Dzomeku et al., Vegetos 2018, 31:2
DOI: 10.4172/2229-4473.1000404

Vegetos- An International Journal of Plant Research

Research Article

A SCITECHNOL JOURNAL

Effects of Integrated Use of Organic and Inorganic Fertilizer on Soil Chemical Properties in the Guinea Savannah Zone of Ghana

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Abstract

A two-year field experiment was conducted at Nyankpala, near Tamale during the 2014 cropping season and continued in 2015, to evaluate the effects of indigenous organic materials on soil chemical properties in the Guinea savannah zone of Ghana. The treatments included 4 organic materials (Biochar, Groundnut shells, Rice husk and Rice straw) applied at 3 rates (*viz.* 2.5, 5.0 and 7.5 t/ha on dry matter basis) and 3 fertilizer N rates using NPK (0,45-30-30, and 90-60-60 kg/ha) in 2014 and sulfan N (0,45 and 90 kg/ha) in 2015. The plots dimensions were 5 m × 5 m with maize planted at 40 cm × 80 cm to maturity stages in both years. The results after the second year revealed that the application rate of 2.5 t/ha groundnut shells without inorganic N supplement was superior in improving soil C, N, P and K but with addition of inorganic fertilizer the same soil nutrients increased most in biochar treated soils. Rice straw without fertilizer N improved the soil pH and Ca levels. The superior effects of groundnut shells and biochar were more pronounced at the application rate of 5 t/ha with or without sulfan N. Similarly, at 7.5 t/ha application of organic materials with or without fertilizer, groundnut shells and biochar enhanced the soil nutrients than the rice materials. The rice materials were found to affect more of soil pH and exchangeable Ca but for soil Mg, biochar appeared the most influential material. We conclude that, application of either groundnut shells or biochar could improve the soil nutrients of the savannah agroecology for crop production whilst with acidic soils and/or Ca deficient soils, rice materials are recommended for use.

Keywords

Biochar; Organic materials; Soil nutrients; Sulfan N

Introduction

Concerns on the potential of agriculture to provide for food needs of a world population projected to exceed 7.5 billion by the year 2020 and its sustainability are alarming. Inappropriate application of fertilizer coupled with the poor management of resources has contributed to environmental degradation. For instance, whereas in developed countries, over-application of inorganic and organic fertilizer has led to contamination of water bodies and soils [1], in most sub-Saharan African countries. However, inorganic fertilizer is not readily available and when obtainable the cost is often limiting to small scale resource poor farmers [2]. This leads to non-use or use of suboptimal quantities of fertilizer to avoid crop failure, thus posing a threat to food security. Henao et al. [3] also noted that harsh climatic conditions, population pressure, land constraints and the decline of traditional soil management practices have often reduced soil fertility.

Among the problems inherent to sub-Saharan African soils, low soil fertility characterized by low pH, low nitrogen, phosphorus, potassium and deficient calcium; low organic matter is the most serious productivity constraint [4]. In Ghana, farmers typically apply insufficient soil inputs, usually below the recommended rate and this along with poor agricultural practices has led to soil nutrient depletion. The soils of the major maize growing areas in Ghana are low in organic carbon (<1.5%), total nitrogen (<0.2%), exchangeable potassium (<100 mg/kg) and available phosphorus (<10 mg/kg) [5,6]. However, fertilizer nutrient application in Ghana is still approximately 8 kg/ha with depletion rates range from about 40 to 60 kg of nitrogen, phosphorus, and potassium (NPK)/ha annually and among the highest in Africa [7].

Many long-term studies have shown that combinations of both organic and inorganic nutrient sources often lead to enhanced nutrient availability and synchronization of nutrient release and better uptake by crops [8,9] and positive effects on soil properties [10]. Beltran et al. [11] also reported that green manures and composted organic material increase soil organic matter, provides nutrients for plant growth, alleviate aluminum toxicity and render phosphorus more available to crops. However, the effects of applied organic materials vary with cropping systems, soil types, organic material management and environmental factors [12,13]. The effect of organic matter on soil is dependent on other factors such as soil type, management and climate and the quality of the material. Organic nutrient management based on biodegradable material is one such alternative. Prescott et al. [14] and Berg et al. [15] noted that there would only be net mineralization during decomposition of litter species that are richer in nutrients. Among the most promising organically based soil nutrient management practices include use of animal manure, incorporation of crop residues and improved legume fallows [16]. It is therefore imperative that other sustainable alternatives of soil fertility management are sought to improve soil fertility, enhance crop production and consequently improved food security. The objective of this study was therefore to determine the effects of indigenous organic materials in combination with or without inorganic fertilizer on the chemical properties of soils in the Guinea savannah zone of Ghana.

