applied sciences

MDPI

Article

The Role of Poultry Litter and Its Biochar on Soil Fertility and *Jatropha curcas* L. Growth on Sandy-Loam Soil

Boitshwarelo Lorato Masocha * and **Oagile Dikinya**

Department of Environmental Sciences, University of Botswana, Private Bag, Gaborone 00704, Botswana
* Correspondence: blmasocha@gmail.com

Abstract: Low agricultural output and a decline in plant-available nutrient content in soil pose significant challenges to developing countries. To test the hypothesis that poultry litter and its biochar improve soil quality, nutrient status, and plant growth, a greenhouse pot experiment with sandy-loam soil was conducted. Selected application rates of poultry litter (0, 15, 30, 60, and 120 g/kg) and its biochar pyrolyzed at 350 °C and 600 °C were used. With the addition of organic amendments, Jatropha plant height, leaf number, and stem diameter improved significantly, as did soil fertility indicators (pH, organic matter content, cation exchange capacity, and plant-available nutrients). When compared to the control, increased application rates ranging from 60 g/kg to 120 g/kg significantly improved soil properties and plant growth. PL (Poultry litter)- and BC350 (Biochar produced at 350 °C)-treated soil outperformed other organic amendments in terms of soil quality, nutrient status, and plant growth. Soil pH, CEC, and OM were found to be positively correlated with available plant nutrients, with PL-treated soils having higher levels of plant available nutrients. Because the properties of the feedstocks complement each other, combined organic amendments improved studied parameters, particularly PLBC600 (Poultry litter mixed with biochar produced at 600 °C) compared to BC600 (Biochar produced at 600 °C). Increased application rates of pure and combined feedstock effectively increased soil fertility and Jatropha growth; however, lower temperature biochar is recommended for use as a soil organic amendment.

Keywords: biochar; nutrient availability; poultry litter; *Jatropha curcas* L.; soil fertility

check for updates

Citation: Masocha, B.L.; Dikinya, O. The Role of Poultry Litter and Its Biochar on Soil Fertility and *Jatropha curcas* L. Growth on Sandy-Loam Soil. *Appl. Sci.* **2022**, *12*, 12294. https://doi.org/10.3390/app122312294

Academic Editor: Dionisios Gasparatos

Received: 31 August 2022
Accepted: 17 November 2022
Published: 1 December 2022

1. Introduction

The decline in plant-available nutrient content in soil is one of the most serious challenges confronting developing countries, particularly those in Sub-Saharan Africa [1]. Crop yield declines due to poor fertile soils have been linked to low agricultural production [2]. Furthermore, the growth of marginalized communities leads to environmental overexploitation through intensive agricultural activities. Human agricultural activities eventually place more strain on agricultural lands [3,4] causing loss of soil nutrients. Continuous soil nutrient loss limits the agricultural sector's contribution to the country's economy [2]. Botswana is a semi-arid region that faces the same problem of lower crop yields due to Arenosols occupying the majority of the land.

Arenosols (sandy soils) typical of arid deserts cover the majority of the country, accounting for roughly two-thirds of arable land area. The soils are classified as arid climate soils with low Cation Exchange Capacity (CEC) and inherent fertility, specifically nitrogen (N) and phosphorus (P) [5]. The Botswana government implemented the Integrated Support Programme for the Arable Agriculture Development (ISPAAD) program in 2008 to assist farmers with chemical fertilizers; however, the problem of declining crop yields in Botswana persists. From 2008 to 2019, the area planted (227,000 ha to 88,000 ha) and harvested (126,000 ha to 23,000 ha) decreased [6]. Despite having the highest per capita gross national income in 2019, Botswana has been identified vulnerable to food insecurity due to the declining agricultural sector's contribution to the economy [7]. Despite the challenges of soil nutrient depletion, agriculture is a critical sector of the country's economy because 70 percent of rural households still rely on it for a significant portion of their income, so sustainable agriculture measures are critical [8].

Organic waste, particularly poultry litter, has grown in popularity as an alternative organic fertilizer source for improving soil quality and crop yields [9–11]. Subsistence farmers—who make up the vast majority of farmers in the agricultural system—have used poultry litter [12]. It has enormous socioeconomic benefits due to its high nutrient content, which is required for improving soil nutrient concentrations [13,14]. Besides improving soil nutrient content, the use of organic waste greatly aids waste management [15,16].

In contrast to the benefits brought about by the expansion of the poultry industry, the rapid increase of poultry waste on the land has become a significant environmental challenge because waste management strategies are insufficient [17–19]. It has been determined that the excessively increasing amounts of solid waste exceed the collection and disposal capacities of local governments [20]. Local farmers in Botswana primarily use accumulated poultry litter as alternative fertilizers at unrecommended rates, so best application guidelines must be recommended. To effectively use organic waste feedstock, the best techniques for improving feedstock quality are required; thus, the study converted poultry litter into biochar to improve feedstock quality.

Biochar is a pyrogenous organic material that is created through the pyrolysis of various biomass (plant/animal) wastes [21]. Biochar's primary advantage is that it is a stable carbon that improves soil fertility, nutrient retention, and crop growth [19,22–24]. Furthermore, the carbon in biochar is sequestered in the soil for a much longer period of time than the original feedstock, which is easily degradable [25,26]. In Botswana, there is still a lack of understanding about biochar, its production and its use. Therefore, the aim of this study was to evaluate the effects of poultry litter and its biochar on selected soil physicochemical properties and *Jatropha curcas* L. morphological growth. The study investigates how different application rates of poultry litter and its biochar affect soil physical properties, fertility indicators, and available soil nutrient content. The study's hypothesis is that increasing the application rates of poultry litter and its biochar will improve soil parameters and enhance Jatropha growth.

2. Materials and Methods

2.1. Collection of Samples

Sub-soil soil samples were collected from 0–20 cm depth in randomly selected and cleared fallow sampling spots at least 4 meters apart on a horticultural farm. The farm is located 20 km north-west of Gaborone, along the Gaborone–Molepolole road in Kweneng district, between latitude (24°54′43.14″ S) and longitude (25°81′33.34″ S). Tswana Pride poultry farm in Notwane provided samples of least one-year-old poultry litter. For two weeks, the poultry litter samples were air-dried to reduce moisture content and pathogens. The collected poultry litter sample was divided into two portions, one for pure organic soil amendment and the other portion for biochar production.

2.2. Experimental Design

A complete randomized greenhouse experiment was set up at Botswana University of Agriculture and Natural Resources Crop Science and Production department. A 3 kg of air-dried sieved sandy-loam soil in plastic pots measuring 25 cm in diameter and 20 cm in height were homogeneously mixed with different application rates of organic amendments before saturating the soil to field capacity. After two weeks of soil saturation, all pots were arranged on raised benches and Jatropha seedlings were transplanted into the pots. Poultry litter (PL), biochar pyrolyzed at 350 °C (BC350), and biochar pyrolyzed at 600 °C (BC600), and their combinations, PLBC350 and PLBC600 were used in this study. T1, control (0 g/kg), T2 (15 g/kg), T3 (30 g/kg), T4 (60 g/kg), and T5 (120 g/kg) were the application rates for each organic amendment. At six weeks of age, *Jatropha curcas* L. seedlings were transplanted into pots, and each treatment's application rate was repeated three times. To keep the soil at the proper moisture content, Jatropha plants were watered every other day. On the plants, no chemicals, fertilizers, or pesticides were used, and all weeding was performed by hand picking.

2.3. Soil Analysis

Before and after the experiment, physicochemical properties of air-dried sieved soil were determined. The soil textural class was identified using the Mastersizer 3000 (Malvern, HydroEV; Malvern Instruments, Ltd., Malvern, UK; Software Version: 3.00), and the hydrometer method was used for further textural analysis [27]. Active soil acidity was measured in a 1:2 soil to water suspension using a hand-held digital multi-parameter PD 300, OakTon Eutech Instrument. Soil moisture content (%) was determined gravimetrically by drying samples in an oven at 105 °C until they reached a constant weight. The droplet counting method developed by [28] was used for water holding capacity (%) analysis. Walkley & Black [29] Wet oxidation method was used to determine organic matter. Furthermore, exchangeable cations (mmol_c/kg) were extracted using ammonium acetate and quantified using Inductively Coupled Plasma (ICP) and their summation was used to compute cation exchange capacity (CEC). The Mehlich 3 procedure described by [30] was used to determine available plant nutrients, and Microwave Plasma Atomic Emission Spectroscopy (MP-AES) was used to quantify available plant nutrients except for phosphorus (P). The intensity of the blue coloration method at a wavelength of 845 nm was used to analyze phosphorus Mehlich 3 extractant (M3-P) using a UV-Visible spectrophotometer (UV-1800 Series).

