land

MDPI

Article

Effect of Biochar on Composting of Cow Manure and Kitchen Waste

Felicien Sebahire [1,2], Faridullah Faridullah [1,*], Muhammad Irshad [1], Aziz Ur Rahim Bacha [3,4,*], Farhan Hafeez [1] and Jean Nduwamungu [5]

1 Department of Environmental Sciences, COMSATS University Islamabad, Abbottabad Campus, Abbottabad 22060, Pakistan; f.sebahire@ines.ac.rw (F.S.); mirshad@cuiatd.edu.pk (M.I.); drfarhan@cuiatd.edu.pk (F.H.)
2 Department of Civil Engineering, INES-Ruhengeri, Ruhengeri 155, Rwanda
3 State Key Laboratory of Urban Water Resource and Environment, Shenzhen Key Laboratory of Advanced Functional Carbon Materials Research and Comprehensive Application, Shenzhen Key Laboratory of Organic Pollution Prevention and Control, School of Civil and Environmental Engineering, Harbin Institute of Technology Shenzhen, Shenzhen 518055, China
4 Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, China
5 Department of Forestry and Nature Conservation, University of Rwanda, Kigali 210, Rwanda; j.nduwamungu@ur.ac.rw
* Correspondence: faridullah@cuiatd.edu.pk (F.F.); urbaziz17@fudan.edu.cn (A.U.R.B.)

Abstract: Composting is a common method for managing organic waste and creating nutrient-rich soil amendments. Recently, biochar, a carbon-rich material from biomass pyrolysis, has been noted for potentially improving composting. This study examines the impact of adding biochar to compost made from cow manure and kitchen waste through a controlled lab experiment. The treatments were labeled as CMX (cow manure), KWX (kitchen waste), and CMKWX (both) with X being the percentage of CM, KW, and CMKW minus that of biochar in the mixture. Key parameters such as temperature (T), pH, and electric conductivity (EC) were tracked during the composting processes, and the final composts were analyzed for total nitrogen (N), available nitrogen (AN), total phosphorus (TP), available phosphorus (AP), total potassium (TK), organic carbon (OC), calcium (Ca^{2+}), magnesium (Mg^{2+}), and organic matter (OM). The results showed that adding less than 10% biochar influenced composting positively. Specifically, 5% biochar amendment led to higher thermophilic temperatures (45–57 °C) and stable pH levels (6.3–8.7) compared to controls. However, biochar did not significantly enhance EC, which peaked at 1.78 dS/m in both the control and 5% biochar treatments. Nutrient analysis revealed that biochar increased Ca^{2+} (13.62 meq/g) and Mg^{2+} (5.73 meq/g) retention in CM composts (CM85 and CM100). The highest OM content was 16.84% in CM90, while the lowest was 3.81% in CM95. Higher OM negatively affected TN, with CM treatments having more OM and KW treatments having more TN. TP and TK were higher in control treatments without biochar. This study highlights the benefits of integrating biochar with organic waste for enhancing compost nutrient profiles and soil fertility. It was observed that the more diverse the compost feedstock, i.e., CMKW, the higher the nutrient content for treatments containing less than 10% biochar.

Keywords: biochar; composting; nutrients; sustainable farming; cow manure; kitchen waste

Citation: Sebahire, F.; Faridullah, F.; Irshad, M.; Bacha, A.U.R.; Hafeez, F.; Nduwamungu, J. Effect of Biochar on Composting of Cow Manure and Kitchen Waste. *Land* **2024**, *13*, 1545. https://doi.org/10.3390/land13101545

Academic Editors: Naser Khan and Md. Jakariya

Received: 28 July 2024
Revised: 15 September 2024
Accepted: 18 September 2024
Published: 24 September 2024

1. Introduction

Globally, the production of solid garbage has skyrocketed in recent years. Urbanization, population increase, and high living standards are the main causes [1]. Municipal solid waste generation was estimated to be 2 billion tons per year in 2016 and is expected to increase to 3.5 billion tons by 2050 [2]. This underlines the importance of good waste management in reducing environmental impact [1,3]. Population expansion leads to increased consumption and solid waste output, which overwhelms urban garbage systems [4,5].

Inefficient waste management causes environmental pollution, greenhouse gas (GHG) emissions, and climate change [6].

Waste recycling, composting, and energy recovery options may be the answers to this crucial issue. Recent studies say we need integrated waste management systems that prioritize waste reduction, resource recovery, and environmental sustainability [7]. If no proper waste management is put in place, this will put more pressure on environmental components [8,9]. Biomass composting is fantastic for the environment, but it may be linked with challenges such as a slowdown of the composting process, unusual odor due to CO_2 and NH_3 emissions, and increased time in mineralization [10,11]. Recent studies have confirmed that adjusting composting conditions can improve efficiency and public acceptance of composting systems [12]. By adding biochar to compost feedstock, microbial activity can be improved and odor production decreased [13]. Composting is a sustainable way of organic waste management, reducing landfill usage, and improving soil fertility. With 30 million tons produced annually, awareness and adoption of composting practices are increasing [14,15]. Waste composting is increasingly recognized in Africa for its role in waste management and soil health improvement, leading to increased agricultural production. However, Africa only produces 1.5 million tons annually, 5% of global compost production, due to inadequate infrastructure, technical expertise, and policy support [12].

Traditionally, composting is done through piling or pitting the available organic waste. Both of these techniques are simple to implement and not expensive, but they may have issues such as prolonged composting times and compromised compost quality [4,7]. Although some other innovative composting techniques, such as vermicomposting, microbial inoculants, and aerobic composting, are in place, these are just a few compared to the available waste to manage [12,16]. Composting is a sustainable method for managing organic matter (OM) in soil, enhancing its structure, and promoting microbial activity. It reduces the use of harmful chemical fertilizers and improves crop yields. Biochar, a carbon-rich material, can enhance composting conditions by adsorbing contaminants and heavy metals, reducing landfill toxicity. Composting also stabilizes active organic waste, reducing GHG emissions during composting. This approach contributes to the sustainability of the environment and the use of compost in agriculture [17,18]. In compost production and application, biochar contributes to an improved quality compost with better nutrient content, and this enhances both soil and crop qualities [19–21].

In Rwanda, waste composting has the primary objectives of increasing the quality and quantity of crop yield in rural areas and enhancing the greenness of the landscape in urban areas. The growth and development of main crops on Rwandan dishes, vegetables, climbing beans, plantains, maize, and potatoes, are positively enhanced by the application of composts from various sources: agriculture, fecal matter, urine, yard trimmings, etc. [22,23]. Scientifically, composting is among the techniques for solid waste management that are environmentally friendly [24]. Not only does it reduce organic waste accumulation and chemical pollutants, composting also increases soil fertility, reduces the impacts of erosion, and can be used as an option for mitigating greenhouse gas emissions [25,26]. This biological decomposition can be affected by climatic conditions, the nature and proportions in composted organic matter, and the type of composting technique.

Although the production and application of compost is not new in sub-Saharan Africa, much remains to be done in studying the effect of biochar on the decomposition of other compost feedstock. This study aimed to demonstrate the ability of co-composting locally produced biochar with cow manure and kitchen waste in the context of understanding the change in physical parameters (pH, T, and EC) during the composting and in nutrients in the final composts after composting. This was carried out in the north of Rwanda, in the Musanze district, at INES-Ruhengeri University.

2. Materials and Methods

Composting is one of the reliable options for biodegradable solid waste management and it basically happens when aerobic microbes degrade organic matter under controlled conditions. These microbes use oxygen and feed on OM. During composting processes, heat, carbon dioxide, and water vapor are released into the surrounding atmosphere. The end product from composting or compost may be less than half the volume of the original composting materials and this can be used for gardening and agricultural purposes. In this study, kitchen waste and cow manure were collected, respectively, from the INES restaurant and from the nearby high school of Ecole des Sciences de Musanze (E.Sc.M). Fresh kitchen waste, mainly composed of 54% banana peels, 35% potato peels, and 11% fresh vegetables, was first sorted to remove impurities and mixed to ensure homogeneity. Fresh cow manure was collected, put in a big plastic basin, and mixed to ensure proper homogeneity.

