

Article

Assessing the Increase in Soil Moisture Storage Capacity and Nutrient Enhancement of Different Organic Amendments in Paddy Soil

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Abstract: Increasing soil moisture storage capacity is a strategy that can be implemented to minimize the use of water in paddy rice cultivation. Organic materials from different sources have the potential to increase soil moisture storage and nutrient enrichment. An incubation study was conducted to evaluate the incorporation of five selected organic amendments—as follows: rice husk biochar (RHB), oil palm empty fruit bunch biochar (EFBB), compost (COMP), rice husk ash (RHA), and oil palm bunch ash (PBA), with a control (no amendment) on soil moisture storage and some chemical properties of soil. The soil was incubated with five amendments for 60 days and sampled at 15-day intervals. After completion of the incubation, a greater extent of gravimetric water content was observed from RHB (0.46 g g⁻¹) and EFBB (0.45 g g⁻¹) followed by compost (0.40 g g⁻¹). The addition of organic amendments significantly influenced soil chemical properties. Maximum soil pH was altered by PBA followed by EFBB compared to its initial value (5.01). The inclusion of EFBB finally contributed to the highest amount of total carbon (7.82%) and nitrogen (0.44%). The addition of PBA showed the highest available P and exchangeable K followed by RHB when compared with the amendments. The results indicated that RHB, EFBB, and compost retain more soil moisture compared to ash sources and added soil nutrients, indicating their potential to improve the chemical and hydrological properties of paddy soil.

Keywords: rice; biochar; nutrient content; gravimetric water; scanning electron microscopy



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1. Introduction

Rice is one of the most widely grown cereals in the world and serves as a staple for half of the world's population, particularly in developing countries. In 2017, approximately 748 million tons of rice were produced over the world, requiring more than 160 million ha of land [1]. Rice is the largest consumer of water and it consumes about 34–43% of irrigation water over the world [2]; producing one kilogram of rice requires 3000 to 5000 L of water [3]. Furthermore, water for agricultural purposes becoming scarce due to climate change and rapid industrialization and urbanization presents a challenge to farmers regarding the production of more rice per unit of land with limited water [4]. Continuous flooding irrigation systems require large quantities of water for rice, and a larger amount of water is lost through evaporation, percolation, and seepage [5]. Many modifications in rice cultivation, such as aerobic rice, direct seeding, alternate wetting, and drying, etc., have been made to save water and are used because of the changing climatic conditions of the earth [6]. Under the circumstances, the approach of using different organic amendments

for rice production has great scope in terms of enhancing soil moisture retention capacity because organic wastes not only retain soil moisture but also supply essential nutrients to plants.

Every year, about 4 million tons of crop residue is produced over the world and burnt in the open air to produce ash [7], which is a source of organic amendment though its contributions to environmental pollution. In the effort to overcome environmental issues, biochar production has great potential—it is a material produced by thermal disintegration of biomass at low temperature (below 700 °C) under limited oxygen conditions which is enriched in carbon and porous by nature [8]. Morphological and chemical properties of biochar vary with the type of biomass used (feedstock), pyrolyzing temperature, and conditions for biochar production [9]. Rice processing industries produce a large quantity of rice husk; after processing, this rice husk biochar has the potential to be used as an organic amendment to enhance the physicochemical properties of soil [10] or rice husk ash can be used for the same. In Malaysia, residue generated from oil palm has great scope for producing biochar (as the main product), empty fruit bunch biochar (EFBB) (which is readily available) [11] or ash produced from oil palm bunch, which is an efficient liming material and also adds nutrients when applied to soil [12].

Application of organic waste either for plant nutrient supply or disposal purposes exerts favorable hydrological properties of soil for crop production and also improves soil structure, porosity, and reduces erosion [13]. Every 1% increase in organic matter increases the soil capacity up to 16,500 gallons of available water per acre [14]. By the application of biochar, the soil is enriched with organic matter as well as organic carbon content and also adds nutrients such as nitrogen, potassium, phosphorus, and magnesium [15,16]. Biochar also contains different kinds of alkaline material which help in raising soil pH of acidic soil and it also alters soil physical properties and enhances soil aggregates and moisture retention [17,18] and helps to improve soil health [19]. Biochar enhances soil moisture storage in two ways: firstly, by changing pore size distribution and aggregation and, secondly, through conserving moisture in pores [20]. Ash produced from direct burning of biomass used as a soil amendment is a common practice; it contains less nitrogen but is dense with other plant nutrients and it also can be used as a liming agent [21]. The application of wood ash increases water availability and also partially supplies nutrients to plants reported by Bonfim-Silva et al. [22]. Compost is one of the most widely used soil amendments enriched with different essential plant nutrients and it has a beneficial effect on water holding capacity and physical properties of soil [23].

Continuous flooded irrigation systems for rice require a large quantity of water. Soil organic matter management by adding suitable organic amendments could help retain soil moisture under water limiting conditions. Previous studies mainly focused on the role of organic amendment in the improvement of soil biochemical properties, carbon sequestration, and greenhouse gas emissions etc., but put comparatively less emphasis on its effect on soil moisture retention and the inclusion of nutrient availability. The addition of a suitable amount of organic amendments in paddy soil may retain more soil water by reducing moisture loss; additionally, it also improves nutrient availability to plants, which facilitates sustainable rice production under water-scarce environments around the earth. The concept of using different organic amendments to increase soil moisture conserving capacity and the consecutive enrichment of soil by essential plant nutrients is a new aspect of this research. In this context, we hypothesized that the application of different organic amendments, i.e., compost, rice husk biochar and ash, oil palm empty fruit bunch biochar, and oil palm bunch ash, would increase the moisture retention capacity and nutrient availability of soil. A soil incubation study was conducted to test these hypotheses. Therefore, the objectives of the study were to investigate the structural and chemical properties of organic amendments and to compare the capacity of organic amendments to retain soil moisture and nutrient release.

2. Materials and Methods

2.1. Collection and Characterization of Soil Sample

Acidic soil was collected from the irrigated paddy field of Tanjung Karang (3°28.2730' N latitude and 101°8.7050' E longitude) Kuala Selangor district of Selangor state in Malaysia. Soil sampling depth was 0–15 cm and, after the collection of soil, it was air-dried followed by crushing and sieving through 10 mesh sieves. The soil sample was then characterized for its physical and chemical properties (Table A1). Particle size of the soil was measured by the hydrometer method [24] and soil texture was classified by the USDA (United States Department of Agriculture) system. Soil pH was determined by a glass electrode pH meter in a 1:2.5 ratio of soil and water, respectively [25]. Total carbon, nitrogen, and sulfur in soil were determined by a CNS analyzer (LECO, Corporation, St. Joseph, MO, USA). Available phosphorus was extracted by the Bray and Kurtz II method [26] using a mixture of 0.03N ammonium fluoride (NH₄Cl) and 0.1N hydrochloric acid (HCl) solution as extractant and measured by Inductively coupled plasma - optical emission spectrometry (ICP-OES, Perkin Elmer, Massachusetts, USA). Exchangeable K, Ca, and Mg were extracted by ammonium acetate (NH₄OAc) solution (pH 7.0) using leaching method in which basic cations adsorbed in soil were replaced by NH₄⁺ ion described by Schollenberger and Simon [27] and K, Ca, and Mg in collected leachate were analyzed by ICP-OES (Perkin Elmer, MA, USA).