2.4. *Jatropha curcas* L. Growth Parameters

The growth rates of Jatropha were calculated using morphological properties collected throughout the growing season. Plant height (cm) was measured weekly with a ruler from the soil surface to the plant's tip; stem diameter (cm) was measured monthly with a digital Venier caliper (cm); and the number of leaves on each plant was counted weekly.

2.5. Biochar Production

A crucible muffle furnace (FO310, Yamoto) was used to produce biochar at pyrolysis temperatures of 350 °C and 600 °C. Biochar samples are referred to as BC350 and BC600 in this study for pyrolysis temperatures of 350 °C and 600 °C, respectively. Nitrogen gas was passed through an inlet pipe inside the tightly closed crucible filled with poultry litter in the closed muffle furnace for 30 s before charring the feedstock. Following that, a continuous flow of nitrogen gas into the furnace was allowed to create an oxygen-limited condition until the charring time had elapsed, and biochar was allowed to cool at room temperature in the furnace. Before being stored in glass jars for analysis and incorporation into the soil, biochar was ground and sieved.

2.6. Poultry Litter and Biochar Analysis

The moisture and dry matter content of the samples were determined by oven-drying them at 105 °C until constant weight was reached [31]. The pH and electrical conductivity (EC) of a (1:10 w/v litter–water extract) were potentiometrically determined using a calibrated multi-parameter digital handheld meter [31]. Organic matter (OM) contents were determined using the loss on ignition method [32] and the biochar analysis procedures were the same as those used for poultry litter, but the quantification reagents followed ASTM D1752-84 guidelines [25].

2.7. Statistical Analysis

All data collected in the experiment were subjected to descriptive statistics and Analysis of Variance (ANOVA) using the statistical package (SPSS version 22.0). The Tukey HSD post hoc test was used to separate means when there were significant differences between treatments at a 5% probability level.

3. Results

3.1. Characteristics of Soil, Poultry Litter, and Its Biochar

Tables 1 and 2 show the analytical results for soil, poultry litter and its biochar, respectively. The soil is sandy-loam, with a moisture content of 0.06% and a water holding capacity of 13.1%. It is composed of 64% sand, 18% clay, and 18% silt. The soil sample has a slightly acidic pH of 6.36, an electrical conductivity of 51.0 µS/cm and a significant organic matter content of 2.81%.

Table 1. Initial soil elements concentrations.

Property	Value
Available plant nutrients (mg/kg)	
Phosphorus (P)	0.80
Potassium (K)	3.58
Calcium (Ca)	10.07
Magnesium (Mg)	3.69
Iron (Fe)	9.31
Manganese (Mn)	2.77
Copper	0.04
Zinc (Zn)	0.24
Exchangeable cations (cmol/kg)	
K	4.13
Ca	22.0
Mg	4.13
Na	6.85

Table 2. Plant available nutrients concentrations in poultry litter and its biochar.

Plant Available Nutrients (mg/kg)	Poultry Litter	Biochar 350 °C	Biochar 600 °C
Phosphorus (P)	33.01	33.37	33.98
Potassium (K)	826.79	1714.08	855.20
Calcium (Ca)	813.48	724.32	748.65
Magnesium (Mg)	349.14	526.35	314.46
Sodium (Na)	137.34	354.75	162.26
Iron (Fe)	12.75	8.53	28.83
Zinc (Zn)	41.37	31.53	25.56
Manganese (Mn)	28.39	51.35	36.67
Copper (Cu)	0.73	1.22	25.56
EC (µS/cm)	13.90	365.33	278.67

PL and BC350 revealed the highest plant available nutrient content when compared to BC600 (Table 2). The pH of PL was moderately alkaline (7.77) compared to the strongly alkaline BC350 pH of 8.58 and 9.21 for BC600 biochars. Organic matter content increased significantly in biochar samples, rising from 5.69% in poultry litter to 28.57% BC350 and 23.82% BC600. Nonetheless, when compared to BC600, biochar produced at a lower pyrolysis temperature contained more organic matter.

3.2. Poultry Litter and Its Biochar Effects on Soil Fertility Indicators

Soil pH, Organic Matter Content and Cation Exchange Capacity

Figure 1 depicts the pH of the soil. A significant gradual increase of soil pH was observed with the increasing application rates. Generally, PL-treated soils had the highest pH level ranging from 7.67 to 8.24, followed by BC350 treated soils (8.20) and then BC600 (7.86) (Figure 1a). The control treatments increased soil pH from the initial 6.36 to slightly alkaline pH range of 7.31 to 7.82 (Figure 1a). A combination of biochar and poultry litter (PLBC350 and PLBC600) displayed an increased soil pH (Figure 1a).

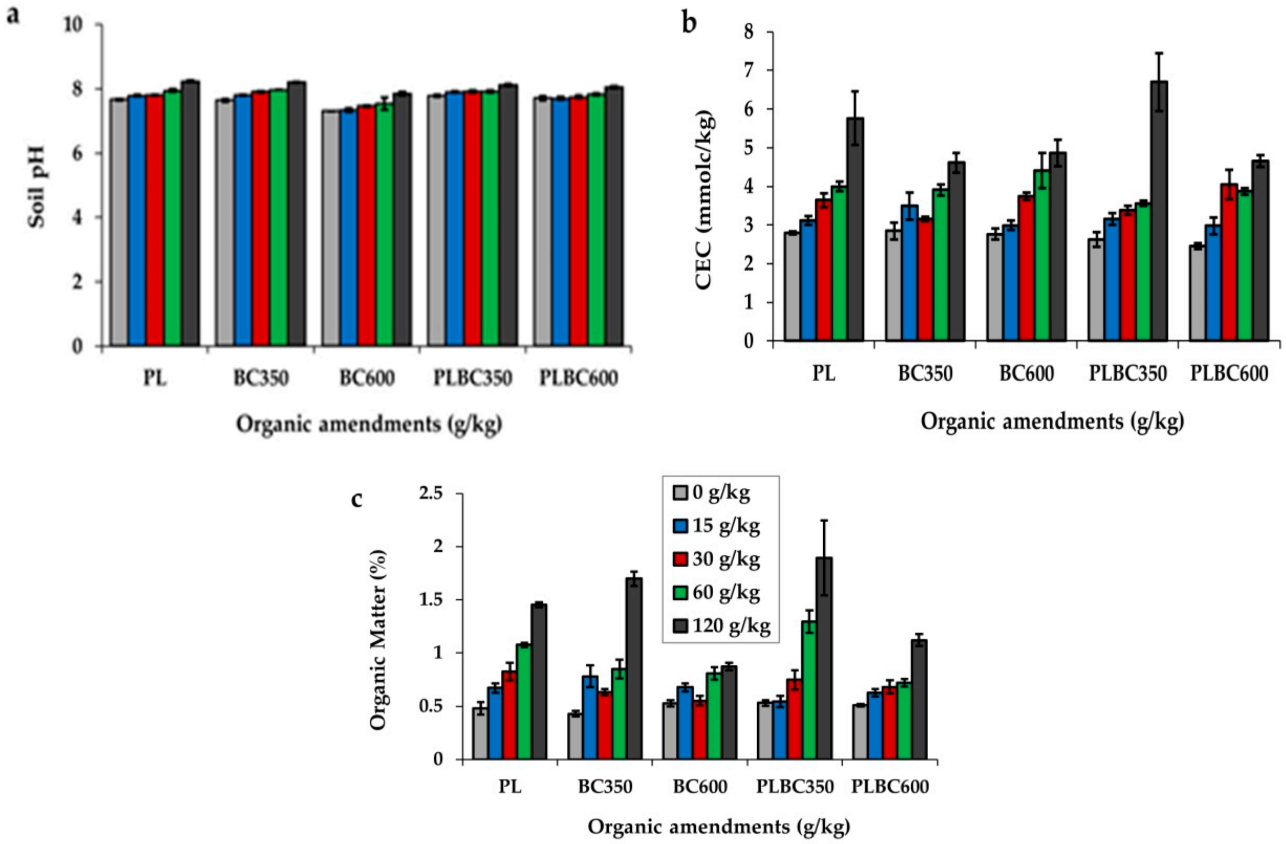

Figure 1. Effects of poultry litter and its biochar on soil pH (**a**), Cation exchange capacity (**b**), and Organic matter content (**c**) at different application rates of 0, 15, 30, 60, and 120 g/kg. Bars represent means and standard errors, $n = 3$.

