agronomy

Article

Efficiency of Rice Husk Biochar with Poultry Litter Co-Composts in Oxisols for Improving Soil Physico-Chemical Properties and Enhancing Maize Performance

Hamed Ahmed Alarefee [1,2], Che Fauziah Ishak [1], Daljit Singh Karam [1,*] and Radziah Othman [1]

[1] Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, Serdang 43400, Malaysia; hamedalarefee@gmail.com (H.A.A.); cfauziah@upm.edu.my (C.F.I.); radziah@upm.edu.my (R.O.)
[2] Department of Soil and Water, Faculty of Agricultural and Veterinary Sciences, University of Zawia, Zawia P.O. Box 16418, Libya
* Correspondence: daljitsingh@upm.edu.my

Abstract: Efficient use of co-composted organic manure with biochar is one of the sustainable management practices in an agriculture system to increase soil fertility and crop yield. The objectives of this research are to evaluate the use of co-composted biochar, biochar in formulation with poultry litter (PL), and PL compost on soil properties and maize growth. Organic amendments were applied at 10 Mg ha^{-1}, and synthetic fertilizer was applied at the recommended rate of maize (N: P_2O_5: K_2O at 60:60:40 kg ha^{-1}). The results showed that addition of organic amendment significantly increased the total biomass parameter compared to the control, which ranged from 23.2% to 988.5%. The pure biochar treatment yielded lower biomass than the control by 27.1%, which was attributed to its low nutrient content. Consequently, the application of the co-composted biochar achieved higher plant height and aerial portion, which ranged from 46.86% to 25.74% and 7.8% to 108.2%, respectively, in comparison to the recommended fertilizer rate. In addition, the soil amended with co-composted biochar had a significant increase in soil organic matter and had significantly higher chlorophyll and nutrient concentrations in plants, which increased with an increase in the biochar ratio of the co-composts. This was probably attributed to the release of the nutrients retained during composting, thereby possibly making the co-composted biochar act as a slow-release fertilizer. In conclusion, the addition of organic manure with biochar enhanced the nutrient supply by gradual release in comparison to the mineral fertilizer.

Keywords: co-composted biochar; rice husk biochar; ratios of poultry litter or compost to biochar; maize performance; acidic tropical oxisols

check for updates

Citation: Alarefee, H.A.; Ishak, C.F.; Karam, D.S.; Othman, R. Efficiency of Rice Husk Biochar with Poultry Litter Co-Composts in Oxisols for Improving Soil Physico-Chemical Properties and Enhancing Maize Performance. *Agronomy* **2021**, *11*, 2409. https://doi.org/10.3390/agronomy11122409

Academic Editors: Othmane Merah, Purushothaman Chirakkuzhyil Abhilash, Magdi T. Abdelhamid, Hailin Zhang and Bachar Zebib

Received: 20 October 2021
Accepted: 24 November 2021
Published: 26 November 2021

1. Introduction

Deficiency of nutrients and depletion of organic matter, as well as reduced quality and fertility of soil have been regarded as primary factors that lead to decreased food security and crop production [1,2]. Such issues are dominant in tropical and arid soils that are then worsened by mounting pressure toward land use, with extensive cultivation to raise the crop yield as a result of food demand and population growth [3,4]. Increasing global food insecurity has been attributed to climate change, resulting from rising temperatures and increasing carbon concentrations in the atmosphere [5]. Moreover, the increasing loss of soil's organic carbon as well as soil erosion worldwide has been attributed to a change in land use. Likewise, intensive agricultural practices have impacts on levels of organic matter and nutrient status [6]. Soil quality decline represents a significant constraint on the productivity and sustainability of agriculture in the tropics, threatening the sustainability of agricultural production [7]. In tropical areas, most agricultural soils are greatly weathered and belong to the order of ultisols and oxisols, which make up approximately 20% and 23%

of global tropics, respectively [8]. Oxisols and ultisols make up a good percentage (72%) of soils of Malaysia, and they are characterized by low fertility, deficiency in soil nutrients and soil organic matter, and exchangeable bases due to their high weathering [9]. For improved productivity of such poor soils, intensive synthetic fertilizer usage becomes inevitable; the consequent negative effects of eutrophication and soil water contamination result from increasing nitrates in groundwater [10]. Continuous usage of traditional fertilizers leads to depletion of SOM, a rise in erosion and acidity of soil, and reduction of the structure of soil [11]. Nevertheless, such inorganic fertilizers are unsustainable in maintaining yields and the fertility of soil [12]. Hence, there is a need for an alternative material to reduce the usage of inorganic fertilizer while increasing soil fertility and crop yield with minimal negative impacts on the environment.

Using organic amendments to improve the fertility of highly weathered soils of the arid areas and tropics is one of the main issues in the management practice for sustainable agriculture [13]. One of the main causes of degradation of soil is the reduced amount of soil organic matter (SOM) available in the soils [14].

Poultry litter is one of the main agricultural organic sources that is widely used as an organic fertilizer by farmers due to its high content of nutrient elements [15]. Globally, poultry litter production was assessed at 457 million tonnes per annum [16]. Among animal wastes, poultry litter is in top production in Malaysia at an average of 90 g/day (40% dry substance) by a broiler [17]. The inappropriate handling of poultry litter could lead to negative impacts on the environment [18]. This is because direct usage of fresh poultry litter to fertilize crops could cause a transfer of pathogens, parasites, fungi, of heavy metal contamination [19]. Furthermore, direct soil application facilitates ammonia volatilization, which can leach into the household water supply, and cause soil acidification and crop damage as a result of sensitivity to changes in soil nitrogen and salinity [20].

One of the main issues concerning organic manures such as poultry litter is their high decomposition rate, particularly under tropical conditions of rainfall and high temperature [21]. The organic matter may undergo complete mineralization within one single crop season. Under moist tropical environments, its sustainability is a major concern [22,23]. Nonetheless, these impacts of organic fertilizers are usually temporary in the tropics, a result of significant rates of decomposition of SOM [24]. Attempts have been made to address this impact via frequent compost application during each season of planting. In a practical sense, the application of compost at a higher rate has certain limitations, such as a toxicity effect due to the presence of heavy metals [25,26].

A solution for rapid restoration and stabilization of soil organic carbon, as well as addressing the issue of heavy metal content, can be achieved when soils are applied with biochar or biochar blended with organic wastes. Hence, one of the major practices currently being employed is land application of biochar to enhance the soils that are greatly degraded and weathered [27]. Research in the tropical regions has used higher biochar application rates that are not economically feasible [28]. Nonetheless, pure and untreated biochar that are wood-based possess a significant level of C. When they are applied to the soil, it can produce high soil N immobilizations, lowering the availability of N for plants and as such, lowering the yield of plants [29,30]. In order to preserve the essential level of plant-available N inside biochar-treated soils, it is imperative to support the growth and yield of plants via application of biochar that are supplemented with substances containing N (such as manure, mineral compounds, composts and fertilizers) [31]. Quality of soil is highly reliant on the support of biochar that is enriched with nutrient [32,33].

Recent evidence suggests that the use of synergistic organic materials with biochar as an organic fertilizer in tropical soil has received scientific and wide public attention due to its positive effect on sustainable crop productivity and soil fertility [34]. Several studies have revealed the beneficial effects of blending organic wastes with biochar on plant production for increased food security and soil health quality [3,29,30]. A recent field study reported that an addition of co-composted biochar to tropical Ferrallisol augmented maize yield and grain production by 9–18% and 10–29%, respectively, when compared to recommended inorganic fertilizers application [35]. In a separate field study that was recently carried out in moderately acidic Nepalese silty loam soils, there was a great agronomic advantage of biochar integrated with organic fertilizers (cow manure and urine), in comparison with NPK-biochar fertilization and organic fertilization alone [36]. Somewhat similar outcomes were collected from compost–biochar combinations on low fertility soils of Laos [37]. It was suggested that co-composted biochar is an appropriate approach to manage biochar nutrient deficiency and nutrient recycling in order to enhance growth of plants and properties of soil. In Nigeria, the impact of application of distinct rates of biochar and poultry manure, and in combination, on properties of soil and radish's yield components, were investigated [38]. The outcomes of this research found that the rate of biochar application at 50 Mg ha^{-1} together with poultry manure at a rate of 5 Mg ha^{-1} enhanced the productivity of radish. This coincides with a rise in root weight of approximately 252%, 252% and 193% compared with biochar and control alone at rates of 50 and 25 Mg ha^{-1}, respectively. They found that the biochar alone was able to raise the soil pH, organic matter, and level of nutrients in yield and soil. Likewise, Kizito et al. [39] reported that enriched biochar application enhanced nutrient release, which ultimately raised the quality of maize yield and soil by increasing soil organic matter (232–514%) and macronutrients (110–230%) in comparison to the control and unenriched biochar treatments. Qayyum et al. (2017) [40] evaluated the effect of co-composted farm manure and garden peat biochar at different ratios (100%:0%; 75%:25; 50%:50%; 25%:75%; 0%:100%) on wheat growth. The treatments were applied at a rate of 2% w/w with full and half fertilizer recommendation and used wheat as a test crop. They reported that the application of co-composted biochar enhances the grain yield and increases soil nutrients versus the control.

In this study, we try to make the PL more environmentally friendly when applied in agriculture by reducing the ammonia emission but not compromising the plant yield. Thus, a comparison is made between compost biochar and adding or mixing biochar to PL compost during land application. Therefore, the identification of the best combinations and application rates that best suit organic amendments is necessary for tropical soils that coincide with demands of crop. This would alleviate any risk of excess nitrate leaching into ground water. Additions of organic amendments should also improve management of soil fertility and increase crop productivity through a greater understanding of nutrient recycling and their efficiency to gradually release nutrients, thus reducing the use of chemical fertilizers. To fill the knowledge gaps, this paper aimed to demonstrate the use of co-composted biochar with different amounts of poultry manure formulations on an acidic tropical soil to improve the nutrient management for higher crop yield.

2. Materials and Methods

2.1. Preparation of Rice Husk Biochar, PL Composted and Co-Composted Biochar

The biochar was prepared using rice husk as a feedstock. The rice husk biochar (RHB) was obtained from Padiberas Nasional Berhad (BERNAS) in Tanjung Karang, Selangor, which was produced at a pyrolysis temperature of approximately 500 °C. Samples of poultry litter were collected from Semenyih farm, Selangor. The samples were pulverized to pass through 4 mm mesh and were then kept in plastic bags and stored. The co-composting of poultry litter (PL) with biochar at various application rates was performed using a plastic drum. The PL and RHB were co-composted at several initial proportions (Table 1). The composting material was mixed at steady intervals, and co-composting was continued for a period of 14 weeks. Blended PL and PL composted with RHB were prepared following the same ratio used in co-composting PL with RHB, except for the high ratio (30%PL: 70%RHB). The organic amendments were applied at the rate of 10 Mg ha^{-1} and mixed with soil and filled in polybags. Soil physical and chemical properties of Field 10 at 30 cm depth are illustrated in Table 2. Table 3 shows the physicochemical characteristics of the organic amendments used in this experiment.

Table 1. List of treatments.

Treatments	Description	PL	PL Compost	RHB	Mixing Ratio (RHB: PL or CO1)
CO	Soil without any amendment	0	0	0	(0:0)
PL	Poultry litter (PL) only	100%	0	0	(0:1)
RHB	Rice husk biochar (RHB) only	0	0	100%	(1:0)
PL-B30	Poultry litter 70% and biochar 30%	70%	0	30%	(0.5:1)
PL-B50	Poultry litter 50% and biochar 50%	50%	0	50%	(1:1)
CO1	Poultry litter composted only	0	0	0	(0:1)
CO2	The co-composting of 70% PL with 30% of RHB	0	0	0	(0.5:1)
CO3	The co-composting of 50% PL with 50% of RHB	0	0	0	(1:1)
CO4	The co-composting of 30% PL with 70% of RHB	0	0	0	(2.5:1)
CO-B30	Poultry litter compost 70% and biochar 30%	0	70%	30%	(0.5:1)
CO-B50	Poultry litter compost 50% and biochar 50%	0	50%	50%	(1:1)
MIN-FER	The recommended dose for MARDI Institute (130 kg/ha urea, 60 kg TSP and 40 kg/ha MOP)				

Table 2. Physicochemical properties of the soil used in the experiments.

Soil Properties	Description and Quantity
pH	4.51
EC (uScm^{-1})	140
Total carbon (%)	0.12
Total nitrogen (%)	0.01
Total Sulfur (%)	0.089
Total Phosphorus (mg/kg)	65
Total Potassium (mg/kg)	575.3
Total Ca (mg/kg)	-
Total Mg (mg/kg)	27.57
Total Mn (mg/kg)	11.93
Total Cu (mg/kg)	25.17
Total Zn (mg/kg)	27.23
Total As (µg/kg)	2.77
Clay particles (%)	65.19
Silt particles (%)	9.28
Sand particles (%)	25.53

Table 3. Physicochemical characteristics of organic amendments used in experiment.