Materials and Methods

Experimental site

The field experiments were carried out in 2014 and continued to the 2015 cropping season at the University for Development Studies, Nyankpala near Tamale. Nyankpala is located on latitude 9°25'14'N, and longitude 0°58'42'W at an altitude of 183 m above sea level [17]. The area experiences unimodal rainfall with an annual mean rainfall of 1000 to 1022 mm. The temperature distribution is fairly uniform

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Received: March 26, 2018 **Accepted:** April 05, 2018 **Published:** April 12, 2018 *doi:10.4172/2229-4473.1000404*

with mean monthly minimum of 21.9 ^{0}C and a maximum of 34.1 ^{0}C. It has a minimum relative humidity of 46% and a maximum of 76.8%. The soil of the study site is of typical upland soil, developed from iron stone gravel and ferruginized iron stone brash [18]. The soil is classified as a *Haplic lixisol* [19] and locally referred to as the Tingoli series [20].

Experimental design, treatments and management

This experiment was established in June, 2014 and continued to November, 2015 (2 years). It was laid out as a 4×3×3 factorial treatment in a randomized complete block design with four replications. The factors comprised 4 organic materials (Biochar, Groundnut shells, Rice husk and Rice straw) applied at 3 rates of 2.5, 5.0 and 7.5 t/ha on dry matter basis; and 3 fertilizer N rates with first application of NPK rate at 0 kg/ha, 45-30-30 kg/ha and 90-60-60 kg/ha in 2014 and in second of sulfan N at 0, 45 and 90 kg/ha in 2015. The plots dimensions were 5m × 5m with maize planted at 40cm × 80cm to maturity stages on all the treated plots in both years.

The biochar was obtained by burning rice husk at high carbon dioxide and low oxygen concentration using a local improvised furnace called '*kuntan*'. All the organic materials were well-dried and chopped to smaller particles (< 5 mm) before manually incorporating into the soil to a depth of about 15 cm during land preparation in the first year. Prior to planting of the maize, the organically amended-plots were left undisturbed for two weeks to enhance decomposition and mineralization of the organic materials. The organic materials were applied only at the start of the first year and their residual effects were determined in the second year.

Soil sampling and analyses

Initial soil samples were collected from 0 to 15 cm depth at the beginning of the experiment in June, 2014 and final soil samples taken after harvesting in November, 2014 and 2015. All collected soil samples were air dried, sieved (2 mm mesh) and analyzed for pH, organic C, total N, available P, K, and exchangeable Ca and Mg.

The sieved (<2 mm mesh) air-dried samples were analyzed for pH in water using soil to water ratio of 1:2.5 [21]. Total N was determined from Kjeldahl distillation and titration method [22]. Available P was measured through the Bray 1 extraction solution procedure [23]. Exchangeable K values in the soil were determined in 1.0M ammonium acetate extract [24]. Exchangeable bases (Ca and Mg) were extracted in 1M KCl followed by colorimetric and titrimetric determination, whilst the organic carbon was determined by the modified Walkley and Black procedure as described by Nelson et al. [25].

The initial soil analysis in 2014 before planting is shown in the table below;

Statistical analysis

Soil parameter data were subjected to descriptive statistics using GENSTAT Statistical Package 9th Edition and the mean values plotted with the help of Sigma Plot 10.0 to show the trend effects of the treatments on soil properties.

Results and Discussions

Initial soil chemical and physical properties

The mean physical and chemical properties of the surface soil taken at a depth of 0–15 cm before the start of the experiment (initial soils) are presented in Table 1. The soils of the experimental site were mainly acidic, with low pH of 5.2. The organic carbon content was 0.18% which is low. The corresponding total nitrogen content was characteristically low (0.01%). The available phosphorus (Bray-1) of 3.6 mg/kg is deemed low for crop growth in these soils. Exchangeable K is medium whilst Ca and Mg are low for crop production in the soils (Table 1).