Figure 1b shows that the increased application rates of soil organic amendments significantly increased cation exchange capacity. In all treatments, the highest application rate of 120 g/kg has shown the highest CEC (Figure 1b). However, PLBC350 exhibited a higher CEC of 6.70 mmol$_c$/kg. In terms of soil organic matter content, increasing the application rates of organic amendments effectively increased organic matter content when compared to the control (Figure 1c). The organic matter content (OM) in PL- and BC350-treated soils increased with application rates (Figure 1c) compared to BC600-treated soils.

3.3. Poultry Litter and Its Biochar on Soil Moisture Content, Bulk Density, and Water Holding Capacity

Figure 2a shows the results for soil moisture content in treated soils. The incorporation of poultry litter and its biochar improved the moisture content of sandy-loam soils significantly. However, except at an application rate of 120 g/kg, where PLBC350 had a moisture content of 7.58%, BC600-treated soils have statistically higher moisture content than other treatments (Figure 2a). Water-holding capacities (WHC) of the treated soils followed the same pattern as moisture content, with the increased application rates significantly improving WHC compared to the control soil (Figure 2b). Even though there was a slight difference in organic amendment application rates, PLBC600 had a higher WHC of 19.09%. Figure 2c also shows that there is no significant difference in bulk density between treatments ($p > 0.05$). However, at application rates of 15, 30, 60, and 120 g/kg, BC350- and PLBC600-treated soils have shown a slight or no increase in bulk (Figure 2c).

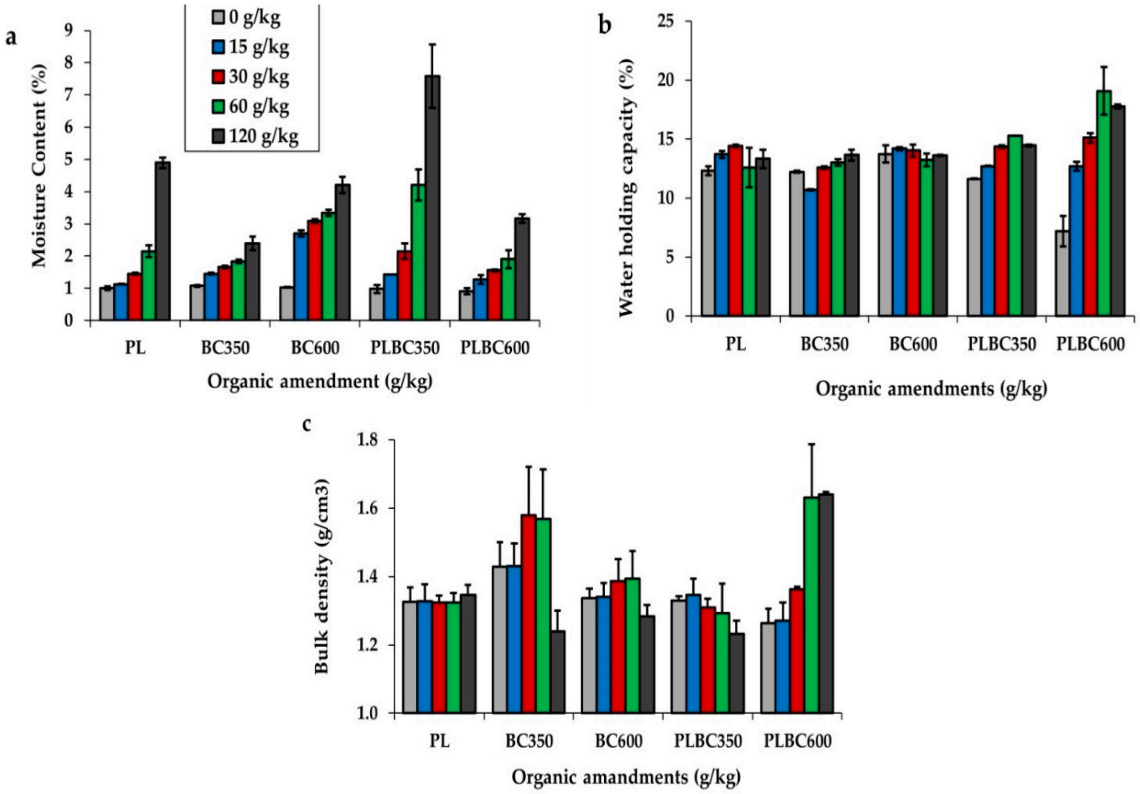

Figure 2. Effects of poultry litter and its biochar on (**a**) Moisture content (%), (**b**) Water holding capacity (%) and (**c**) Bulk density (g/cm^3) at different application rates of 0, 15, 30, 60, and 120 (g/kg). Graphs represent mean and standard error, *n* = 3.

3.4. Poultry Litter and Its Biochar on Available Plant Nutrients Concentration in the Soil

Table 3 displays the macro and micro nutrients in the soil (P, K, Ca, Mg, Fe, Mn, Cu, and Zn). Macronutrients were significantly more available at high concentrations than micronutrients (Table 3) with Ca > Mg > K and P being the most abundant. The level of macronutrient in the soil increased as the application rate increased. The decreasing concentration order for micronutrients was Fe > Mn > Zn > Cu, with a significant statistical difference ($p < 0.05$) observed at different application rates (Table 3). Iron (Fe) concentrations increased even in alkaline soil pH when compared to other soil micronutrients. Furthermore, the combination of organic amendments resulted in a slight increase in nutrient concentration when compared to pure organic amendments.

Table 3. Available plant nutrient concentrations in soils incorporated with different application rates of poultry litter and its biochar at harvest.

Organic Amendments	Application Rates (g/kg)	P	K	Mg	Ca	Zn	Cu	Fe	Mn
		(mg/kg)							
PL	0	1.14 ± 0.08^{d}	3.56 ± 0.05^{c}	4.28 ± 0.05^{c}	10.99 ± 0.58^{c}	0.03 ± 0.01^{d}	0.05 ± 0.01^{b}	8.46 ± 0.27^{b}	2.61 ± 0.06^{a}
	15	3.58 ± 0.33^{cd}	4.91 ± 0.50^{c}	4.79 ± 0.34^{c}	11.49 ± 0.33^{c}	0.12 ± 0.01^{cd}	0.04 ± 0.01^{b}	8.89 ± 0.80^{b}	2.84 ± 0.26^{a}
	30	6.02 ± 1.27^{c}	7.88 ± 1.83^{bc}	5.96 ± 0.36^{bc}	13.88 ± 0.94^{bc}	0.21 ± 0.04^{c}	0.06 ± 0.01^{ab}	9.34 ± 0.69^{ab}	3.13 ± 0.18^{a}
	60	9.33 ± 0.10^{b}	11.29 ± 0.39^{b}	7.53 ± 0.41^{b}	18.01 ± 1.07^{ab}	0.32 ± 0.01^{b}	0.07 ± 0.01^{ab}	10.19 ± 0.41^{ab}	3.37 ± 0.10^{a}
	120	16.15 ± 0.73^{a}	21.30 ± 0.99^{a}	11.13 ± 0.60^{a}	21.21 ± 2.40^{a}	1.02 ± 0.02^{a}	0.09 ± 0.01^{a}	11.86 ± 0.68^{a}	3.53 ± 0.53^{a}
BC350	0	1.33 ± 0.05^{e}	4.34 ± 0.26^{c}	4.30 ± 0.06^{d}	11.44 ± 0.22^{d}	0.04 ± 0.01^{d}	0.05 ± 0.01^{a}	8.91 ± 0.38^{c}	2.59 ± 0.04^{b}
	15	2.97 ± 0.37^{d}	4.88 ± 0.26^{c}	5.37 ± 0.18^{c}	12.68 ± 0.30^{cd}	0.10 ± 0.01^{d}	0.05 ± 0.01^{a}	10.51 ± 0.39^{bc}	2.96 ± 0.16^{b}
	30	4.32 ± 0.33^{c}	7.15 ± 0.25^{c}	5.16 ± 0.16^{c}	14.11 ± 0.36^{c}	0.17 ± 0.01^{c}	0.05 ± 0.01^{a}	11.28 ± 0.38^{ab}	3.19 ± 0.12^{ab}
	60	7.24 ± 0.02^{b}	12.98 ± 1.29^{b}	7.87 ± 0.08^{b}	19.46 ± 0.31^{b}	0.25 ± 0.02^{b}	0.09 ± 0.02^{a}	12.28 ± 0.74^{ab}	4.23 ± 0.53^{a}
	120	12.51 ± 0.17^{a}	20.67 ± 0.76^{a}	10.20 ± 0.26^{a}	24.93 ± 0.58^{a}	0.26 ± 0.02^{a}	0.08 ± 0.01^{a}	13.41 ± 0.52^{a}	4.21 ± 0.18^{a}

