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Use of Biochar-Compost for Phosphorus Availability to Maize in a Concretionary Ferric Lixisol in Northern GHANA

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Abstract: A pot experiment was conducted to investigate the effect of biochar-compost on availability of P for maize cultivation in a concretionary Lixisol of northern Ghana and residual soil characteristics thereof. Sawdust biochar was co-composted with kitchen waste and cow dung in various proportions. Four biochar-composts were selected based on their superior carbon and available P content, lower pH, and electrical conductivity (EC). These were amended to attain the standard phosphorus requirement (SPR) and half the SPR of the Lixisol. Triple superphosphate and $(NH_4)_2 SO_4$ were, respectively, applied as inorganic fertilizer to meet the SPR and the average total nitrogen of the selected biochar-compost treatments. A control without any soil amendment was included. Maize was grown to tasseling (eight weeks) and shoot dry matter and P uptake determined. A 2.71 to 3.71-fold increase in P uptake led to a 1.51 to 2.33-fold increase in shoot dry matter in biochar-compost-amended soils over the control. Residual soil C, pH, and total and available P in the biochar-compost-amended soils were enhanced. Biochar-composts at half the SPR level produced maize with higher shoot dry matter than the equivalent inorganic amendment at full SPR.

Keywords: biochar; Lixisol; biochar-compost; standard phosphorus requirement (SPR); concretionary soil; Ghana

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1. Introduction

Maize (*Zea mays*) is a very important staple food crop in Ghana and ranks first as the most important cereal produced and consumed [1]. Maize yield is affected by phosphorus (P), a basic and fundamental element for plant growth. Soils of northern Ghana are rich in ferruginous nodules and oxides/oxyhydroxides of Fe and Al [2,3]. These properties, together with the presence of kaolinitic clay minerals and low pH lead to fixation of P in the soils [3,4]. Consequently, the soils are low in available P. Phosphorus deficiency as a plant available nutrient is, thus, a key problem in soils of northern Ghana. Significant P fertilizer applications are, therefore, needed to produce arable crops of high yield [4].

Saturation of soil with P, followed by lower P additions to enhance crop production to ensure long-term residual P [5], have been implemented as a means to overcome severe P deficiency. Phosphorus fertilizer placement by banding the fertilizer near the roots is preferred to broadcasting or ring application. This strategy seeks to saturate the root sorption sites by minimizing P contact with soil, thus creating higher solution concentrations [6]. However, P fertilizer efficiency may be reduced by banding when precipitation reactions dominate [7]. The gap in these approaches is how to build-up organic matter to minimize P-fixation, and hence improve the extent of P-availability.

Organic materials have the ability to alleviate the unavailability of P in these soils through the release of organic acids which minimize the sorption of P onto the kaolinitic surfaces [8–10]. Organic materials also improve P availability through the minimization of P precipitation by free Fe and Al in solution [11,12]. These roles of organic materials are, however, undermined by low return to the soil and subsequent quick mineralization due to the high temperatures in northern Ghana. Therefore, a more recalcitrant form of organic matter could be exploited as a means of supplying the soil with a sustainable P source.

Biochar, charcoal manufactured under controlled pyrolysis conditions has been used as a soil amendment or in sequestration of carbon (C) [13]. Scientists have devoted considerable time to biochar due to its persistence in soils [14], soil fertility enhancement [15] and sustainability properties [16]. Biochar is also regarded as a reservoir for available P [17]. Therefore, to ensure P availability, particularly in the interim, the direct release of this soluble P may be utilized [18]. However, due to biochar's limitation as a poor source of N, it is recommended to co-compost it with other organic materials to produce a more N-P balanced biochar-compost. Co-composting with biochar increases yield and plant nutritive value of the final product [19]. Upon incorporation of mature compost, soil quality is improved, plant growth and development enhanced, and many soil-borne disease-causing plant pathogens are suppressed [20,21]. Composts have been proven to increase biological activity and nutrient supply to plants [22], thereby improving crop productivity.

