CO_2 captured per 2,000,000 kg soil or 1 ha furrow slice soil. This observation suggests that applying co-composted poultry manure and CRH will improve soil health, enhance plant growth, and help capture CO_2, a primary greenhouse gas. Research findings mentioned that mixing and composting rice husk biochar in poultry litter with a C:N ratio of 25 helps reduce CO_2 emissions [24]. Similarly, rice hull with amine-functionalized can adsorb a large amount of CO_2 at the highest total amount of CO_2 adsorbed at 25,338.57 mg of CO_2/g [30].

4. Conclusions

This study examined the chemical properties of composts derived from organic biomass wastes with varying C:N ratios and their effects on the morpho-physiological responses of corn, earthworm behavior, and CO_2 emissions associated with compost applications. Findings show that increasing C:N ratios of biomass wastes decreased the pH of the resulting compost but maintained high values of OC, total N, total P, total P, total K, and total NPK content. The application of PMRS and PMCRH improved soil pH, and increased values of OC, available P, and exchangeable K. Additionally, their applications increased plant biomass, root weight, root length, and plant height. The avoidance test revealed that compost applications (10% v/v) did not adversely affect the earthworm populations. All PMCRH treatments resulted in net CO_2 sequestration. The study concluded that co-composting poultry manure and CRH produces an enriched organic soil amendment and offers greater carbon capture potential than conventional biomass composting methods.

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6. Ethical approval

The research was granted ethical clearance by the Silliman University Research Ethics Committee on August 18, 2020 with a grant no. 20200819-0001.

7. Conflicts of interest

The authors declare that they have no conflict of interest.

8. References

[1] Eleria K, Vargas D. Farmers' Extent of Awareness in Rice Straw Proper Disposal and Utlization in Farming Production Activities. SSRN Electron J. 2021; 1:12-13.

[2] Corrales-Ureña YR, Villalobos-Bermúdez C, Pereira R, Camacho M, Estrada E, Argüello-Miranda O, et al. Biogenic silica-based microparticles obtained as a sub-product of the nanocellulose extraction process from pineapple peels. Sci Rep. 2018; 10:8(1):104-117.

[3] Neri Jr AC, Baguhin IA, Cabahug RR. An investigation on the compressive strength of concrete with rice husk ash as cement replacement and addition of chemical admixtures. Mindanao J Sci Technol. 2023;21(1):224-236

[4] Rehman SU, De Castro F, Aprile A, Benedetti M, Fanizzi FP. Vermicompost: Enhancing plant growth and combating abiotic and biotic stress. Agronomy. 2023:16;13(4):11-34.

[5] Bulfa Jr AD, Cubelo JEC. Chemical properties and recovery of vermicompost from mixed shredded leaves and poultry manure using *Eudrilus eugeniae* under different loading schemes. Silliman J. 2022;63(1):2024-2034.

[6] Ayangbenro AS, Chukwuneme CF, Ayilara MS, Kutu FR, Khantsi M, Adeleke BS, et al. Harnessing the rhizosphere soil microbiome of organically amended soil for plant productivity. Agronomy. 2022; 15;12(12):31-79.

[7] Araujo JHR, Pando-Bahuon A, Hartmann C, Aroui-Boukbida H, Desjardins T, Lerch TZ. Making Green(s) With Black and White: Constructing soils for urban agriculture using earthworms, organic and mineral wastes. Front Ecol Evol. 2022; 18:10:884134.

[8] Ahmed N, Al-Mutairi KA. Earthworms effect on microbial population and soil fertility as well as their interaction with agriculture practices. Sustainability. 2022; 27:14(13):7803.

[9] Kamboj N, Kumar A, Kamboj V, Bisht A, Pandey N, Bharti M. Role of earthworm biodiversity in soil fertility and crop productivity improvement. Biol Divers Curr Status Conserv Policies. 2021; 65:230–241.

[10] Ajrd B, Chuang F, Cubelo J, Alvarado MC. Enhancing the chemical properties and recovery rates of organic fertilizer through Carbon-to-Nitrogen (C/N) ratio manipulations of biomass wastes. In: International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 2024; 10:2024-2034.