Table 3. *Cont.*

Organic Amendments	Application Rates (g/kg)	P	K	Mg	Ca	Zn	Cu	Fe	Mn
		(mg/kg)							
BC600	0	1.00 ± 0.09 ^{d}	3.51 ± 0.12 ^{d}	4.33 ± 0.04 ^{c}	11.43± 0.56 ^{c}	0.02 ± 0.01 ^{d}	0.05 ± 0.01 ^{a}	9.08 ± 0.44 ^{b}	2.62 ± 0.07 ^{b}
	15	2.87 ± 0.07 ^{c}	5.17 ± 0.08 ^{cd}	4.96 ± 0.14 ^{bc}	13.54 ± 0.42 ^{bc}	0.17 ± 0.01 ^{c}	0.05 ± 0.01 ^{a}	10.76 ± 0.14 ^{ab}	2.74 ± 0.04 ^{b}
	30	3.75 ± 0.04 ^{c}	6.43 ± 0.53 ^{c}	5.06 ± 0.51 ^{bc}	17.87 ± 1.54 ^{bc}	0.18 ± 0.01 ^{c}	0.05 ± 0.01 ^{a}	10.97 ± 1.15 ^{ab}	2.86 ± 0.07 ^{b}
	60	6.86 ± 0.23 ^{b}	10.10 ± 1.09 ^{b}	6.76 ± 0.29 ^{b}	19.44 ± 0.55 ^{b}	0.53 ± 0.01 ^{b}	0.06 ± 0.01 ^{a}	15.15 ± 1.77 ^{a}	3.98 ± 0.08 ^{a}
	120	10.23 ± 0.57 ^{a}	15.51 ± 0.30 ^{a}	10.33 ± 0.78 ^{a}	27.90 ± 3.15 ^{a}	0.63 ± 0.01 ^{a}	0.07 ± 0.01 ^{a}	14.72 ± 0.05 ^{a}	3.71 ± 0.12 ^{a}
PLBC350	0	0.88 ± 0.04 ^{d}	3.36 ± 0.21 ^{c}	4.36 ± 0.06 ^{d}	11.12 ± 0.24 ^{d}	0.23 ± 0.02 ^{d}	0.05 ± 0.01 ^{b}	7.56 ± 0.36 ^{b}	2.53 ± 0.13 ^{b}
	15	2.17 ± 0.04 ^{cd}	4.47 ± 0.24 ^{bc}	5.44 ± 0.28 ^{cd}	13.64 ± 0.78 ^{cd}	0.18 ± 0.04 ^{d}	0.11 ± 0.01 ^{ab}	7.36 ± 0.16 ^{b}	2.34 ± 0.12 ^{b}
	30	4.10 ± 0.13 ^{c}	6.38 ± 0.47 ^{bc}	6.56 ± 0.14 ^{c}	16.17 ± 0.27 ^{bc}	0.37 ± 0.04 ^{c}	0.17 ± 0.02 ^{ab}	7.72 ± 0.13 ^{b}	2.58 ± 0.02 ^{b}
	60	7.33 ± 0.72 ^{b}	7.83 ± 0.12 ^{b}	8.20 ± 0.53 ^{b}	18.92 ± 1.00 ^{b}	0.67 ± 0.02 ^{b}	0.14 ± 0.06 ^{ab}	8.08 ± 0.43 ^{b}	2.91 ± 0.06 ^{b}
	120	17.56 ± 0.77 ^{a}	25.41 ± 1.68 ^{a}	14.44 ± 0.48 ^{a}	35.02 ± 1.50 ^{a}	1.26 ± 0.02 ^{a}	0.19 ± 0.01 ^{a}	10.59 ± 0.34 ^{a}	4.00 ± 0.29 ^{a}
PLBC600	0	1.07 ± 0.21 ^{d}	3.02 ± 0.11 ^{c}	4.17 ± 0.23 ^{c}	10.81 ± 0.69 ^{c}	0.26 ± 0.01 ^{e}	0.05 ± 0.01 ^{b}	8.44 ± 0.20 ^{c}	2.54 ± 0.11 ^{b}
	15	2.34 ± 0.04 ^{cd}	4.47 ± 0.27 ^{c}	5.03 ± 0.24 ^{c}	12.56 ± 0.51 ^{bc}	0.67 ± 0.03 ^{d}	0.04 ± 0.02 ^{ab}	9.26 ± 0.62 ^{bc}	2.76 ± 0.17 ^{ab}
	30	3.60 ± 0.20 ^{c}	6.25 ± 0.30 ^{c}	6.69 ± 0.29 ^{bc}	15.74 ± 0.07 ^{bc}	0.80 ± 0.02 ^{c}	0.09 ± 0.02 ^{ab}	10.13 ± 0.14 ^{abc}	3.15 ± 0.15 ^{ab}
	60	6.65 ± 1.00 ^{b}	9.56 ± 0.19 ^{b}	7.92 ± 0.87 ^{b}	17.74 ± 0.39 ^{b}	0.94 ± 0.02 ^{b}	0.12 ± 0.02 ^{ab}	10.64 ± 0.23 ^{ab}	3.18 ± 0.08 ^{ab}
	120	11.88 ± 0.59 ^{a}	20.36 ± 1.51 ^{a}	11.10 ± 0.83 ^{a}	26.12 ± 2.94 ^{a}	1.17 ± 0.02 ^{a}	0.11 ± 0.01 ^{a}	11.93 ± 0.55 ^{a}	3.54 ± 0.28 ^{a}

According to the Tukey HSD test, values in the same row, followed by the same letter, are not significantly different at $p < 0.05$. All data were reported as means ± standard error (n =3).

3.5. Correlation between Soil Properties and Available Plant Nutrients in the Soil

Table 4 shows the correlation results between soil properties and nutrient concentrations. A moderate to high positive correlation was found between nutrient content, organic carbon, and CEC. Soil pH has a moderately positive correlation to lower positive correlation with the nutrients, but no relationship was found between soil pH and available Cu (Table 4). Cation exchange capacity (CEC) was statistically positively correlated to the determined macronutrients (Table 4). Furthermore, bulk density has shown a negative correlation with macronutrients and a markedly low and negligible correlation with the micronutrients. Moisture content, on the other hand, has a high positive significant correlation ($p < 0.01$) with macronutrients and a moderate-to-low positive correlation with micronutrients. In terms of soil nutrients, phosphorus and potassium had a significantly higher positive correlation (r = 0.96, $p < 0.01$) (Table 4).

Table 4. Correlation coefficients between soil properties and available plant nutrients concentration in the soil.

	Variables	M	SD	1	2	3	4	5	6	7	8	9	10	11	12
1	pH	7.8	0.2												
2	CEC	3.7	1.1	0.487 **											
3	BD	1.4	0.2	0.020	−0.060										
4	MC	2.3	1.6	0.337 **	0.763 **	−0.200									
5	P	5.9	4.7	0.612 **	0.864 **	−0.050	0.803 **								
6	K	9.2	6.5	0.611 **	0.831 **	−0.010	0.766 **	0.960 **							
7	Mg	6.9	2.7	0.620 **	0.861 **	−0.050	0.810 **	0.948 **	0.935 **						
8	Ca	17.0	6.3	0.455 **	0.827 **	−0.060	0.817 **	0.866 **	0.892 **	0.922 **					
9	Zn	0.4	0.4	0.553 **	0.726 **	0.010	0.682 **	0.783 **	0.780 **	0.838 **	0.753 **				
10	Fe	10.3	2.2	0.080	0.490 **	0.090	0.388 **	0.522 **	0.584 **	0.472 **	0.538 **	0.361 **			
11	Mn	3.1	0.6	0.353 **	0.567 **	0.090	0.513 **	0.712 **	0.777 **	0.683 **	0.686 **	0.508 **	0.770 **		
12	Cu	0.1	0.1	0.000	0.180	−0.120	0.265 *	0.180	0.190	0.190	0.220	0.220	0.336 **	0.268 *	

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05. Abbreviations: CEC, Cation exchange capacity; M, mean; SD, standard deviation.