Bawku is in the Sudan Savanna Ecological Zone of Ghana where availability of plant sources of organic matter is a major challenge. Crop residues after harvest are preserved for animal feeding during the ensuing six-month dry season. Consequently, organic matter return to soil is low, accounting in part for the low carbon and poor P availability of the Ferric Lixisols. The most readily available organic wastes in the communities are kitchen and market waste, sawdust and, to a very small extent, cow dung. Sawdust, being non-agricultural and a waste from tree species, has a high C:N ratio and provides a more recalcitrant product when charred. It was therefore hypothesized that when sawdust biochar is co-composted with kitchen waste and cow dung, the resultant product will be a soil amendment with a high recalcitrant C pool that will make P more available in the Ferric Lixisols of Bawku. It is in this regard that biochar-compost composed of sawdust biochar, kitchen waste, and cow dung mixed at different ratios and co-composted, was used as a P source for maize growth on this concretionary Ferric Lixisol from Bawku, Ghana. The objectives of the study were, therefore, to (i) investigate the effect of biochar-compost amendments on the availability of P to maize; (ii) determine which ratio of sawdust biochar: kitchen waste: cow dung for composting would provide optimum P availability for maize growth in the Ferric Lixisol of Bawku; and (iii) ascertain the influence of the amendments on residual soil characteristics.

2. Materials and Methods

2.1. Soil Sampling and Sample Preparation

The soil for the study, Varempere Series, classified as a Ferric Lixisol according to the FAO-UNESCO classification [23], was sampled from Bawku, located in the Sudan Savannah Agro-Ecological Zone in the Upper East Region of Ghana. The zone, which is the driest part of Ghana, is characterized by well-defined wet and dry seasons of about the same duration, with an average yearly rainfall of 900–1100 mm [24]. Mean monthly temperatures also range from 25 °C to more than 33 °C, with relative humidity recordings ranging from 35% in the dry seasons to 75% in the rainy season. The sampling site has a predominant vegetation of tall grasses such as *Pennisetum* sp., *Panicum maximum* and *Sporobolus pyramidalis* dotted with neem trees and shrubs.

The soil was randomly sampled at a depth of 0–20 cm, bulked and homogenized. A sub-sample for routine analysis was air-dried, gently ground using a mortar and pestle and passed through a 2 mm sieve to obtain the fine earth fraction for the determination of some physical and chemical properties. The unprocessed fraction was weighed into pots for a screen house experiment. Undisturbed samples were also taken for bulk density determination.

The biochar used was produced from sawdust at a pyrolysis temperature of between 450 and 480 °C using a retort stove. After pyrolysis, the biochar was mixed with kitchen waste (KW), a mixture of cabbage, lettuce, carrots, yam peels, oranges and watermelon and cow dung (CD) and co-composted. The KW and CD were mixed in a ratio of (1 KW: 1 CD) and (1 KW: 2 CD) on a volume to volume basis, and the biochar added to each KW: CD mixture to form ten compost mixtures of composition: (10 (1 KW: 1 CD): 0 Biochar), (9 (1 KW: 1 CD): 1 Biochar), (8 (1 KW: 1 CD): 2 Biochar), (7 (1 KW: 1 CD): 3 Biochar), (6 (1 KW: 1 CD): 4 Biochar), (10 (1 KW: 2 CD): 0 Biochar), (9 (1 KW: 2 CD): 1 Biochar), (8 (1 KW: 2 CD): 2 Biochar), (7 (1 KW: 2 CD): 3 Biochar) and (6 (1 KW: 2 CD): 4 Biochar) (v/v). Samples from the biochar-composts on maturing after three months of composting, were air dried, ground and passed through a 2 mm sieve for analysis. Four of the biochar-composts were selected for efficacy trial on maize. The four biochar-composts were selected based on their superior contents of available P, lower pH and EC (electrical conductivity), and higher carbon contents (Table 1). The compost types were applied to meet the SPR (standard P requirements) and half the SPR of the Lixisol soil at rates indicated in Table 2. Amounts equivalent to half the SPR of the soils for each of the four aforementioned biochar-compost amendments were also applied (Table 2) to test whether there would be any significant difference between the two rates. Should the efficacy of the two rates be statistically similar, then the half-SPR could be recommended as that would imply cost savings of the organic material. These four organic amendments at half the SPR were designated as 1/2 (T1), 1/2 (T2), 1/2 (T3), and 1/2 (T4). The inorganic fertilizer used in the study was a combination of triple superphosphate (TSP) and ammonium sulphate $(NH_4)_2SO_4$.

Table 1. Selected characteristics of the biochar-compost mixtures (dry weight).