2.1. Compost Feedstock Characterization

Compost feedstock characterization is a crucial step in understanding and optimizing the composting process and ensures the production of a high-quality compost product [27]. This involves the evaluation of the physical, chemical, and biological properties of the feedstock to be used in the composting process. A balanced diet for composting microbes, the right moisture and pH, and a good temperature range positively impact the composting processes [28].

2.1.1. Physical Properties

The particle size distribution of the feedstock which influences the aeration and porosity of the compost pile, the density which affects compaction and air movement within the composting pile, and the moisture content that impacts the overall water balance during composting are the main physical properties [27]. Evaluation of the porosity and water-holding capacity in the feedstock is crucial for the composting process as good aeration and proper moisture promote correct organic decomposition [28].

2.1.2. Chemical Properties

pH and EC are chemically critical parameters of the composting process. They directly affect microbial activity, the availability of nutrients in the final compost, and its quality [29]. Initial pH level can also affect microbial activity as compost microbes generally work best in a slightly acidic to neutral pH range: 6.0–8.0, and the main nutrient content in the feedstock is essential to understanding the potential of the end product, as agricultural fertilizers are termed as chemical properties [30–32]. Soluble salts, in terms of Mg^{2+}, Ca^{2+}, and K^{+} concentrations, are directly proportional to the EC values measured in the compost [33]. High EC values are not favorable for microbial metabolism because they indicate a high salinity level. However, moderate EC levels are essential to maintain good conditions for microbial activity, thereby ensuring the availability of important nutrients [34]. When composting materials high in salt, such as kitchen waste and cow manure, knowledge of EC levels is essential in compost production, as steps can be taken to avoid phytotoxic problems on plants after the application of the final compost to the soil [35].

2.1.3. Biological Properties

For efficient composting, high essential microbial content and activity in the feedstock are indispensable. The understanding of composting systems in terms of biological factors is important for the success of treatment operations. Thus, there is a need to check for the existence of pathogens in the composting feedstock and, possibly, how much they are eliminated in the produced compost after composting [36,37].

2.2. Biochar Production

Biochar production involves converting organic materials into a type of charcoal through a process called pyrolysis. Pyrolysis is the decomposition of organic substances at high temperatures in the absence of oxygen. Figure 1 is a simplified breakdown of biochar production as used in this study:

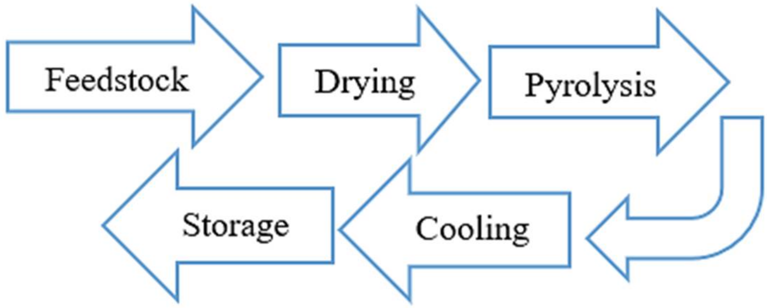

Figure 1. Biochar production was adopted in this study.

Biochar feedstock was selected from wooden sawdust waste. This feedstock was dried to reduce its initial moisture content. Lower moisture levels help in achieving higher temperatures during pyrolysis, which is conducted in a controlled environment, typically at temperatures ranging from 400 to 800 °C in the absence of oxygen to prevent combustion, thus encouraging the production of biochar. The resulting biochar was then cooled rapidly by air cooling to stop the pyrolysis process and then stored [38]. This produced biochar can be used in various applications, such as soil improvement, carbon sequestration, or even as a component in certain types of filters [39,40]. Eucalyptus sawdust was collected from Benjamin's wood workshop and dried in the sun for 3 days. A concentric metallic drum for the production of biochar was fabricated by local metal craftsmen. The drum has an inner part, a metallic barrel with a capacity of 50 L separated by 20 cm with the outer metallic part. The inner part was loaded with well-dried sawdust and the outer part was filled with firewood to fuel the system. The biochar production system was kept between 550 to 650 °C for six hours and the produced biochar was cooled down and kept in airtight plastic bags.

2.3. Composting Experiment

Fifteen composting plastic baskets of 20 L capacity each were installed in a screening house at INES University (Figure 2). Although there are many ways to make compost, our research team opted for perforated composting bins or plastic baskets due to their ease of transportation and air circulation during composting processes. The proportion and detailed composition of kitchen waste, cow dung, and biochar used in the preparation of compost for our research can be found in Table 1.

Figure 2. Composting setup at the INES-Ruhengeri site.

Table 1. Initial composition of compost mixtures.

Composting Unit	Composition in Percent Volume		
	Cow Manure (CM)	Kitchen Waste (KW)	Biochar
Control 1 (CM100)	100	0	0
CM95	95	0	5
CM90	90	0	10
CM85	85	0	15
CM80	80	0	20
Control 2 (KW100)	0	100	0
KW95	0	95	5
KW90	0	90	10
KW85	0	85	15
KW80	0	80	20
Control 3 (CMKW100)	50	50	0
CMKW95	47.5	47.5	5
CMKW90	45	45	10
CMKW85	42.5	42.5	15
CMKW80	40	40	20

2.4. Data Collection Process

Temperature, pH, and electric conductivity were measured at the center of each composting bin every week from 24 July 2023 until the 8th week of composting. At the end of the composting processes, compost samples of 200 g each were taken from respective composting bins for analysis of physicochemical parameters such as pH, OC, OM, Ca^{2+}, Mg^{2+}, TN, TP, AP ($H_2PO_4^-$ + $H_2PO_4^{2-}$), AN (NO_3^{2+} + NH_4^+), and TK.

2.5. Analytical Observations

Weekly temperature values were obtained using a digital thermometer (Reotemp digital thermometer made in the Unites States of America with ± 0.95 ^{0}F accuracy), which was inserted into the center of the composting bin [41]. EC measurement was performed with the extracted compost–water slurry, allowing it to settle, and then using a conductivity meter (Jenway 4510) to read EC values [42]. pH was determined by preparing a 1:5 compost sample to water ratio, followed by pH meter IQ240 calibration and immersion to acquire the pH value [43]. Stabilized compost samples from 15 treatments were air-dried, crushed, and sieved (<0.5 mm) to guarantee homogeneity. These samples were digested in a mixture of duplicate acids (HNO_3 and $HClO_4$). Total elements, i.e., phosphorous, potassium, calcium, and magnesium, in the digested compost samples were determined by atomic absorption spectrophotometer (SP-IAA1800H). Ammonium acetate soluble cations (Ca, Mg, and K) as well as water soluble cations were extracted. The contents of all these elements were determined using an atomic absorption spectrophotometer (SP-IAA1800H). The TC and TN measurements were obtained by dry combustion via an elemental analyzer [44]. AP involved the extraction of phosphorus with sodium bicarbonate and its calorimetric measurement by the Olsen method [45]. AN was obtained by KCl extraction followed by ion chromatography [46].

2.6. Statistical Analysis

The data of physical–chemical parameters were obtained from 15 compost bins. The analytical results were presented as means (n = 3) ± standard error deviation for all assessed composts. The One-Way ANOVA was used to examine group differences with $p < 0.05$ considered as statistically significant.

3. Results

3.1. Temperature Variation

All cow dung and biochar composting treatments were in a mesophilic condition in the first week (Figure 3 Gr1). Thermophilic conditions were obtained in CM95 within week 2, CM100 in week 3, and CM90 in week 2 with respective temperatures of 56, 48, and 43 °C. All temperature variations in Figure 3 Gr1 show that week 5 was the starting of stabilization and curing of compost, although there was not much variation in temperatures when 20% and 15% biochar were applied. In kitchen waste and biochar composting, thermophilic temperatures (53 °C and 47 °C) were more pronounced in KW95 between week 2 and week 4. All kitchen waste and biochar composting treatments attained the stabilization stage at week 6 except the control KW100 (Figure 3 Gr2) which continued to have an increased temperature. In cow manure, kitchen waste, and biochar composting, thermophilic temperatures, 56 °C, and 47 °C were more pronounced in CMKW95 between week 2 and week 4 (Figure 3 Gr3).