3.6. Poultry Litter and Its Biochar on *Jatropha curcas* L. Morphological Properties

3.6.1. Plant Height

Plant height (cm), stem diameter (mm), and leaf number were all measured in various treatments at different application rates. Figure 3 depicts the average plant height from week 1 to week 6 at different application rates of poultry litter (PL) and its biochar (BC350, BC600). From week 1 to week 6, all treatments showed an increase in plant height with increasing application rate. Furthermore, the plant height in the control samples

(0 g/kg) was lower in all weeks than the plants height in the treated soils (Figure 3). Plants grown in BC600-treated soils grow at a slower rate than plants grown in other treatments, despite increased plant height. There was no statistical difference ($p > 0.05$) between weeks 1 and 3; however, there was a significant difference ($p < 0.05$) in all treatments between weeks 4 and 6 (week 4, $p = 0.51$, week 5, $p = 0.69$, and week 6, $p = 0.30$). Overall, the height of the plants for PLBC600 at 120 g/kg was significantly ($p = 0.26$) higher (24.17 cm) than for the other treatments (Figure 3).

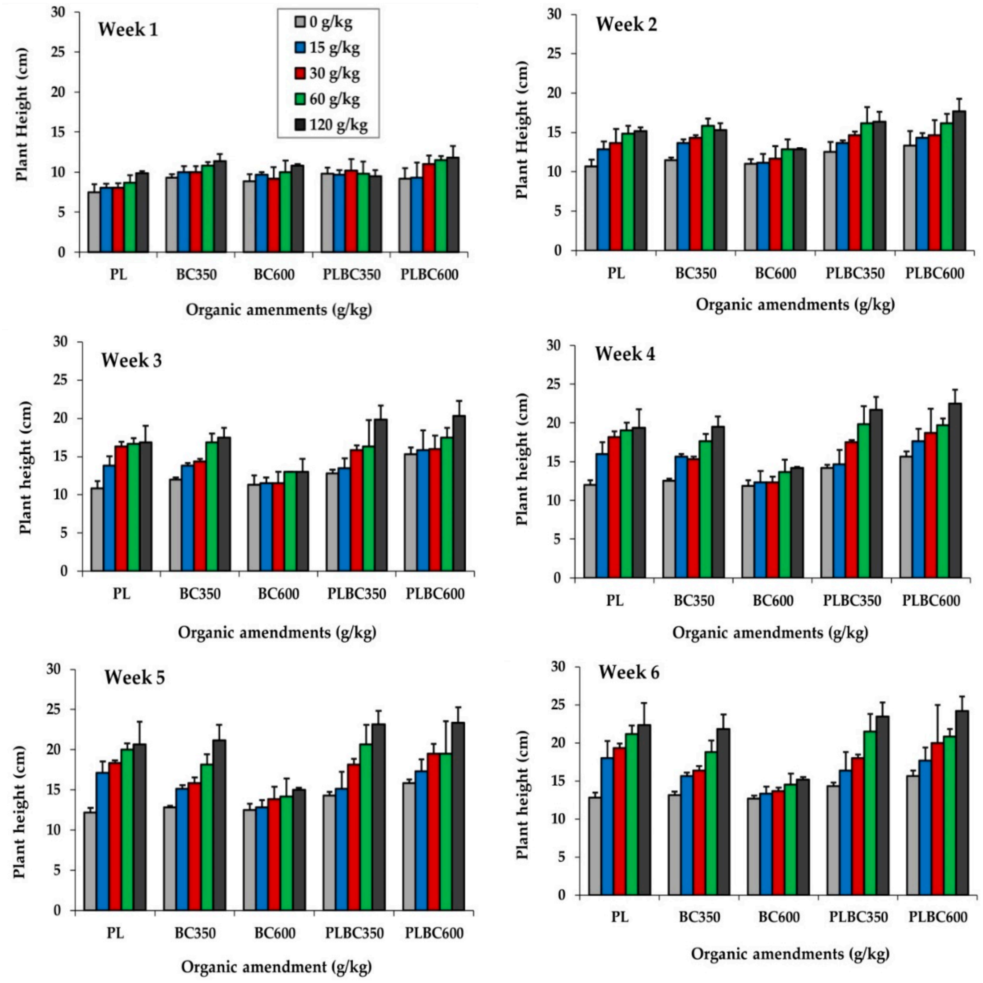

Figure 3. Effects of poultry litter and its biochar on Jatropha plant height from week 1 to week 6 at different application rates of 0, 15, 30, 60 and 120 g/kg recorded on weekly basis. Error bars correspond to the standard error ($p < 0.05$).

3.6.2. Stem Diameter

From 8 weeks after transplanting until the end of 48 weeks, the diameter of the Jatropha stems increased for all plants (Table 5). The stem diameter increased in increasing application rate from 6.47 ± 1.05 mm to 11.80 ± 0.20 mm (PL), 9.17 ± 1.10 mm to 10.80 ± 0.26 mm (BC350), and 7.93 ± 0.74 mm to 8.40 ± 1.01 mm (BC600). Plants grown in PL-treated soil had the most prominent stem diameter readings (11.80 ± 0.20 mm) for the first and last month (19.57 ± 0.45 mm) at a rate of 30 g/kg (Table 5). Plants grown in soil treated with PL and BC350 grew faster than plants grown in soil treated with blended organic amendments (PLBC350, PLBC600) and BC600.

Table 5. Effects of poultry litter and its biochar on Jatropha stem diameter (mm) at different application rates.

Application Rate (g/kg)	PL	BC350	BC600	PLBC350	PLBC600
			8 Weeks		
0	8.20 ± 0.81^{b}	9.17 ± 0.64^{a}	9.4 ± 0.36^{a}	8.87 ± 0.50^{ab}	9.13 ± 0.74^{a}
15	11.30 ± 0.62^{ab}	9.77 ± 0.37^{a}	9.00 ± 0.66^{a}	10.63 ± 0.92^{a}	10.43 ± 0.97^{a}
30	11.80 ± 0.12^{a}	9.90 ± 0.45^{a}	9.17 ± 0.99^{a}	10.60 ± 0.76^{a}	9.50 ± 0.72^{a}
60	10.37 ± 0.90^{ab}	10.77 ± 0.13^{a}	7.93 ± 0.43^{a}	9.80 ± 0.72^{a}	11.40 ± 0.65^{a}
120	6.47 ± 0.61^{b}	10.80 ± 0.15^{a}	8.40 ± 0.59^{a}	6.23 ± 0.41^{ab}	8.17 ± 1.24^{a}
p-value	0.01	0.07	0.51	0.01	0.18
			48 Weeks		
0	14.13 ± 0.70^{a}	15.17 ± 0.42^{b}	9.47 ± 0.42^{a}	13.00 ± 0.90^{b}	14.67 ± 1.16^{a}
15	18.03 ± 0.77^{a}	15.80 ± 0.51^{b}	9.07 ± 1.68^{a}	16.33 ± 0.38^{b}	17.17 ± 0.32^{a}
30	19.57 ± 0.26^{a}	17.67 ± 0.38^{a}	9.67 ± 1.45^{a}	16.90 ± 0.55^{a}	15.93 ± 0.71^{a}
60	19.57 ± 1.02^{a}	18.60 ± 0.42^{a}	8.10 ± 0.87^{a}	16.97 ± 0.97^{a}	18.57 ± 0.34^{a}
120	19.57 ± 3.07^{a}	19.13 ± 0.22^{a}	10.50 ± 0.72^{a}	10.97 ± 2.34^{a}	14.03 ± 1.76^{a}
p-value	0.04	0.01	0.67	0.02	0.06

Values are means ± standard error. Means in the same column with the same letter are not significantly different ($p < 0.05$).

3.6.3. Number of Leaves

From week 1 to week 6, the statistical analysis results revealed that the average number of leaves increased significantly with the application rate in both treatments (Figure 4). All treatments produced significantly higher number of leaves than the control plants. Plants grown in soil treated with PL, BC350, and PLBC600 showed a statistical difference ($p < 0.05$) from week 2 to week 6; however, no statistical difference ($p > 0.05$) was observed for any of the treatments during week 1. Plants grown in PLBC600 soil had the most leaves (18), followed by PL (14), BC350 (13), and PLBC350 (12) (Figure 4).