Parameters	PL	RHB	CO1	CO2	CO3	CO4
pH	8.74	7.73	8.11	7.22	7.24	7.47
EC (mS cm^{-1})	4.66	0.92	4.62	3.82	3.09	2.37
Moisture content (%)	23	6	55.33	50.33	48.66	46.17
Total carbon (%)	36.06	28.55	40.56	28.52	23.89	21.67
Total nitrogen (%)	2.30	0.57	2.44	1.87	1.25	0.85
C/N ratio	15.68	50.09	16.66	15.37	19.18	25.64
Total Phosphorus (%)	3.26	0.036	4.49	3.68	2.92	2.46
Total Potassium (%)	2.61	0.37	3.84	2.99	2.29	1.81

Table 3. *Cont.*

Parameters	PL	RHB	CO1	CO2	CO3	CO4
Total Ca (%)	2.02	0.01	3.12	2.05	1.16	0.67
Total Mg (%)	0.64	0.09	0.83	0.60	0.45	0.32
Total Cu (mg/kg)	344.3	58	471.5	314.7	199.9c	126.2
Total Zn (mg/kg)	461.6	50.17	624.5	417.8	252	188.3
Total Fe (mg/kg)	3610.9	648	3079	3404	2333	1491
Total Mn (mg/kg)	378.2	161.67	536.1	594.5	429.9	342.5
Total As (µg/kg)	17.53	0.19	17.3	14.9	10.14	7.64
NH_4^+ (mg/kg)	3132	37	0.83	0.35	0.28	0.25
NO_3^- (mg/kg)	1878	21	1.63	3.20	3.27	2.24
Seed germination index (%)	-	-	63.86	72.84	83.66	79.71

2.2. Experimental Site and Design

The research was conducted with a randomized complete block design in 12 treatments and four replications of each treatment. Detailed information on the treatments is presented in Table 1. The soil sample used for the glasshouse study is the Munchong Series soil. The soil was sampled from Field 10, Faculty of Agriculture, Universiti Putra Malaysia, which lies within the geographical coordinates 2°, 58′, 65′ N and latitude 101°, 42′, 46′ E and 52 m above sea level. The soils were air-dried, sieved with a 4.00 mm sieve and stored for analysis. A pot experiment was conducted to elucidate different organic amendment types on the performance of sweet maize sown for 50 days. The following treatments were utilized with a randomized complete block design (RCBD): CO (control), PL (poultry litter), RHB (rice husk biochar), PL-B30 (poultry litter blended at 70% with biochar at 30%), PL-B50 (poultry litter blended at 50% with biochar at 50%), CO1 (composted poultry litter), CO2 (co-composted of PL at 70% with biochar at 30%), CO3 (co-composted PL at 50% and biochar at 50%), CO4 (co-composted PL at 30% and biochar at 70%), CO-B30 (composted PL blended at 70% with 30% biochar), CO-B50 (composted PL blended at 50% with 50% biochar), MIN-FER (mineral fertilizer at recommended rate based on MARDI recommendation; 130 kg N/ha in the form of urea, 60 kg P_2O_5 in the form of triple superphosphate and 40 kg K_2O in the form of muriate of potash). Full fertilizer treatment was applied based on MARDI's recommended rates, which its addition to 8 kg soil basis was equivalent to 0.2 g urea, 0.2 g TSP and 1.15 g NPK fertilizer (15-15-15). Amendments were applied at 10 Mg ha^{-1} of each treatment by thoroughly mixing the treatments with soil and filling in polybags. Sweet maize (*Zea mays* L.) variety Masmadu was obtained from the Malaysian Agricultural and Research Development Institute (MARDI). The seeds underwent germination under laboratory condition and then moved into polybags after 24 h. Each polybag held 8 kg of sieved soil. Three seeds were initially transplanted but were then thinned to one plant per polybag after one week. The plants were watered daily to equivalent field capacity of the soil, and they were destructively harvested at 50 days after planting, as they were about to silk.

2.3. Plant Growth Parameters

Plant growth parameters such as plant height, chlorophyll, leaf area and root/shoot ratio were measured as dry weight. The methodology employed for the evaluation of these parameters was according to Pandit et al. [41]. Plant height was presented as the length from the base of the leafstalk to the leaf tip of the biggest leaf. At the end of the growing period, the plant was separated into root and shoots for fresh weight determination with a balance. The roots were carefully removed from the polybag to record root weight, while the above ground measurement was taken as shoot weight. The leaf area was measured directly after harvest using the LI-3100 USA leaf area meter scanner. The SPAD (soil and plant analyzer development) value was measured at the center of the biggest leaflet using a chlorophyll meter (SPAD–502, Konica Minolta, Osaka, Japan). The chlorophyll content recorded for each plant was the average value of three reading taken on the SPAD-502 chlorophyll meter.

2.4. Plant Analyses

After 50 days, the plants were harvested. The separated plant parts were then washed with distilled water and oven dried at 70 °C one week. After drying, the root dry weight and the aerial portion of the plant of each sample were recorded. The dry samples were ground and passed through a 1.0 mm sized sieve. The ground tissue was stored in a tight plastic vial and the carbon, nitrogen and sulfur was determined by combustion technique using a LECO CR-412 carbon analyzer (LECO, Corporation, St. Joseph, MO, USA) with a one-gram plant weighted into a tarred ceramic boat and determined by carbon analyzer. The plant tissues were digested using the dry ashing method for P, K, Ca, Mg, Cu, Zn, and As [42]. Dry ashing (oxidation) is normally performed by placing the sample in an open vessel (crucible) and destroying the organic (combustible) parts in the sample by heat in a muffle furnace at a temperature of 550 °C. In this method, 1 g of oven-dried sample was weighed into a crucible and placed in a muffle furnace to ash at an initial temperature of 300 °C for 1 h, and then the temperature was subsequently raised to 500 °C for 4 h. After cooling in a desiccator, the samples were then placed in a fume cupboard, a few drops of distilled water were added to the ash samples, followed by 2 mL concentrated HCl, and then it was allowed to evaporate to dryness on a hot plate. Subsequently, 10 mL of 20% HNO_3 (200 mL HNO_3 in 1 L distilled water) was added to the samples and was then placed in a hot bath for 1 h. The samples were then filtered using a Whatman No. 2 filter paper into a 100 mL volumetric flask and made up to volume with distilled water. The concentration of P, K, Ca, Mg, Mn, Cu, and Zn in the solutions was determined by Perkin Elmer Model AAS 3110 atomic absorption spectrophotometers (AAS), while AS was estimated via the atomic absorption spectroscopy graphite furnace. The nutrient uptake of the various elements was subsequently calculated.

$$\text{Nutrient uptake g/plant} = \text{concentration (\%)} \times \text{dry weight of plant (g)}/100 \quad (1)$$

$$\text{Nutrient uptake mg/plant} = \text{concentration (mg/kg)} \times \text{dry weight of plant (g)}/1000 \quad (2)$$

2.5. Soil Analyses

Soil samples were collected from each treatment alongside destructive harvesting. The soil samples were air-dried and then passed through a 2 mm sieve, and the soil samples were analyzed for selected chemical and physical properties. Soil pH was measured at soil-to-distilled water ratio of 1:2.5, and the pH was afterward read using a pH meter (Model Metrohm 827, Riverview, FL, USA) [43]. Electrical conductivity (EC) was determined at the soil-to-distilled water ratio of 1:5, and EC was subsequently measured using electrical conductivity meter (Mettler Toledo Seven Easy TM Conductivity Meter S30, Hamilton, New Zealand). Total elements and some heavy metals were analyzed for total nutrients (P, K, Ca, Mg, Cu, Zn, Mn and As) using aqua regia method in the soil samples [44]. Afterward, 0.5 g of the samples were placed in digestion tube. Four milliliters of mixture of concentrated hydrochloric acid (HCl), and nitric acid (HNO_3) in a ratio of 3:1 was added to samples. The samples in the digestion tube were left overnight until the color changed from brown to yellow. The next day, the samples in the tube were digested under fume hood at 110 °C until solution became 2 mL. The samples were cooled down, and 10 mL of 1.2% HNO_3 was added. The samples were heated at 80 °C for 30 min and then cooled. The samples were transferred to a volumetric flask of 50 mL. The digestion tube was rinsed several times to ensure that the entire mixture was transferred to the volumetric flask. The samples were then made up to volume with deionized water. The samples were filtered through double ring qualitative 101 filter paper. The solutions afterward were analyzed using Perkin Elmer Zeeman 4100 graphite furnace atomic absorption spectroscopy (Perkin Elmer, Wellesley, MA, USA), with other nutrients by using the Atomic Absorption Spectrometer

(AAS) (Perkin Elmer; PE 500, Waltham, MA, USA). The total contents of C, TOC, OM, N and S in biochar samples were measured by CHN analyzer (LECO, Corporation, St. Joseph, MO, USA).

2.6. Statistical Analysis

All data were checked for normality and homogeneity of variances. The precision of the data was calculated and expressed as standard error (SE). Data were subjected to ANOVA procedure for RCBD using SAS software pack (version). The significance level was set at a 95% confidence level ($\alpha = 0.05$), and the Tukey test was employed to test for significant differences among the treatment means.

3. Results and Discussion

Generally, organic amendments enhanced the growth of plant and concentrations of foliar nutrient. The largest responses were found with the combined application of compost and biochar, which agrees with many studies [35,41,42].

3.1. Chlorophyll Measurement of Maize

The greenness and nitrogen content of maize leaves were measured using chlorophyll meter. Figure 1 present the results of maize chlorophyll measurement as a function of treatments. The results of chlorophyll content for all treatments were significantly different ($p \leq 0.05$). The treatment CO4 recorded a significantly higher chlorophyll content of 44.20, which occurred at the plant's later growth stages, which indicates the slow release of nitrogen, while a significantly ($p \leq 0.05$) lower chlorophyll content of 21 was recorded in the biochar treatment (RHB) by which this occurrence was mainly due to nitrogen mineralization by soil microbes and retention of nitrogen on the biochar surface [13]. Co-compost application to the soils had a positive effect on the amount of chlorophyll present in the maize leaves during the glasshouse experiment. The healthy growth of plants relies on nitrogen, which is a key aspect of the plant's green color (chlorophyll). As such, leaves with sufficient nitrogen have a greater rate of photosynthesis and shade of green [45]. The current results have been confirmed via statistical analysis, especially with the highly positive correlation between the plant's nitrogen and chlorophyll levels. In general, the N elements' role in plants is to act as an essential aspect of protein and act in the generation of chlorophyll. As such, N has the role of making parts of plants greener, raising the height of plants and accelerating the growth of plants.

Plants obtain nitrogen through the mineralization of organic nitrogen to the inorganic form by microorganisms. The maximum chlorophyll level at the harvest (Figure 1) was significantly higher ($p \leq 0.05$) in the CO4 treatment compared to CO, RHB, CO1, CO2, CO-B30, CO-B50 and mineral fertilizer, but it was not significantly distinct ($p \geq 0.05$) from the remaining treatments. Increased chlorophyll content in plants can be due to the higher nitrogen content of the supplied composts, which results in an increase in the greenness of corn leaves. The same outcome was found by Souza et al. [46], who reported that high maize leaf chlorophyll content increased with an increase in the quantity of compost application. It was reported that plants with a great level of chlorophyll can produce greater photosynthetic materials [47]. The chlorophyll content of mineral fertilizer treatment is not significantly different from PL and PL compost. This experiment indicated that the effects of poultry litter and mineral fertilizer were dominant at the early plant growth stages because of their chlorophyll content (data not shown). This was probably due to their low C/N ratio that could lead to a fast release of nitrogen. However, at the harvest, the co-composted biochar had an improved chlorophyll content (Figure 1), which indicates a slow release of nitrogen caused by the high C/N ratio [48]. The outcomes also imply that greater mineralization of native soil nitrogen is a result of the priming influence following application of such amendments, which improved the soil microorganisms growth [49].