Changes in soil pH and organic C concentrations

Soil pH: Relative to the initial soil pH of 5.2, the soil pH (5.2–5.8) of all plots varied considerable when treated with organic material with or without sulfan N (Figure 1a-c). The soil pH levels increased in all the treated plots with regards to the type of organic material, quantities of organic and sulfan N applied. At the organic application rate of 2.5 t/ha without sulfan N, the plots treated with rice straw increased the soil pH (pH = 5.7) higher than the rest, with the least (pH = 5.2) increment found in rice husk treated plots (Figure 1a). With the addition of Sulfan at 45 kg N/ha, the soilpH ranged between 5.5 and 5.8. The rice straw treated plots dropped slightly in soil pH (5.5) whilst the rest increased relative to plots without fertilizer N. When 90 kg N/ha from sulfan was applied to the organic amended plots, the soil pH varied between 5.2 and 5.7. The rice husk and groundnut shell treated plots dropped drastically relative to their pH values at 45 kg N/ha. The results revealed that at applying the organic material at 2.5 t/ha without fertilizer N, rice straw is improving soil pH better than the rest. When sulfan is added at 45 kg N/ha, groundnut shells does better but at when at 90 kg N/ha is added, biochar is more superior (Figure 1a).

With organic material application rate of 5 t/ha, the soil pH ranges were 5.2–5.7; 5.4–5.7; and 5.5–5.7 at 0,45 and 90 kg N/ha, respectively (Figure 1b). At the application rate of 5 tons organic materials per ha, the rice straw treated plots without N and also with 45 kg N/ha additions produced consistently higher soil pH than the corresponding treatments with the rest of the materials. However, at a rate of 90 kg N/ha, the plots with biochar dominates with respect to soil pH enhancement (Figure 1b).

Figure 1c presents the changes in soil pH when the organic materials were applied at 7.5 t/ha. The soil pH had narrow variations as (5.5-5.7 and 5.4-5.6 among the organic materials at 0 and 45 kg N/ha, respectively. The variation in plots with addition of 90 kg N/ha was 5.3–5.8 (Figure 1c). The rice straw has shown to be an effective enhancer of soil pH when no fertilizer N added. Similarly, biochar indicated in all cases but Figure 1c, to be effective in improving soil pH at higher N levels. The findings illustrated in Figures 1a-c, are useful to the extent that most of the soils in the Guinea savannah zone of Ghana have low pH values (<5.4) and are therefore, acidic with deleterious effects on crop nutrient uptake. The soil pH increasing potential of the observed treatments above suggests the importance of using the organic materials to ameliorate the acidic soils of study area for crop growth [26].

Table 1: Initial Soil Analysis in 2014.

Initial soil analysis	pH	OC (%)	N (%)	P (mg/kg)	K (mg/kg)	Ca (cmol+/kg)	Mg (cmol+/kg)
	5.2	0.18	0.01	3.6	51.8	0.32	0.23