Scheme 1.	pH (1:10)$_{water}$	EC (dS/m)	Total P (mg/kg)	Available P (mg/kg)	Total C (g/kg)	Total N (g/kg)
10 (1KW: 1CD): 0 Biochar	9.0 ± 0.0	6.2 ± 0.1	6776 ± 669 f	295.9 ± 14.9 a	136.9 ± 0.90 a	15.7 ± 0.11 c
9 (1KW: 1CD): 1 Biochar	8.9 ± 0.0	6.1 ± 0.1	6211 ± 668 e	410.3 ± 50.9 b	191.6 ± 0.27 c	15.2 ± 0.02 c
8 (1KW: 1CD): 2 Biochar	8.9 ± 0.0	5.9 ± 0.1	5130 ± 460 b	658.0 ± 43.7 c	193.9 ± 0.57 c	13.1 ± 0.04 ab
7 (1KW: 1CD): 3 Biochar	8.8 ± 0.0	5.4 ± 0.0	6028 ± 648 d	809.7 ± 57.3 e	228.3 ± 1.47 d	13.9 ± 0.07 b
6 (1KW: 1CD): 4 Biochar	8.7 ± 0.0	5.1 ± 0.0	4582 ± 410 a	938.8 ± 48.9 g	251.1 ± 0.49 e	13.8 ± 0.01 b
10 (1KW: 2CD): 0 Biochar	9.0 ± 0.0	5.7 ± 0.1	6338 ± 317 e	663.8 ± 39.5 c	132.5 ± 0.16 a	13.2 ± 0.02 ab
9 (1KW: 2CD): 1 Biochar	9.0 ± 0.0	5.6 ± 0.1	5801 ± 437 c	777.4 ± 40.6 d	157.0 ± 0.53 b	12.8 ± 0.04 a
8 (1KW: 2CD): 2 Biochar	8.9 ± 0.0	5.8 ± 0.1	5733 ± 383 c	877.5 ± 5.3 f	229.0 ± 0.64 d	15.8 ± 0.04 c
7 (1KW: 2CD): 3 Biochar	8.6 ± 0.0	4.9 ± 0.1	6346 ± 452 e	901.0 ± 10.2 f	230.4 ± 0.94 d	13.3 ± 0.06 ab
6 (1KW: 2CD): 4 Biochar	8.3 ± 0.0	4.6 ± 0.0	5125 ± 261 a	1016.9 ± 45.2 h	247.5 ± 1.41 e	13.2 ± 0.04 ab

Means with the same alphabet are not significantly ($p < 0.05$) different.

Table 2. Rates of amendments to meet the standard phosphorus requirement (SPR) and half SPR of the soil.

Treatment	* ID	Full SPR Amendment Application Rate (g/kg Soil)	Half SPR Amendment Application Rate (g/kg Soil)
Control (No amendment)	T0	0	0
[7 (1KW:1CD):3 Biochar]	T1	45.7	22.9
[6 (1KW:1CD):4 Biochar]	T2	39.4	19.7
[7 (1KW:2CD):3 Biochar]	T3	41.1	20.5
[6 (1KW:2CD):4 Biochar]	T4	36.4	18.2
Inorganic amendment (Triple superphosphate)	T5	0.18	** na

* ID = Treatment number; ** na = not applied.

2.2. Analytical Methods

The pH of the soil was measured in both water and KCl at 1:1 solution:soil ratio and for biochar-compost, at biochar-compost:water (1:10) suspensions. Total C and N contents of the soil and biochar-compost samples were determined by dry combustion using a LECO Trumac CNS analyzer (LECO Corporation, Michigan, US). Particle size distribution of the soil was determined by the Bouyoucos hydrometer method [25]. Total P of the samples was analyzed by wet digestion using HNO_3 and 60% $HClO_4$ in the ratio of 1:1.5 of the two reagents. Available P for the soil was extracted using the method of Bray and Kurtz [26], while that of the biochar-compost was extracted by the method of Watanabe and Olsen [27]. The extracted P from all the methods was determined using the molybdate-ascorbic acid colour development method of Murphy and Riley [28]. The standard P requirement of the soil was determined using the method of sorption study described by Fox and Kamprath [29]. Selected properties of the biochar-composts are shown in Table 1, while that of the soil are shown in Table 3.

Table 3. Some characteristics of the soil.