[11] OECD. Test No. 208: Terrestrial Plant Test: Seedling *Emergence and Seedling Growth Test*. OECD; 2006. (OECD Guidelines for the Testing of Chemicals, Section 2).

[12] Sánchez A, Artola A, Font X, Gea T, Barrena R, Gabriel D, Mondini C. Greenhouse gas emissions from organic waste composting. Environ Chem Lett. 2015; 13:223-238.

[13] Bulfa A, Villegas-Pangga G, Cubelo JE. Corn-cob Biochar characterization and application effects to Carbon Dioxide (CO_2) evolution in acid soil added with different types of fertilizers. Philipp J Sci. 2021;150(5):40-45.

[14] Piper CS. Soil and plant analysis. Scientific Publishers. 2019.

[15] Jackson ML. Soil Chemical Analysis. Englewood Cliffs, NJ: Prentice Hall, Inc. 1958; 46–47.

[16] Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 1945; 59(1):39–46.

[17] Peech M. Determination of Exchangeable Cations and Exchange Capacity of Soils—Rapid micromethods utilizing centrifuge and spectrophotometer. Soil Sci. 1945; 59(1): 5-10.

[18] Black CA, editor. Methods of Soil Analysis: Part 1 physical and mineralogical properties, including statistics of measurement and sampling. Madison, WI, USA: American society of agronomy, Soil Science Society of America; 1965 [cited 2025 Feb 10]. (Agronomy Monographs).

[19] Walkley A. A Critical examination of a rapid method for determining organic carbon in soils effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 1947;63(4)：251-264.

[20] Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 1945;59(1):39–46.

[21] Buladaco MS, Navarro DAG, Sanchez PB, Medina SM. Ecotoxicological effects of chromium (VI) on seedling growth, soil nitrification and earthworm behavior. J Int Soc Southeast Asian Agric Sci. 2020;26(2):106-122.

[22] Singh M, Sarkar B, Sarkar S, Churchman J, Bolan N, Mandal S, Stabilization of soil organic carbon as influenced by clay mineralogy. In: Advances in Agronomy. Elsevier. 2018; 11:33–84.

[23] Grewling T, Peech M. 1960. Chemical soil tests. Cornell University Agricultural Experimentation Station. Bulletin. 1960; 96: 34–36.

[24] Richard T, Trautmann N. C/N Ratio. Cornell Composting, Science and Engineering. Cornell University Ithaca NY Cornell. WMI. 1996; 3:30-50.

[25] Song Z, Gao H, Zhu P, Peng C, Deng A, Zheng C, et al. Organic amendments increase corn yield by enhancing soil resilience to climate change. Crop J. 2015;3(2):110–117.

[26] Macias-Corral MA, Cueto-Wong JA, Morán-Martínez J, Reynoso-Cuevas L. Effect of different initial C/N ratio of cow manure and straw on microbial quality of compost. Int J Recycl Org Waste Agric. 2019;8(S1): 357–365.

[27] Yang H, Zhang H, Qiu H, Anning DK, Li M, Wang Y, et al. Effects of C/N ratio on lignocellulose degradation and enzyme activities in aerobic composting. Horticulturae. 2021; 10;7(11): 40-82.

[28] Chen X, Chen Y, Zhang W, Zhang W, Wang H, Zhou Q. Response characteristics of root to moisture change at seedling stage of Kengyilia hirsuta. Front Plant Sci. 2023 ;6;13:1052-1791.

[29] Alarefee HA, Ishak CF, Othman R, Karam DS. Effectiveness of mixing poultry litter compost with rice husk biochar in mitigating ammonia volatilization and carbon dioxide emission. J Environ Manage. 2023; 329:117-151.

[30] Abang S, Janaun J, Anisuzzaman SM, Ikhwan FS. Development of carbon dioxide adsorbent from rice husk char. IOP Conf Ser Earth Environ Sci. 2016; 36:12-22.