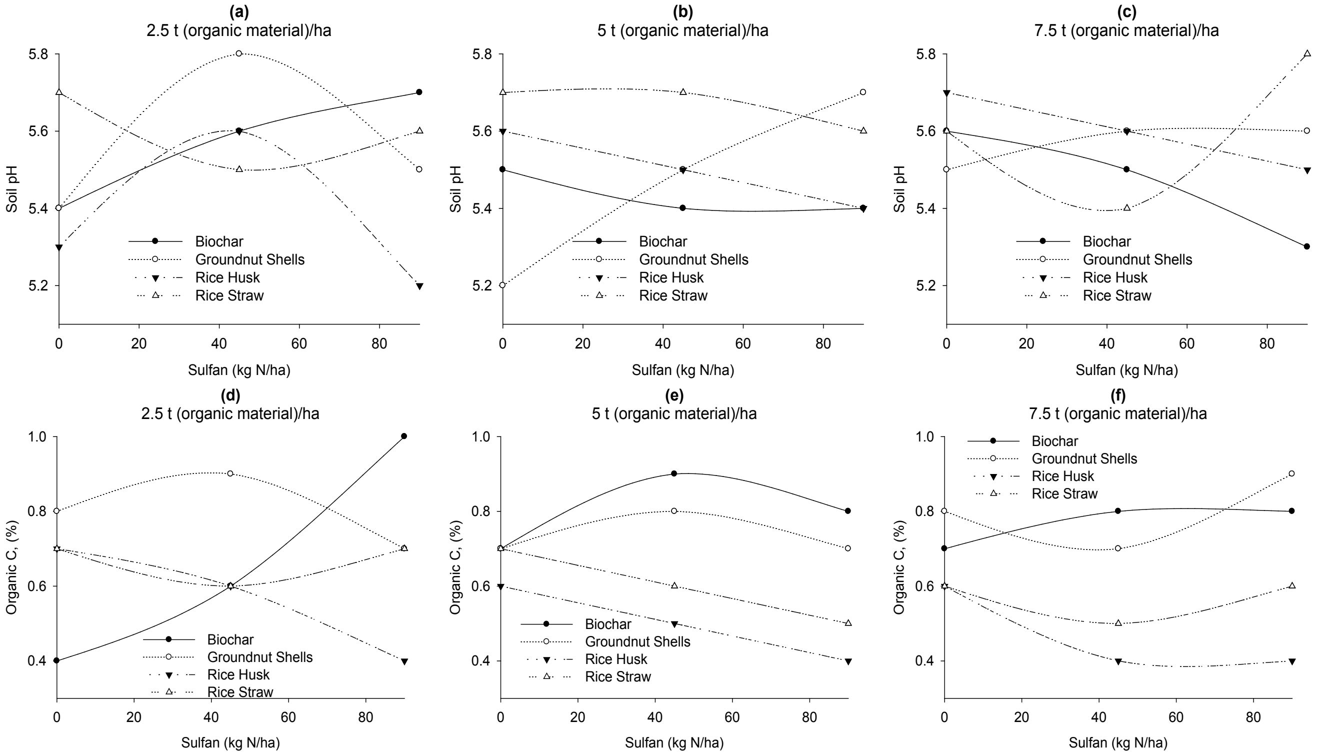

Figure 1: Interaction effects of organic materials types and quantities with or without different rates of NPK on soil pH and organic C concentrations after cropping for 2 years in the Guinea savannah zone of Ghana.

Organic C: Organic materials and their interactions with N fertilizer affected the soil organic C concentrations after two years of cropping (Figure 1d-f). Relative to the initial %C of 0.18%, all plots treated with 2.5 t/ha organic material with or without N fertilizer increased the soil C concentrations. At the application rates of 2.5 t/ha, the soil C ranged as 0.4 0.8% from plots without added fertilizer N; 0.6–0.9 % from plots with 45 kg N/ha addition and 0.4–1.0 % from plots with 90 kg N/ha (Figure 1d). With the addition of 2.5 t/ha organic materials, groundnut shells appeared superior to increasing soil C at both zero and 45 kg N/ha fertilizer additions. Biochar however, tended to improve the soil C than the rest of the materials when 90 kg N was added. On applying the organic materials at 5 t/ha, the changes in soil C after two years of cropping ranged as, 0.6–0.7; 0.5–0.9; and 0.4–0.8% at 0,45, and 90 kg N/ha, respectively (Figure 1e). The biochar consistently enhanced the soil C levels with or without the addition of N fertilizer when compared with the other materials. Similarly, when the amounts of organic materials added were 7.5 t/ha, biochar and groundnut shells performed better in terms of increasing the soil C concentrations (Figure 1f). The contribution of organic materials to soil organic C reflects the balance between losses by decomposition and gains from addition of organic materials [27].

Changes in soil N and P concentrations

Soil Nitrogen: Figures 2a-c present the soil N changes as affected by integrated use of organic materials and fertilizer N. Considerable improvements in the soil N levels relative to the initial N concentration were observed in all the treated plots after the two years of cropping. The soil N ranged 0.04 – 0.08 %; 0.06 – 0.08 % and 0.04 – 0.09 %, when the organic materials were applied at 2.5 t/ha and followed respectively without N; with 45 kg N/ha and with 90 kg N/ha additions from sulfan fertilizer (Figure 2a). Among the organic materials applied, groundnut shells had higher soil N improvement potential when low (45 kg N/ha) to no fertilizer N is added. However, at higher N additions from inorganic fertilizer, biochar became the most effective material for soil N improvements (Figure 2a).