Parameters	Results
Moisture content at field capacity (%)	15.02 ± 0.75
Sand (%)	77.8
Silt (%)	10.5
Clay (%)	11.7
Textural class	Sandy loam
Bulk density (Mg/m^3)	1.59 ± 0.5
Concretions (%); > 2 mm	9.3 ± 0.6
pH $(1:1)_{water}$	5.8 ± 0.0
pH $(1:1)_{KCl}$	4.8 ± 0.0
Electrical conductivity (dS/m)	0.23 ± 0.02
Total carbon (g/kg)	2.2 ± 0.3
Total P (mg/kg)	100 ± 4.4
Available P (mg/kg)	13.16 ± 0.33
Ca ($cmol_c/kg$)	2.42
Mg ($cmol_c/kg$)	0.66
K ($cmol_c/kg$)	0.13
Na ($cmol_c/kg$)	0.07
* PBS (%)	33.13
CEC *** ($cmol_c/kg$)	9.9 ± 1.0
** SPR (mg P/kg)	37 ± 0.8

* PBS = Percent base saturation, ** SPR = Standard P requirement, *** CEC = Cation exchange capacity.

2.3. Experimental Design and Screen House Experiment

The experimental design used for the study was a completely randomized design (CRD). The experiment was established using two P application rates for the biochar-composts, i.e., application to meet the standard P requirement (SPR) of the soil and half the SPR. The inorganic amendment was, on the other hand, applied at only one rate. The nitrogen in the $(NH_4)_2SO_4$ was applied based on the average total N (13.6 g/kg) in the four selected biochar-composts, while the TSP (0.18 g) was added to meet the SPR of the soil. Therefore, with no amendment (control), four organic amendments at 2 rates, one inorganic amendment at one rate, all with three replicates, there were $\{(4 \times 2) + 1 + 1\} \times 3 = 30$ experimental units.

Fifteen kilograms of the unprocessed (bulk) soil was packed into pots to attain the field bulk density of the soil. The organic amendments were thoroughly mixed with the soil and watered to 60% field capacity. These were allowed to equilibrate for about one week, after which three seeds of maize (Obatanpa) of 90% germination were sown per pot and later thinned to two per pot after one week of germination. The daily decrease in weight of the pots watered to 60% field capacity was noted, and the equivalent amount of water lost was applied daily to the treatments with the maize plants. Thus, water in the seeded pots was maintained at 60% field capacity throughout the experimental period. At tasseling, the shoot was cut at the soil level, dried at 65 °C, and the dry matter taken. The roots were carefully removed, and extraneous soil washed off. The root volume was determined by the water displacement method and root dry matter taken after oven drying at 65 °C.

2.4. Statistical Analysis

The results obtained were subjected to analysis of variance (ANOVA) using Genstat 12th edition to establish if there were any significant treatment effects at $p < 0.05$. Mean separations were done using Tukey's Lsd (0.05).

3. Results

3.1. Characterization of Soil

Some physical and chemical properties of the soil used for the study are shown (Table 3). The sand fraction (77.8%) was about 6.65 times more than the clay fraction (11.7%). The soil had a silt fraction of 10.5%, giving it a sandy loam texture. The soil, with a 9.3% concretion content, had a high bulk density of 1.59 Mg/m^3. Moisture content at field capacity was 15%. The pH in water was slightly acidic, decreasing by one unit in KCl. The electrical conductivity of 0.23 dS/m was low. The total carbon content, typical of soils in northern Ghana, was also very low (2.2 g/kg). Consequently, total nitrogen was undetectable by the Trumac CNS analyzer. The soil had a low total P concentration, of which only about 13.16% was available. This level of available P, approximately equivalent to 41.8 kg P/ha, is considered to be of medium availability [30] and, on average, higher than values reported for most soils of northern Ghana. The levels of the exchangeable cations, typical of soils in northern Ghana, were generally low and in the order Na < K < Mg < Ca.