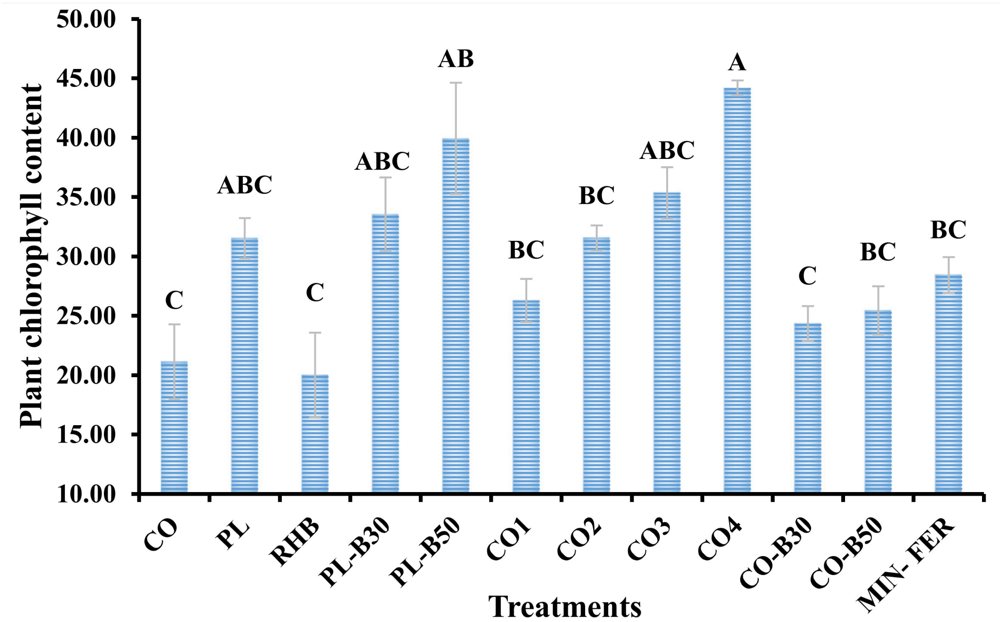

Figure 1. Chlorophyll measurement of plants according to treatment effects. Key: CO, control; PL, poultry litter; RHB, rice husk biochar; PL-B30, poultry litter blended with 30% biochar; PL-B50, poultry litter blended with 50% biochar; CO1, PL compost, CO2, CO3, CO4; CO-B30, PL compost blended with 30% biochar; CO1-B50, PL compost blended with 50% biochar; MIN-FER, mineral fertilizer at recommended rate. Different capital letters indicate significant difference between plant chlorophyll content between each treatment according to Tukey test set at 95% confidence level ($\alpha = 0.05$).

3.2. Maize Plant Performance at Harvest

Table 4 presents the mean plant biomass of maize plants, aerial portion, root and the root:shoot ratio at harvest (50 DAS) for all treatments. Maize plant parameters were significant ($p \leq 0.05$) among treatments. Total plant biomass is greatly distinct ($p \leq 0.05$) among the treatments measured. CO1 recorded significantly higher total plant biomass with 66.4 g/plant, while RHB recorded the least total plant biomass with 4.8 g/plant (Table 4). This result was in line with the result of previous studies [35]. However, PL-only applied treatment also recorded a significant amount of total plant biomass in comparison with other treatments, with the exception of CO1. Moreover, this result indicates that PL and CO1 had a higher amount of nutrient content than control, which agrees with Schulz et al. [50] and Oladotun et al. [51]. The authors attributed this increased biomass to their fairly high content of nutrient in soil organic matter. The measured total plant biomass and percentage of increase over the control (6.1 g) in treatments were 60.7 g (895.1%), 38.1 g (524.6%), 23.3 g (281.9%), 66.4 g (988.5%), 55.4 g (808.2%), 38.4 g (529.5%), 18 g (195.1%), 58 g (850.8%), 34.4 g (463.9%), and 31.9 g (422.9%) for PL, PL-B30, PL-B50, CO1, CO2, CO3, CO4, CO-B30, CO-B50 and MIN-FER, respectively. In contrast, the decreasing total plant biomass and percentage less than control was 4.8 g (−21.3%) as observed in rice husk biochar treatment (Table 4). Our results suggest a great improvement of the growth of maize in this acidic tropical soil could be attributed to the incorporation of biochar and compost. Maize aerial portion at 50 days following sowing in all the treatments are presented in Table 4. Significantly higher aerial portion was recorded in CO1 with 45.87 g/plant in relation to RHB, which recorded a significantly ($p \leq 0.05$) lower aerial portion of 3.35 g/plant at 50 days after sowing, but the aerial portion production of CO1 is not significantly different from those treated with PL and CO-B30. There was an increase in plant biomass production with the increase in compost and poultry litter proportion in treatments as compared to the control (CO) and RHB treatments. An increase in plant height is an indication of the availability of plant nutrients, which ultimately increases plant biomass production. Cogger et al. [52] reported that when nutrient elements are available in the plant rhizosphere, they can easily be accessed by plant roots and can enhance plant growth.

Table 4. Plant parts biomass at harvest.

Treatments	Aerial Portion (g)	Total Plant Biomass (g)	Root (g)	Leaf Area cm^2 $Plant^{-1}$	Root: Shoot Ratio
CO	4.46 ± 0.27e	6.1 ± 0.26f	1.59 ± 0.02f	249.2 ± 6.1d	0.35 ± 0.02d
PL	41.69 ± 0.16ab	60.7 ± 0.69ab	19.06 ± 0.69ab	2835.4 ± 189.9a	0.46 ± 0.03a
RHB	3.35 ± 0.16e	4.8 ± 0.16f	1.35 ± 0.01f	235.2 ± 6.6d	0.38 ± 0.01cd
PL-B30	26.84 ± 0.48c	38.1 ± 3.05cd	11.15 ± 1.16c	2269.8 ± 140.5ab	0.42 ± 0.04ab
PL-B50	17.41 ± 1.21d	23.3 ± 2.49e	5.89 ± 0.35de	1533.1 ± 190.9bc	0.34 ± 0.03ab
CO1	45.87 ± 1.55a	66.4 ± 2.05a	20.49 ± 0.94a	2865.9 ± 101.3a	0.45 ± 0.03ab
CO2	39.66 ± 0.35b	55.4 ± 2.68b	15.74 ± 1.03b	2499.1 ± 220.8a	0.40 ± 0.02ab
CO3	29.17 ± 2.54c	38.4 ± 4.61c	9.23 ± 0.72cd	2236.4 ± 172.7ab	0.33 ± 0.05ab
CO4	13.05 ± 0.61d	18.21 ± 1.91e	5.16 ± 0.55e	1162.6 ± 149.5c	0.39 ± 0.02ab
CO-B30	40.93 ± 0.33ab	58.9 ± 2.54b	18.00 ± 1.03ab	2723.4 ± 119.6a	0.44 ± 0.02ab
CO-B50	24.77 ± 0.56c	34.4 ± 2.99cd	9.65 ± 1.33cd	2345.1 ± 228.1 a	0.39 ± 0.05ab
MIN-FER	24.73 ± 1.01c	31.9 ± 2.09d	7.21 ± 0.13cde	2180.9 ± 93.6ab	0.29 ± 0.01bc
	*	*	*	*	*

All values (mean ± standard error) are averages of three replicated trials. Note that in each column, same means with the same letter are not significantly different at a probability level of 0.05. Key: CO, control; PL, poultry litter; RHB, rice husk biochar; PL-B30, poultry litter blended with 30% biochar; PL-B50, poultry litter blended with 50% biochar; CO1, PL compost, CO2, CO3, CO4; CO-B30, PL compost blended with 30% biochar; CO-B50, PL compost blended with 50% biochar; MIN-FER; mineral fertilizer at recommended rate. * and different letters indicate significance difference detected within the same column for plant part biomass at each treatment according to Tukey test set at 95% confidence level (α = 0.05).

Compared to the recommended fertilizer (MIN-FER) treatment, the aerial portion of sweet maize significantly increased by 68.6%, 8.5%, 85.5%, 60.37%, 17.95%, 65.5% and 0.16% in PL, PL-B30%, CO1, CO2, CO3, CO-B30, CO-B50 treatments, respectively. However, there was a significant decrease by 81.9%, 86.5%, 29.6% and 47.2% in CO, RHB, PL-B50 and CO4 treatments, respectively, in comparison to the recommended fertilizer (Table 4), indicating that the PL, CO1, and combined CO1 with biochar incorporation at the rate of 10 (Mg ha^{-1}) promoted the growth of sweet maize but inhibited its growth in the only biochar (RHB) and control (CO) treatments.

Table 4 also showed that the mean plant performance of root and shoot:root mean plant performance of maize at 50 days after harvest are significantly different ($p \leq 0.05$). Significantly higher maize roots of 20.49 g/plants were recorded in treatments that were applied with CO1 and were significantly lower in treatments that were applied with RHB only (1.35 g/plant), possibly because of the low nutrient content and high recalcitrant elements (C and N) found in rice husk biochar. The lowest maize root at 50 days after sowing was recorded in RHB-treated pots, but it is not significantly different from the control. However, maize plants that were applied with PL and CO-B30 were not significantly distinct ($p \geq 0.05$) from the CO1 treatment, probably because of the higher labile carbon and nitrogen and easily mineralizable elements found in poultry litter and co-composts. The biochar lowered the mineralization of added C [53,54] and lowered nitrogen mineralization [55], as shown in field studies and laboratory incubation. Biochar was found to be able to counteract positive priming of SOC by maize plants. This caused 48% lower SOC losses [56]. Zavalloni et al. [57] observed similar outcomes, in which the recalcitrant OM transformation into available C in soils was amended with glucose. The quality of the C content was found to influence the mineralization of organic amendments, including straw compost, vermicomposting and poultry manure [58]. This study indicates that the addition of co-compost and combination of organic wastes with biochar could improve root growth, which was in synchrony with the increase in biomass of sweet maize, which was consistent with findings of Luo et al. [59]. Similarly, Lehmann et al. [60] found that a low application rate of organic material might not improve the shoot biomass production as a result of few roots growing. In the current study, the total root weight was in the order of CO1 > PL > CO-B30 > CO2 > PL-B30 > CO-B50 > CO3 > MIN-FIR > PL-B50 > CO4 > CO > RHB, being significantly higher for CO1 compared to the other treatments. These results suggest that the root morphological development under these treatments of high poultry litter and compost proportion in co-composting and blending to allocation of more resources into the root system. However, in biochar and control treatments, all the root morphological parameters decreased because of the insufficiency of resource for the plant growth from biochar additions. The addition of biochar caused the nitrogen immobilization by soil microbes probably because of the increased C/N ratio of soil [61]. Bruun et al. [62] pointed out that suitable application rates of biochar improved the root growth and biomass because the biochar retained more nutrients and water in the soil. Therefore, the present study confirmed that the addition of poultry litter and their composts combined with biochar should be formulated at an optimum level to produce positive results. Nonetheless, our outcomes suggest that blending compost with poultry litter only influenced root morphological development because of the high nutrient content found in these treatments.

Figure 2 shows the mean plant height of the maize plants at 50 days after sowing. The results of the effects of co-composts and blended composting materials application on maize plant height in a glasshouse showed that different compost applications had significant effects ($p \leq 0.05$) on maize growth performance. Plants that were applied PL were significantly higher than the other treatments, although it was not significantly different ($p \geq 0.05$) from PL-B30, CO1, CO2, CO3, CO-B30 and CO-B50. However, the results were significantly different ($p \leq 0.05$) from the other treatments (MIN-FIR, PL-B50, CO4, CO, RHB). The significantly lower maize plant height was recorded in treatments that were amended with RHB only and control treatment (CO), and they were significantly different from all other treatments. An increase in plants height indicates the availability of plant nutrients. Cogger et al. [52] reported that when nutrient elements are available in the plant rhizosphere, they can easily be accessed by plant roots and enhance plant growth. The maize that was applied with RHB only and the control were lower in height, possibly because of the lower nutrients in the applied and also due to nitrogen immobilization [61]. Increased plant height with time can possibly be linked to organic matter mineralization, which leads to gradual nutrients release from the added amendments. Nitrogen is an essential element in plants that plays a crucial role in enhancing plant growth and augmenting plant height. Organic fertilizer enhances nutrient mineralization and consequently accelerate plant performance [63]. Plant growth can also be accomplished by decreasing the toxic content of heavy metals in organic-amended soil [64]. Surprisingly, organic nourishments such as blending PL with biochar can also restore nutrient deficiencies and content of soil organic matter in agroecosystems.

The increase in maize plant height at 50 days after sowing as observed may be due to improved soil fertility due to compost application, which resulted in increased nutrient availability for plant root uptake to improve plant growth. The results are in agreement with the findings of Adejobi et al. [65] in which composts as an organic fertilizer/amendment contribute to the improvement in crop growth by upgrading the chemical and physical properties of the soil. Ndubuisi et al. [66] reported that composts could provide different nutrients to the soil to facilitate a better nutritional soil balance to support plant growth.

The increase in plant height and growth of the treatments can be ranked in the order PL > CO1 > CO-B30 > CO2 > PL-B30 > CO3> CO-B50 > MIN-FIR > PL-B50 > CO4 > CO > RHB, being significantly higher for PL and CO1 compared to the other treatments, which were also similar (Figure 2). Compared to the mineral fertilizer treatment, the plant height of maize significantly increased by 49.33% in PL treatment, 46.86% in CO1, 45.06% in CO-B30, 40.67% in CO2, 32.48% in PL-B30, 25.74% in CO3, and 25.62% in CO-B50, while significantly decreasing by 2.58% in PL-B50, 15.16% in CO4, 67.52% in CO and 69.21% in RHB treatments (Figure 2). These results suggest that the co-composted biochar, PL, CO1 or their mixture with biochar addition at the same rate (e.g., 10 Mg ha^{-1}) promoted the performance of maize but inhibited its growth at the high proportion of biochar in treatments (e.g., 70%).