2.2. Characterization of Organic Amendments

The rice husk biochar used in the study was purchased from Sendi Enterprise (Sungai Burong, Selangor), produced by pyrolyzing rice husk at 300 °C. Oil palm empty fruit bunch biochar was collected from Parkar Go Green SdnBhd (Sri Kenari, Kajang), pyrolyzed at 450 °C. Rice husk ash and commercial compost were directly bought from D Syria Enterprise (Taman Sri Serdang, Seri Kembangan). Oil palm bunch ash was supplied by Odorata Enterprise (Kota Tinggi, Johor). The pH of organic amendments was determined in a 1:10 ratio (w/w) of solid and water [28]. A CNS analyzer was used for analyzing the total C, N, and S of different organic amendments; total P, Ca, and Mg were determined by dry ashing (Cotennie, 1980) followed by ICP-OES determination described earlier. Total phosphorus, potassium, calcium, and magnesium in different amendments were determined by dry ashing followed by ICP-OES (Perkin Elmer, Massachusetts, USA). Chemical properties of different organic amendments are shown in Table A2.

2.3. Gravimetric Water Content

At each incubation sampling campaign, fresh soil was collected in an aluminum container and weighed in a balance with ±0.001 g precision and then oven-dried at 105° for 24 h to find the gravimetric water content following Cooper [29]:

Gravimetric water content (g g^{-1}) = (weight of wet soil – weight of dry soil) / (weight of dry soil).

2.4. Scanning Electron Microscopy (SEM) of Organic Amendments

The organic amendments used in the experiment were dried and metallized using BAL-TECB sputter coater system (SCD 005, BALZERS) to achieve an ideal conductive surface. After metallizing, the samples were magnified by 1000× and analyzed using a LEO 1455VP (Oxford instrument and INCA software, London, UK) scanning electron microscope (SEM) at 15 kV from the microscopic unit of Institute of Biosciences (IBS), Universiti Putra Malaysia.

2.5. Incubation Study

An incubation experiment was conducted in the laboratory of the Land Management Department of Universiti Putra Malaysia (UPM), Serdang, from 15 May to 13 July 2019 (60 days). The experiment was conducted by a completely randomized design (CRD) with three replications. A composite soil sample (0–15 cm) was collected from a wetland paddy field of Tanjung Karang, air-dried, and sieved by 2 mm mesh. The soil (350 g) was

placed in each of the plastic pots with Whatman no.42 filter paper placed at the bottom of the containers to check loss of soil particles through the 2 mm hole at the bottom of each pot which facilitated excess water drainage. Five organic amendment treatments (rice husk biochar, oil palm empty fruit bunch biochar, compost, rice husk ash, and oil palm bunch ash) were used at a rate of 4% (weight/weight) and mixed thoroughly with soil; soil without amendment was considered as the control. Soil was saturated by adding 150 mL of deionized water. Four sets of pots for each treatment with three replications ($4 \times 6 \times 3 = 72$) were incubated at $26 \pm 2^\circ\text{C}$ temperature for 60 days. Soil sampling was performed for each set at 15, 30, 45, and 60 days of incubation followed by a destructive sampling method. After the harvest of each set, the remaining sets were saturated by adding 150 mL of deionized water. The collected sample was used to determine moisture content, pH, percentage of total C and %N, available P, and exchangeable K, Ca, and Mg by the method used for the initial soil mentioned above.

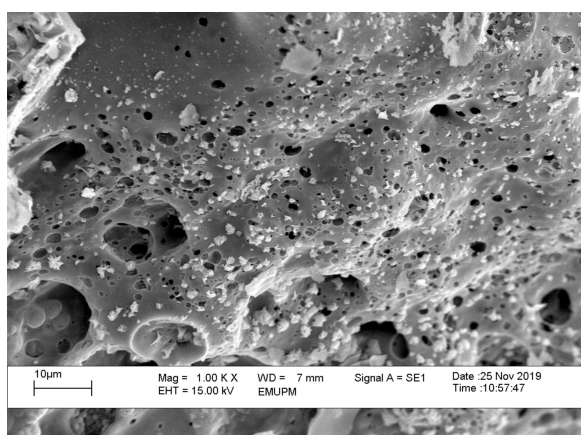
2.6. Statistical Analysis

Analysis of variance (ANOVA) was used to calculate statistical difference among various treatments using the R statistical software and to detect significant differences between the treatment means; Tukey's test at a 5% level of confidence ($p < 0.05$) was considered.

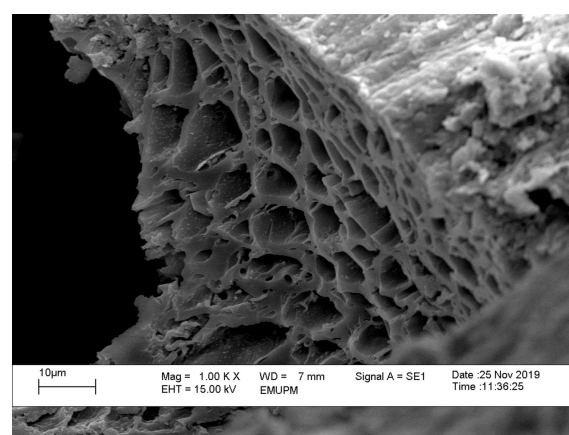
3. Results

3.1. Scanning Electron Microscopy (SEM) Visualization of Organic Amendments

SEM micrograph analysis was conducted to characterize the morphological structure of various organic amendments used in the study (Figure 1). Micropores observed in rice husk biochar (RHB) and oil palm empty fruit bunch biochar (EFBB) were absent in the rice husk ash (RHA), compost (COMP), and oil Palm Bunch Ash (PBA). RHA and PBA exhibited irregular structures, though both were also from plant origin, akin to RHB and EFBB. Biochar produced from rice husk exhibited pores marked by cell wall structures ranging from 0.5 to 10 μm . Oil palm EFBB also showed the same origin of pore structure similar to rice husk but the size of the pore ranged between 1 and 10 μm . The number of micropores sized $< 1 \mu\text{m}$ were found to be higher in the case of rice husk biochar. Compost showed a large surface area and intra spaces between different particles but the porous structure was missing.

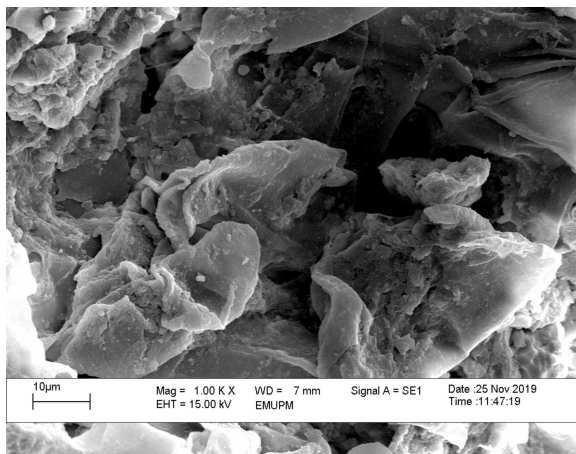


(a) Rice husk biochar

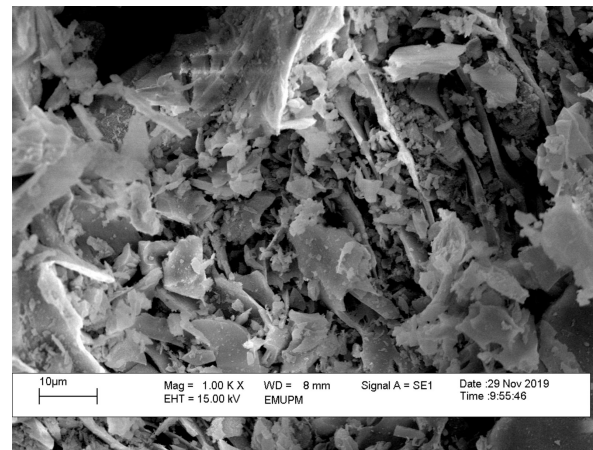


(b) Oil palm empty fruit bunch biochar

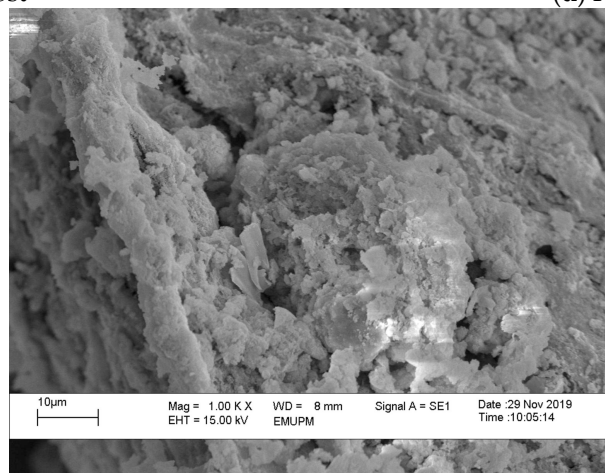
Figure 1. Cont.