3.2. Effect of the Amendments on Shoot Dry Matter Yield of Maize

Table 4 presents results of the effects of the ten treatments on shoot and root dry matter and root volume of the maize at tasseling. The biochar-compost amendments produced plants with significantly higher shoot dry matter yield ($p < 0.05$) than plants from both the un-amended (control) and T5 (the inorganically amended soil). Apart from 1/2 (T3) where maize plants had statistically similar shoot dry matter as T5, all the biochar-compost-amended soils had significantly higher shoot dry matter yield than T5. Shoot dry matter from the T4-amended soil was 2.33 and 1.65 times higher than its counterparts grown in the un-amended and inorganic amended soils, respectively. The T3-amended soil also had shoot dry matter that was approximately 2.1 and 1.5 times heavier than its counterparts from the un-amended and inorganic amended soils, respectively. It is worth noting that when T1 was applied at half the SPR, shoot dry matter yield at tasseling was superior to its counterparts amended to the soil at full SPR. Shoot dry matter from the T4, T2 and T1 organic compost types applied at half the SPR were 1.29, 1.24 and 1.24 times, respectively, heavier than their counterparts from the TSP-amended soil at full SPR.

Table 4. Effects of amendments on agronomic parameters.

Treatment	Shoot Dry Matter (g)	Root Dry Matter (g)	Root Volume (cm^3)	P Uptake (g/pot)
T1	70.91 ± 1.28 cd	11.06 ± 0.25 b	96.7 ± 20.8 b	0.303 ± 0.010 de
1/2 (T1)	75.15 ± 4.22 ef	13.13 ± 0.68 c	120.0 ± 10.0 bc	0.287 ± 0.020 cd
T2	72.28 ± 5.21 de	12.89 ± 0.28 c	105.0 ± 17.3 b	0.300 ± 0.010 de
1/2 (T2)	75.13 ± 3.88 de	15.44 ± 0.96 d	120.0 ± 30.0 bc	0.280 ± 0.020 cd
T3	89.83 ± 2.56 f	16.90 ± 0.35 d	146.7 ± 20.8 c	0.360 ± 0.020 f
1/2 (T3)	65.46 ± 3.72 bc	12.46 ± 0.71 bc	113.3 ± 15.3 bc	0.263 ± 0.020 c
T4	100.44 ± 1.58 g	23.98 ± 1.00 e	223.3 ± 25.2 d	0.320 ± 0.010 e
1/2 (T4)	78.29 ± 7.04 e	16.77 ± 0.44 d	130.0 ± 10.0 bc	0.290 ± 0.010 de
T5	60.82 ± 1.07 b	16.28 ± 0.94 d	123.3 ± 11.5 bc	0.200 ± 0.010 b
T0	43.13 ± 2.43 a	7.50 ± 0.69 a	43.3 ± 5.8 a	0.097 ± 0.010 a
* CV (%)	4.7	5.7	14.4	5.3

Means with the same alphabet are not significantly ($p < 0.05$) different. * CV = coefficient of variation.

3.3. Effects of the Amendments on Root Dry Matter and Root Volume of Maize

All the amendments recorded significantly higher maize root dry matter yields at tasseling ($p < 0.05$) than from the un-amended soil (Table 4). Just as was observed for shoot dry matter, the highest root dry matter was recorded in T4, followed by T3, T2, and T1. The root dry matter of maize at tasseling from the 1/2 (T4) was also statistically similar to that of T3. Generally, the root dry matter yield at the full SPR was statistically higher than those at half the SPR in T3 and T4, whereas the opposite was observed in T1 and T2 ($p < 0.05$). Root dry matter at tasseling from T4 was about 1.5 and 3.2 times heavier than counterparts from the TSP-amended and un-amended pots, respectively. The smallest root volume was observed in plants from the un-amended soil (T0). Root volume increased 2.85-fold upon amendment with TSP at full SPR. Root volumes from the TSP-amended pot did not vary significantly from those of the organically amended pots, except for the T4 treatment where there was a further 1.81-fold increase beyond that of the TSP-amended pot.

3.4. Effects of the Amendments on P Uptake

Phosphorus uptake by maize shoot when fertilized with TSP at full SPR was about 2.06 times higher than when the soil was not amended (Table 4). All the biochar-compost amended soils recorded significantly higher P uptake by the maize ($p < 0.05$) than the TSP-amended soil (T5) at full SPR. Treatment T3 recorded the highest P uptake, followed by T4, T1 and then T2. The least P uptake by the maize among the biochar-compost-amended soils was recorded in 1/2(T3), 1/2(T2), and 1/2(T1). Apart from T3 which yielded maize plants with higher P uptake than its half SPR counterpart, the other composts treatments had statistically similar maize shoot P uptake as their half SPR counterparts.