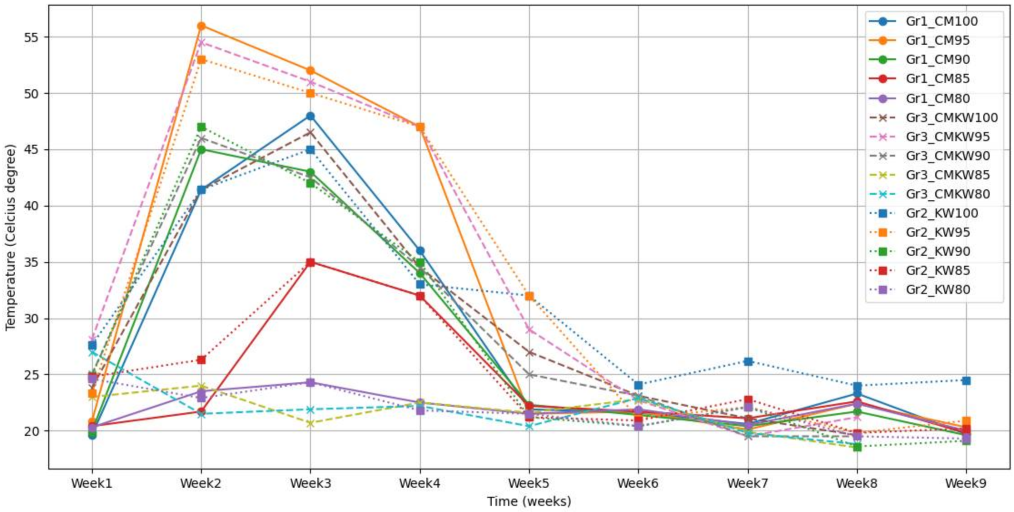

Figure 3. Temperature variation over time in different composting bins. Treatments were grouped into 3 groups: Gr1 or Group 1, treatments made from cow dung with or without biochar (CM80, CM85, CM90, CM95, and CM100); Gr2 or Group 2, treatments made from kitchen waste with or without biochar (KW80, KW85, KW90, KW95, and KW100); and Gr3 or Group 3, treatments made from cow dung + kitchen waste with or without biochar (CMKW80, CMKW85, CMKW90, CMKW95, and CMKW100).

3.2. pH Variation

From week 1 to week 3, the pH increased in all cow dung and biochar composting treatments from 4.5 to 8.5 (Figure 4 Gr1). From the end of the third week to the fourth week, the pH reduced in all treatments and then slightly increased up to the eighth week and reduced in the ninth week. Generally, the pH values of the control treatment CM100 were lower than the values in other treatments except in CM90 in week 2. In all cow dung, kitchen waste, and biochar treatments, the pH increased from the first week to the sixth week with a slight decreased from week 6 to week 8 in CMKW95, CMKW90, CMKW85, and CMKW80 (Figure 4 Gr3). Generally, the pH values of the control treatment in CMKW100 were lower than the values in other treatments except in CMKW85 in week 9. In all kitchen waste and biochar composting treatments as shown in Figure 4 Gr2, the pH increased from week 1 to week 3. In the fourth week, the pH reduced in all treatments and slightly increased up to the eighth week. The pH values of the control treatment in KW100 are lower than the values in other treatments except in KW90 between week 4 and week 6.

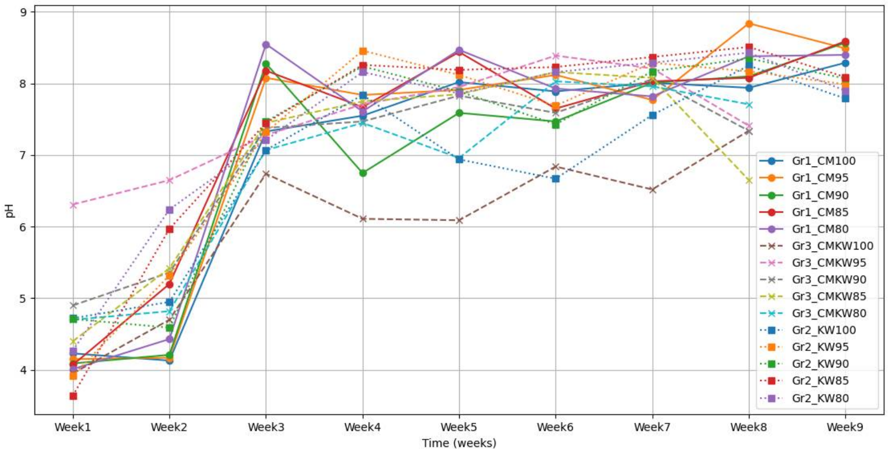

Figure 4. pH variation over time in different composting bins. Treatments were grouped into 3 groups: Gr1 or Group 1, treatments made from cow dung with or without biochar (CM80, CM85, CM90, CM95, and CM100); Gr2 or Group 2, treatments made from kitchen waste with or without biochar (KW80, KW85, KW90, KW95, and KW100); and Gr3 or Group 3, treatments made from cow dung + kitchen waste with or without biochar (CMKW80, CMKW85, CMKW90, CMKW95, and CMKW100).

3.3. EC Variation

From Figure 5 Gr1, all treatments of cow manure and biochar composting have shown a gentle decrease in EC from week 1 to week 7, and the maximum EC value of 1.78 dS/m was observed in CM100. From week 7 to week 9, there was a sharp decrease in EC with a minimum value of 1.52 dS/m in CM80 (Figure 5 Gr1). Control treatment CMKW100 has shown a gentle decrease in EC from week 1 to week 5, whereas CMKW80 and CMKW95 increased between week 1 and week 2 (Figure 5 Gr3). The minimum EC value of 1.53 dS/m was observed in CMKW85. From week 5 to week 7, there was a sharp decrease in EC, and in weeks 7 and 8, another increase was observed in all treatments with a maximum value in CMKW100 (Figure 5 Gr3). All treatments of kitchen waste and biochar composting (Figure 5 Gr2) showed a sharp increase in EC from week 1 to week 2, stabilization between week 2 and week 6, and a sharp decrease between week 6 and week 8. The minimum and maximum EC values of 1.524 and 1.78 dS/m were observed in KW95, respectively, in week 1 and week 6.

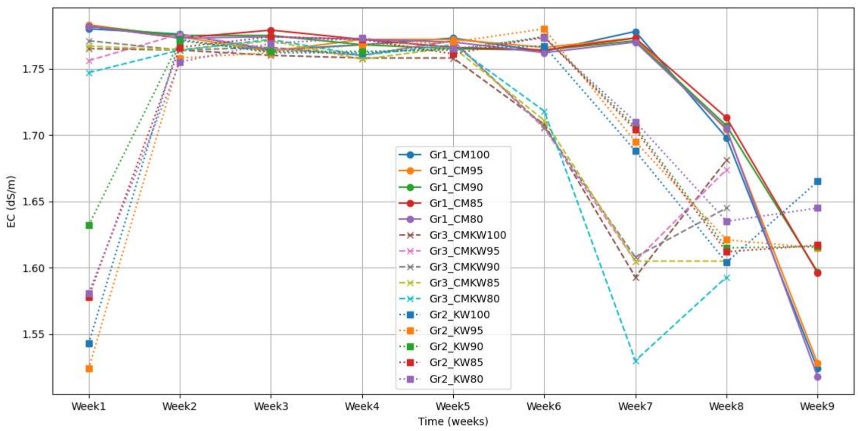

Figure 5. Electric conductivity variation over time in different composting bins. Treatments were grouped into 3 groups: Gr1 or Group 1, treatments made from cow dung with or without biochar (CM80, CM85, CM90, CM95, and CM100); Gr2 or Group 2, treatments made from kitchen waste with or without biochar (KW80, KW85, KW90, KW95, and KW100); and Gr3 or Group 3, treatments made from cow dung + kitchen waste with or without biochar (CMKW80, CMKW85, CMKW90, CMKW95, and CMKW100).