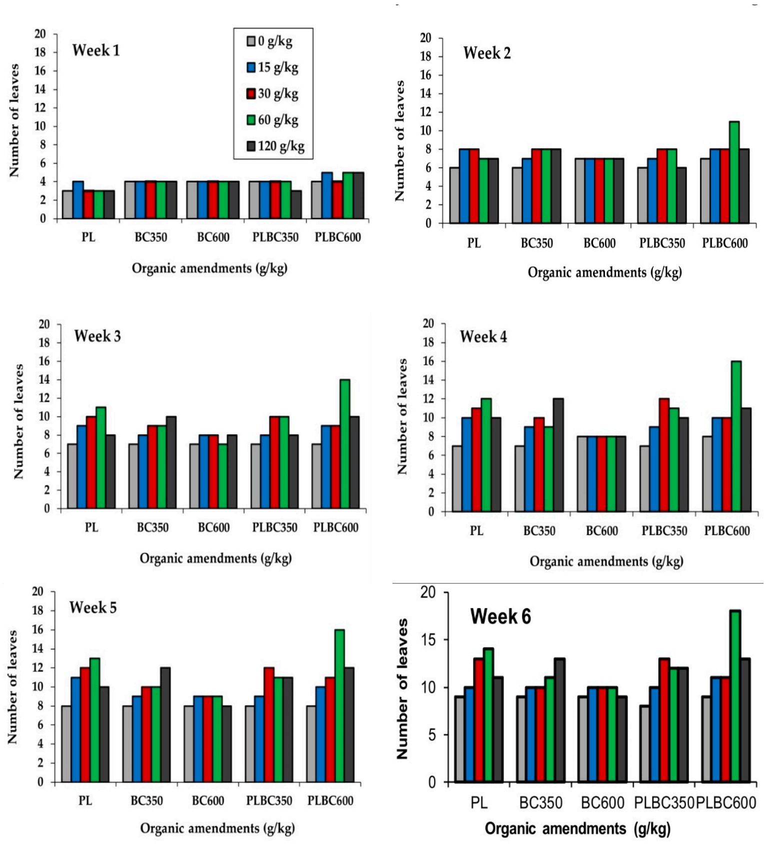

Figure 4. Effects of poultry litter and its biochar on the Jatropha number of leaves at different application rates (g/kg) of 0, 15, 30, 60, and 120 g/kg from week 1 to week 6.

4. Discussion

4.1. Characteristics of Soil, Poultry Litter, and Its Biochar

When compared to BC600, PL and BC350 had the highest concentration of plant-available-nutrient content (Table 2). The findings are consistent with [33], who demonstrated that biochar produced at lower pyrolysis temperatures contains more nutrients than biochar produced at higher temperatures. Soil organic amendments with a higher nutrient content have the potential to be used as an effective organic fertilizer [34]. The pH of biochar increased with the pyrolysis temperature, with biochar produced at 600 °C (9.21) having the highest pH and biochar produced at 300 °C having the lowest (8.58). Similarly, Novak et al. [35] showed the same biochar pH results. Furthermore, the findings are consistent with those of [34], who discovered a 19.71% pH increase in biochar produced at 300 °C when compared to poultry litter feedstock.

4.2. Soil pH, Organic Matter Content, and Cation Exchange Capacity

Soil pH measures hydronium ion (H_3O^+, or more commonly the H^+) activity in the soil solution [36] which influences nutrient solubility and availability in the soil [37]. The ion exchange reaction may have contributed to the increase of soil pH in PL treated soils when OH^- of Al or Fe^{2+} hydroxyl oxides are replaced by organic anions [38]. The observed increase in soil pH from acidic (6.36) to alkaline pH (8.24) indicates the potential liming effect of poultry litter and its biochar as observed by [39]. The soil alkalinity of biochars may have been attributed to ash content which elevates soil pH [33]. Basic cations are released during microbial decarboxylation [40], and reduced cations leaching increased soil pH. Increased base cations released in the soil may explain the increased soil pH in PL and BC350 with the increasing application rates [41]. Furthermore, higher organic matter content produces more alkali oxides, which hydrolyze and generate OH groups, increasing pH values [42], as shown in Figure 1a. The deacidifying effect findings agree with [43] which indicates a liming effect after applying 1% and 2% of biochars to the soil. Revell et al. [44] also demonstrated an increase in soil pH following the incorporation of organic amendments into the soil.

Cation exchange capacity (CEC) is a measurement of the number of negatively charged sites on soil surfaces to retain positively charged ions (cations) Akça & Namli [45]. It is directly affected by soil pH and indicates the soil's ability to retain and supply nutrients to a crop. The additions of organic material increased soil's CEC over time [45] due to the influence of soil pH (Figure 1a). Besides soil pH, an increase in organic matter content may have contributed to an increase in CEC because more cations bind to organic matter particles. Furthermore, the findings agree with those of [46], who discovered an increase in CEC with the incorporation of poultry litter into soil. The Ross & Ketterings [47] study found that rice-husk biochar increased soil pH and cation exchange capacity in tropical Alfisols which agrees with this study. CEC values are low for clay-poor soils, i.e., control soils and soils amended with low application rates had the lowest CEC.

The increased soil pH increases soil organic matter solubility by increasing the dissolution of acid functional groups [48]. The incorporation of organic amendments may also improve soil drainage, which reduces aeration and, as a result, the decreased rate of decomposition leads to increased organic matter content [33].

4.3. Soil Moisture Content, Bulk Density, and Water Holding Capacity

The findings of this study show that increasing the rate of organic amendments application improved soil water retention. The increased organic matter content (Figure 1c) may be contributed to improved soil moisture and water holding capacity. These findings were consistent with the previous study of, which found that adding biochar to sandy-loam soil increased water holding capacity linearly [49] also discovered an increase in water retention with the addition of poultry litter, which may be attributed to the high carbon content. Soil organic matter binds the individual clay particles together to form micro aggregate, which then cluster into macro-aggregates, improving drainage and moisture retention. Moreover, the increased soil moisture content may be due to a combination of more micropores that form pore spaces following the incorporation of poultry litter and its biochar into the soil. Furthermore, biochar produced at high pyrolysis temperatures has a high surface area, hence water retention was greatly improved in soils treated with BC600 and PLBC600. Higher bulk density reduces pore spaces, which means fewer spaces for water retention and a more stable soil structure [40]; hence the control samples had lower moisture content than treated soils. Ross & Ketterings [47] observed that using 0.5% and 1% biochar rice husk a reduced bulk density and increased in water retention.

4.4. Available Plant Nutrients Concentration in the Soil

As shown in Figure 1c, biochar incorporation into soil increased organic matter concentration, possibly water-extractable organic carbon, and stimulates soil microbial biomass and activities [44], ultimately increasing nutrient availability [33]. Organic amendments had higher concentrations of organic matter at first (Figure 1c), which may have contributed to increased nutrient availability in the soil. This is demonstrated by a linear increase in soil nutrient availability as application rate increases (Table 3). Furthermore, biochar's high aromatic composition is suitable for carbon sequestration due to more C=O and C-H functional groups that serve as nutrient exchange sites after oxidation [33], which may increase nutrient availability in the soil. The higher nutrient content in soil incorporated with biochar produced at lower pyrolysis temperatures (BC350) compared to BC600 may be attributed to surface charge [33,50,51] reducing reactivity surfaces in soils [40]. Furthermore, biochar made at lower temperatures has aliphatic and cellulose structures that are suitable substrates for mineralization by bacteria and fungi during the nutrient turnover process [33] that increases nutrient availability in the soil.

Soil pH has a significant effect on plant nutrient availability in the soil. According to [37], K, Ca, and Mg are more available to plants within a pH range of 6.5 to 8, and nutrients are available to plants in lesser amounts outside of these optimal ranges. As a result, the initial soil samples with a slightly acidic pH of 6.36 showed lower concentrations of macronutrients. Additionally, base cations (Ca, K, and Mg) are more weakly bound to the soil and more prone to leaching at low pH, which may have contributed to lower base cations concentration in control samples. Phosphorus (P) is most available between pH range of 6 to 7 [37], hence its concentration levels were lower than those of K, Ca, and Mg (Table 3). Additionally, as soil pH values approach strongly alkaline pH ranges, micronutrient availability decreases due to cations being more strongly bound to the soil and not as easily exchangeable. This was observed because micronutrient concentrations decreased as soil pH increased (Table 3). Furthermore, blended organic amendments showed a slight increase in soil nutrients, particularly for PLBC600. The significant interaction effect of biochar and PL indicates the feedstock's efficacy of the feedstock as organic soil amendments.