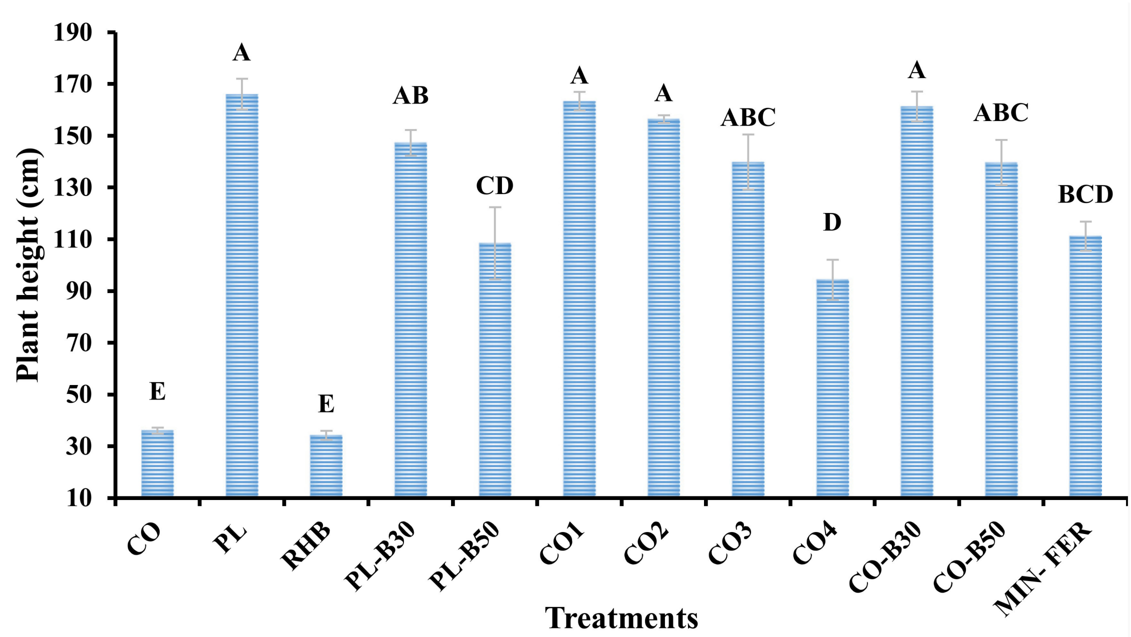

Figure 2. Maize plant height at harvest according to treatments. Key: CO, control; PL, poultry litter; RHB, rice husk biochar; PL-B30, poultry litter blended with 30% biochar; PL-B50, poultry litter blended with 50% biochar; CO1, PL compost, CO2, CO3, CO4; CO-B30, PL compost blended with 30% biochar; CO-B50, PL compost blended with 50% biochar; MIN-FER, mineral fertilizer at recommended rate. Different letters indicate significance difference detected between plant height between treatments according to Tukey test set at 95% confidence level (α = 0.05).

Findings revealed that poultry litter and compost-enriched biochar, which was added at an optimal rate, produced the desired plant performance results (e.g., high plant height, bigger roots, stem elongation, girth enhancement and greenness of leaves). This study has confirmed an increase in the plant height and growth due to an increase the proportion of poultry litter and compost in the treatments that might be attributed to its fairly high nutrient content, which supplemented the nutrient requirements, especially N for plant growth, as well as improved soil properties.

3.3. Maize Nutrients Concentrations and Uptake at Harvest

The availability of essential nutrients affects the yield and yield components of crops [67]. The major source of plant nutrients depends on soil and organic fertilizer features. Supplementing plant nutrient requirements in agriculture is vital to ensure health and sustainable plant growth [68]. Moreover, for plant growth, increases in foliar nutrient concentrations are supported and documented in the literature review [3,30,35,48,67].

In this present study, the mean corn nutrient concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in maize plants at 50 days after sowing are presented in Table 5. The results of the concentrations of the nutrients were significantly different ($p \leq 0.05$). CO4-treated pots were significantly higher in nitrogen concentration at 50 days after sowing; however, PL compost (CO1) is significantly lower in nitrogen content 50 days after sowing.

The results show that the nutrient uptake of nitrogen phosphorus, potassium, calcium, and magnesium by the maize plants are significantly different ($p \leq 0.05$). Significantly different and higher nitrogen concentration at 50 days after sowing were recorded in maize plants that were applied CO4 at 10 Mg ha^{-1} (Table 6). However, these results were not significantly different from the other treatments, including applied mineral fertilizer in full dose and the control plants. The lower concentration of N recorded in poultry litter compost might be attributed to the fast release of N from composts and poultry litter without biochar addition versus the treatments with biochar. Results also showed that the nitrogen concentration and chlorophyll increased (Figure 1), and an increasing ratio of biochar in the organic treatments was an indicator of slow release of nitrogen. A similar result was also observed by Qayyum et al. [40], who co-composted biochar with farm manure. Similarly, Kizito et al. [39] pointed out that adding enriched biochar by digestate nutrients improves soil fertility by increasing organic matter and improving the release of micronutrients gradually compared to conventional chemical fertilizer. Another reason behind the decrease in N concentration was mainly due to the increase in dry weight (Table 4), termed as the dilution effect.

Hanajima et al. [69] stated that the valuable impact of adding blending organic fertilizer with biochar on soil fertility depended on application time and nutrient release with time. Similarly, Adekiya et al. [38] reported that the low C/N ratio and the high nutrient concentrations of the poultry manure led to increased decomposition and nutrient release for short duration crops, which enhanced radish growth and increased nutrient content in the soil. Rogeri et al. [70] reported from a study of nitrogen mineralization from applied poultry litter compost that lower values of nitrogen recorded coupled with the low C/N ratio could be because of a slowing down in nitrogen mineralization due to stabilization of the added N forms that are recalcitrant or difficult to mineralize (humified N). Additionally, volatilization and denitrification losses may have occurred. In addition, biochar can improve the efficiency of nutrient retention, adsorbed volatilized ammonia [71], and enhanced microbial immobilization, which can be clarified by the fact that the addition of biochar to organic amendment or soil may increase the C/N ratio and reduce the nutrient concentration of soil [27]. In co-composted biochar, higher N concentration, which was slow-released, can be elucidated by continuous mineralization, which depends on co-composted quality and stability. The rates of annual nitrogen mineralization are around 3–8% from compost [72].

Phosphorus uptake by plants was also not significantly different in treatments CO4 and PL-B50, a probable indication that CO4 and PL-B50 released more phosphorus during the glasshouse experiment in which they differ significantly from the control. According to Islam et al. [73], organic fertilizer-treated soils have higher amounts of phosphorus versus control. The reasoning can be attributed to the explanation and mechanism for adsorption of phosphate (PO_4^{3-}) and function in its gradual release. Many studies attest that biochar can adsorb phosphate from solution and function in the gradual release of the adsorbed P, thus reducing the loss of phosphate [74–76]. Another reason is that the biochar enhances the enzyme that catalyzes the hydrolysis of ester-phosphate bonds for the release of phosphate [77–79]. However, enriched biochar with organic manure has high affinity for Al^{3+} and Fe^{2+}, a process known to minimize P fixation by Al^{3+} and Fe^{2+} in highly weathered acidic soils [39,80]. Furthermore, compost addition can block adsorption sites for Fe and Al, thereby reducing $H_2PO_4^-$ fixation ability and increasing P mobility in organic forms within the soil profile [81]. The release of H^+ by roots compensates for an imbalance in the charge because the unequal uptake of cations might be another reason for weaker liming influence on the rhizosphere soil [82]. The release of exchangeable cations, for example, K^+, Ca^{2+} and Mg^{2+}, from biochar promoted their uptake by maize and, in turn, weakened the liming effect of biochar in the rhizosphere soil. This can possibly be attributed to a higher amount of the treatment applied, which was mineralized, thus releasing and making more organic phosphorus available, thereby reducing fixation. Ahmad et al. [83] reported that, in comparison to control plots, significantly different results for K was observed in the other treatments. Islam et al. [73] also supported this result, who reported that exchangeable soil K increased when organic fertilizers were applied to soil. The Ca and Mg uptakes by corn at harvest were significantly different ($p \leq 0.05$). Heavy metal contents in the composts used in the present study were also well below the critical limits.

Table 5. Plant nutrients concentrations at 50 days after harvest.

Treatments	Nitrogen %	Phosphorus mg/kg	Potassium %	Calcium mg/kg	Magnesium mg/kg	Manganese mg/kg	Copper mg/kg	Zinc mg/kg
CO	1.34 ± 0.04ab	459.5 ± 26.1b	0.209 ± 0.031a	801.7 ± 86.6ef	691.7 ± 28.1abc	87.37 ± 2.56b	4.03 ± 0.09ab	58.15 ± 1.38bcd
PL	1.20 ± 0.09abc	232.3 ± 22.3c	0.132 ± 0.013a	1441.4 ± 167.6ab	791.3 ± 71.7ab	86.45 ± 9.49b	1.73 ± 0.14de	45.93 ± 2.69d
RHB	1.29 ± 0.01abc	436.75 ± 5.9bc	0.206 ± 0.014a	1114.1 ± 103.8bcde	797.7 ± 46.6ab	86.65 ± 4.32b	3.25 ± 0.25dc	57.93 ± 5.69bcd
PL-B30	1.27 ± 0.11abc	387.1 ± 14.9bc	0.180 ± 0.022a	1016.1 ± 73.9cde	741.9 ± 32.1abc	99.93 ± 1.02ab	0.50 ± 0.04f	51.65 ± 5.08bcd
PL-B50	2.06 ± 0.06ab	740.8 ± 31.31a	0.210 ± 0.010a	677.9 ± 27.6f	620.7 ± 35.8bc	110.93 ± 1.86ab	2.30 ± 0.11d	81.78 ± 4.43a
CO1	0.54 ± 0.02c	249.3 ± 21.1bc	0.159 ± 0.003a	1553.2 ± 71.3a	781.7 ± 24.1abc	98.95 ± 7.57ab	1.28 ± 0.09e	44.20 ± 1.50d
CO2	0.88 ± 0.06c	324.1 ± 29.9bc	0.192 ± 0.015a	1301.5 ± 37.8abc	818.1 ± 31.9ab	113.75 ± 9.62ab	2.18 ± 0.18d	71.85 ± 5.01ab
CO3	1.13 ± 0.11bc	426.5 ± 45.3bc	0.194 ± 0.022a	663.5 ± 47.4f	664.6 ± 27.9abc	100.30 ± 6.62ab	3.15 ± 0.13c	51.73 ± 5.53bcd
CO4	2.08 ± 0.06a	726.5 ± 45.6a	0.222 ± 0.018a	717.9 ± 35.1ef	635.1 ± 34.2bc	129.43 ± 9.78a	3.73 ± 0.26bc	68.01 ± 3.14abc
CO-B30	0.66 ± 0.05c	270.3 ± 29.2bc	0.195 ± 0.027a	1490.2 ± 114.4ab	713.8 ± 55.2abc	111.53 ± 9.04ab	1.35 ± 0.10e	49.38 ± 2.21bcd
CO-B50	1.07 ± 0.09c	384.8 ± 39.2bc	0.148 ± 0.010a	856.8 ± 41.4def	580.4 ± 34.3c	84.56 ± 4.25b	0.44 ± 0.03f	43.60 ± 5.36d
MIN-FER	1.01 ± 0.03abc	429.1 ± 41.3b	0.164 ± 0.039a	1202.4 ± 33.9abcd	866.4 ± 32.8a	84.12 ± 10.1b	4.68 ± 0.21a	54.35 ± 3.81bcd
	*	*	NS	*	*	*	*	*

All values (mean ± standard error) are averages of three replicated trials. Note that in each column, same means with the same letter are not significantly different at a probability level of 0.05. Key: CO, control; PL, poultry litter; RHB, rice husk biochar; PL-B30, poultry litter blended with 30% biochar; PL-B50, poultry litter blended with 50% biochar; CO1, PL compost; CO2, CO3, CO4, CO-B30, PL compost blended with 30% biochar; CO-B50, PL compost blended with 50% biochar; MIN FER, mineral fertilizer at recommended rate. * and different letters indicate significance difference detected within the same column for plant nutrient concentration at 50 days after harvest between treatments according to Tukey test set at 95% confidence level (α = 0.05).