3.5. Effects of the Amendments on Residual Soil pH, Total C, Total P, and Available P

The effect of the amendments on the residual pH, total C, total P and available P after harvesting maize at tasseling (eight weeks) are presented in Table 5. The pH of the un-amended soil remained slightly acidic as was the soil pH at the onset of the experiment (Table 3). However, the residual pH of the soil after amendment with inorganic fertilizer (T5) reduced significantly by 0.7 pH units into the acidic range to 5.1. All the biochar-compost amendments raised the residual pH of the soil to the neutral range. In fact, the increase in pH was between 1.0 and 1.7 pH units. The amendments at full SPR, i.e., T1, T2, T3, and T4 showed the highest increase in pH. The least residual pH of 6.8 was recorded in the (1/2) T4 treatment.

Table 5. Effects of amendments on residual soil characteristics.

Treatment	pH (1:1 H_2O)	Total P (mg/kg)	Available P (mg/kg)	Total C (g/kg)
T1	7.5 ± 0.1	253 ± 27.7ef	94.77 ± 2.95 ef	11.97 ± 1.00 c
1/2(T1)	7.3 ± 0.1	220 ± 30.7 cde	68.12 ± 2.91 cd	9.21 ± 1.24 b
T2	7.5 ± 0.2	269 ± 1.5 f	115.12 ± 8.24 g	14.21 ± 1.85 d
1/2(T2)	7.3 ± 0.2	189 ± 13.1 bc	73.27 ± 8.16 d	11.04 ± 0.55 c
T3	7.5 ± 0.1	223 ± 27.2 de	100.15 ± 11.58 f	12.39 ± 1.44 c
1/2(T3)	7.2 ±0.2	208 ± 13.3 bcd	61.93 ± 4.58 c	7.97 ± 0.75 b
T4	7.4 ± 0.2	245 ± 42.3 ef	89.90 ± 6.79 e	12.52 ± 1.70 c
1/2(T4)	6.8 ± 0.2	187 ± 14.2 bc	47.11 ± 1.90 b	8.21 ± 2.14 b
T5	5.1 ± 0.2	117 ± 24.4 a	14.83 ± 0.93 a	3.65 ± 0.49 a
T0	5.9 ± 0.1	99 ± 17.8 a	8.65 ± 0.27 a	3.47 ± 0.26 a
CV (%)		9	7.1	9.9

Means with the same alphabet are not significantly ($p < 0.05$) different.

The un-amended residual soil had similar total P concentration as at the onset of the screen house experiment (Tables 3 and 5). The residual P from the TSP-amended soil at full SPR (T5) also did not differ significantly ($p < 0.05$) from the un-amended soil. All the biochar-compost-amended soils had significantly higher total P than the inorganic and un-amended soils (Table 5). The T1, T2, and T4 biochar-compost types that were applied at full SPR had the highest significant residual total P content ($p < 0.05$). These residual P levels had increased 2.23 to 2.69-fold over the level at the onset of the screen house experiment. Residual total P in the soils amended at half SPR was 1.87 to 2.20 times higher than the total P in the soil at the onset of the experiment.

4. Discussion

4.1. Soil Characteristics

The sandy loam texture of the soil, its >9% concretions and low organic carbon content suggest that the plough layer of the soil would have poor water retention as evidenced in the low moisture content at field capacity. The high bulk density could limit root penetration, impede root development, and culminate in smaller root volume of maize.

The slightly acidic pH of the soil in water is an indication of leaching of basic cations due to the sandy texture and high gravel content of the soil. The low levels of exchangeable cations in the soil are reflected in the low base saturation of the soil. The slightly acid pH of the soil, which dropped by one pH unit in KCl, implies that the soil had a net negative charge [2]. The low organic carbon content of the soil, even though farmers in the area apply cow dung to their soil yearly, lends credence to the assertion that there is fast decomposition of organic matter in the region. The soil was sampled from the Sudan Savanna, the hottest part of Ghana where average temperatures are between 25 °C and 33 °C. These high temperatures would promote fast organic matter decomposition as depicted by the very low organic carbon content of 2.2 g/kg. The kaolinitic nature of the soil [2] coupled with low organic carbon content, in part, account for the low CEC. Storage of cationic nutrients would be low as revealed by the low levels of exchangeable bases. The aforementioned characteristics are indicators of a soil which is poor in fertility. They also suggest a soil with a poor fertilizer use efficiency which would give good response to P fertilization. These, therefore, prompted the choice of this soil for the efficacy trials with biochar-compost.