4.5. Jatropha curcas L. Plant Height, Stem Diameter, and Number of Leaves

The observed increase of Jatropha plant height with the increasing organic amendments application rate could be attributed to improved soil physical properties and nutrient availability; similar results were reported by [39]. Plant height was lower in BC600-treated soils (Figure 3), as was stem diameter, indicating a possible linear correlation relationship between the two parameters and the number of leaves (Figure 4). Furthermore, increased soil nutrient content correlates with increased Jatropha growth parameters (Table 3), indicating that increased nutrient availability promotes Jatropha growth rate. In terms of leaf number, the Jatropha plant's inherent mechanism of leaf shedding to reduce transpiration rate may explain the variation in leaf number observed throughout the study period [52]. Furthermore, the increase in leaf number with organic amendments is consistent with the [52] study's findings. Ogura et al. [53] discovered that torrefied biomass-amended aridisol improved initial plant growth and elemental uptake. The study's findings are consistent with those of [39], who discovered that higher nutrient concentrations promoted plant growth. The study of [54] of compost and biochar on soil and plant growth on

Ferralsol also observed increased soil fertility, which significantly improved plant growth, both for sole biochar application and for combination of biochar and compost, and these findings agree with the study results.

5. Conclusions

Biochar produced at lower temperature (350 °C) at an application rate of 30–120 g/kg is recommended for use in low-nutrient soils, and poultry litter is recommended for use as an organic soil amendment. The recommendations are based on the study findings, which show an improvement in soil fertility indicators as well as improved *Jatropha curcas* L. growth parameters. Poultry litter and its biochar are effective organic soil amendments that can be used to regenerate depleted soil and improve plant growth. Additionally, the increased application rates resulted in increased Jatropha growth, indicating that nutrient provision is required for higher Jatropha yields. Furthermore, available land with sandy-loam soil can be used for Jatropha plantation without competing with Botswana's other stable crops. Organic feedstock conversion into biochar may also aid in waste management. The limitation of this study is that it was only a greenhouse study; therefore further research, particularly in field areas, is recommended to determine whether interference from outside conditions will still yield the same conclusion.

Author Contributions: Conceptualization, B.L.M. and O.D.; methodology, B.L.M.; data analysis, B.L.M.; writing—original draft preparation B.L.M.; writing—review and editing, B.L.M. and O.D.; supervision, O.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Botswana Japan Jatropha Research project.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to acknowledge the Botswana University of Agriculture and Natural Resources for allowing us to use their greenhouse.

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

References

1. Bationo, A.; Waswa, B.; Kihara, J.; Kimetu, J. Advances in Integrated Soil Fertility Management in Sub Saharan Africa: Challenges and Opportunities. *Nutr. Cycl. Agroecosyst.* **2007**, 1–2. [CrossRef]
2. Fageria, N.K.; Baligar, V.C. Enhancing Nitrogen Use Efficiency in Crop Plants. *Adv. Agron.* **2005**, *88*, 97–185.
3. Gwebu, T.D. Population, Development, and Waste Management in Botswana: Conceptual and Policy Implications for Climate Change. *Environ. Manag.* **2003**, *31*, 348–354. [CrossRef] [PubMed]
4. Karlen, D.; Rice, C. Soil Degradation: Will Humankind Ever Learn? *Sustainability* **2015**, *7*, 12490–12501. [CrossRef]
5. Pule-Meulenberg, F. Solutions for Food Security in Africa through Sustainable Soil Fertility Management of Ecosystems under Climate Change. *Symbiosis* **2018**, *75*, 165–166. [CrossRef]
6. Botswana, S. *Annual Agricultural Survey Report 2019*; Traditional Sector; Statistics Botswana: Gaborone, Botswana, 2019.
7. Kgathi, D.L.; Mfundisi, K.B.; Mmopelwa, G.; Mosepele, K. Potential Impacts of Biofuel Development on Food Security in Botswana: A Contribution to Energy Policy. *Energy Policy* **2012**, *43*, 70–79. [CrossRef]
8. Moyin-Jesu, E.I. Simple and Blended Organic Fertilizers Improve Fertility of Degraded Nursery Soils for Production of Kolanut (*Cola acuminate*) Seedlings in Nigeria. In *Soil Fertility Improvement and Integrated Nutrient Management—A Global Perspective*; IntechOpen: London, UK, 2011; p. 293.
9. Dikinya, O.; Mufwanzala, N. Chicken Manure-Enhanced Soil Fertility and Productivity: Effects of Application Rates. *J. Soil Sci. Environ. Manag.* **2010**, *1*, 46–54.
10. Madisa, M.E.; Mathowa, T.; Mpofu, C.; Stephen, N.; Machacha, S. Effect of Chicken Manure and Commercial Fertilizer on Performance of Jute Mallow (*Corchorus olitorius*). *Agric. Biol. J. N. Am.* **2013**, *4*, 617–622.
11. Mojeremane, W.; Motladi, M.; Mathowa, T.; Legwaila, G.M. Effect of Different Application Rates of Organic Fertilizer on Growth, Development and Yield of Rape (*Brassica napus* L.). *Int. J. Innov. Res. Sci. Eng. Technol.* **2015**, *4*, 11680–11688. [CrossRef]
12. Bernhart, M.; Fasina, O.O. Moisture Effect on the Storage, Handling and Flow Properties of Poultry Litter. *Waste Manag.* **2009**, *29*, 1392–1398. [CrossRef]