At the organic residue application rate of 5 t/ha, the changes soil N ranged as 0.06–0.07%, 0.05–0.08% and 0.04–0.077% after the additions of 0,45 and 90 kg N/ha of inorganic fertilizer, respectively (Figure 2b). At this (5 t/ha) rate of application of organic materials, groundnut shells and biochar were the most effective treatments as far as soil N improvement was concern. Similar consistency of soil N improvement was observed for groundnut shells and biochar with or without inorganic fertilizer when the application rates of organic materials were increased to 7.5 t/ha (Figure 2c). Murwira et al. [28] studying mineralization from organic fertilizers found that mineralization of manure N increased to a maximum of 46% in the third season of application.

Soil phosphorus: The initial soil P of 3.6 mg/kg indicated the soils were very deficient in available P. Amending the soils with 2.5 t/ha organic materials without fertilizer N addition, raised the P levels of the soils to a range of 3.9–5.7 mg/kg (Figure 2d). The groundnut shells appeared superior to the other organic materials in the absence of inorganic fertilizer N. This observation appeared consistent with increasing application rates (5 and 7.5 t/ha) of the organic materials (Figure 2e,f). Upon addition of 45 kg N/ha of sulfan to the 2.5 t/ha organic treated soils, the P levels of the plots with groundnut shells did not differ from the corresponding treated soil without fertilizer N addition. However, with regards to rice straw and biochar, the P levels increased but decreased in the case of rice husk-treated soils (Figure

2d). Addition of 90 kg N/ha of sulfan fertilizer to 2.5 t/ha organic treated-soils enhanced the soil P levels. The biochar became more favourable to soil P improvement at the higher application of rate of inorganic fertilizer (Figure 2d).

Although the P levels of the soils increased at the organic application rate of 5 t/ha with or without sulfan N application, the variations due to organic material types and/or rate of added inorganic fertilizer N were not conspicuous (Figure 2e). Considerably variations were however, observed to be attributable to the organic material type when they were applied at a rate of 7.5 t/ha (Figure 2f). With respect to fertilizer N addition, less changes could be attributed to sulfan effects except in rice straw treated-soils where an unexpected dramatic decline in soil P was measured at 90 kg (Figure 2f).

Changes in soil exchangeable K, Ca and Mg concentrations

Soil K changes: There was moderate amount (51 mg/kg) of soil exchangeable K before the start of the study. However, after 2 years of cropping, the exchangeable K moved from medium to high as the ranges measured were 54–100 mg/kg, 53–87 mg/kg, and 52–96 mg/kg under the organic materials applied respectively at 2.5, 5 and 7.5 t/ha with or without sulfan N (Figure 3a-c). At the application rate of 2.5 t/ha of organic material, there was a general decline of the K levels when 45 kg N/ha of sulfan fertilizer was added relative to the corresponding soil K levels without inorganic fertilizer (Figure 3a). Groundnut shell consistently out-performed the other materials with respect the increasing the soil K levels (Figure 3a). Considerable variations attributable to the organic material type or quality were pronounced when 90 kg N/ha of inorganic fertilizer were supplemented. Although biochar was the least of the materials when 0 and 45 kg N/ha were added, it became superior next to groundnut shell upon addition of 90 kg N/ha (Figure 3a). The trends indicated there were no soil K benefits when 45 kg N/ha of inorganic fertilizer was added to the 2.5 t/ha organic material treated soils.

Figure 3b showed a marked departure of the K trends from Figure 3a exhibited by the organic materials. With the exception of the rice husk, the soil K of soils treated with 5t/ha organic material plus were higher at 45 kg N/ha than at 0 and 90 kg N/ha. The rice straw gave high K values when inorganic fertilizer was added at 90 kg N/ha. The soil K improvement trends changed when treated with organic materials at 7.5 t/ha rate of application (Figure 3c). Rice husk produced its maximum k improvement when 45 kg N/ha of fertilizer was added but the rest were higher in the presence of 90 kg N/ha sulfan. Comparatively, soils treated with groundnut shells consistently yielded higher soil K values (Figure 3c).