3.4. Chemical Parameter Results after Composting

Table 2 provides the mean values and associated standard deviation errors for pH, OC, OM, Ca^{2+}, Mg^{2+}, TP, AP, TN, AN, and TK across different treatments in final composts. The study data indicate that the pH levels for all treatments are slightly alkaline, ranging from 9.15 to 11.23. The cow dung and biochar treatment (CM80–CM100) show a stable pH of around 9.68 to 10.06, while treatments involving kitchen waste (KW80–KW100) demonstrate slightly higher variability, peaking at 10.87. Organic carbon content shows significant variation among treatments. Cow dung and biochar combination treatments have a broad range from 2.3 to 9.77%. In contrast, the kitchen waste and biochar treatments exhibit more stable OC percentages, with the highest at 7.07% (KW90). Organic matter follows a similar trend to organic carbon, with cow dung and biochar treatments showing higher values, particularly CM90 at 16.84%. Kitchen waste results showed moderate OM values, with a peak at 12.18% for KW90. Calcium levels are relatively high in cow dung and kitchen waste combinations, particularly CMKW85 at 11.71 meq/g. Magnesium content shows notable peaks in CM100 and CMKW95. Phosphorus availability, both TP and AP, is highest in the CM85 treatment. The highest TN was observed in CM85 (11.08%), and the highest AN is in CMKW100 (1.88%). Potassium levels were consistent across treatments, with the highest observed in CM80 and CMKW100.

Table 2. Variation of chemical parameters in finished composts with mean ± standard error (*n* = 3).

Compost Treatment	pH	OC (%)	OM (%)	Ca^{2+} (meq/gr)	Mg^{2+} (meq/gr)	TP (ppm)	AP (ppm)	TN (%)	AN (%)	TK (meq/100 gr)
CM80	9.21 ± 0.03	7.20 ± 0.10	12.41 ± 0.18	12.11 ± 0.17	1.03 ± 0.01	34.8 ± 0.49	30.12 ± 0.43	3.67 ± 0.05	1.02 ± 0.01	1.86 ± 0.03
CM85	9.15 ± 0.10	2.30 ± 0.03	3.96 ± 0.06	13.62 ± 0.19	4.10 ± 0.06	42.71 ± 0.60	36.42 ± 0.52	11.08 ± 0.16	2.16 ± 0.03	2.42 ± 0.03
CM90	9.68 ± 0.05	9.77 ± 0.23	16.84 ± 0.40	7.14 ± 0.17	5.24 ± 0.12	30.96 ± 0.73	28.46 ± 0.67	0.29 ± 0.01	0.08 ± 0.00	0.98 ± 0.02
CM95	10.07 ± 0.14	2.21 ± 0.04	3.81 ± 0.07	7.75 ± 0.15	2.75 ± 0.05	43.64 ± 0.82	32.71 ± 0.62	0.80 ± 0.02	0.16 ± 0.00	0.78 ± 0.01
CM100	9.83 ± 0.06	6.58 ± 0.14	11.34 ± 0.24	5.91 ± 0.13	5.73 ± 0.12	45.18 ± 0.96	30.23 ± 0.64	7.77 ± 0.16	1.03 ± 0.02	2.13 ± 0.05
CMKW80	10.80 ± 0.13	7.03 ± 0.12	12.11 ± 0.20	6.11 ± 0.10	0.16 ± 0.00	40.56 ± 0.67	26.46 ± 0.44	0.48 ± 0.01	0.81 ± 0.01	0.41 ± 0.01
CMKW85	10.05 ± 0.20	6.08 ± 0.07	10.48 ± 0.12	11.71 ± 0.14	0.10 ± 0.00	40.11 ± 0.47	33.15 ± 0.39	3.27 ± 0.04	1.07 ± 0.01	0.78 ± 0.01
CMKW90	10.92 ± 0.08	3.43 ± 0.04	5.91 ± 0.07	7.67 ± 0.09	2.60 ± 0.03	39.45 ± 0.46	30.42 ± 0.36	0.31 ± 0.00	0.26 ± 0.00	0.66 ± 0.01
CMKW95	10.06 ± 0.28	2.61 ± 0.03	4.49 ± 0.05	11.25 ± 0.13	0.97 ± 0.01	38.16 ± 0.45	34.18 ± 0.40	6.73 ± 0.08	1.16 ± 0.01	1.04 ± 0.01
CMKW100	11.23 ± 0.31	2.24 ± 0.05	3.86 ± 0.09	6.07 ± 0.14	3.30 ± 0.08	44.55 ± 1.05	31.48 ± 0.74	10.31 ± 0.24	1.88 ± 0.04	1.22 ± 0.03
KW80	10.07 ± 0.22	2.23 ± 0.04	3.84 ± 0.06	3.39 ± 0.06	1.36 ± 0.02	41.21 ± 0.68	38.66 ± 0.64	6.88 ± 0.11	1.05 ± 0.02	0.99 ± 0.02
KW85	10.24 ± 0.06	6.29 ± 0.07	10.84 ± 0.13	2.36 ± 0.03	2.05 ± 0.02	40.26 ± 0.47	34.62 ± 0.41	3.74 ± 0.04	0.83 ± 0.01	1.28 ± 0.02
KW90	10.63 ± 0.05	7.07 ± 0.08	12.18 ± 0.14	5.45 ± 0.06	1.37 ± 0.02	41.21 ± 0.49	33.12 ± 0.39	5.54 ± 0.07	0.82 ± 0.01	1.23 ± 0.01
KW95	10.50 ± 0.14	2.26 ± 0.03	3.89 ± 0.05	2.11 ± 0.02	5.40 ± 0.06	40.51 ± 0.48	31.51 ± 0.37	2.82 ± 0.03	0.42 ± 0.00	0.74 ± 0.01
KW100	10.87 ± 0.14	5.85 ± 0.14	10.08 ± 0.24	5.91 ± 0.14	2.17 ± 0.05	42.13 ± 0.99	30.58 ± 0.72	2.26 ± 0.05	0.19 ± 0.00	0.69 ± 0.02

3.5. Variability of Chemical Parameters

The boxplots in Figure 6 reveal substantial variability across treatments. pH values are generally alkaline, with the highest median observed in treatments involving CMKW treatments. OC and OM exhibit higher values in KW treatments, indicating improved soil fertility [1]. Ca^{2+} and Mg^{2+} levels vary widely, with notable peaks in specific CM treatments, suggesting these combinations may enhance soil mineral content [47]. TP and AP are highest in CM biochar-amended treatments, highlighting their potential to improve phosphorus availability [48]. TN and AN are highest in CMKW treatments, reflecting better nitrogen content. These findings align with recent studies highlighting the benefits of integrating biochar with organic waste for enhancing soil nutrient profiles and fertility [49]. CM treatments in Figure 6 Gr1 exhibit moderate variability in pH (9.15–10.07), OC (2.3–7.2%), and OM (3.81–16.84%), with a significant range in OM. CMKW treatment Group 3 shows slightly higher variability in pH (10.05–11.23) and moderate variability in OC (2.24–7.03%) and OM (3.86–12.18%). KW treatments demonstrate moderate variability in pH (10.07–10.87) and OC (2.23–7.07%), with a consistent OM range (3.84–12.18%) as shown in Figure 6 Gr2. Ca^{2+} levels in CM and CMKW treatments exhibit moderate variability, while KW treatments show lower variability. Mg^{2+} levels are moderately variable in all treatments. TP shows moderate variability in CM treatments, with slightly lower variability in CMKW. Available phosphorus variability is slightly higher in KW compared to CM and CMKW. TN shows significant variability in CM, moderate in CMKW, and lower in KW. AN variability is moderate in CM and lower in CMKW and KW, while TK exhibits moderate variability in all treatments. The ANOVA test results (Table 3) indicate that, for most parameters, there are no statistically significant differences among the three groups (p-value > 0.05) with exceptions for pH and Ca^{2+}.