Table 6. Table of mean plant nutrient uptake by maize at 50 days.

Parameters	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Manganese	Copper	Zinc	Sulphur
Treatments		g/Plant				mg/Plant			
CO	0.088 ± 0.02cd	2.05 ± 0.18b	0.009 ± 0.001ed	3.64 ± 0.59e	3.06 ± 0.08d	0.39 ± 0.03d	0.018 ± 0.001ef	0.26 ± 0.01e	0.008 ± 0.002e
PL	0.486 ± 0.04a	9.68 ± 0.93a	0.055 ± 0.005abc	65.11 ± 2.97ab	35.04 ± 1.02a	3.59 ± 0.36ab	0.072 ± 0.005bc	1.91 ± 0.10bcd	0.056 ± 0.003a
RHB	0.043 ± 0.01d	1.46 ± 0.08b	0.07 ± 0.001ed	3.74 ± 0.45e	2.68 ± 0.25d	0.29 ± 0.02d	0.011 ± 0.001f	0.19 ± 0.02f	0.005 ± 0.001e
PL-B 30	0.341 ± 003ab	10.39 ± 0.55a	0.048 ± 0.006bcd	27.10 ± 1.22c	19.91 ± 1.09b	2.48 ± 0.21bc	0.011 ± 0.003f	1.39 ± 0.15de	0.039 ± 0.003bc
PL-B50	0.340 ± 0.04ab	11.77 ± 0.61a	0.036 ± 0.002cd	11.74 ± 0.63de	10.83 ± 1.08c	1.77 ± 0.07c	0.040 ± 0.003de	1.43 ± 0.15cde	0.032 ± 0.003cd
CO1	0.238 ± 0.02bc	11.44 ± 1.06a	0.073 ± 0.003ab	71.34 ± 4.58a	35.93 ± 2.15a	4.55 ± 0.41a	0.058 ± 0.004cd	2.03 ± 0.14b	0.052 ± 0.002ab
CO2	0.320 ± 0.05b	12.85 ± 1.19a	0.076 ± 0.006a	51.63 ± 1.59b	32.45 ± 1.32a	4.51 ± 0.37a	0.086 ± 0.007b	2.85 ± 0.20a	0.048 ± 0.002ab
CO3	0.308 ± 0.03b	12.11 ± 0.62a	0.056 ± 0.006abc	19.03 ± 0.87cd	19.36 ± 1.89b	2.88 ± 0.13bc	0.092 ± 0.008ab	1.47 ± 0.08bcde	0.041 ± 0.002bc
CO4	0.273 ± 0.04b	10.43 ± 1.28a	0.029 ± 0.002ed	9.35 ± 0.52de	8.27 ± 0.48cd	1.69 ± 0.14c	0.049 ± 0.004cd	0.89 ± 0.08e	0.024 ± 0.001d
CO-B30	0.268 ± 0.02b	11.05 ± 1.17a	0.080 ± 0.011a	60.89 ± 4.32ab	29.21 ± 2.27a	4.56 ± 0.36a	0.055 ± 0.004cd	2.02 ± 0.08bc	0.046 ± 0.002b
CO-B50	0.218 ± 0.03bc	9.51 ± 0.93a	0.037 ± 0.002cd	21.20 ± 1.06cd	15.12 ± 0.67bc	2.10 ± 0.14c	0.011 ± 0.001f	1.09 ± 0.15de	0.028 ± 0.001d
MIN-FER	0.286 ± 0.04b	11.05 ± 0.88a	0.040 ± 0.008cd	29.73 ± 1.47c	18.52 ± 2.72b	2.09 ± 0.29c	0.116 ± 0.010a	1.34 ± 0.09de	0.032 ± 0.001cd
	*	*	*	*	*	*	*	*	*

All values (mean ± standard error) are averages of three replicated trials. Note that in each column, same means with the same letter are not significantly different at a probability level of 0.05. Key: CO, control; PL, poultry litter; RHB, rice husk biochar; PL-B30, poultry litter blended with 30% biochar; PL-B50, poultry litter blended with 50% biochar; CO1, PL compost; CO2, CO3, CO4, CO-B30, PL compost blended with 30% biochar; CO-B50, PL compost blended with 50% biochar; MIN FER, mineral fertilizer at recommended rate. * and different letters indicate significance difference detected within the same column for plant nutrient uptake by maize at 50 days between treatments according to Tukey test set at 95% confidence level (α = 0.05).

After maize harvest, the nutrient uptake of maize plants was affected by the application of organic amendments. The application of these materials gave a highly significant increase in nutrient uptake of maize plants than the control. It was noted that the present or increased proportion of biochar in co-compost caused a decreased nutrient uptake as compared to both poultry raw material and composted treatments. This result showed that biochar might enhance the nutrient's stability in the form of complex forms that provides the important nutrients to the plants for good performance [84]. The nutrients available for plant uptake after mineralization into inorganic nutrients formed under the different treatments are displayed in Tables 5 and 6. The mineralization of organic products and transformation of nutrients strongly depend on the organic carbon degradation, environmental condition and the C/N ratio of the organic material in the treatments [40,85]. All co-compost treatments resulted in significantly lower heavy metal tissue uptake than the control and pure NPK treatments probably due to increased heavy metal immobilization [39]. The reduction in growth parameters with decreased nutrient uptake at high proportion from biochar application in our organic amendments may attribute to increased nutrient retention and immobilization due to biochar aging. Similar findings were reported by Zama et al. [86], who reported that the heavy metals that reacted with biochar facilitate the complexation and chemisorption of metalloids due to physical adsorption and surface functional group.

3.4. Soil Properties after Harvest

Soil properties and soil nutrient content at harvest are presented in Tables 7 and 8. Plants absorbed nutrients from the soil as well from the soil amendment, which explained the decrease in soil nutrients at the final stage of the glasshouse experiment. Application of organic amendments and mineral fertilizer decreased the acidity of soil for the glasshouse study, but it was not significantly different ($p \geq 0.05$). As the pH of the soil increased due to mineralization, the decrease of pH followed by the increased proportion of biochar in co-composting could be due to the nitrification process. The result is in agreement with Giannakis et al. [87], who reported an increase in soil pH as a result of compost application, which likely occurred as a result of OH^- production and basic cation release. Paradelo and Barral [88] reported that an increase in soil pH should be expected upon compost application to acidic soils mainly due to buffering capacity of the added amendment and presence of carbonates in the composts. Conversely, the pH decreases with an increase in the proportion of biochar in co-composted biochar, attributed to the nitrification process, adsorption of basic ions K^+, Ca^{2+}, and Mg^{2+} and the pH in compost [89]. The results of the glasshouse experiment revealed a decrease in soil EC, whereby a higher proportion of biochar was utilized in the co-compost versus PL (Table 7). The results of the current study indicated that soil organic matter increases with an increase in the proportion of biochar in treatment, which led to increased carbon sequestration through increased soil stability and improved carbon return to soils, causing increased crop productivity [90].

Soil nutrient status at harvest and compost amended soils at harvest extracted with aqua regia extracted samples for P were significantly different ($p \leq 0.05$), while K and Mg were not significantly different ($p \geq 0.05$). Soil nutrient concentrations were significantly increased in all organic amendments in comparison to control treatment. The higher concentrations of nutrients in soil with a higher ration of poultry litter and compost in the treatment resulted from their high nutrient concentrations and low C/N ratio, which increased decomposition and nutrient release for short duration crops [38]. Conversely, reduced nutrient content with increased proportion of biochar in treatment was attributed to the dilution effect, which reduced the nutrient concentrations, decreased the decomposition, and increased the C/N ratio. Therefore, co-composted biochar has different mineralization rates and times (later nutrient release for long duration). These results were in accordance with the observations made by Adekiya et al. [38]. Another possible reason that the plant consumed the late nutrient release at the same time that the nutrient concentration of plant increased (Table 5) with the increased biochar percentage in treatments [40], is that the maize plant required a great amount of nutrients within a short crop duration. Finally, the application rate of co-composted biochar with a high percentage of biochar was not sufficient for plant growth due to reducing the amount of PL and PL compost in treatments. For example, nitrogen concentrations in maize plants were higher for all treatments in comparison with the control, whereas minimum nitrogen was found in soil with biochar only. Increased nitrogen concentration in plants and lower concentrations in soil were more pronounced in co-composted biochar and PL or PL compost mixed with biochar (at the same ratio). This reason depends on nitrogen content and C/N ratio, which affected the release of nitrogen from organic nitrogen mineralization [38,61]. However, the contrary results were stated in previous studies, in which biochar addition significantly reduced the subsequent NH_4^+ and NO_3^- concentration [91,92]. In addition, soil P concentrations were higher in respective treatments with full poultry litter and compost, versus other treatments, when mixed with a high percentage of biochar. Generally, increasing the pH and organic matter in soil leads to reduced phosphorus adsorption on the soil colloid, thereby increasing phosphorus availability for plant uptake [93]. Increased soil pH contributes favorably to reducing aluminum toxicity through a decrease in exchangeable aluminum, lowering phosphate fixation in soils. Soil K content reduced the organic amendment application in relation to the control, while the increase was higher in the biochar treatment, which can indicate reduced plant uptake and growth (less dry weight); thus, the K soil content will be higher. Strojakis et al. [94] also reported that soil nutrient elements increase due to compost application. The Cu and Zn soil contents at harvest are both not significantly different ($p \geq 0.05$) between all treatments and are below the critical limits. The amounts of the heavy metals applied to the soil through compost addition may be low because of the low compost content of the metals and, as a result, to retain heavy metal concentration and increase pH. Low and undetectable limits of Cu and Zn have also been reported by Giannakis et al. [87], and they also attributed it to the low content of compost heavy metal content. The result of this study is consistent with the findings stated by Bashir et al. [95], who stated that the addition of farmyard manure and co-composted biochar linearly decreased soil-available Cd with an increasing ratio of biochar in compost. In addition, Agegnehu et al. [3] also found that biochar co-composts might be suitable for declining metal availability in contaminated soil.

Table 7. Soil properties at harvest.

Treatments	pH	EC	TC %	TOC %	OM %
CO	5.15 ± 0.004de	42.25 ± 0.99f	0.38 ± 0.05ac	0.31 ± 0.01f	0.53 ± 0.01a
PL	5.34 ± 0.017a	89.23 ± 2.78bc	0.64 ± 0.03abc	0.47 ± 0.02de	0.80 ± 0.03a
RHB	5.06 ± 0.011f	115.75 ± 3.83a	0.87 ± 0.08a	0.73 ± 0.02a	1.26 ± 0.03a
PL-B30	5.27 ± 0.013b	58.15 ± 2.26ef	0.67 ± 0.01ab	0.51 ± 0.01cde	0.88 ± 0.01a
PL-B50	5.28 ± 0.021b	72.13 ± 2.18de	0.78 ± 0.07ab	0.63 ± 0.02b	1.09 ± 0.02a
CO1	5.25 ± 0.006bc	96.78 ± 4.09b	0.58 ± 0.02abc	0.45 ± 0.01e	0.77 ± 0.01a
CO2	5.24 ± 0.007cd	72.63 ± 6.14de	0.72 ± 0.01a	0.54 ± 0.01dc	0.93 ± 0.01a
CO3	5.23 ± 0.009bc	70.90 ± 1.11de	0.76 ± 0.01bc	0.62 ± 0.01b	1.06 ± 0.01a
CO4	5.21 ± 0.010cd	79.83 ± 2.83cd	0.79 ± 0.01ab	0.54 ± 0.02c	0.94 ± 0.02a
CO-B30	5.10 ± 0.012ef	98.90 ± 3.24b	0.72 ± 0.02ab	0.53 ± 0.01cd	0.92 ± 0.02a
CO-B50	5.14 ± 0.009e	74.83 ± 2.99cd	0.61 ± 0.03abc	0.45 ± 0.02e	0.78 ± 0.03a
MIN-FER	5.22 ± 0.017bc	51.45 ± 2.89f	0.19 ± 0.01c	0.15 ± 0.01g	0.25 ± 0.02a
	*	*	*	*	*

All values (mean ± standard error) are averages of three replicated trials. Note that in each column, same means with the same letter are not significantly different at a probability level of 0.05. Key: CO, control; PL, poultry litter; RHB, rice husk biochar; PL-B30, poultry litter blended with 30% biochar; PL-B50, poultry litter blended with 50% biochar; CO1, PL compost; CO2, CO3, CO4, CO-B30, PL compost blended with 30% biochar; CO-B50, PL compost blended with 50% biochar; MIN-FER, mineral fertilizer at recommended rate. * and different letters indicate significance difference detected within the same column for soil properties at harvest between treatments according to Tukey test set at 95% confidence level ($\alpha = 0.05$).

Table 8. Soil properties at harvest.