Soil exchangeable Ca: The soil exchangeable Ca values measured after 2 years cropping under soils treated with 2.5, 5 and 7.5 t/ha with or without fertilizer N varied respectively as 2.0–2.9, 1.8–2.5, and 1.8–2.7 cmol+/kg soil (Figure 3d-f). These ranges showed remarkable soil Ca improvements relative to the initial Ca concentration of 0.32 cmol+/kg (Table 1).With the organic application rate of 2.5 t/ha organic materials without fertilizer N, rice straw recorded the highest Ca concentration but sharply decline when fertilizer N (45 and 90 kg N/ha) was added. Groundnut shells and rice husk showed similar trends of Ca improvement at an application rate of 2.5 t/ha with or without fertilizer N application (Figure 3d). At the rate of 2.5 t/ha organic material application, the best material for soil Ca improvement is rice straw without fertilizer N addition.

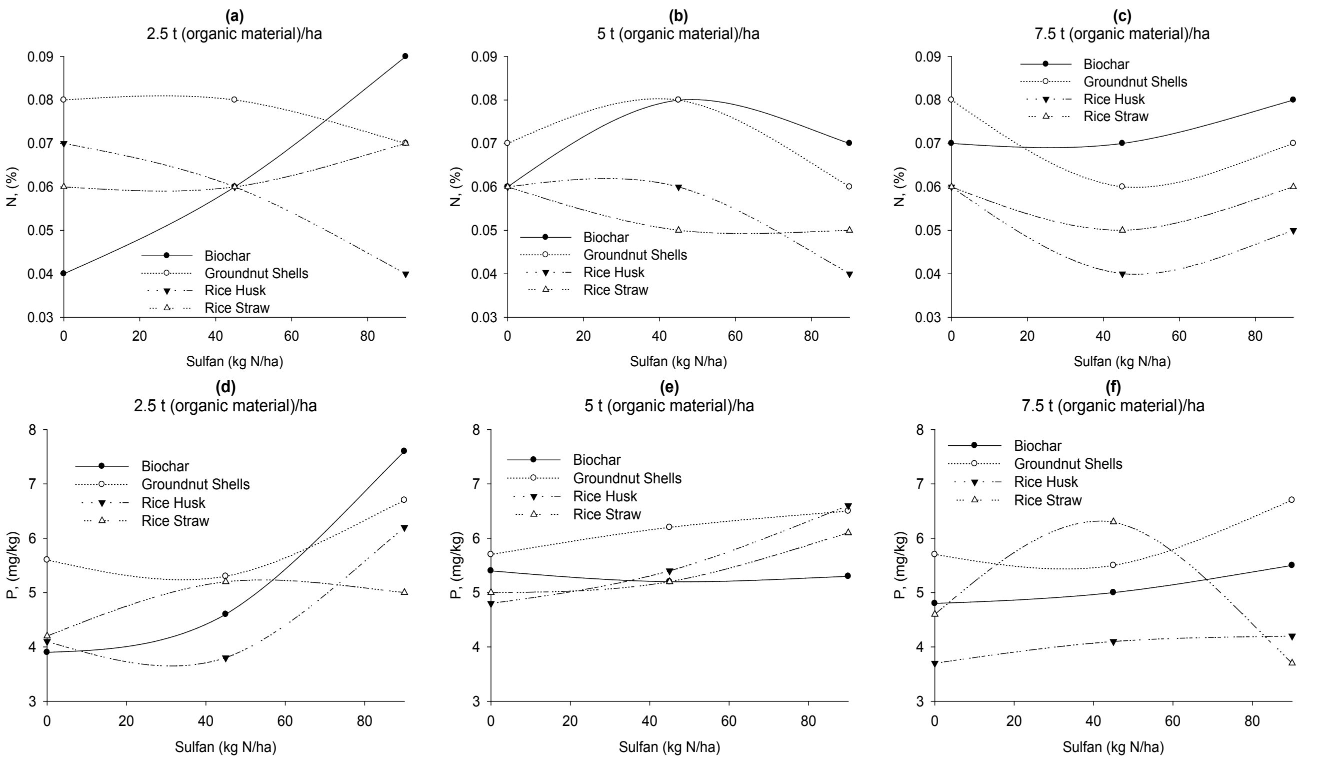

Figure 2: Interaction effects of organic materials types and quantities with or without different rates of NPK on soil N and P concentrations after cropping for 2 years in the Guinea savannah zone of Ghana.