(c) Compost



(d) Rice husk ash



(e) Oil palm bunch ash

Figure 1. Micrograph of organic amendments used in the study by scanning electron microscopy at 1000× magnification.

3.2. Soil pH

Soil pH was significantly affected ($p < 0.05$) by organic matter amendment but not with the incubation time (except two biochars and PBA). Between different organic amendments—compost, RHA, and control—showed significant changes in soil pH with incubation time (Table 1). A sharp increase in soil pH was observed in all the treatments including control at 15 days of incubation (DOIs) compared to soil initial pH (5.01) (Table A1). The highest increment of soil pH was observed in PBA (6.91) followed by EFBB (6.16); at amendments at 15 DOI and then on further DOIs the pH was quite stable. A small increase in soil pH was also observed in compost and RHA amended soils compared to initial pH at 15 DOI and remained unaffected at the later incubation campaigns. At the end of incubation, PBA produced the highest pH value (6.95) followed by EFBB (6.26), while others showed statistically similar values.

Table 1. pH dynamics affected by selected organic amendments at different incubation periods.

Organic Amendment	pH (Soil: H ₂ O = 1:2.5)			
	15 Days	30 Days	45 Days	60 Days
RHB	5.77 ± 0.11 Ca	5.74 ± 0.04 Ca	5.88 ± 0.05 Ca	5.94 ± 0.01 Ca
EFBB	6.16 ± 0.02 Ba	6.17 ± 0.04 Ba	6.12 ± 0.01 Ba	6.26 ± 0.09 Ba
COMP	5.82 ± 0.03 Cab	5.87 ± 0.01 Cab	5.68 ± 0.10 CDb	5.93 ± 0.06 Ca
RHA	5.92 ± 0.07 Ca	5.89 ± 0.04 Ca	5.65 ± 0.02 Db	5.83 ± 0.04 Ca
PBA	6.91 ± 0.02 Aa	7.00 ± 0.00 Aa	6.90 ± 0.07 Ba	6.95 ± 0.02 Aa
Control	5.51 ± 0.05 Db	6.16 ± 0.12 Ba	5.75 ± 0.06 CDb	5.85 ± 0.12 Cab

Values are presented as mean ± standard error with different uppercase letters in the same column and lowercase letters in the same row indicating significant difference ($p < 0.05$) among the organic amendments and incubation days, respectively. RHB, Rice husk biochar; EFBB, Oil palm empty fruit bunch biochar; COMP, Compost; RHA, Rice husk ash; PBA, Oil palm bunch ash, and control, no amendment.

3.3. Total Carbon, Total Nitrogen and Carbon Nitrogen (CN) Ratio

Application of different organic materials significantly ($p < 0.05$) changed total carbon, total nitrogen, and CN ratio in soil when incubated for 60 days (Table 2), but there was no significant variation within their incubation time except for the CN ratio.

Table 2. Changes in soil total carbon (TC), total nitrogen (TN), and carbon nitrogen (CN) ratio influenced by selected organic amendments at different incubation periods.

Organic Amendment	% Total Carbon (TC)			
	15 Days	30 Days	45 Days	60 Days
RHB	6.70 ± 0.15 Ba	6.88 ± 0.13 ABCa	6.48 ± 0.12 Ba	6.59 ± 0.11 Ba
EFBB	8.20 ± 0.14 Aa	8.05 ± 0.11 Aa	8.10 ± 0.12 Aa	7.82 ± 0.13 Aa
COMP	6.51 ± 0.18 Ba	7.25 ± 0.32 ABa	6.91 ± 0.15 Ba	6.80 ± 0.14 Ba
RHA	6.33 ± 0.03 Ba	6.38 ± 0.05 BCDA	6.33 ± 0.15 Ba	6.34 ± 0.02 Ba
PBA	5.08 ± 0.09 Ca	5.69 ± 0.51 CDA	5.10 ± 0.10 Ca	4.84 ± 0.08 Ca
Control	5.47 ± 0.13 Ca	5.42 ± 0.06 Da	5.50 ± 0.03 Ca	5.31 ± 0.09 Ca
Organic Amendment	% Total nitrogen (TN)			
	15 Days	30 Days	45 Days	60 Days
RHB	0.37 ± 0.00 BCa	0.39 ± 0.01 ABa	0.38 ± 0.01 BCa	0.39 ± 0.00 Ba
EFBB	0.43 ± 0.00 Aa	0.43 ± 0.01 Aa	0.44 ± 0.00 Aa	0.44 ± 0.01 Aa
COMP	0.39 ± 0.01 Ba	0.42 ± 0.01 Aa	0.43 ± 0.00 Aa	0.43 ± 0.01 Aa
RHA	0.36 ± 0.00 CDA	0.37 ± 0.00 Ba	0.39 ± 0.01 BCa	0.37 ± 0.01 BCa
PBA	0.35 ± 0.01 Da	0.36 ± 0.01 Ba	0.36 ± 0.01 Ca	0.35 ± 0.01 Ca
Control	0.37 ± 0.01 BCDB	0.39 ± 0.01 ABa	0.39 ± 0.00 Ba	0.38 ± 0.00 BCab
Organic Amendment	CN ratio			
	15 Days	30 Days	45 Days	60 Days
RHB	17.95 ± 0.50 ABa	17.49 ± 0.26 ABa	16.90 ± 0.03 Ba	17.05 ± 0.28 Ba
EFBB	19.22 ± 0.22 Aa	18.86 ± 0.12 Aab	18.54 ± 0.19 Aab	17.92 ± 0.36 Ab
COMP	16.68 ± 0.27 Ba	17.10 ± 0.37 ABa	16.20 ± 0.24 Ba	15.94 ± 0.05 Ba
RHA	17.43 ± 0.08 Ba	17.09 ± 0.19 ABab	16.37 ± 0.13 Bb	17.00 ± 0.28 Bab
PBA	14.50 ± 0.09 Ca	15.88 ± 0.93 BCa	14.15 ± 0.12 Ca	13.97 ± 0.08 Ca
Control	14.78 ± 0.17 Ca	13.91 ± 0.33 Ca	13.99 ± 0.03 Ca	14.09 ± 0.12 Ca

Values are presented as mean ± standard error with different uppercase letters in the same column and lowercase letters in the same row indicating significant difference ($p < 0.05$) among the organic amendments and incubation days, respectively. RHB, Rice husk biochar; EFBB, Oil palm empty fruit bunch biochar; COMP, Compost; RHA, Rice husk ash; PBA, Oil palm bunch ash, and control, no amendment.