The medium concentration of available P, despite the low concentration of total P was a result of the yearly application of organic matter to the soils by farmers in the area. Organic matter is dominated by carboxylic, citric, oxalic, and acetic acid functional groups. At the pH of the soil, 1.1 pH units above the pKa (4.7) of the carboxylic groups [31], it is expected that these acids will deprotonate, leaving a high concentration of carboxylate functional groups in the soil solution. The soil used for the study, being a Ferric Lixisol, is expected to be high in Fe and kaolinite. The carboxylate anions will compete with the phosphate ions in solution for the kaolinitic surfaces, and hence, reduce adsorption of P. The carboxylate functional groups could also chelate species of Al and Fe that may be in solution, minimizing P precipitation [17]. Biochar-compost amendment to the soil should, therefore, increased P availability.

4.2. Effects of Amendments on Growth Parameters

Phosphorus is very important for the formation and development of plant roots [32]. Factors such as optimum pH (near neutral to neutral), availability of organic acids from organic matter and addition of P should enhance P availability in the Ferric Lixisol used. Fageria and Filho [33] observed a significant increase in the shoot dry weight of rice grown on P-deficient soils upon fertilization with P. The supply of P at the SPR of the soil with the amendments meant a concentration of at least 0.2 mg P/L in soil solution was maintained for plant growth. This would explain the significantly higher root dry matter and volume in all the amended soils compared to their un-amended counterpart (control) (Table 4). Application of TSP in T5 at the SPR of the soil increased P availability. This translated into an almost 2.85-fold increase in root volume with a consequential 2.2 increase in root dry matter. This resulted in the two-fold increase in P uptake in the T5 SPR maize plants over their un-amended counterparts. This higher P uptake resulted in heavier shoot dry matter, which was 17.69 g greater than its counterparts from the un-amended soil.

Compost has been proven to increase biological activity and nutrient supply to plants [22] and hence improve crop productivity. The compost types had other nutrients such as the secondary macro nutrient Mg and micro nutrients which the $(NH_4)_2SO_4$ and TSP did not provide. The release of organic acids from these organic amendments may have also minimized P sorption onto the kaolinitic surfaces [8–10] and precipitation by free Fe and Al in solution [11,12]. The neutral pH of these organically amended soils, as evident in their residual pH, meant that P was more readily available compared to the TSP amended soil. With a superior P availability as seen in the residual soils after the screen house experiment, it is not surprising that the organically amended soils had higher root dry matter which translated into higher P uptake with a concomitant higher shoot dry matter.

The very high level of available P in the T4 amended soil resulted in the highest maize root volume. This was almost 76.6 cm^3 higher than the second highest root volume grown in T3. The high root volume certainly influenced the root dry matter, making it the highest as well. With such a root volume and dry matter, it was not surprising that the T4 treatment had the second highest shoot P uptake, culminating in the highest shoot dry matter. A higher root volume and dry matter means better exploitation for available P, enhanced P uptake and, hence, higher shoot dry matter. These may, in part, explain the respective 1.65 and 2.33-fold increases in shoot dry matter of plants grown in the T4 amended soils over their TSP-amended and un-amended counterparts.

The fact that soils amended with half the SPR rate of the organic amendments in T3 and T4 produced significantly smaller shoot dry matter yield than those grown in their full SPR counterparts implies that in using these amendments as P sources, the full SPR rate of T3 and T4 should be the preferred choices. On the other hand, the half SPR rate of T1 should be used instead of the full rate, as it produced statistically higher shoot dry matter. The half SPR rate of T2 should be the preferred choice on a Ferric Lixisol as maize dry matter from that treatment was statistically similar to that for the full SPR. This is because it would be economically cheaper to produce T1 and T2 at half the SPR rate.