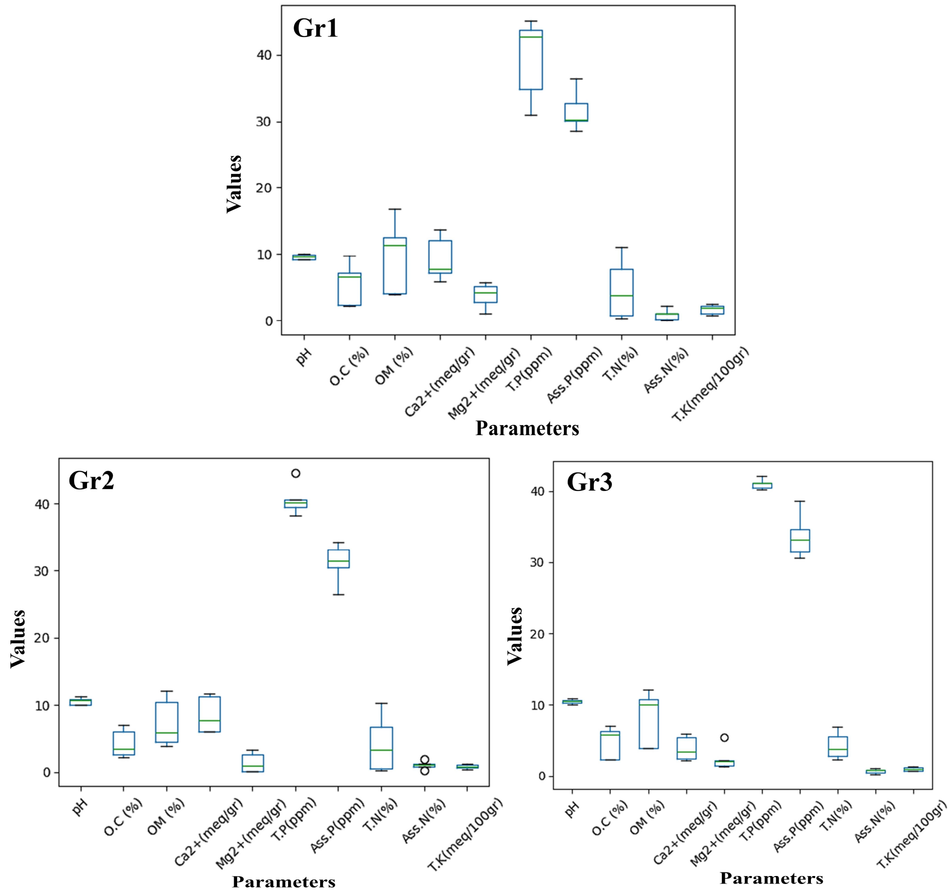

Figure 6. Variability of the chemical parameters (pH, OC, OM, Ca^{2+}, Mg^{2+}, TN, TP, AP, AN, and TK) across all treatments after composting. Treatments were grouped into 3 groups: Group 1 (Gr1), treatments made from cow dung with or without biochar, Group 3 (Gr3) treatments made from cow dung + kitchen waste with or without biochar, and Group 2 (Gr2) treatments made from kitchen waste with or without biochar.

Table 3. Summary of results from One-Way ANOVA test on chemical parameters of finished composts.

Parameter	pH	OC	OM	Ca^{2+}	Mg^{2+}	TP	AP	TN	AN	TK
Standard deviation	0.5912	2.4203	4.1723	3.4184	1.7926	3.5282	2.98	3.4162	0.5809	0.5546
F-statistic test	1.4502	0.1188	0.119	6.6346	0.7264	0.1585	1.2368	0.0097	0.574	1.0438
p-value	0.2621	0.8887	0.8885	0.0074	0.4981	0.8547	0.3152	0.9904	0.5738	0.3736

4. Discussion

Understanding the dynamics of T, pH, and EC is vital in compost production. Optimization and control of these factors determine the composting process efficiency and the quality of the final compost [50,51].

In CM treatment bins at week 1, the temperature was still low, around 19.6–20.8 °C, but in week 2, there was a sharp increase to 56 °C in CM95, particularly. Generally, temperatures above 45 °C facilitate a rapid decomposition of organic matter and pathogen elimination [52]. Thermophilic conditions were obtained in CM95 within week 2, CM100 in week 3, and CM90 in week 2 with respective temperatures of 56, 48, and 43 °C. All temperature variations in CM treatments show that week 5 was the beginning of compost stabilization and curing, although there was not much variation in temperatures for the 20–15% biochar applications. The increase in biochar application would not favor the composting parameters [53]. In KW treatments, thermophilic temperatures (53 °C and 47 °C) were more pronounced, especially for KW95 between week 2 and week 4. These KW treatments achieved the stabilization stage at week 6, except for the control KW100. In CMKW treatments, thermophilic temperatures (47–56 °C) were more pronounced in CMKW95 between week 2 and week 4 [53].

The increase in pH in the CM composting treatments between week 1 and week 4 is attributed to the production and accumulation of ammonia in all treatments [54,55]. Generally, the pH values of the control treatment (CM100) were lower than the values in other treatments except in CM90 in week 2. As confirmed by other studies [56], the pH value of biochar co-composting materials is higher than the pH in the same materials without biochar. In all CMKW treatments with applications of 5 to 20% biochar, pH increased from week 1 to week 6, with a slight decrease from week 6 to week 8. This increase can again be attributed to the production and accumulation of ammonia in these treatments [54,55]. Generally, the pH values of the control treatment (CMKW100) were lower than the values in other treatments except in CMKW85 in week 9. As confirmed by other studies [56], the pH value of biochar co-composting materials is bigger than the pH in the same materials without biochar. The increase of pH in KW treatments between week 1 and week 3 may be attributed to the production and accumulation of ammonia [54,55]. Generally, the pH in co-composting units with biochar must be greater than the same materials composted without biochar [57]. Generally, the pH [7.5, 8.5] in all composting bins except CM 95 and the thermophilic temperatures between week 2 and week 4 explain the rapid organic matter degradation and high microbial activity, having both means rapid composting [52–54].

EC fell marginally in all CM treatments from week 1 to week 7, with the control CM100 having the highest EC value (1.78 dS/m). A significant decrease was seen from week 7 to week 9, with a minimum EC value of 1.52 dS/m in the CM80 treatment. The increase in biochar in all composting treatments contributed to the decrease in EC in all CM treatments as the composting process progressed, elucidating biochar's role in stabilizing organic matter in compost at medium salinity and nutrient absorption [58,59]. Initially, EC values were slightly low in all CMKW treatments, beginning around 1.77 dS/m in week 1. A progressive decrease in EC was seen across the weeks, with a steeper decline in week 7 from 1.59 to 1.61 dS/m. By week 9, the EC continued to fall, particularly in CMKW100 (1.681 dS/m) and CMKW80 (1.59 dS/m). This variance could be attributed to a more complex interaction between cow dung, kitchen trash, and biochar, perhaps resulting in quicker microbial consumption or nutrient depletion [60]. EC values in KW treatments followed a distinct pattern, with lower beginning values in week 1 (1.54 dS/m). This EC steadily rose, culminating around week 6 in KW95 (1.78 dS/m). However, the EC stabilized about week 9, particularly in KW100 (1.67 dS/m) and KW95 (1.62 dS/m). The increase in EC could imply a delayed organic matter decomposition process, in which soluble ions are gradually released as the organic matter decomposes [61].

The study data show that the pH levels for all treatments are somewhat alkaline, ranging from 9.15 to 11.23. Alkalinity, in stabilized compost, is beneficial for nutrient availability and microbial activity in the soil [62]. The pH of the cow dung and biochar treatments (CM80–CM100) is consistent, ranging from 9.68 to 10.06, whereas the pH of the kitchen waste treatments (KW80–KW100) varies slightly more, peaking at 10.87. OM concentration varies significantly among treatments. CM treatments yield a wide range of 2.3 to 9.77% OM. In comparison, the KW treatments have more consistent OC percentages. High OC indicates the possibility to improve soil fertility and structure [63]. OM exhibits a similar pattern to OC, with CM treatments having greater levels, particularly CM90 at 16.84%. This is indicative of enhanced soil microbial activity and better nutrient retention [64].