Soil treated with EFBB showed the maximum value of total carbon in soil followed by COMP and RHB. During all days of incubation (DOIs), EFBB treated soil exhibited the maximum value of total carbon (TC) which was significantly higher than in COMP and RHB treated soils; further, these two materials produced statistically similar values. The lowest total C% was observed in PBA treated soil which was statistically similar to the control. After 60 DOI, EFBB produced 7.82% of total C in soil which is significantly higher

than other treatments, while the lowest value was obtained from PBA (4.84%), which is identical to the control (5.31%).

Total N content in soil was also significantly ($p < 0.05$) affected by different organic matter management methods but changes between the amendments were insignificant at 15, 20, 45, and 60 DOI for all soils except the control (Table 2). Similar to total C, total N was also the highest in the EFBB treated soil at 15, 30, 45, and 60 DOI (0.43%, 0.43%, 0.44%, and 0.44% respectively), which was statistically similar over the COMP treated soil at 30, 45, and 60 DOI (0.42%, 0.43%, and 0.43% respectively). The lowest total N content was found in PBA over all intervals excluding 45 DOI and the values were statistically identical to the control.

The CN ratio of the soil was calculated using the ratio of total carbon and total nitrogen, and the addition of organic amendment increased the CN ratio of the soil; the effect of incubation time was also significant ($p < 0.05$) for EFBB and RHA while others were unaffected (Table 2). Soil treated with EFBB showed the maximum CN ratio (19.22) at 15 DOI and slightly decreased over time (17.92 at 60 DOI). Incorporation of RHB, COMP, and RHA exhibited statistically identical CN ratios at distinct DOIs, although these were different from EFBB. Throughout the DOIs, the PBA and control treatments produced the lowest and statistically similar CN ratios among other organic materials.

3.4. Available Phosphorus

Phosphorus availability in soil was significantly affected by different organic amendments and DOIs ($p < 0.05$). For all the organic amendments, P availability curves peaked at 30 DOI, and then there was a sharp drop at 30 DOI and then they flattened (Table 3). In the PBA amended soil, the highest P availability was 68.56 mg kg^{-1} at 30 DOI and the lowest was 33 mg kg^{-1} at 45 DOI which was more than three-fold higher compared to the inherent P availability observed in the control. Among the organic amendments, the highest P availability was observed with PBA followed by RHB while the lowest P availability was observed in the control (soil without amendment). COMP and EFBB amendments almost had the same pattern of P availability between the DOIs which is almost similar to the P availability pattern in the control. After 60 DOI, maximum available P (41.41 mg kg^{-1}) was obtained by PBA treatment and minimum available P from the control (8.39 mg kg^{-1}), which is similar to compost (9.03 mg kg^{-1}).

Table 3. Changes in available P in soil influenced by selected organic amendments at different incubation periods.

Organic Amendment	Available P (mg kg^{-1})			
	15 Days	30 Days	45 Days	60 Days
RHB	36.85 ± 2.72 Bb	46.89 ± 1.27 Ba	20.52 ± 1.65 BCc	19.90 ± 0.10 Bc
EFBB	18.16 ± 0.93 Db	31.37 ± 1.48 CDa	9.81 ± 0.38 Dc	12.35 ± 0.36 Dc
COMP	24.75 ± 1.32 Ca	27.73 ± 0.86 CDa	10.97 ± 0.90 Db	9.03 ± 0.91 Eb
RHA	33.03 ± 1.22 Bb	37.10 ± 1.14 BCa	21.57 ± 1.14 Bc	16.34 ± 0.49 Cd
PBA	64.28 ± 2.64 Aa	68.56 ± 8.55 Aa	33.00 ± 3.29 Ab	41.41 ± 1.70 Ab
Control	20.37 ± 1.34 CDa	23.62 ± 0.97 Da	14.64 ± 1.12 CDb	8.39 ± 0.16 Ec

Values are presented as mean \pm standard error with different uppercase letters in the same column and lowercase letters in the same row indicating significant difference ($p < 0.05$) among the organic amendments and incubation days, respectively. RHB, Rice husk biochar; EFBB, Oil palm empty fruit bunch biochar; COMP, Compost; RHA, Rice husk ash; PBA, Oil palm bunch ash, and control, no amendment.

3.5. Exchangeable Potassium

Exchangeable potassium of soil under study was significantly ($p < 0.05$) influenced by the DOI and type of organic amendment (Table 4). The K availability pattern followed the same as observed for P availability. Exchangeable K with PBA amendment showed a sharp increase at 30 DOI compared to that at 15 DOI and then the availability was relatively stable at 45 and 60 DOI. The highest exchangeable K with PBA amendment was observed at 45 DOI ($8.20 \text{ cmol}_c \text{ kg}^{-1}$) and the lowest at 15 DOI (4.71). An eight times

higher exchangeable K availability was observed at all the sampling days when compared to control. EFBB amendment followed the PBA amendment for K availability and the K availability was relatively stable at all the sampling days maintaining a 4–7 fold higher compared to control. The other three amendments—RHB, RHA, and COMP—almost had the same levels of exchangeable K across the DOIs. Among the organic amendments overall, PBA exhibited the highest value of exchangeable K in all DOIs.

Table 4. Changes in soil exchangeable K influenced by selected organic amendments at different incubation periods.

Organic Amendment	Exchangeable K (cmol _c kg ^{−1})			
	15 Days	30 Days	45 Days	60 Days
RHB	1.41 ± 0.03 Bb	1.74 ± 0.05 Ca	1.80 ± 0.02 Ca	1.81 ± 0.05 Ca
EFBB	4.35 ± 0.12 Aab	4.22 ± 0.08 Bab	4.56 ± 0.17 Ba	3.95 ± 0.06 Bb
COMP	0.72 ± 0.02 Bc	0.79 ± 0.16 Dbc	1.26 ± 0.13 Da	1.15 ± 0.07 Dab
RHA	1.18 ± 0.03 Bc	1.47 ± 0.07 Cb	1.72 ± 0.02 Ca	1.52 ± 0.06 CDb
PBA	4.71 ± 0.97 Ab	7.83 ± 0.13 Aa	8.20 ± 0.16 Aa	7.81 ± 0.41 Aa
Control	0.59 ± 0.02 Bb	0.87 ± 0.04 Da	0.85 ± 0.08 Ea	0.99 ± 0.04 Da

Values are presented as mean ± standard error with different uppercase letters in the same column and lowercase letters in the same row indicating significant difference ($p < 0.05$) among the organic amendments and incubation days, respectively. RHB, Rice husk biochar; EFBB, Oil palm empty fruit bunch biochar; COMP, Compost; RHA, Rice husk ash; PBA, Oil palm bunch ash, and control, no amendment.

3.6. Exchangeable Calcium (Ca) and Magnesium (Mg)

Incubation time significantly ($p < 0.05$) affected the exchangeable Ca and Mg in soil when amended with organic material (Table 5). Initially, exchangeable Ca and Mg were high at 15 DOI for all treatments and then decreased in 30 and 45 DOI. Both exchangeable Ca and Mg peaked at 60 DOI and were statistically significant ($p < 0.05$) over the rest of the DOIs (except 15 DOI).

Table 5. Changes in soil exchangeable Ca and Mg influenced by selected organic amendments at different incubation periods.