13. Akanni, K.A.; Benson, O.B. Poultry Wastes Management Strategies and Environmental Implications on Human Health in Ogun State of Nigeria. *Adv. Econ. Bus.* **2014**, *2*, 164–171. [CrossRef]
14. Bolan, N.; Szogi, A.A.; Chuasavathi, T.; Seshadri, B.; Rothrock JR, M.J.; Panneerselvam, P. Uses and Management of Poultry Litter. *World's Poult. Sci. J.* **2010**, *66*, 673–698. [CrossRef]
15. Manafi, M. *Poultry Science*; BoD—Books on Demand: Norderstedt, Germany, 2017; ISBN 978-953-51-2945-5.
16. Musa, W.I.; Saidu, L.; Kaltungo, B.Y.; Abubakar, U.B.; Wakawa, A.M. Poultry Litter Selection, Management and Utilization in Nigeria. *Asian J. Poult. Sci.* **2012**, *6*, 44–55. [CrossRef]
17. Agegnehu, G.; Bass, A.M.; Nelson, P.N.; Muirhead, B.; Wright, G.; Bird, M.I. Biochar and Biochar-Compost as Soil Amendments: Effects on Peanut Yield, Soil Properties and Greenhouse Gas Emissions in Tropical North Queensland, Australia. *Agric. Ecosyst. Environ.* **2015**, *213*, 72–85. [CrossRef]
18. Agu, R.S.; Ezema, R.A.; Udegbunam, O.N.; Okoro, A.C. Effect of Different Rates of Poultry Manure on Growth and Yield of Cucumber (*Cucumis sativum*) in Iwollo, Southeastern Nigeria. *Agro-Science* **2015**, *14*, 41–44.
19. Chan, K.Y.; Van Zwieten, L.; Meszaros, I.; Downie, A.; Joseph, S. Agronomic Values of Greenwaste Biochar as a Soil Amendment. *Soil Res.* **2008**, *45*, 629–634. [CrossRef]
20. Yabe, J.; Ishizuka, M.; Umemura, T. Current Levels of Heavy Metal Pollution in Africa. *J. Vet. Med. Sci.* **2010**, *72*, 1257–1263. [CrossRef]
21. Tomczyk, A.; Sokołowska, Z.; Boguta, P. Biochar Physicochemical Properties: Pyrolysis Temperature and Feedstock Kind Effects. *Rev. Environ. Sci. Bio/Technol.* **2020**, *19*, 191–215. [CrossRef]
22. Abbasi, M.K.; Anwar, A.A. Ameliorating Effects of Biochar Derived from Poultry Manure and White Clover Residues on Soil Nutrient Status and Plant Growth Promotion-Greenhouse Experiments. *PLoS ONE* **2015**, *10*, e0131592. [CrossRef] [PubMed]
23. Srinivasarao, C.; Venkateswarlu, B.; Lal, R.; Singh, A.K.; Kundu, S. Sustainable Management of Soils of Dryland Ecosystems of India for Enhancing Agronomic Productivity and Sequestering Carbon. In *Advances in Agronomy*; Elsevier: Amsterdam, The Netherlands, 2013; Volume 121, pp. 253–329.
24. Suppadit, T.; Kitikoon, V.; Phubphol, A.; Neumnoi, P. Effect of Quail Litter Biochar on Productivity of Four New Physic Nut Varieties Planted in Cadmium-Contaminated Soil. *Chil. J. Agric. Res.* **2012**, *72*, 125. [CrossRef]
25. *IBI 2012*; Standardized Product Definition and Testing Guidelines for Biochar That Is Used in Soil. International Biochar Initiative: Canandaigua, NY, USA, 2012.
26. Lehmann, J.; Gaunt, J.; Rondon, M. Bio-Char Sequestration in Terrestrial Ecosystems—A Review. *Mitig. Adapt. Strateg. Glob. Chang.* **2006**, *11*, 403–427. [CrossRef]
27. Bouyoucos, G.J. A Recalibration of the Hydrometer Method for Making Mechanical Analysis of Soils 1. *Agron. J.* **1951**, *43*, 434–438. [CrossRef]
28. Brischke, C.; Wegener, F.L. Impact of Water Holding Capacity and Moisture Content of Soil Substrates on the Moisture Content of Wood in Terrestrial Microcosms. *Forests* **2019**, *10*, 485. [CrossRef]
29. Walkley, A.; Black, I.A. An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method. *Soil Sci.* **1934**, *37*, 29–38. [CrossRef]
30. Ziadi, N.; Tran, T.S. Mehlich 3-Extractable Elements. In *Soil Sampling and Methods of Analysis*; Taylor & Francis Group: Abingdon, UK, 2008; pp. 81–88.
31. Peters, J.; Combs, S.; Hoskins, B.; Jarman, J.; Kovar, J.; Watson, M.; Wolf, A.; Wolf, N. *Recommended Methods of Manure Analysis*; University of Wisconsin Cooperative Extension Publishing: Madison, WI, USA, 2003.
32. Matthiessen, M.K.; Larney, F.J.; Selinger, L.B.; Olson, A.F. Influence of Loss-on-Ignition Temperature and Heating Time on Ash Content of Compost and Manure. *Commun. Soil Sci. Plant Anal.* **2005**, *36*, 2561–2573. [CrossRef]
33. Novak, J.M.; Lima, I.; Xing, B.; Gaskin, J.W.; Steiner, C.; Das, K.C.; Ahmedna, M.; Rehrah, D.; Watts, D.W.; Busscher, W.J. Characterization of Designer Biochar Produced at Different Temperatures and Their Effects on a Loamy Sand. *Ann. Environ. Sci.* **2009**, *3*, 195–206.
34. Sikder, S.; Joardar, J.C. Biochar Production from Poultry Litter as Management Approach and Effects on Plant Growth. *Int. J. Recycl. Org. Waste Agric.* **2019**, *8*, 47–58. [CrossRef]
35. Novak, J.M.; Ippolito, J.A.; Watts, D.W.; Sigua, G.C.; Ducey, T.F.; Johnson, M.G. Biochar Compost Blends Facilitate Switchgrass Growth in Mine Soils by Reducing Cd and Zn Bioavailability. *Biochar* **2019**, *1*, 97–114. [CrossRef]
36. Eckert, D.; Sims, J.T. Recommended Soil PH and Lime Requirement Tests. *Recomm. Soil Test. Proced. Northeast. United States Northeast. Reg. Bull.* **1995**, *493*, 11–16.
37. McCauley, A.; Jones, C.; Jacobsen, J. Soil PH and Organic Matter. *Nutr. Manag. Modul.* **2009**, *8*, 1–12.
38. Duruigbo, C.I.; Obiefuna, J.C.; Onweremadu, E.U. Effect of Poultry Manure Rates on Soil Acidity in an Ultisol. *Int. J. Soil Sci.* **2007**, *2*, 154–158.
39. Yu, C.-H.; Wang, S.-L.; Tongsiri, P.; Cheng, M.-P.; Lai, H.-Y. Effects of Poultry-Litter Biochar on Soil Properties and Growth of Water Spinach (*Ipomoea aquatica* Forsk.). *Sustainability* **2018**, *10*, 2536. [CrossRef]
40. Shetty, R.; Prakash, N.B. Effect of Different Biochars on Acid Soil and Growth Parameters of Rice Plants under Aluminium Toxicity. *Sci. Rep.* **2020**, *10*, 12249. [CrossRef] [PubMed]
41. 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]

42. Gondek, K.; Mierzwa-Hersztek, M. Effect of Thermal Conversion of Pig Manure and Poultry Litter on the Content and Mobility of Mn and Fe in Biochars and in Soil after Their Application. *Chil. J. Agric. Res.* **2016**, *76*, 349–355. [CrossRef]
43. Gondek, K.; Mierzwa-Hersztek, M. Effect of Low-Temperature Biochar Derived from Pig Manure and Poultry Litter on Mobile and Organic Matter-Bound Forms of Cu, Cd, Pb and Zn in Sandy Soil. *Soil Use Manag.* **2016**, *32*, 357–367. [CrossRef]
44. Revell, K.T.; Maguire, R.O.; Agblevor, F.A. Influence of Poultry Litter Biochar on Soil Properties and Plant Growth. *Soil Sci.* **2012**, *177*, 402. [CrossRef]
45. Akça, M.O.; Namlı, A. Effects of Poultry Litter Biochar on Soil Enzyme Activities and Tomato, Pepper and Lettuce Plants Growth. *Eurasian J. Soil Sci. EJSS* **2015**, *4*, 161. [CrossRef]
46. Neina, D. The Role of Soil PH in Plant Nutrition and Soil Remediation. *Appl. Environ. Soil Sci.* **2019**, *2019*, 5794869. [CrossRef]
47. Ross, D.S.; Ketterings, Q. Recommended Methods for Determining Soil Cation Exchange Capacity. *Recomm. Soil Test. Proced. Northeast. U. S.* **1995**, *493*, 62.
48. Toluwase Oreoluwa, A.; Tolulope Yetunde, A.; Joseph, U.E.; Chengsen, Z.; Hongyan, W. Effect of Biochar and Poultry Litter Application on Chemical Properties and Nutrient Availability of an Acidic Soil. *Commun. Soil Sci. Plant Anal.* **2020**, *51*, 1670–1679. [CrossRef]
49. Gamage, D.N.V.; Mapa, R.B.; Dharmakeerthi, R.S.; Biswas, A.; Gamage, D.N.V.; Mapa, R.B.; Dharmakeerthi, R.S.; Biswas, A. Effect of Rice-Husk Biochar on Selected Soil Properties in Tropical Alfisols. *Soil Res.* **2016**, *54*, 302–310. [CrossRef]
50. Rawls, W.J.; Pachepsky, Y.A.; Ritchie, J.C.; Sobecki, T.M.; Bloodworth, H. Effect of Soil Organic Carbon on Soil Water Retention. *Geoderma* **2003**, *116*, 61–76. [CrossRef]
51. Gai, X.; Wang, H.; Liu, J.; Zhai, L.; Liu, S.; Ren, T.; Liu, H. Effects of Feedstock and Pyrolysis Temperature on Biochar Adsorption of Ammonium and Nitrate. *PLoS ONE* **2014**, *9*, e113888. [CrossRef]
52. Sop, T.K.; Kagambega, F.W.; Bellefontaine, R.; Schmiedel, U.; Thiombiano, A. Effects of Organic Amendment on Early Growth Performance of *Jatropha curcas* L. on a Severely Degraded Site in the Sub-Sahel of Burkina Faso. *Agrofor. Syst.* **2012**, *86*, 387–399. [CrossRef]
53. Ogura, T.; Date, Y.; Masukujane, M.; Coetzee, T.; Akashi, K.; Kikuchi, J. Improvement of Physical, Chemical and Biological Properties of Aridisol from Botswana by the Incorporation of Torrefied Biomass. *Sci. Rep.* **2016**, *6*, 28011. [CrossRef] [PubMed]
54. Agegnehu, G.; Bird, M.I.; Nelson, P.N.; Bass, A.M.; Agegnehu, G.; Bird, M.I.; Nelson, P.N.; Bass, A.M. The Ameliorating Effects of Biochar and Compost on Soil Quality and Plant Growth on a Ferralsol. *Soil Res.* **2015**, *53*, 1–12. [CrossRef]