Ca^{2+} levels are fairly elevated in CMKW treatments, particularly CMKW85 (11.71 meq/g). Mg^{2+} content exhibits considerable rises in CM100 and CMKW95, indicating their capacity to relieve magnesium shortages in soil. Ca^{2+} and Mg^{2+} concentrations are crucial for plant health [33,65,66]. Phosphorus availability (TP and AP) is highest in the CM85 treatment, indicating that cow dung and biochar considerably increase phosphorus concentration. This is vital for root development and energy transfer in plants [67]. TN and AN are critical for plant growth [68]. The highest TN is observed in CM85 (11.08%), and the highest AN is in CMKW100 (1.88%). The variability in these values reflects the differential decomposition rates and nutrient release patterns among treatments. Potassium levels are comparable among treatments, with the greatest being observed in CM80 and CMKW100. This consistency suggests biochar's role in stabilizing potassium content in compost [69]. These findings align with recent research indicating that biochar, when combined with organic wastes like cow dung and kitchen waste, enhances soil properties and nutrient availability. Studies by [70,71] corroborate these results, emphasizing the benefits of biochar in improving soil fertility and plant growth through increased nutrient retention and microbial activity.

The F-statistic for pH is 1.4502 with a p-value of 0.2621, this indicates that there is no significant difference among the groups. This suggests that the composting process stabilized the pH across the different treatments, which is crucial for microbial activity and nutrient availability in compost [72]. The F-statistic for Ca^{2+} is 6.6346 with a p-value of 0.0074, indicating a significant difference among the groups. This suggests that different treatments affected the calcium content in the compost. Calcium is vital for plant growth, and its availability can be influenced by the types of organic waste used [73]. Both OC and OM have very low F-statistics (0.1188 and 0.119, respectively) and high p-values (0.8887 and 0.8885, respectively), showing no significant differences among the groups. This implies that the source of the organic material did not significantly affect the carbon content and organic matter composition of the compost [74]. The F-statistics for other parameters (Mg^{2+}, total P, available P, total N, available N, and total K) range from 0.0097 to 1.2368, with p-values well above 0.05, indicating no significant differences among the groups. The results from different treatments were consistent with a good amount of nutrients.

5. Conclusions

The research findings presented in this study revealed a significant impact of biochar addition in cow manure + kitchen waste compost feedstock. Particularly, the addition of 5% biochar was found to definitely influence thermophilic temperatures and stabilize pH levels, which are essential for effective organic matter breakdown and microbial activity. Based on a detailed analysis of the studied parameters [T, pH, EC, OM, and nutrients (TN, TP, K, OC, Ca^{2+}, and Mg^{2+})], it was obvious that the incorporation of 0 to 10% biochar into composting feedstock has remarkable benefits on the final composts. The inclusion of biochar, particularly in CMKW feedstock compost treatments, generally enhances nutrient content and stability across various parameters in the final composts. During this study, it was revealed that adding biochar reduces variability in compost parameters compared to control compost treatments (CM100, KW100, CMKW100). CM and KW composts showed improved stability in pH, OC, and nutrients, while CMKW exhibited enhanced nutrient content and uniformity. These benefits make biochar a valuable additive for sustainable waste management and soil fertility in Musanze, Rwanda. Further research is needed to optimize biochar application rates and understand the long-term effects on compost quality and soil health, as well as its role in reducing greenhouse gas emissions.

Author Contributions: Conceptualization, F.S. and F.F.; methodology, F.S. and F.F.; validation, F.H.; formal analysis, F.S., A.U.R.B. and F.H.; writing—review and editing, F.S., F.F., M.I., A.U.R.B., F.H. and J.N.; supervision, F.F.; software, F.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors would like to acknowledge the contributions of the World Academy of Science (TWAS) and COMSATS University Islamabad (CUI) in the success of this PhD research. The authors would also like to thank INES-Ruhengeri University for providing laboratory and space facilities for experimentation.

Conflicts of Interest: The authors declares no conflicts of interest.

References

1. Sayara, T.; Basheer-Salimia, R.; Hawamde, F.; Sánchez, A. Recycling of organic wastes through composting: Process performance and compost application in agriculture. *Agronomy* **2020**, *10*, 1838. [CrossRef]
2. Sharma, K.D.; Jain, S. Municipal solid waste generation, composition, and management: The global scenario. *Soc. Responsib. J.* **2020**, *16*, 917–948. [CrossRef]
3. Kaza, S.; Yao, L.; Bhada-Tata, P.; Van Woerden, F. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*; World Bank Publications: Chicago, IL, USA, 2018.
4. Hoornweg, D.; Bhada-Tata, P. *What a Waste: A Global Review of Solid Waste Management*; World Bank Publications: Chicago, IL, USA, 2012.
5. Maalouf, A.; Mavropoulos, A. Re-assessing global municipal solid waste generation. *Waste Manag. Res.* **2023**, *41*, 936–947. [CrossRef] [PubMed]
6. Zhang, D.; Huang, G.; Xu, Y.; Zhou, B. Waste Management Strategies for Urban Sustainability. *Sustain. Cities Soc.* **2022**, *74*, 103–119.
7. Kumar, S.; Singh, R. Advancements in Solid Waste Management: A Review. *Waste Manag. Res.* **2023**, *41*, 215–230.
8. Ayilara, M.S.; Olanrewaju, O.S.; Babalola, O.O.; Odeyemi, O. Waste management through composting: Challenges and potentials. *Sustainability* **2020**, *12*, 4456. [CrossRef]
9. Zorpas, A.A. Strategy development in the framework of waste management. *Sci. Total Environ.* **2020**, *716*, 137088. [CrossRef]
10. Pajura, R. Composting municipal solid waste and animal manure in response to the current fertilizer crisis-a recent review. *Sci. Total Environ.* **2023**, *912*, 169221. [CrossRef]
11. Buda, G. Seven Businesses Using Principles of Circular Economy in Sub-Saharan Africa: Results of Field Research in Uganda. *Hung. J. Afr. Stud.* **2022**, *16*, 5. [CrossRef]
12. Guo, X.X.; Liu, H.T.; Zhang, J. The role of biochar in organic waste composting and soil improvement: A review. *Waste Manag.* **2020**, *102*, 884–899. [CrossRef]
13. Chiappero, M.; Norouzi, O.; Hu, M.; Demichelis, F.; Berruti, F.; Di Maria, F.; Mašek, O.; Fiore, S. Review of biochar role as additive in anaerobic digestion processes. *Renew. Sustain. Energy Rev.* **2020**, *131*, 110037. [CrossRef]
14. Raclavská, H.; Růžičková, J.; Raclavský, K.; Juchelková, D.; Kucbel, M.; Švédová, B.; Slamová, K.; Kacprzak, M. Effect of biochar addition on the improvement of the quality parameters of compost used for land reclamation. *Environ. Sci. Pollution Res.* **2021**, *30*, 8563–8581. [CrossRef] [PubMed]
15. Chen, T.; Zhang, S.; Yuan, Z. Adoption of solid organic waste composting products: A critical review. *J. Clean. Prod.* **2020**, *272*, 122712. [CrossRef]
16. Chen DM, C.; Bodirsky, B.L.; Krueger, T.; Mishra, A.; Popp, A. The world's growing municipal solid waste: Trends and impacts. *Environ. Res. Lett.* **2020**, *15*, 074021. [CrossRef]
17. Lehmann, J.; Joseph, S. *Biochar for Environmental Management: Science, Technology, and Implementation*; Routledge: London, UK, 2015.
18. Laird, D.A.; Rogovska, N. *Biochar and Soil Properties*; Springer: Berlin/Heidelberg, Germany, 2015.
19. Kammann, C.; Ratering, S.; Eckhard, C.; Müller, C. Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. *Agric. Ecosyst. Environ.* **2012**, *144*, 175–187.
20. Schmidt, H.P.; Pandit, B.H.; Martinsen, V.; Cornelissen, G.; Conte, P. Fourfold increase in pumpkin yield in response to low-dosage root zone application of urine-enhanced biochar to a fertile tropical soil. *Agriculture* **2015**, *5*, 723–741. [CrossRef]
21. Agegnehu, G.; Bass, A.M.; Nelson, P.N.; Bird, M.I. Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Sci. Total Environ.* **2016**, *543*, 295–306. [CrossRef]
22. Diogo RV, C.; Bizimana, M.; Nieder, R.; Rukazambuga Ntirushwa, D.T.; Naramabuye, F.X.; Buerkert, A. Effects of compost type and storage conditions on climbing bean on Technosols of Tantalum mining sites in Western Rwanda. *J. Plant Nutr. Soil Sci.* **2017**, *180*, 482–490. [CrossRef]
23. Uwamahoro, L.; Nyagatare, G.; Shingiro, C. Effect of different composts on soil chemical conditions and green bean yield in Bugesera District, Eastern Province of Rwanda. *Agric. Biol. Sci. J.* **2019**, *5*, 132–137.
24. Prajapati, P.; Varjani, S.; Singhania, R.R.; Patel, A.K.; Awasthi, M.K.; Sindhu, R.; Zhang, Z.; Binod, P.; Awasthi, S.K.; Chaturvedi, P. Critical review on technological advancements for effective waste management of municipal solid waste—Updates and way forward. *Environ. Technol. Innov.* **2021**, *23*, 101749. [CrossRef]
25. Abu Qdais, H.; Wuensch, C.; Dornack, C.; Nassour, A. The role of solid waste composting in mitigating climate change in Jordan. *Waste Manag. Res.* **2019**, *37*, 833–842. [CrossRef] [PubMed]