Organic Amendment	Exchangeable Ca (cmol _c kg ^{−1})			
	15 Days	30 Days	45 Days	60 Days
RHB	17.70 ± 0.65 Ba	10.66 ± 0.39 Ab	11.23 ± 0.26 Bb	20.26 ± 1.16 Aa
EFBB	18.92 ± 0.29 ABa	10.39 ± 0.19 Ab	10.98 ± 0.37 Bb	21.89 ± 1.71 Aa
COMP	21.00 ± 0.41 Aa	11.50 ± 1.89 Ab	11.71 ± 0.34 ABb	22.55 ± 2.00 Aa
RHA	16.69 ± 0.60 Bab	12.21 ± 0.44 Ab	10.86 ± 0.14 Bb	20.06 ± 2.41 Aa
PBA	19.66 ± 0.71 ABa	12.03 ± 0.27 Ab	14.08 ± 0.93 Ab	21.89 ± 0.82 Aa
Control	17.19 ± 0.50 Ba	12.04 ± 0.07 Ab	11.20 ± 0.55 Bb	17.05 ± 1.46 Aa
Organic Amendment	Exchangeable Mg (cmol _c kg ^{−1})			
	15 Days	30 Days	45 Days	60 Days
RHB	12.11 ± 0.43 BCa	6.08 ± 0.22 ABb	5.79 ± 0.13 Cb	13.25 ± 0.76 ABa
EFBB	13.21 ± 0.33 Ba	5.64 ± 0.03 Bc	5.70 ± 0.16 Cc	13.95 ± 0.72 ABa
COMP	12.57 ± 0.16 BCa	5.51 ± 1.05 Bb	6.49 ± 0.15 Bb	12.57 ± 1.06 Ba
RHA	11.12 ± 0.42 CDa	6.38 ± 0.27 ABb	5.74 ± 0.14 BCb	12.91 ± 1.53 ABa
PBA	15.46 ± 0.54 Aa	7.63 ± 0.20 Ab	8.60 ± 0.22 Ab	16.30 ± 0.80 Aa
Control	11.57 ± 0.35 Db	6.30 ± 0.04 ABc	6.22 ± 0.14 Cc	11.03 ± 0.78 Bb

Values are presented as mean ± standard error with different uppercase letters in the same column and lowercase letters in the same row indicating significant difference ($p < 0.05$) among the organic amendments and incubation days, respectively. RHB, Rice husk biochar; EFBB, Oil palm empty fruit bunch biochar; COMP, Compost; RHA, Rice husk ash; PBA, Oil palm bunch ash, and control, no amendment.

Organic materials significantly altered ($p < 0.05$) the exchangeable Ca concentration of the soil over 15 and 45 DOI (Table 4); the addition of PBA maximized exchangeable calcium during these DOIs (19.66 and 14.08 cmol_c kg^{−1}, respectively). However, at 60 DOI, the five amendments produced statistically similar values of exchangeable Ca in soil.

Magnesium concentration exhibited a small but statistically significant ($p < 0.05$) variation among different organic amendments. Soil amended with PBA showed the highest exchangeable Mg concentration at 60 DOI ($16.30 \text{ cmol}_c \text{ kg}^{-1}$) which was statistically similar to EFBB, RHB, and RHA, and the minimum value was obtained in the control ($11.03 \text{ cmol}_c \text{ kg}^{-1}$).

3.7. Gravimetric Water Content

The gravimetric water content in soil was significantly influenced ($p < 0.05$) by DOI and type of organic matter amendments. The highest water content was observed with RHB amendment while the lowest water content was observed in the control (Figure 2) and the variation was about two-fold higher between them. A gradual increasing trend of water content was observed with increasing DOIs in all the organic amendments with the exceptions of RHA amendment and control, while the water content trend was quite unchanged for PBA amendment. Water content under the control condition showed a decreasing trend with as the days of incubation increased; highest gravimetric water (0.29 g g^{-1}) was obtained at 15 DOI, while the lowest was obtained at the end of incubation (0.17 g g^{-1}). For RHB, maximum gravimetric moisture (0.46 g g^{-1}) was obtained at 60 DOI followed by 0.44 g g^{-1} at 45 DOI, while a sharp drop was observed at 30 and 15 DOI, with moisture values of 0.36 and 0.35 g g^{-1} . Fairly good and stable moisture contents were observed for COMP amendment with moisture content variation between 0.36 and 0.40 g g^{-1} across the whole incubation period. The values of gravimetric water content of soil treated with organic amendments at different DOIs given in Supplementary Table (Table S1).

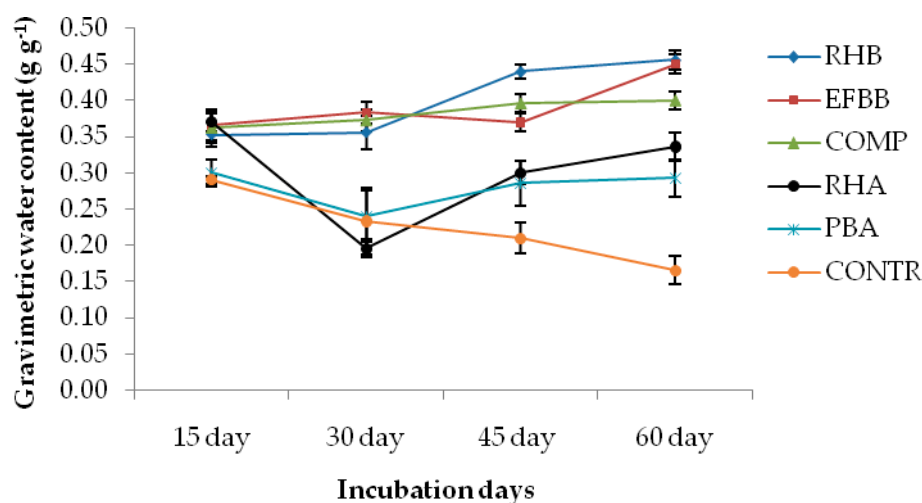


Figure 2. Variation in gravimetric water content (g g^{-1}) affected by selected organic amendments at different incubation periods. Vertical bars in the graph indicate standard error of means ($\pm \text{SE}$, $n = 3$). RHB, Rice husk biochar; EFBB, Oil palm empty fruit bunch biochar; COMP, Compost; RHA, Rice husk ash; PBA, Oil palm bunch ash, and CONTR (control), no amendment.

3.8. Relationship between Different Soil Properties Influenced by Organic Amendments during the Incubation Period

Pearson's correlation analysis was performed to determine the relationship between soil properties. From the analysis (Table 6), it was observed that gravimetric water content (GWC) significantly positively correlated with the TC, TN, and CN ratio and soil pH had a significant negative relation with the TC, TN, and CN ratio, while pH exhibited a significant positive correlation with available P and exchangeable. K. Furthermore, significant positive correlations were observed between available P and exchangeable. K, and also between exchangeable. Ca and Mg.

Table 6. Correlation coefficients among different soil properties.

Parameters	pH	TC	TN	CN Ratio	Av. P	Exch. K	Exch. Ca	Exch. Mg
pH	-	-	-	-	-	-	-	-
TC	−0.31 **	-	-	-	-	-	-	-
TN	−0.35 **	0.83 **	-	-	-	-	-	-
CN ratio	−0.25 *	0.91 **	0.53 **	-	-	-	-	-
Av. P	0.58 **	−0.31 **	−0.54 **	−0.08 ns	-	-	-	-
Exch. K	0.87 **	−0.13 ns	−0.22 ns	−0.09 ns	0.47 ***	-	-	-
Exch. Ca	0.11 ns	−0.19 ns	−0.20 ns	−0.15 ns	−0.12 ns	0.01 ns	-	-
Exch. Mg	0.27 *	−0.18 ns	−0.27 *	−0.10 ns	0.07 ns	0.18 ns	0.88 **	-
GWC	−0.16 ns	0.58 **	0.45 **	0.56 **	−0.21 ns	−0.09 ns	0.08 ns	0.13 ns

TC: total carbon; TN: total nitrogen; Av. P: available phosphorus; GWC: gravimetric water content; ns: not significant; * $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

4.1. Impact of Biochar on Nutrient Release

At the end of incubation, pH was remarkably increased in the soil receiving PBA and EFBB treatments compared to the control; the change in EFBB was less compared to PBA. pH increases by PBA and EFBB were 1.1 and 1.1 and 0.41 units, respectively, compared to control. This may be due to the high pH of PBA and EFBB, which accelerates soil pH toward neutral. Other organic amendments did not make significant changes in soil pH because they were neutral to slightly acidic. Oil palm bunch ash contains a large amount of calcium; it showed alkaline properties and improved soil pH [30]. EFBB was also alkaline and alleviates soil acidity by improving soil pH, as reported by Abdulrahman et al. [31]. EFBB causes a reduction in Al^{3+} activity and increased floodwater pH of low land paddy soil [15]. Generally, rice husk biochar incorporated soil increases in pH did not occur in our study because the rice husk biochar used in this study exhibited a low pH which also agrees with the findings of Wang and Liu [32].