4.3. Effects of Amendments on Residual Soil pH, Total C, Total P, and Available P

The stability of the pH in the un-amended soil after eight weeks of planting was most likely due to the limited amount of amendment added to the soil. Nutrient uptake by the maize, which was minimal, may not have appreciably affected the release of ions into soil solution, hence maintaining the pH of the growth medium. In the case of the inorganically amended soil (T5), the 0.7 unit drop in pH into the acidic range could likely be attributed to the composition of the amendment. The $(NH_4)_2SO_4$ added to the TSP might have decreased the soil pH significantly due to nitrification of the NH_4^+. The $(NH_4)_2SO_4$ applied dissociated into NH_4^+ and SO_4^{2-}. Subsequently, the NH_4^+ was oxidized to nitrate and in the process, H^+ was produced as depicted in Equations (1) and (2). The H^+ released as in Equation (2) led to a decrease in pH of the soil.

$$(NH_4)_2SO_4 \rightarrow 2NH_4{}^+ + SO_4{}^{2-} \quad (1)$$

$$NH_4{}^+ + 2O_2 \rightarrow NO_3{}^- + 2H^+ + H_2O \quad (2)$$

The neutral pH of the residual soil amended with biochar-composts could most likely be attributed to the alkaline pH of the organic amendments. All the four compost types, T1, T2, T3, and T4, upon addition to the soil may have equilibrated to neutral pH after eight weeks.

Due to P uptake, available P in the un-amended residual soil was reduced by 4.95 mg/kg compared to the initial concentration. The small P uptake in the control soil may have led to the marginal decrease of 1 mg/kg in total P when compared to the original soil.

Total P in the residual soil of the TSP-amended soil did not increase significantly over that of the control and the original soil, probably because most of the added P was channeled into the shoot. Thus, just a paltry 17 mg/kg was added to the total P of the original soil. The over two-fold increase in total P of the residual soils of the biochar-compost-amended treatments compared to their un-amended counterparts was a result of the inherently high total P of the amendments.

Available P in the biochar-compost-amended residual soils was higher than that of the initial soil, T0, and the inorganically-amended T5. This result agrees with the findings of Morales et al. [34], who observed that biochar reduces P-fixing capacities of degraded tropical acidic soils. The coating of the surface of kaolinitic clay minerals, sesquioxides, and concretions by biochar-composts, reducing their P-fixing capacities, is a possibility. This helped to reduce the sorption sites for P, thus enhancing availability. Another reason could be the competition between the decomposition products of the biochar-compost and free phosphate ions for sorption sites, and the release of H^+ and phosphatase enzymes from microorganisms [35]. By amending the soils with biochar-composts, microbial activity [36] and the release of microbial metabolites such as organic acids were enhanced. These allowed more P to be available in the biochar-compost-amended soils than in T0 and T5. In addition, the neutral pH of the biochar-compost-amended soils may have contributed to the increase in the availability of P in the residual soils. The high available P in the biochar-compost-amended residual soils could also be due to the higher P content of the amendments.

The higher residual total carbon in the compost-amended residual soils than in the T0 and T5 residual soils and the original soil, was likely due to the high total carbon content of the amended biochar-composts. Each of the T1, T2, T3, and T4 composts applied at full SPR had higher total C content than their half-SPR counterparts. Consequently, the four compost types applied at half SPR added relatively lower residual carbon.

5. Conclusions

The study was conducted with the objective of using locally available organic wastes in Bawku to produce P-rich organic amendments for high concretionary, low carbon and low P soils of the municipality. This was done with a view to improving P availability and carbon profile of the soil and ultimately to increase maize yield.

The study concludes that amending the Ferric Lixisol from Bawku with T1, T2 and T4 biochar-compost types to half the standard P requirement (SPR) to attain a soil P solution of 0.1 mg P/L (equivalent to 18.5 mg P/kg—see Table 3), produced maize with shoot dry matter significantly higher than when the full SPR equivalent of inorganic P from TSP and N from ammonium sulphate were used to grow the crop.

The biochar-composts, due to their slightly acidic pH ameliorating effect, could also serve as liming materials. The biochar-composts, which are rich sources of P would help to boost the C content of Ferric Lixisol due to their high recalcitrant C content. Biochar-composts applied at rates to meet the SPR of the Ferric Lixisol soil in Bawku (37 mgP/kg) could more than triple the total carbon content in the soil.

The study concludes that with the exception of T3, (7(1KW: 2 CD): 3 Biochar), biochar-composts applied to meet half the SPR (18.5 mg P/kg) will produce maize with shoot dry matter significantly higher than when the inorganic amendment is applied to meet the full SPR.

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Data Availability Statement: Data would be made available upon reasonable request since it is being used to formulate a commercial amendment.

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