26. Rashid, M.I.; Shahzad, K. Food waste recycling for compost production and its economic and environmental assessment as circular economy indicators of solid waste management. *J. Clean. Prod.* **2021**, *317*, 128467. [CrossRef]
27. Rynk, R.; Schwarz, M.; Richard, T.L.; Cotton, M.; Halbach, T.; Siebert, S. Compost feedstocks. In *The Composting Handbook*; Academic Press: Cambridge, MA, USA, 2022; pp. 103–157.
28. Savage, G.M. The importance of waste characteristics and processing in the production of quality compost. In *The Science of Composting*; Springer: Dordrecht, The Netherlands, 1996; pp. 784–791.
29. Xie, Y.; Zhou, L.; Dai, J.; Chen, J.; Yang, X.; Wang, X.; Wang, Z.; Feng, L. Effects of the C/N ratio on the microbial community and lignocellulose degradation, during branch waste composting. *Bioprocess Biosyst. Eng.* **2022**, *45*, 1163–1174. [CrossRef] [PubMed]
30. Peña, H.; Mendoza, H.; Diánez, F.; Santos, M. Parameter selection for the evaluation of compost quality. *Agronomy* **2020**, *10*, 1567. [CrossRef]
31. Yin, Z.; Zhang, L.; Li, R. Effects of additives on physical, chemical, and microbiological properties during green waste composting. *Bioresour. Technol.* **2021**, *340*, 125719. [CrossRef]
32. Mohammad, A.; Goli VS, N.S.; Barroso, P.M.; Vaverková, M.D.; Singh, D.N. Effect of physico-chemico-biological and operational parameters on composting of organic fraction of municipal solid waste and gaseous products emission. *Environ. Technol. Rev.* **2021**, *10*, 271–294. [CrossRef]
33. Gondek, M.; Weindorf, D.C.; Thiel, C.; Kleinheinz, G. Soluble salts in compost and their effects on soil and plants: A review. *Compos. Sci. Util.* **2020**, *28*, 59–75. [CrossRef]
34. Hou, Y.; Zeng, W.; Hou, M.; Wang, Z.; Luo, Y.; Lei, G.; Zhou, B.; Huang, J. Responses of the soil microbial community to salinity stress in maize fields. *Biology* **2021**, *10*, 1114. [CrossRef]
35. Goldan, E.; Nedeff, V.; Barsan, N.; Culea, M.; Panainte-Lehadus, M.; Mosnegutu, E.; Tomozei, C.; Chitimus, D.; Irimia, O. Assessment of manure compost used as soil amendment—A review. *Processes* **2023**, *11*, 1167. [CrossRef]
36. Ghinea, C.; Leahu, A. Monitoring of fruit and vegetable waste composting process: Relationship between microorganisms and physico-chemical parameters. *Processes* **2020**, *8*, 302. [CrossRef]
37. American Association of Cereal Chemists. *Approved Methods Committee*; American Association of Cereal Chemists: Saint Paul, MN, USA, 2000.
38. Wang, D.; Jiang, P.; Zhang, H.; Yuan, W. Biochar production and applications in agro and forestry systems: A review. *Sci. Total Environ.* **2020**, *723*, 137775. [CrossRef] [PubMed]
39. Marsolla, L.D.; Brito, G.M.; Freitas, J.C.C.; Coelho, E.R.C. *Effect of Pyrolysis Temperature on Biochar and Biochar Composites Produced from Agricultural Biomass and Marble Waste*; Elsevier: Amsterdam, The Netherlands, 2024. [CrossRef]
40. Arslan, E.; Obek, E.; Kirbag, S.; Ipek, U.; Topal, M. Determination of the effect of compost on soil microorganisms. *Int. J. Sci. Technol.* **2008**, *3*, 151–159.
41. Andrade, R.R.; Tinôco ID, F.F.; Damasceno, F.A.; Freitas LC DS, R.; Ferreira CD, F.S.; Barbari, M.; de Jesus Folgôa Baptista, F.; de Rezende Coelho, D.J. Spatial distribution of bed variables, animal welfare indicators, and milk production in a closed compost-bedded pack barn with a negative tunnel ventilation system. *J. Ther. Biol.* **2022**, *105*, 103111. [CrossRef] [PubMed]
42. Chitthaluri, S.; Rao, P.V. Composting of grease trap scum waste and green waste: Studying the effects of mix composition on physicochemical and biological process parameters. *Int. J. Recycl. Org. Waste Agric.* **2023**, *12*, 305–324.
43. Bartusevics, F. The Applicability of a Field pH Meter in a Laboratory Setting: Evaluation of Field pH Meter in Compost and Soil Monitoring as a Resource-Efficient Alternative to Standardised Methodology. Master's Thesis, Tampere University of Applied Sciences, Ampere, Finland, 2022.
44. Pudełko, A.; Chodak, M. Estimation of total nitrogen and organic carbon contents in mine soils with NIR reflectance spectroscopy and various chemometric methods. *Geoderma* **2020**, *368*, 114306. [CrossRef]
45. Li, H.; Zhang, J.; Wang, Y. Comparative Analysis of Four Methods for Accurate Estimation of Soil Phosphorus Storage Capacity: A Case Study in a Typical Red Soil. *Eurasian Soil Sci.* **2024**, *57*, 1163–1175. [CrossRef]
46. Chandra, S.; Medha, I.; Bhattacharya, J. Potassium-iron rice straw biochar composite for sorption of nitrate, phosphate, and ammonium ions in soil for timely and controlled release. *Sci. Total Environ.* **2020**, *712*, 136337. [CrossRef]
47. Chaudhry, A.H.; Nayab, S.; Hussain, S.B.; Ali, M.; Pan, Z. Current understandings on magnesium deficiency and future outlooks for sustainable agriculture. *Int. J. Mol. Sci.* **2021**, *22*, 1819. [CrossRef]
48. Li, F.; Liang, X.; Niyungeko, C.; Sun, T.; Liu, F.; Arai, Y. Effects of biochar amendments on soil phosphorus transformation in agricultural soils. *Adv. Agron.* **2019**, *158*, 131–172.
49. Abdelghany, G. Agronomic Investigations of Australian Native Rice Species to Support Indigenous Enterprise Development in Tropical Northern Australia. Doctoral Dissertation, Charles Darwin University, Casuarina, NT, Australia, 2024.
50. Li, M.; Li, S.; Chen, S.; Meng, Q.; Wang, Y.; Yang, W.; Guo, X.; Shi, L.; Ding, F.; Zhu, J.; et al. Measures for controlling gaseous emissions during composting: A review. *Int. J. Environ. Res. Public Health* **2023**, *20*, 3587. [CrossRef]
51. Ajaweed, A.N.; Hassan, F.M.; Hyder, N.H. Evaluation of physio-chemical characteristics of bio fertilizer produced from organic solid waste using composting bins. *Sustainability* **2022**, *14*, 4738. [CrossRef]
52. Wang, M.; Zhu, J.; Mao, X. Removal of pathogens in onsite wastewater treatment systems: A review of design considerations and influencing factors. *Water* **2021**, *13*, 1190. [CrossRef]