At the end of incubation, the maximum carbon added by EFBB was 47% higher compared to the control, whereas RHB and compost increased carbon by 24% and 28%, respectively. PBA incorporation decreased the total carbon by 8% compared to control, which may be due to the very low carbon (2.10) content; an increase in carbon in soil is directly proportional to the extent of carbon present in the organic amendment. Incorporation of biochar and compost in soil increased soil total carbon, which is also reported by Mensah and Frimpong [33]. Wang and Liu [32] mentioned that biochar has unique properties to enhance long-term carbon storage in soil. Organic amendments such as EFBB and compost rich in nitrogen increased total nitrogen by 16% and 13%, respectively, compared to control, whereas PBA incorporation reduced it by 7% in due to low N content (0.02%). An increase in the total nitrogen of soil occurred due to the N-rich amendment reported by Bakar et al. [15]. Lehmann [34] also highlighted soil nitrogen enrichment by biochar and compost.

The increased available phosphorus in soil until the first thirty days of incubation in this study is similar to the findings of Scheffe et al. [35]. Microbial mineralization of organic amendments may have flushed this increased available P in soil [36,37]. Later, the concentration of available P reduced with time due to the fixation of available P by the hydrous oxides of Al and Fe; this was the same in all the amendments. Tropical soil rich in soluble Fe fixes available P [38]. A decrease in available P in the latter days contradicts the findings of Opala et al. [39], who reported increased P availability with organic amendments. We also found the same for PBA—increased available P compared to the control even at the final days (60 DOI) of incubation. This biochar is very rich in P compared to other biochars and composts, which happens to increased available P all along the incubation time (similar to the findings of Wang et al. [40]; Glaser and Lehr [41]. Among different organic amendments (except RHB), P content was comparatively higher in lower C and N materials consecutively; P content was lower in the highest C material,

EFBB (Table A2), which was reflected after the materials were incorporated into the soil; this is a possible cause for the negative correlation between total C, N, and available P.

At 60 DOI, the K contents of PBA and EFBB increased by about 690% and 300%, respectively, compared to the control; increased exchangeable K with incubation time was due to high potassium content in PBA and EFBB (Table A2). The addition of biochar increased soil exchangeable K; these findings are well supported by many researchers [16,42]. Generally, biochar increases K availability due to high ash content; further, it absorbs K ions on its surface and reduces leaching loss [43,44]. Moreover, biochar application promotes K solubilizing bacterial growth and enhances K release from K-rich clay minerals [44]. Compost contributed a little increase in available K due to its poor K content; however, the same result was also obtained by Lashermes et al. [45]. A slight drop in K availability occurred from 45 to 60 days, which may be due to K fixation in the clay interlayers [46].

Available Ca^{2+} in soil increased due to the calcium-rich amendments, PBA, and compost. All amendments raised exchangeable calcium in soil compared to initial soil. The addition of calcium-rich amendments increased available Ca^{2+} reported by Ch'ng et al. [36]. Except for PBA, amendments did not show any remarkable change in exchangeable Mg^{2+} concentration in the soils; these findings are similar to the study of Hirzel et al. [47], who also reported small changes in magnesium from a short incubation study. From correlation analysis, a negative relation was observed between total C and N with exchangeable Ca^{2+} and Mg^{2+} ; in this study, biochars were carbon-rich materials though their low Ca contents. Further, biochar has a unique surface chemistry and different functional groups [48], which were possible causes for initial nutrient absorption to its surface and reduced their availability at early DOIs. At the end of incubation, increased availability may be due to the microbial decomposition. In correlation analysis, we considered the data of all DOIs, and the relationship was weak and nonsignificant.

4.2. Impact of Biochar on Water Retention

At the DOIs, biochars and compost increased up to 170% and 135% compared to the control. Biochar amendment in the soil increases the water retention capacity of soil due to its very high surface area. Biochars and compost amendment increased the soil moisture content over the DOIs but PBA did not, as the carbon content in PBA was very low. From correlation analysis (Table 6), total C and N of soil has a positive and significant relation with gravimetric water content. The application of biochar improved soil water retention, due to its high surface area and carbon-rich properties that facilitate enhanced soil porosity by accelerating soil macroaggregate formation and stability, but reduced bulk density [49,50]. The leading two biochars in terms of water retention, used in this experiment, originated from rice husk and oil palm. Głab et al. [51] and Chen et al. [42] also noted that the application of biochar improves soil water storage. To determine why there is a tendency of biochar to retain water, biochars were analyzed for SEM micrographs. The SEM micrographs showed that, among the biochars used in this study, rice husk and oil palm empty fruit bunch had cellular structure pores as well as the highest surface areas, leading to very high water retention capacities [52]. Micropores in RHB and EFBB observed from the SEM micrograph boosted the water retention capacity. Improved moisture retained by biochar increased soil moisture storage directly by its large surface area and high quantity of pores that act as a capillary reserves of water [53]. Wang et al. [54] further elaborated on the improved soil porosity with biochar by raising soil inter- and intraparticle porosity. Therefore, it can be summarized that biochars with very high surface areas and pore volumes can improve soil water retention capacity through reducing the soil bulk density [51] and increasing surface area [55] as well as soil porosity [50]. All these improved soil properties through biochar amendments lead to improved soil water retention [56].

5. Conclusions

After this 60-day incubation study, it was observed that the incorporation of selected organic amendments—as follows: RHB, EFBB, COMP, RHA, and PBA—at rates of 4% (weight/weight) in soil improved the chemical properties and moisture retention of a clay textured paddy soil. The initial properties of the amendments played a major role in changing the chemical properties of the soil. Among the amendments, two biochars (RHB and EFBB) conserved high gravimetric water contents. From the structural analysis of biochars by scanning electron microscopy, the presence of porous structures and the large surface areas helped retain soil moisture by storing water in micropores. Amendments such as RHB and EFBB biochars enrich plant nutrients and increase the water holding capacity of paddy soil. The results of this study are material, dose, soil, and lab-environment specific; field validation of the results is imperative to demonstrate the soil improvement effects of the two biochars.

Supplementary Materials: The following are available online at <https://www.mdpi.com/2077-0472/11/1/44/s1>, Table S1: Variation in gravimetric water content affected by selected organic amendments at different incubation periods.

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Appendix A

Table A1. Selected physical and chemical properties of the experimental soil.

Parameter	Value
%Sand	6.60
%Silt	29.62
%Clay	63.79
Textural class	Clay
pH	5.01
Total Carbon (%)	4.94
Total Nitrogen (%)	0.36
Available P (mg kg ⁻¹)	12.03
Exchangeable K (cmol _c kg ⁻¹)	0.59
Exchangeable Ca (cmol _c kg ⁻¹)	13.18
Exchangeable Mg (cmol _c kg ⁻¹)	9.61
Total S (mg kg ⁻¹)	1924
% Moisture (at field capacity)	27.34

Table A2. Chemical characteristics of different organic amendments.