Treatments	N (%)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	S (mg/kg)
CO	0.0075 ± 0.0003h	63.2 ± 2.05de	330.3 ± 13.20ab	1.34 ± 0.15f	29.20 ± 0.74ab	67.48 ± 4.27a	18.8 ± 1.59a	82.7 ± 3.31a	0.087 ± 0.004a
PL	0.0175 ± 0.0003ab	77.3 ± 5.45cde	302.8 ± 20.00abc	10.13 ± 0.09a	28.65 ± 0.67abc	61.90 ± 0.52ab	16.5 ± 0.98ab	78.9 ± 1.84abc	0.087 ± 0.005a
RHB	0.0103 ± 0.0005g	73.1 ± 1.06cde	362.8 ± 17.90a	1.65 ± 0.03f	29.05 ± 0.48ab	62.85 ± 1.24ab	15.03 ± 0.74ab	76.8 ± 0.80abcd	0.069 ± 0.009a
PL-B30	0.0163 ± 0.0005bc	78.1 ± 5.64cde	331.9 ± 6.70ab	5.23 ± 0.09de	29.20 ± 1.18ab	63.58 ± 1.10ab	16.6 ± 0.88ab	79.6 ± 3.66abc	0.070 ± 0.005a
PL-B50	0.0142 ± 0.0007de	82.5 ± 4.19bcd	284.9 ± 15.30abc	1.43 ± 0.04f	28.63 ± 0.89abc	63.45 ± 1.16ab	14.53 ± 0.48ab	78.7 ± 3.32abcd	0.079 ± 0.005a
CO1	0.0187 ± 0.0002a	107.8 ± 5.40a	278.9 ± 13.10bc	9.20 ± 0.26b	30.75 ± 1.02a	65.38 ± 1.70ab	17.3 ± 02.20ab	84.1 ± 2.28ab	0.081 ± 0.002a
CO2	0.0153 ± 0.0004cd	102.3 ± 6.53ab	265.1 ± 14.70bc	6.15 ± 0.06c	29.98 ± 0.29ab	65.20 ± 0.75ab	16.9 ± 1.11ab	78.9 ± 2.65abc	0.077 ± 0.005a
CO3	0.0141 ± 0.0004de	95.1 ± 4.34abc	280.8 ± 35.20bc	5.50 ± 0.09d	28.83 ± 1.65abc	65.70 ± 2.66a	16.7 ± 1.72ab	57.1 ± 7.27bcd	0.074 ± 0.003a
CO4	0.0136 ± 0.0002de	81.6 ± 2.08cd	257.7 ± 14.70bcd	4.78 ± 0.09e	25.65 ± 0.66bc	63.58 ± 1.16ab	13.8 ± 1.68ab	40.2 ± 0.66cd	0.079 ± 0.007a
CO-B30	0.0141 ± 0.0002de	112.5 ± 4.97a	238.1 ± 13.70cde	6.08 ± 0.10c	30.78 ± 0.98a	68.20 ± 2.65a	16.6 ± 0.73ab	47.8 ± 2.88bcd	0.078 ± 0.005a
CO-B50	0.0133 ± 0.0001ef	80.5 ± 5.70cde	184.2 ± 15.50de	1.42 ± 0.02f	24.35 ± 0.86cd	58.5 ± 0.98ab	11.28 ± 1.01b	38.6 ± 2.12cd	0.084 ± 0.001a
MIN-FER	0.0121 ± 0.0004fg	63.3 ± 2.33e	173.8 ± 13.30e	1.22 ± 0.06f	20.73 ± 0.89d	55.65 ± 1.32b	11.20 ± 1.71b	36.1 ± 0.47d	0.081 ± 0.005a
	*	*	*	*	*	*	*	*	*

All values (mean ± standard error) are averages of three replicated trials. Note that in each column, same means with the same letter are not significantly different at a probability level of 0.05. Key: CO, control; PL, poultry litter; RHB, rice husk biochar; PL-B30, poultry litter blended with 30% biochar; PL-B50, poultry litter blended with 50% biochar; CO1, PL compost; CO2, CO3, CO4, CO-B30, PL compost blended with 30% biochar; CO-B50, PL compost blended with 50% biochar; MIN-FER, mineral fertilizer at recommended rate. * and different letters indicate significance difference detected within the same column for soil properties at harvest between treatments according to Tukey test set at 95% confidence level (α = 0.05).

The poultry litter and their compost utilized in our study contributed to a higher proportion of N in treatments. Moreover, an increasing biochar ratio in the compost increased the N concentration despite reduced poultry litter and compost proportions.

3.5. Correlations between Soil Properties and Plant Nutrient Uptake

The correlation between soil properties at the end of the glasshouse study and maize nutrients uptake is presented in Table 9. The correlation table shows that maize nutrient uptake was highly positively correlated among the analyzed nutrient elements of nitrogen, phosphorus, potassium, calcium, magnesium, copper and zinc, which is related to nutrient availability in soil with plant ability nutrient uptake. For the soil nutrient contents, the results are almost positively significantly correlated, except for the antagonism between the nutrients. For instance, soil nitrogen and phosphorus were highly positively correlated with all nutrients in plants and soil (Table 9). This indicated a nitrogen and phosphorus concentration less than or near critical value in the plant. However, potassium and zinc concentrations are negatively correlated with other nutrients because of the critical level in the plant found in range, despite the age of the plant. Leaf chlorophyll and soil nitrogen were highly significantly correlated with nitrogen concentration in maize leaf ($r = 0.51$; $p \leq 0.001$) and ($r = 0.68$; $p \leq 0.0001$), respectively. This may be due to improvements in soil organic matter and nutrient release by added organic amendments.

Soil zinc content at harvest is negatively correlated to calcium, phosphorus, copper and zinc uptake in plants. Soil zinc and manganese at harvest are negatively correlated to the uptake of nutrients by maize at 50 days after sowing. Soil zinc and manganese are negatively correlated to calcium, phosphorus, and copper uptake by plants due to the antagonism between the nutrients (Table 9). Although the zinc and copper contents of the composts measured in one study was well below critical limits, care must be taken to the amounts of the composts applied and compost heavy metal content. Heavy metal uptake by crops sown in compost-amended soils is one of the major problems restricting compost use as organic fertilizer, especially organic manure and compost. Paradelo and Barral. [88] applied municipal solid waste (MSW) composts at 30 and 60 Mg ha^{-1} and observed a significant increase in copper, nickel, lead, and zinc contents in the soil at higher application rates. Similarly, Mokolobate and Haynes [96] reported that compost addition at 10 and 20 Mg ha^{-1} ameliorated acidic soils. They observed that there was marked reduction in plant growth and development attendant with high amounts of compost application around 100 Mg ha^{-1}, which led to reduced nitrification and increased nutrient immobilization.

Table 9. Pearson correlation coefficient (r) between the means of selected soil physicochemical, plant growth and nutrient uptake in greenhouse studies conducted on 12 treatments on Oxisols soil.

	N-S	**P-S**	**K-S**	**Ca-S**	**Mg-S**	**Mn-S**	**Cu-S**	**Zn-S**	**pH**	**EC**	**Chlorophyl**	**N-up**	**P-up**	**K-up**	**Ca-up**	**Mg-p**	**Mn-up**	**Cu-up**	**Zn-up**
N-S	1																		
P-S	0.5 **	1																	
K-S	−0.07 ns	−0.02 ns	1																
Ca-S	0.80 ***	0.52 ***	0.13 ns	1															
Mg-S	0.24 ns	0.62 ***	0.61 ***	0.43 *	1														
Mn-S	0.04 ns	0.39 **	0.38 **	0.25 ns	0.70 ***	1													
Cu-S	0.1 ns	0.43 **	0.50 **	0.34 *	0.73 ***	0.59 ***	1												
Zn-S	−0.06 ns	−0.06 ns	0.61 ***	0.13 ns	0.52 ***	0.53 ***	0.54 ***	1											
pH	0.62 ***	−0.05 ns	0.04 ns	0.49 ***	−0.002 ns	−0.04 ns	0.11 ns	0.13 ns	1										
EC	0.31 *	0.46 **	0.17 ns	0.37 **	0.31 *	0.09 ns	0.06 ns	−0.06 ns	−0.29 *	1									
SPAD	0.29 *	−0.17 ns	−0.05 ns	0.08 ns	−0.25 ns	−0.05 ns	−0.21 ns	−0.18 ns	0.48 ***	−0.16 ns	1								
N-up	0.68 ***	0.09 ns	−0.14 ns	0.53 ***	−0.07 ns	−0.13 ns	−0.07 ns	−0.15 ns	0.74 ***	−0.06 ns	0.51 ***	1							
P-up	0.65 ***	0.43 **	−0.46 ***	0.41 **	−0.07 ns	−0.1 ns	−0.14 ns	−0.33 *	0.49 ***	−0.08 *	0.41 **	0.70 ***	1						
K-up	0.69 ***	0.67 ***	−0.21 ns	0.67 ***	0.25 ns	0.19 ns	0.15 ns	−0.09 ns	0.29 *	0.2 ns	−0.003 ns	0.54 ***	0.68 ***	1					
Ca-up	0.72 ***	0.55 ***	−0.18 ns	0.79 ***	0.27 ns	0.08 ns	0.17 ns	−0.002 ns	0.27 ns	0.32 *	−0.17 ns	0.44 ***	0.49 ***	0.81 ***	1				
Mg-up	0.76 ***	0.55 ***	−0.24 ns	0.78 ***	0.23 ns	0.06 ns	0.15 ns	−0.05 ns	0.43 **	0.19 ns	−0.08 ns	0.55 ***	0.63 ***	0.83 ***	0.94 ***	1			
Mn-up	0.76 ***	0.64 ***	−0.25 ns	0.75 ***	0.28 ns	0.19 ns	0.15 ns	−0.11 ns	0.33 *	0.24 ns	0.05 ns	0.58 ***	0.71 ***	0.88 ***	0.89 ***	0.94 ***	1		
Cu-up	0.23 ns	0.16 ns	−0.35 *	0.31 *	−0.17 ns	−0.1 ns	−0.07 ns	−0.28 *	0.38 **	−0.13 ns	0.09 ns	0.42 **	0.52 ***	0.45 ***	0.41 **	0.55 ***	0.49 ***	1	
Zn-up	0.70 ***	0.60 ***	−0.26 ns	0.64 ***	0.23 ns	0.1 ns	0.08 ns	−0.05 ns	0.39 **	0.1 ns	0.06 ns	0.61 ***	0.73 ***	0.83 ***	0.78 ***	0.86 ***	0.88 ***	0.53 ***	1

Abbreviations: N-S, soil nitrogen; P-S, soil phosphorus; K-S, soil potassium; Ca-S, soil calcium; Mg-S, soil magnesium; Mn-S, soil manganese; Cu-S, soil copper; Zn-S, soil zinc; EC, electrical conductivity; SPAD, chlorophyll content; N-up, nitrogen uptake; P-up, phosphorus uptake; K-up, plant potassium uptake; Ca-up, calcium uptake; Mg-up, magnesium uptake; Mn-up, manganese uptake; Cu-up, copper uptake; Zn-up, zinc uptake; ns, not significant. * significant at $p < 0.05$, ** $p < 0.001$, *** $p < 0.0001$.

4. Conclusions

Application of poultry wastes to the soil without negative impact is best achieved through co-composting with biochar and co-composted biochar combinations at different ratios, increased macronutrients, and reduced heavy metal uptake by maize. The results of this experiment have shown the effect of the added materials on maize for 50 days. Most of the parameters measured were all significantly different, were significantly higher for the measurements recorded in PL and CO1, and were higher than RHB or control soils. Therefore, the results of our study are based on a short-term experiment and need more field and laboratory work to explore sequences of nutrient release, carbon sequestration, and induced gaseous N loss under different application rates of biochar co-composts.

Author Contributions: Conceptualization, H.A.A. and C.F.I.; Formal analysis, H.A.A.; Funding acquisition, C.F.I.; Investigation, H.A.A.; Methodology, H.A.A. and D.S.K.; Project administration, C.F.I.; Resources, C.F.I.; Supervision, C.F.I., R.O. and D.S.K.; Validation, H.A.A., C.F.I., R.O. and D.S.K.; Writing—original draft, H.A.A.; Writing—review and editing, H.A.A., C.F.I., R.O. and D.S.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data reported in this study is contained within the article.