53. Czekała, W.; Malińska, K.; Cáceres, R.; Janczak, D.; Dach, J.; Lewicki, A. Co-composting of poultry manure mixtures amended with biochar–The effect of biochar on temperature and C-CO_2 emission. *Bioresour. Technol.* **2016**, *200*, 921–927. [CrossRef] [PubMed]
54. Li, Y.B.; Liu, T.T.; Song, J.L.; Lv, J.H.; Jiang, J.S. Effects of chemical additives on emissions of ammonia and greenhouse gas during sewage sludge composting. *Process Saf. Environ. Prot.* **2020**, *143*, 129–137. [CrossRef]
55. Xiong, S.; Liu, Y.; Zhang, H.; Xu, S.; Li, S.; Fan, X.; Chen, R.; Ding, G.; Li, J.; Wei, Y. Effects of chemical additives and mature compost on reducing nitrogen loss during food waste composting. *Environ. Sci. Pollut. Res.* **2023**, *30*, 39000–39011. [CrossRef] [PubMed]
56. Teodoro, M.; Trakal, L.; Gallagher, B.N.; Šimek, P.; Soudek, P.; Pohořelý, M.; Mohan, D.; Beesley, L.; Jačka, L.; Kovář, M.; et al. Application of co-composted biochar significantly improved plant-growth relevant physical/chemical properties of a metal contaminated soil. *Chemosphere* **2020**, *242*, 125255. [CrossRef]
57. Sánchez-Monedero, M.A.; Cayuela, M.L.; Sánchez-García, M.; Vandecasteele, B.; D'Hose, T.; López, G.; Martínez-Gaitán, C.; Kuikman, P.J.; Sinicco, T.; Mondini, C. Agronomic evaluation of biochar, compost and biochar-blended compost across different cropping systems: Perspective from the European project FERTIPLUS. *Agronomy* **2019**, *9*, 225. [CrossRef]
58. Sanchez-Monedero, M.A.; Cayuela, M.L.; Roig, A.; Jindo, K.; Mondini, C.; Bolan, N.J.B.T. Role of biochar as an additive in organic waste composting. *Bioresour. Technol.* **2018**, *247*, 1155–1164. [CrossRef]
59. Chen, H.; Awasthi, S.K.; Liu, T.; Duan, Y.; Ren, X.; Zhang, Z.; Pandey, A.; Awasthi, M.K. Effects of microbial culture and chicken manure biochar on compost maturity and greenhouse gas emissions during chicken manure composting. *J. Hazard. Mater.* **2020**, *389*, 121908. [CrossRef]
60. Bello, A.; Deng, L.; Sheng, S.; Jiang, X.; Yang, W.; Meng, Q.; Wu, X.; Han, Y.; Zhu, H.; Xu, X. Biochar reduces nutrient loss and improves microbial biomass of composted cattle manure and maize straw. *Biotechnol. Appl. Biochem.* **2020**, *67*, 799–811. [CrossRef]
61. Kong, X.; Luo, G.; Yan, B.; Su, N.; Zeng, P.; Kang, J.; Zhang, Y.; Xie, G. Dissolved organic matter evolution can reflect the maturity of compost: Insight into common composting technology and material composition. *J. Environ. Manag.* **2023**, *326*, 116747. [CrossRef] [PubMed]
62. Jien, S.H.; Wang, C.C.; Lee, C.H.; Lee, T.Y. Stabilization of organic matter by biochar application in compost-amended soils with contrasting pH values and textures. *Sustainability* **2015**, *7*, 13317–13333. [CrossRef]
63. Chen, M.; Zhang, S.; Liu, L.; Liu, J.; Ding, X. Organic fertilization increased soil organic carbon stability and sequestration by improving aggregate stability and iron oxide transformation in saline-alkaline soil. *Plant Soil* **2022**, *474*, 233–249. [CrossRef]
64. Githongo, M.; Ngatia, L.; Kiboi, M.; Muriuki, A.; Fliessbach, A.; Musafiri, C.; Fu, R.; Ngetich, F. The structural quality of soil organic matter under selected soil fertility management practices in the central highlands of Kenya. *Sustainability* **2023**, *15*, 6500. [CrossRef]
65. Coonan, E.C.; Kirkby, C.A.; Kirkegaard, J.A.; Amidy, M.R.; Strong, C.L.; Richardson, A.E. Microorganisms and nutrient stoichiometry as mediators of soil organic matter dynamics. *Nutr. Cycl. Agroecosyst.* **2020**, *117*, 273–298. [CrossRef]
66. Zhang, X.; Si, J.; Li, Y.; Chen, Z.; Ren, D.; Zhang, S. Effects of Ca^{2+} and Mg^{2+} on Cu binding in hydrophilic and hydrophobic dissolved organic matter fractions extracted from agricultural soil. *Chemosphere* **2024**, *352*, 141441. [CrossRef]
67. Liu, D. Root developmental responses to phosphorus nutrition. *J. Integr. Plant Biol.* **2021**, *63*, 1065–1090. [CrossRef]
68. Ngoc, N.P.; Quynh, L.N.; Ly, L.M.; Thao PT, P.; Van Dang, L.; Em, T.H.; Hung, N.N. Enhancing NPK Uptake and Biomass of Blueberries in Alluvial Clay Soil Using Biochar and Compost. *Open Agric. J.* **2021**, *17*, e18743315278527. [CrossRef]
69. Nguyen, M.K.; Lin, C.; Hoang, H.G.; Sanderson, P.; Dang, B.T.; Bui, X.T.; Nguyen, N.S.; Vo, D.V.; Tran, H.T. Effects of biochar on soil properties and crop yield: A review. *Bioresour. Technol.* **2022**, *358*, 123984.
70. Melo, L.C.A.; Lehmann, J.; Carneiro, J.S.D.S.; Camps-Arbestain, M. Impact of biochar on soil nutrient dynamics and crop productivity: Meta-analysis and future perspectives. *Agric. Syst.* **2023**, *198*, 103391.
71. Chung, W.; Shim, J.; Chang, S.W.; Ravindran, B. Co-composting of agricultural waste with biochar: Influence on nutrient dynamics and greenhouse gas emissions. *J. Clean. Prod.* **2022**, *358*, 132019.
72. Ge, M.; Shen, Y.; Ding, J.; Meng, H.; Zhou, H.; Zhou, J.; Liu, J.; Cheng, H.; Zhang, X.; Wang, J.; et al. New insight into the impact of moisture content and pH on dissolved organic matter and microbial dynamics during cattle manure composting. *Bioresour. Technol.* **2022**, *344*, 126236. [CrossRef] [PubMed]
73. Niamat, B.; Naveed, M.; Ahmad, Z.; Yaseen, M.; Ditta, A.; Mustafa, A.; Rafique, M.; Bibi, R.; Sun, N.; Xu, M. Calcium-enriched animal manure alleviates the adverse effects of salt stress on growth, physiology and nutrients homeostasis of *Zea mays* L. *Plants* **2019**, *8*, 480. [CrossRef] [PubMed]
74. Wu, J.; Zhang, A.; Li, G.; Wei, Y.; He, S.; Lin, Z.; Shen, X.; Wang, Q. Effect of different components of single superphosphate on organic matter degradation and maturity during pig manure composting. *Sci. Total Environ.* **2019**, *646*, 587–594. [CrossRef] [PubMed]