Organic Amendment	pH Soil: H ₂ O (1:2.5)	C	N	P	K %	Ca	Mg	S
Rice husk biochar	7.12	24.86	0.38	0.31	0.75	0.17	0.17	0.15
Oil palm empty fruit bunch biochar	8.50	52.11	1.13	0.19	5.08	0.71	0.39	0.15
Compost	6.45	28.95	0.93	0.10	0.36	1.38	0.23	0.25
Rice husk ash	7.20	22.73	0.26	0.23	1.67	0.11	0.15	0.10
Oil Palm Bunch Ash	10.64	2.10	0.02	0.99	6.28	3.28	0.13	0.12

References

1. FAO. Rice market monitor. In *Proceedings of the Food and Agriculture Organization Proceedings*; Food and Agriculture Organization: Rome, Italy, 2018; pp. 1–35.
2. *Rice Knowledge Bank*; International Rice Research Institute (IRRI): Los Baños, Philippines, 2018.
3. Bouman, B.A.M.; Hengsdijk, H.; Hardy, B.; Bindraban, P.S.; Tuong, T.P. Water-wise rice production. In *Proceedings of the International Workshop on Water-wise Rice Production*; International Rice Research Institute (IRRI): Los Baños, Philippines, 2002; p. 356.
4. Wu, X.H.; Wang, W.; Yin, C.M.; Hou, H.J.; Xie, K.J.; Xie, X.L. Water consumption, grain yield, and water productivity in response to field water management in double rice systems in China. *PLoS ONE* **2017**, *12*, e0189280. [[CrossRef](#)] [[PubMed](#)]
5. Dong, N.M.; Brandt, K.K.; Sørensen, J.; Hung, N.N.; Van Hach, C.; Tan, P.S.; Dalsgaard, T. Effects of alternating wetting and drying versus continuous flooding on fertilizer nitrogen fate in rice fields in the Mekong Delta, Vietnam. *Soil Biol. Biochem.* **2012**, *47*, 166–174. [[CrossRef](#)]
6. Monaco, F.; Sali, G.; Ben Hassen, M.; Facchi, A.; Romani, M.; Valè, G. Water Management Options for Rice Cultivation in a Temperate Area: A Multi-Objective Model to Explore Economic and Water Saving Results. *Water* **2016**, *8*, 336. [[CrossRef](#)]
7. Bhattacharyya, P.; Barman, D. Crop residue management and greenhouse gases emissions in tropical rice lands. In *Soil Management and Climate Change*; Academic Press: London, UK, 2018; pp. 323–335.
8. Lehmann, J. A handful of carbon. *Nat. Cell Biol.* **2007**, *447*, 143–144. [[CrossRef](#)] [[PubMed](#)]
9. Ippolito, J.A.; Spokas, K.A.; Novak, J.M.; Lentz, R.D.; Cantrell, K.B. Biochar elemental composition and factors influencing nutrient retention. In *Biochar for Environmental Management: Science, Technology and Implementation*; Routledge: Abingdon, UK, 2015; pp. 137–161.
10. Ghorbani, M.; Asadi, H.; Abrishamkesh, S. Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. *Int. Soil Water Conserv. Res.* **2019**, *7*, 258–265. [[CrossRef](#)]
11. Sukiran, M.A.; Kheang, L.S.; Bakar, N.A.; May, C.Y. Production and Characterization of Bio-Char from the Pyrolysis of Empty Fruit Bunches. *Am. J. Appl. Sci.* **2011**, *8*, 984–988. [[CrossRef](#)]
12. Awodun, M.A.; Ojeniyi, S.O.; Adeboye, A.; Odedina, S.A. Effect of oilpalm bunch refuse ash on soil and plant nutrient composition and yield of maize. *Am. J. Sustain. Agric.* **2007**, *1*, 50–54.
13. Subhan, A.; Khan, Q.U.; Mansoor, M.; Khan, M.J. Effect of Organic and Inorganic Fertilizer on the Water Use Efficiency and Yield Attributes of Wheat under Heavy Textured Soil. *Sarhad J. Agric.* **2017**, *33*. [[CrossRef](#)]
14. Gould, M.C. *Compost Increases the Water Holding Capacity of Droughty Soils*; Michigan State University Extension: Michigan, MI, USA, 2012.
15. Abu Bakar, R.; Razak, Z.A.; Ahmad, S.H.; Seh-Bardan, B.J.; Tsong, L.C.; Meng, C.P. Influence of Oil Palm Empty Fruit Bunch Biochar on Floodwater pH and Yield Components of Rice Cultivated on Acid Sulphate Soil under Rice Intensification Practices. *Plant Prod. Sci.* **2015**, *18*, 491–500. [[CrossRef](#)]
16. Solaiman, Z.M.; Shafi, M.I.; Beamont, E.; Anawar, H.M. Poultry Litter Biochar Increases Mycorrhizal Colonisation, Soil Fertility and Cucumber Yield in a Fertigation System on Sandy Soil. *Agriculture* **2020**, *10*, 480. [[CrossRef](#)]
17. Hussain, M.; Farooq, M.; Nawaz, A.; Al-Sadi, A.M.; Solaiman, Z.M.; Alghamdi, S.S.; Ammara, U.; Ok, Y.S.; Siddique, K.H.M. Biochar for crop production: Potential benefits and risks. *J. Soils Sediments* **2017**, *17*, 685–716. [[CrossRef](#)]
18. Saletnik, B.; Zagula, G.; Bajcar, M.; Tarapatsky, M.; Puchalski, C. Biochar and Biomass Ash as a Soil Ameliorant: The Effect on Selected Soil Properties and Yield of Giant Miscanthus (*Miscanthus x giganteus*). *Energies* **2018**, *11*, 2535. [[CrossRef](#)]
19. Solaiman, Z.M.; Anawar, H.M. Application of Biochars for Soil Constraints: Challenges and Solutions. *Pedosphere* **2015**, *25*, 631–638. [[CrossRef](#)]
20. Downie, A.; Crosky, A.; Munroe, P. Biochar for environmental management, science and technology. In *Physical Properties of Biochar*; Earthscan: London, UK, 2009; pp. 13–32.
21. Schiemenz, K.; Eichler-Löbermann, B. Biomass ashes and their phosphorus fertilizing effect on different crops. *Nutr. Cycl. Agroecosystems* **2010**, *87*, 471–482. [[CrossRef](#)]
22. Bonfim-Silva, E.M.; Bezerra, M.D.L.; Da Silva, T.J.A.; Fenner, W.; Damasceno, A.P.A.B. Wood ash and water availability in the production of Paiaguás-grass. *Ambient. Agua Interdiscip. J. Appl. Sci.* **2019**, *14*, 1–15. [[CrossRef](#)]