Acknowledgments: The authors wish to acknowledge the technical support provided by staff members and students of the Department of Land Management, Faculty of Agriculture, UPM during the conduct of this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jones, D.L.; Cross, P.; Withers, P.J.A.; Deluca, T.H.; Robinson, D.A.; Quilliam, R.S.; Harris, I.M.; Chadwick, D.R.; Edwards-Jones, G. REVIEW: Nutrient stripping: The global disparity between food security and soil nutrient stocks. *J. Appl. Ecol.* **2013**, *50*, 851–862. [CrossRef]
2. Oladele, S.; Awodun, M. Response of Lowland Rice to Biofertilizesr Inoculation and their Effects on Growth and Yield in Southwestern Nigeria. *J. Agric. Environ. Sci.* **2014**, *3*, 371–390.
3. Agegnehu, G.; Srivastava, A.K.; Bird, M.I. The role of biochar and biochar-compost in improving soil quality and crop performance: A review. *Appl. Soil Ecol.* **2017**, *119*, 156–170. [CrossRef]
4. Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 20260–20264. [CrossRef]
5. Bandara, J.S.; Cai, Y. The impact of climate change on food crop productivity, food prices and food security in South Asia. *Econ. Anal. Policy* **2014**, *44*, 451–465. [CrossRef]
6. Ramesh, T.; Bolan, N.S.; Kirkham, M.B.; Wijesekara, H.; Kanchikerimath, M.; Srinivasa Rao, C.; Sandeep, S.; Rinklebe, J.; Ok, Y.S.; Choudhury, B.U.; et al. Soil organic carbon dynamics: Impact of land use changes and management practices: A review. *Adv. Agron.* **2019**, *156*, 1–107. [CrossRef]
7. IPCC. *Climate Change 2007-Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the IPCC (Vol. 4)*; Parry, M., Parry, M.L., Canziani, O., Palutikof, J., Van der Linden, P., Hanson, C., Eds.; Cambridge University Press: Cambridge, MA, USA, 2007.
8. Sanchez, P.A.; Logan, T.J. Myths and science about the chemistry and fertility of soils in the tropics. *Myth. Sci. Soils Trop.* **1992**, *29*, 35–46.
9. Shamshuddin, J.; Anda, M.; Fauziah, C.I.; Omar, S.S.R. Growth of cocoa planted on highly weathered soil as affected by application of basalt and/or compost. *Commun. Soil Sci. Plant Anal.* **2011**, *42*, 2751–2766. [CrossRef]
10. Huang, J.; Xu, C.C.; Ridoutt, B.G.; Wang, X.C.; Ren, P. an Nitrogen and phosphorus losses and eutrophication potential associated with fertilizer application to cropland in China. *J. Clean. Prod.* **2017**, *159*, 171–179. [CrossRef]
11. Agbede, T.M. Tillage and fertilizer effects on some soil properties, leaf nutrient concentrations, growth and sweet potato yield on an Alfisol in southwestern Nigeria. *Soil Tillage Res.* **2010**, *110*, 25–32. [CrossRef]
12. Shambhavi, S.; Kumar, R.; Sharma, S.P.; Verma, G.; Sharma, R.P.; Sharma, S.K. Long-term effect of inorganic fertilizers and amendments on productivity and root dynamics under maize-wheat intensive cropping in an acid Alfisol. *J. Appl. Nat. Sci.* **2017**, *9*, 2004–2012. [CrossRef]

13. Glaser, B.; Lehmann, J.; Zech, W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—A review. *Biol. Fertil. Soils* **2002**, *35*, 219–230. [CrossRef]
14. Ayuke, F.O.; Brussaard, L.; Vanlauwe, B.; Six, J.; Lelei, D.K.; Kibunja, C.N.; Pulleman, M.M. Soil fertility management: Impacts on soil macrofauna, soil aggregation and soil organic matter allocation. *Appl. Soil Ecol.* **2011**, *48*, 53–62. [CrossRef]
15. Dikinya, O.; Mufwanzala, N. Chicken manure-enhanced soil fertility and productivity: Effects of application rates. *J. Soil Sci. Environ. Manag.* **2010**, *1*, 46–54.
16. Sekar, S.; Karthikeyan, S.; Iyappan, P. Trends in patenting and commercial utilisation of poultry farm excreta. *Worlds Poult. Sci. J.* **2010**, *66*, 533–572. [CrossRef]
17. Burton, C.H.; Turner, C. *Manure Management: Treatment Strategies for Sustainable Agriculture*; Editions Quae: Versailles, France, 2003.
18. Bernal, M.P.; Alburquerque, J.A.; Moral, R. Composting of animal manures and chemical criteria for compost maturity assessment. A review. *Bioresour. Technol.* **2009**, *100*, 5444–5453. [CrossRef]
19. Kyakuwaire, M.; Olupot, G.; Amoding, A.; Nkedi-Kizza, P.; Ateenyi Basamba, T. How safe is chicken litter for land application as an organic fertilizer?: A review. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3521. [CrossRef]
20. Li, X.; Payne, J.B.; Santos, F.B.; Levine, J.F.; Anderson, K.E.; Sheldon, B.W. Salmonella populations and prevalence in layer feces from commercial high-rise houses and characterization of the Salmonella isolates by serotyping, antibiotic resistance analysis, and pulsed field gel electrophoresis. *Poult. Sci.* **2007**, *86*, 591–597. [CrossRef]
21. Diels, J.; Vanlauwe, B.; Van Der Meersch, M.K.; Sanginga, N.; Merckx, R. Long-term soil organic carbon dynamics in a subhumid tropical climate: 13C data in mixed C3/C4 cropping and modeling with ROTHC. *Soil Biol. Biochem.* **2004**, *36*, 1739–1750. [CrossRef]
22. Tiessen, H.; Cuevas, E.; Chacon, P. The role of soil organic matter in sustaining soil fertility. *Nature* **1994**, *371*, 783–785. [CrossRef]
23. Zech, W.; Senesi, N.; Guggenberger, G.; Kaiser, K.; Lehmann, J.; Miano, T.M.; Miltner, A.; Schroth, G. Factors controlling humification and mineralization of soil organic matter in the tropics. *Geoderma* **1997**, *79*, 117–161. [CrossRef]
24. Liu, E.; Yan, C.; Mei, X.; He, W.; Bing, S.H.; Ding, L.; Liu, Q.; Liu, S.; Fan, T. Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. *Geoderma* **2010**, *158*, 173–180. [CrossRef]
25. Amlinger, F.; Peyr, J.; Geszti, P.; Dreher, W.; Nortcliff, S.K. *Beneficial Effects of Compost Application on Fertility and Productivity of Soils*; Federal Ministry for Agricultural and Forestry, Environment and Water Management, Lebensministerium: Vienna, Austria, 2007.
26. Ayari, F.; Hamdi, H.; Jedidi, N.; Gharbi, N.; Kossai, R. Heavy metal distribution in soil and plant in municipal solid waste compost amended plots. *Int. J. Environ. Sci. Technol.* **2010**, *7*, 465–472. [CrossRef]
27. Lehmann, J.; Rondon, M. Bio-Char Soil Management on Highly Weathered Soils in the Humid Tropics. *Biol. Approaches Sustain. Soil Syst.* **2006**, *113*, 517–529. [CrossRef]
28. Atkinson, C.J.; Fitzgerald, J.D.; Hipps, N.A. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. *Plant Soil* **2010**, *337*, 1–18. [CrossRef]
29. Gaskin, J.W.; Speir, R.A.; Harris, K.; Das, K.C.; Lee, R.D.; Morris, L.A.; Fisher, D.S. Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. *Agron. J.* **2010**, *102*, 623–633. [CrossRef]
30. Rajkovich, S.; Enders, A.; Hanley, K.; Hyland, C.; Zimmerman, A.R.; Lehmann, J. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biol. Fertil. Soils* **2012**, *48*, 271–284. [CrossRef]
31. Nielsen, S.; Minchin, T.; Kimber, S.; van Zwieten, L.; Gilbert, J.; Munroe, P.; Joseph, S.; Thomas, T. Comparative analysis of the microbial communities in agricultural soil amended with enhanced biochars or traditional fertilisers. *Agric. Ecosyst. Environ.* **2014**, *191*, 73–82. [CrossRef]
32. Glaser, B.; Birk, J.J. State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de índio). *Geochim. Cosmochim. Acta* **2012**, *82*, 39–51. [CrossRef]
33. Clough, T.J.; Condron, L.M.; Kammann, C.; Müller, C. A review of biochar and soil nitrogen dynamics. *Agronomy* **2013**, *3*, 275–293. [CrossRef]
34. Naeem, M.A.; Khalid, M.; Aon, M.; Abbas, G.; Amjad, M.; Murtaza, B.; Khan, W.D.; Ahmad, N. Combined application of biochar with compost and fertilizer improves soil properties and grain yield of maize. *J. Plant Nutr.* **2018**, *41*, 112–122. [CrossRef]
35. 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]
36. Schmidt, H.P.; Pandit, B.H.; Cornelissen, G.; Kammann, C.I. Biochar-Based Fertilization with Liquid Nutrient Enrichment: 21 Field Trials Covering 13 Crop Species in Nepal. *L. Degrad. Dev.* **2017**, *28*, 2324–2342. [CrossRef]
37. Mekuria, W.; Noble, A.; Sengtaheuanghoung, O.; Hoanh, C.T.; Bossio, D.; Sipaseuth, N.; McCartney, M.; Langan, S. Organic and Clay-Based Soil Amendments Increase Maize Yield, Total Nutrient Uptake, and Soil Properties in Lao PDR. *Agroecol. Sustain. Food Syst.* **2014**, *38*, 936–961. [CrossRef]
38. Adekiya, A.O.; Agbede, T.M.; Aboyeji, C.M.; Dunsin, O.; Simeon, V.T. Biochar and poultry manure effects on soil properties and radish (*Raphanus sativus* L.) yield. *Biol. Agric. Hortic.* **2019**, *35*, 33–45. [CrossRef]
39. Kizito, S.; Luo, H.; Lu, J.; Bah, H.; Dong, R.; Wu, S. Role of nutrient-enriched biochar as a soil amendment during maize growth: Exploring practical alternatives to recycle agricultural residuals and to reduce chemical fertilizer demand. *Sustainability* **2019**, *11*, 3211. [CrossRef]