At the application rate of 5 t/ha organic materials, the K improvements potentials of the materials were generally high when no fertilizer N was applied except biochar that recorded its high Ca upon addition of 45 kg N/ha sufan (Figure 3e). There was sharp division among the Ca patterns influenced by the organic materials such that biochar and groundnut shells increased in soil Ca concentration with inorganic N additions whilst the rice materials (rice husk and straw) decreased in soil Ca with inorganic fertilizer N additions. Compared with organic material amended-soils without inorganic fertilizer N addition, the soil K of all the organic treated soils with 90 kg N/ha sulfan were low and with narrow variations (Figure 3e). When 5 t/ha of organic materials were applied, rice straw without fertilizer N was best for soil Ca improvement but when 45 kg N/ha was added, biochar appeared best to improve the soil exchangeable Ca levels.

Changes of soil Ca as affected by the application rate of 7.5 t/ha with or without fertilizer N are presented in Figure 3i. The rice materials yielded high Ca concentrations with the least Ca from groundnut shells without fertilizer N. Except the groundnut shells that responded positively with addition of fertilizer N, the rest appeared non-responsive to addition of inorganic fertilizer N (Figure 3i). The application of 7.5 t/ha groundnut shells with 90 kg N/ha produced the highest soil exchangeable Ca value of 2.6 cmol+/kg.

Soil exchangeable Mg: With the initial soil exchangeable Mg of 0.23 cmol+/kg, the application of organic materials at 2.5, 5 and 7.5 t/ha with or without inorganic fertilizer N enhanced the soil Mg the ranges; 0.8–1.4, 0.7–1.2, and 0.7-1.3 cmol+/kg, respectively (Figure 3g-i). This result was not in line with Mugwe et al. [26] who observed a decline in soil Mg after 4 year of cropping with organic materials. With or without fertilizer N addition, 2.5 t/ha biochar treated soils produced high concentration of Mg than the other corresponding organic materials (Fig 3g). The rice materials (husk and straw) applied at 2.5 t/ha were negatively affected with the addition of fertilizer N,