23. Maheshwari, D.K. Composting for Sustainable Agriculture. In *Sustainable Development and Biodiversity*; Maheshwari, D.K., Ed.; Springer: Berlin/Heidelberg, Germany, 2014; Volume 3, ISBN 978-3-319-08003-1.
24. Teh, C.B.S.; Talib, J.B. *Soil Physics Analyses*; University Putra Malaysia Press: Serikembangan, Malaysia, 2006; ISBN 983-3455-64-6.
25. Benton, J.J. *Laboratory Guide for Conducting Soil Tests and Plant Analysis*; CRC Press: Boca Raton, FL, USA, 2001; ISBN 9780429132117.
26. Bray, R.H.; Kurtz, L.T. Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci.* **1945**, *59*, 39–46. [[CrossRef](#)]
27. Schollenberger, C.J.; Simon, R.H. Determination of exchange capacity and exchangeable bases in soil—Ammonium acetate method. *Soil Sci.* **2006**, *59*, 13–24. [[CrossRef](#)]
28. Dey, A.; Srivastava, P.C.; Pachauri, S.P.; Shukla, A.K. Time-dependent release of some plant nutrients from different organic amendments in a laboratory study. *Int. J. Recycl. Org. Waste Agric.* **2019**, *8*, 173–188. [[CrossRef](#)]
29. Cooper, J.D. Gravimetric Method. In *Soil Water Measurement*; Wiley: Hoboken, NJ, USA, 2016; pp. 26–42.
30. Udoetok, I.A. Characterization of ash made from oil palm empty fruit bunches (oefb). *Int. J. Environ. Sci.* **2012**, *3*, 518–524.
31. Abdulrahman, D.K.; Othman, R.; Saud, H.M. Effects of empty fruit bunch biochar and nitrogen-fixing bacteria on soil properties and growth of sweet corn. *Malaysian J. Soil Sci.* **2016**, *8*, 177–194.
32. Wang, Y.; Liu, R. Improvement of acidic soil properties by biochar from fast pyrolysis. *Environ. Prog. Sustain. Energy* **2018**, *37*, 1743–1749. [[CrossRef](#)]
33. Mensah, A.K.; Frimpong, K.A. Biochar and/or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. *Int. J. Agron.* **2018**, *2018*, 1–8. [[CrossRef](#)]
34. Lehmann, J. Bio-energy in the black. *Front. Ecol. Environ.* **2007**, *5*, 381–387. [[CrossRef](#)]
35. Scheffe, C.R.; Patti, A.F.; Clune, T.S.; Jackson, W.R. Organic amendment addition enhances phosphate fertiliser uptake and wheat growth in an acid soil. *Soil Res.* **2008**, *46*, 686–693. [[CrossRef](#)]
36. Ch'Ng, H.Y.; Ahmed, O.H.; Majid, N.M.A. Improving Phosphorus Availability in an Acid Soil Using Organic Amendments Produced from Agroindustrial Wastes. *Sci. World J.* **2014**, *2014*, 1–6. [[CrossRef](#)] [[PubMed](#)]
37. Madiba, O.F.; Solaiman, Z.M.; Carson, J.K.; Murphy, D.V. Biochar increases availability and uptake of phosphorus to wheat under leaching conditions. *Biol. Fertil. Soils* **2016**, *52*, 439–446. [[CrossRef](#)]
38. Marsi, M.; Sabaruddin, S. Phosphate adsorption capacity and organic matter effect on dynamics of P availability in upland ultisol and lowland inceptisol. *J. Trop. Soils* **2011**, *16*, 107–114. [[CrossRef](#)]
39. Opala, P.A.; Okalebo, J.; Othieno, C.O. Effects of Organic and Inorganic Materials on Soil Acidity and Phosphorus Availability in a Soil Incubation Study. *ISRN Agron.* **2012**, *2012*, 1–10. [[CrossRef](#)]
40. Wang, T.; Camps-Arbestain, M.; Hedley, M. The fate of phosphorus of ash-rich biochars in a soil-plant system. *Plant Soil* **2013**, *375*, 61–74. [[CrossRef](#)]
41. Glaser, B.; Lehr, V.I. Biochar effects on phosphorus availability in agricultural soils: A meta-analysis. *Sci. Rep.* **2019**, *9*, 1–9. [[CrossRef](#)]
42. Chen, L.; Liu, M.; Ali, A.; Zhou, Q.; Zhan, S.; Chen, Y.; Pan, X.; Zeng, Y. Effects of Biochar on Paddy Soil Fertility Under Different Water Management Modes. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 1810–1818. [[CrossRef](#)]
43. Martinsen, V.; Mulder, J.; Shitumbanuma, V.; Sparrevik, M.; Børresen, T.; Cornelissen, G. Farmer-led maize biochar trials: Effect on crop yield and soil nutrients under conservation farming. *J. Plant Nutr. Soil Sci.* **2014**, *177*, 681–695. [[CrossRef](#)]
44. Wang, L.; Xue, C.; Nie, X.; Liu, Y.; Chen, F. Effects of biochar application on soil potassium dynamics and crop uptake. *J. Plant Nutr. Soil Sci.* **2018**, *181*, 635–643. [[CrossRef](#)]
45. Lashermes, G.; Houot, S.; Barriuso, E. Sorption and mineralization of organic pollutants during different stages of composting. *Chemosphere* **2010**, *79*, 455–462. [[CrossRef](#)] [[PubMed](#)]
46. Simonsson, M.; Hillier, S.; Öborn, I. Changes in clay minerals and potassium fixation capacity as a result of release and fixation of potassium in long-term field experiments. *Geoderma* **2009**, *151*, 109–120. [[CrossRef](#)]
47. Hirzel, J.; Donnay, D.; Fernández, C.; Meier, S.; Lagos, O.; Mejias-Barrera, P.; Rodríguez, F. Evolution of nutrients and soil chemical properties of seven organic fertilizers in two contrasting soils under controlled conditions. *Chil. J. Agric. Anim. Sci.* **2018**, *34*, 77–88. [[CrossRef](#)]
48. DeLuca, T.H. Influence of Biochar on Soil Nutrient Transformations, Nutrient Leaching, and Crop Yield. *Adv. Plants Agric. Res.* **2016**, *4*, 4. [[CrossRef](#)]
49. Jien, S.H.; Wang, C.S. Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena* **2013**, *110*, 225–233. [[CrossRef](#)]
50. Obia, A.; Mulder, J.; Martinsen, V.; Cornelissen, G.; Børresen, T. In situ effects of biochar on aggregation, water retention and porosity in light-textured tropical soils. *Soil Tillage Res.* **2016**, *155*, 35–44. [[CrossRef](#)]
51. Głab, T.; Palmowska, J.; Zaleski, T.; Gondek, K. Effect of biochar application on soil hydrological properties and physical quality of sandy soil. *Geoderma* **2016**, *281*, 11–20. [[CrossRef](#)]
52. Kameyama, K.; Miyamoto, T.; Iwata, Y. The Preliminary Study of Water-Retention Related Properties of Biochar Produced from Various Feedstock at Different Pyrolysis Temperatures. *Materials* **2019**, *12*, 1732. [[CrossRef](#)] [[PubMed](#)]
53. Batista, E.M.C.C.; Shultz, J.; Matos, T.T.S.; Fornari, M.R.; Ferreira, T.M.; Szpoganicz, B.; De Freitas, R.A.; Mangrich, A.S. Effect of surface and porosity of biochar on water holding capacity aiming indirectly at preservation of the Amazon biome. *Sci. Rep.* **2018**, *8*, 1–9. [[CrossRef](#)] [[PubMed](#)]

-
54. Wang, D.; Li, C.; Parikh, S.J.; Scow, K.M. Impact of biochar on water retention of two agricultural soils—A multi-scale analysis. *Geoderma* **2019**, *340*, 185–191. [[CrossRef](#)]
 55. Laird, D.A.; Fleming, P.; Davis, D.D.; Horton, R.; Wang, B.; Karlen, D.L. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma* **2010**, *158*, 443–449. [[CrossRef](#)]
 56. Gray, M.; Johnson, M.G.; Dragila, M.I.; Kleber, M. Water uptake in biochars: The roles of porosity and hydrophobicity. *Biomass Bioenergy* **2014**, *61*, 196–205. [[CrossRef](#)]