40. Qayyum, M.F.; Liaquat, F.; Rehman, R.A.; Gul, M.; ul Hye, M.Z.; Rizwan, M.; Rehaman, M.Z. ur Effects of co-composting of farm manure and biochar on plant growth and carbon mineralization in an alkaline soil. *Environ. Sci. Pollut. Res.* **2017**, *24*, 26060–26068. [CrossRef]
41. Pandit, N.R.; Mulder, J.; Hale, S.E.; Martinsen, V.; Schmidt, H.P.; Cornelissen, G. Biochar improves maize growth by alleviation of nutrient stress in a moderately acidic low-input Nepalese soil. *Sci. Total Environ.* **2018**, *625*, 1380–1389. [CrossRef]
42. Wright, R.J.; Stuczynski, T. Atomic absorption and flame emission spectrometry. In *Methods of Soil Analysis*; John Wiley & Sons: Hoboken, NJ, USA, 1996; pp. 65–90.
43. Peech, H. Hydrogen-ion activity. In *Methods of Soil Analysis*; Black, C.A., Evans, D.D., Ensminger, L.E., White, J.L., Clark, F.E., Dinauer, R.C., Eds.; American Society of Agronomy: Madison, WI, USA, 1965; p. 64.
44. McGrath, S.P.; Cunliffe, C.H. A simplified method for the extraction of the metals Fe, Zn, Cu, Ni, Cd, Pb, Cr, Co and Mn from soils and sewage sludges. *J. Sci. Food Agric.* **1985**, *36*, 794–798. [CrossRef]
45. Havlin, J.L.; Tisdale, S.L.; Nelson, W.L.; Beaton, J.D. *Soil Fertility and Fertilizers*; Pearson Education India: London, UK, 2016.
46. Souza, H.A.D.; Melo, M.D.; Primo, A.A.; Vieira, L.V.; Pompeu, R.C.F.F.; Guedes, F.L.; Natale, W. Use of organic compost containing waste from small ruminants in corn production. *Rev. Bras. Ciência do Solo Viçosa* **2016**, *40*, 1–16. [CrossRef]
47. Taiz, L.; Zeiger, E. *Fisiologia Vegetal*, 4th ed.; Artmed Editora: Porto Alegre, Brazil, 2009.
48. Lehmann, M.F.; Bernasconi, S.M.; Barbieri, A.; McKenzie, J. Preservation of organic matter and alteration of its carbon and nitrogen isotope composition during simulated and in situ early sedimentary diagenesis. *Geochim. Cosmochim. Acta* **2002**, *66*, 3573–3584. [CrossRef]
49. Hamer, U.; Marschner, B.; Brodowski, S.; Amelung, W. Interactive priming of black carbon and glucose mineralisation. *Org. Geochem.* **2004**, *35*, 823–830. [CrossRef]
50. Schulz, H.; Dunst, G.; Glaser, B. Positive effects of composted biochar on plant growth and soil fertility. *Agron. Sustain. Dev.* **2013**, *33*, 817–827. [CrossRef]
51. Oladotun, A.O. Managing Manure as a Fertilizer. In *Saskatchewani, Agriculture, Food and Rural Revitalization*; FAO: Rome, Italy, 2002; p. 5.
52. Cogger, C.; Hummel, R.; Hart, J.; Bary, A. Soil and redosier dogwood response to incorporated and surface-applied compost. *HortScience* **2008**, *43*, 2143–2150. [CrossRef]
53. Kuzyakov, Y.; Subbotina, I.; Chen, H.; Bogomolova, I.; Xu, X. Black carbon decomposition and incorporation into soil microbial biomass estimated by 14C labeling. *Soil Biol. Biochem.* **2009**, *41*, 210–219. [CrossRef]
54. Zimmerman, A.R.; Gao, B.; Ahn, M.Y. Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils. *Soil Biol. Biochem.* **2011**, *43*, 1169–1179. [CrossRef]
55. Jeffery, S.; Verheijen, F.G.A.; van der Velde, M.; Bastos, A.C. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agric. Ecosyst. Environ.* **2011**, *144*, 175–187. [CrossRef]
56. Whitman, T.; Enders, A.; Lehmann, J. Pyrogenic carbon additions to soil counteract positive priming of soil carbon mineralization by plants. *Soil Biol. Biochem.* **2014**, *73*, 33–41. [CrossRef]
57. Zavalloni, C.; Alberti, G.; Biasiol, S.; Vedove, G.D.; Fornasier, F.; Liu, J.; Peressotti, A. Microbial mineralization of biochar and wheat straw mixture in soil: A short-term study. *Appl. Soil Ecol.* **2011**, *50*, 45–51. [CrossRef]
58. Flavel, T.C.; Murphy, D.V. Carbon and Nitrogen Mineralization Rates after Application of Organic Amendments to Soil. *J. Environ. Qual.* **2006**, *35*, 183–193. [CrossRef] [PubMed]
59. Luo, X.; Liu, G.; Xia, Y.; Chen, L.; Jiang, Z.; Zheng, H.; Wang, Z. Use of biochar-compost to improve properties and productivity of the degraded coastal soil in the Yellow River Delta, China. *J. Soils Sediments* **2017**, *17*, 780–789. [CrossRef]
60. Lehmann, J.; Rillig, M.C.; Thies, J.; Masiello, C.A.; Hockaday, W.C.; Crowley, D. Biochar effects on soil biota—A review. *Soil Biol. Biochem.* **2011**, *43*, 1812–1836. [CrossRef]
61. Ippolito, J.A.; Laird, D.A.; Busscher, W.J. Environmental Benefits of Biochar. *J. Environ. Qual.* **2012**, *41*, 967–972. [CrossRef]
62. Bruun, S.; Clauson-Kaas, S.; Bobul'ská, L.; Thomsen, I.K. Carbon dioxide emissions from biochar in soil: Role of clay, microorganisms and carbonates. *Eur. J. Soil Sci.* **2014**, *65*, 52–59. [CrossRef]
63. Hargreaves, J.; Adl, M.S.; Warman, P.R.; Rupasinghe, H.P.V. The effects of organic amendments on mineral element uptake and fruit quality of raspberries. *Plant Soil* **2008**, *308*, 213–226. [CrossRef]
64. Yuksel, O. Influence of municipal solid waste compost application on heavy metal content in soil. *Environ. Monit. Assess.* **2015**, *187*, 313. [CrossRef]
65. Adejobi, K.B.; Akanbi, O.S.; Ugioro, O.; Adeosun, S.A.; Mohammed, I.; Nduka, B.A.; Adeniyi, D.O. Comparative effects of NPK fertilizer, cowpea pod husk and some tree crops wastes on soil, leaf chemical properties and growth performance of cocoa (*Theobroma cacao* L.). *Afr. J. Plant Sci.* **2014**, *8*, 103–107. [CrossRef]
66. Ndubuisi-Nnaji, U.U.; Adegoke, A.A.; Ogbu, H.I.; Ezenobi, N.O.; Okoh, A.I. Effect of long-term organic fertilizer application on soil microbial dynamics. *Afr. J. Biotechnol.* **2011**, *10*, 556–559. [CrossRef]
67. Ye, R.; Wright, A.L.; McCray, J.M. Seasonal changes in nutrient availability for sulfur-amended everglades soils under sugarcane. *J. Plant Nutr.* **2011**, *34*, 2095–2113. [CrossRef]
68. Novak, J.M.; Busscher, W.J.; Laird, D.L.; Ahmedna, M.; Watts, D.W.; Niandou, M.A.S. Impact of biochar amendment on fertility of a southeastern coastal plain soil. *Soil Sci.* **2009**, *174*, 105–112. [CrossRef]

69. Hanajima, D.; Kuroda, K.; Morishita, K.; Fujita, J.; Maeda, K.; Morioka, R. Key odor components responsible for the impact on olfactory sense during swine feces composting. *Bioresour. Technol.* **2010**, *101*, 2306–2310. [CrossRef]
70. Rogeri, D.A.; Ernani, P.R.; Lourenco, K.S.; Cassol, P.C.; Gatiboni, L.C. Mineralization and nitrification of nitrogen from poultry litter applied to soil/Mineralizacao e nitrificacao do nitrogenio proveniente da cama de aves aplicada ao solo. *Rev. Bras. Eng. Agric. Ambient.* **2015**, *19*, 534–541. [CrossRef]
71. Chintala, R.; Mollinedo, J.; Schumacher, T.E.; Malo, D.D.; Julson, J.L. Effect of biochar on chemical properties of acidic soil. *Arch. Agron. Soil Sci.* **2014**, *60*, 393–404. [CrossRef]
72. Gabrielle, B.; Da-Silveira, J.; Houot, S.; Michelin, J. Field-scale modelling of carbon and nitrogen dynamics in soils amended with urban waste composts. *Agric. Ecosyst. Environ.* **2005**, *110*, 289–299. [CrossRef]
73. Islam, M.; Chowdhury, M.; Saha, B.; Hasan, M. Integrated nutrient management on soil fertility, growth and yield of tomato. *J. Bangladesh Agric. Univ.* **2014**, *11*, 33–40. [CrossRef]
74. Peng, F.; He, P.W.; Luo, Y.; Lu, X.; Liang, Y.; Fu, J. Adsorption of Phosphate by Biomass Char Deriving from Fast Pyrolysis of Biomass Waste. *Clean Soil Air Water* **2012**, *40*, 493–498. [CrossRef]
75. Streubel, J.D.; Collins, H.P.; Tarara, J.M.; Cochran, R.L. Biochar Produced from Anaerobically Digested Fiber Reduces Phosphorus in Dairy Lagoons. *J. Environ. Qual.* **2012**, *41*, 1166–1174. [CrossRef]
76. Yao, Y.; Gao, B.; Chen, J.; Yang, L. Engineered biochar reclaiming phosphate from aqueous solutions: Mechanisms and potential application as a slow-release fertilizer. *Environ. Sci. Technol.* **2013**, *47*, 8700–8708. [CrossRef]
77. Paz-Ferreiro, J.; Gascó, G.; Gutiérrez, B.; Méndez, A. Soil biochemical activities and the geometric mean of enzyme activities after application of sewage sludge and sewage sludge biochar to soil. *Biol. Fertil. Soils* **2012**, *48*, 511–517. [CrossRef]
78. Yoo, G.; Kang, H. Effects of Biochar Addition on Greenhouse Gas Emissions and Microbial Responses in a Short-Term Laboratory Experiment. *J. Environ. Qual.* **2012**, *41*, 1193–1202. [CrossRef]
79. Zhai, L.; Cai, Z.J.; Liu, J.; Wang, H.; Ren, T.; Gai, X.; Xi, B.; Liu, H. Short-term effects of maize residue biochar on phosphorus availability in two soils with different phosphorus sorption capacities. *Biol. Fertil. Soils* **2015**, *51*, 113–122. [CrossRef]
80. Nur, M.S.M.; Islami, T.; Handayanto, E.; Nugroho, W.H.; Utomo, W.H. The use of biochar fortified compost on calcareous soil of East Nusa Tenggara, Indonesia: 2. Effect on the yield of maize (*Zea mays* L) and phosphate absorption. *Am. J. Sustain. Agric.* **2014**, *8*, 105–112.
81. De Novais, R.F.; Alvarez, V.V.H.; de Barros, N.F.; Fontes, R.L.F.; Cantarutti, R.B.; Neves, J.C. *Fertilidade do Solo*; Sociedade Brasileira de Ciência do Solo: Viçosa, Brasil, 2007; 1017p.
82. Wang, Z.; Göttlein, A.; Bartonek, G. Effects of growing roots of Norway spruce (*Picea abies* [L.] Karst.) and European beech (*Fagus sylvatica* L.) on rhizosphere soil solution chemistry. *J. Plant Nutr. Soil Sci.* **2001**, *164*, 35–41. [CrossRef]
83. Ahmad, W.; Shah, Z.; Khan, F.; Ali, S.; Malik, W. Maize yield and soil properties as influenced by integrated use of organic, inorganic and bio-fertilizers in a low fertility soil. *Soil Environ.* **2013**, *32*, 121–129.
84. Rizwan, M.; Ali, S.; Qayyum, M.F.; Ibrahim, M.; Zia-ur-Rehman, M.; Abbas, T.; Ok, Y.S. Mechanisms of biochar-mediated alleviation of toxicity of trace elements in plants: A critical review. *Environ. Sci. Pollut. Res.* **2016**, *23*, 2230–2248. [CrossRef]
85. Fischer, D.; Glaser, B. Synergisms between Compost and Biochar for Sustainable Soil Amelioration. In *Management of Organic Waste*; Kumar, S., Ngarti, A., Eds.; IntechOpen: Rijeka, Croatia, 2012. [CrossRef]
86. Zama, E.F.; Zhu, Y.G.; Reid, B.J.; Sun, G.X. The role of biochar properties in influencing the sorption and desorption of Pb(II), Cd(II) and As(III) in aqueous solution. *J. Clean. Prod.* **2017**, *148*, 127–136. [CrossRef]
87. Giannakis, G.V.; Kourgialas, N.N.; Paranychianakis, N.V.; Nikolaidis, N.P.; Kalogerakis, N. Effects of municipal solid waste compost on soil properties and vegetables growth. *Compost Sci. Util.* **2014**, *22*, 116–131. [CrossRef]
88. Paradelo, R.; Barral, M.T. Disponibilidade e fracionamento do Cu, Pb e Zn num solo ácido da Galiza (NW Espanha) corrigido com um composto de resíduos sólidos urbanos. *Spanish J. Soil Sci.* **2017**, *7*, 31–39. [CrossRef]
89. Mkhabela, M.S.; Warman, P.R. The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash sandy loam soil in Nova Scotia. *Agric. Ecosyst. Environ.* **2005**, *106*, 57–67. [CrossRef]
90. Paradelo, R.; Moldes, A.B.; Barral, M.T. Evolution of organic matter during the mesophilic composting of lignocellulosic winery wastes. *J. Environ. Manag.* **2013**, *116*, 18–26. [CrossRef]
91. Zheng, H.; Wang, Z.; Deng, X.; Herbert, S.; Xing, B. Impacts of adding biochar on nitrogen retention and bioavailability in agricultural soil. *Geoderma* **2013**, *206*, 32–39. [CrossRef]
92. Wang, Q.; Awasthi, M.K.; Ren, X.; Zhao, J.; Li, R.; Wang, Z.; Wang, M.; Chen, H.; Zhang, Z. Combining biochar, zeolite and wood vinegar for composting of pig manure: The effect on greenhouse gas emission and nitrogen conservation. *Waste Manag.* **2018**, *74*, 221–230. [CrossRef] [PubMed]
93. Arruda, B.; Dall'orsoletta, D.J.; Heidemann, J.C.; Gatiboni, L.C. Phosphorus dynamics in the rhizosphere of two wheat cultivars in a soil with high organic matter content. *Arch. Agron. Soil Sci.* **2018**, *64*, 1011–1020. [CrossRef]
94. Strojaki, T.V.; da Silva, V.R.; Somavilla, A.; Da Ros, C.O.; de Moraes, M.T. Atributos químicos do solo e produtividade de girassol e milho em função da aplicação de composto de lixo urbano. *Pesqui. Agropecu. Trop.* **2013**, *43*, 278–285. [CrossRef]

95. Bashir, A.; Rizwan, M.; Zia ur Rehman, M.; Zubair, M.; Riaz, M.; Qayyum, M.F.; Alharby, H.F.; Bamagoos, A.A.; Ali, S. Application of co-composted farm manure and biochar increased the wheat growth and decreased cadmium accumulation in plants under different water regimes. *Chemosphere* **2020**, *246*, 125809. [CrossRef]
96. Mokolobate, M.S.; Haynes, R.J. Comparative liming effect of four organic residues applied to an acid soil. *Biol. Fertil. Soils* **2002**, *35*, 79–85. [CrossRef]