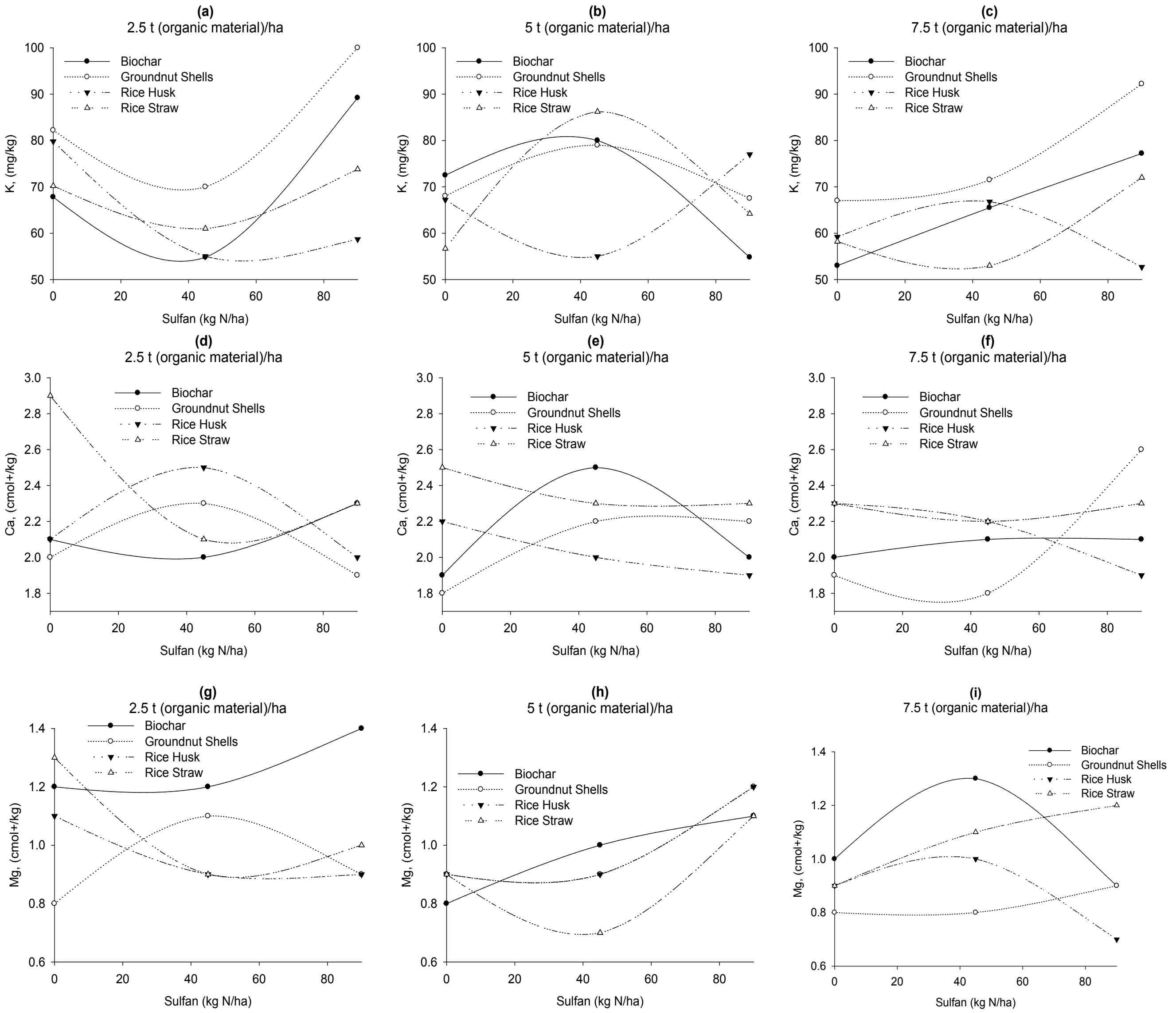

Figure 3: Interaction effects of organic materials types and quantities with or without different rate of NPK on soil K, Ca and Mg concentrations after cropping for 2 years in the Guinea savannah zone of Ghana.

doi:10.4172/2229-4473.1000404

and consequently produced the low soil Mg. The high exchangeable Mg of 1.4 cmol+/kg was measured under soils with biochar plus 90 kg N/ha (Figure 3g).

When the organic materials were applied at 5 t/ha, plots without fertilizer N amendments yielded low soil exchangeable Mg (Figure 3h). Addition of fertilizer N enhanced the effects of the organic materials on soil Mg production. Rice straw produced the least soil Mg when 45 kg N/ha of inorganic fertilizer was added (Figure 3h). All materials were very effective for soil Mg improvement when 90 kg N/ha inorganic fertilizer was applied. Contrary to the Mg production trend of the organic materials applied at 5 t/ha, addition of 90 kg N/ha to soils treated with 7.5t/ha declined in soil Mg yields (Figure 3i). The highest soil Mg among the 7.5 t/ha organic materials was realized under 7.5 t/ha plus 45 kg N/ha.

Conclusion

Biochar and Groundnut shells showed superiority in increasing soil fertility properties, especially pH, N, P, K, Ca, Mg and C compared with other Rice husk and Rice straw. Biochar and Groundnut shells were the only organic materials that increased soil C significantly. The superior effects of groundnut shells and biochar were more pronounced at the application rate of 5 t/ha with or without sulfan N. Similarly, at 7.5 t/ha application of organic materials with or without fertilizer, groundnut shells and biochar enhanced the soil nutrients than the rice materials. The rice materials were found to affect more of soil pH and exchangeable Ca but for soil Mg, biochar appeared the most influential material. We conclude that, application of either groundnut shells or biochar could improve the soil nutrients of the savanna agroecology for crop productions whilst with acidic soils and/or Ca deficient soils, rice materials are recommended for use. If technically feasible, the rice straw must be harvested and kept dry during the fallow period and applied as mulch during the cropping season to prevent losses during the fallow time.

Acknowlegdments

The authors gratefully acknowledge the sponsorship of USAID through the International Fertilizer Development Center (IFDC) ATT – Grant, Tamale Ghana Office in 2015. We also appreciate and extend our sincere thanks to the hard working staff in all departments that helped to shape this effort.

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