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Effect of Rice Husk Biochar as an Amendment on a Marginal Soil in Guyana

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Abstract The use of bio-char as a soil amendment has received attention owing to its potential to improve physical and chemical soil properties as well as contributing towards soil carbon sequestration. An experiment was carried under shade house conditions at Mon Repos to study the effects of biochar made from rice husk and its potential as a soil amendment on Tabela sand. Bio-char was produced by slow pyrolysis and applied at rates of 0, 5, 25, and 50 t/ha in combination with inorganic fertilizers. Application of biochar increased soil pH, organic matter content, soil water holding capacity, exchangeable cations, nitrogen, phosphorous, cation exchange capacity and decreased bulk density and iron concentration. There was a 32.81% increase in biomass using 25 t/ha application rate in the first crop cycle compared to the control. However, plant biomass was significantly reduced for all treatments, and for every parameter measured in the second cropping cycle. The results of this study suggest that the beneficial effects of rice husk biochar did not last beyond one cropping cycle. The results showed that the application of rice husk biochar can be used to improve soil quality of marginal soils in Guyana.

Keywords Biochar, Rice Husk, Soil Amendment, Tabela Sand

1. General Introduction and Overview

Guyana's fragile economy, relying heavily on an agricultural base justifies the need for the development of its vast interior for agricultural purposes (Holder, 1995). In Guyana, there is an abundance (34,809 km^2) of sand and sandy loam soils (800 Soil Series) located in the Intermediate Savannahs, and the Soesdyke Highway also called the hilly, sand and clay region; one of four natural regions found in Guyana, that is presently under-utilized but can be improved for agricultural production. However, these soils are extremely fragile, extremely acidic, excessively drained and extremely low in natural fertility and will require an amendment to make them productive (Ahmad, 1989). The application of biochar to these soils may be both beneficial and economically feasible.

Owing to the increasing evidence to support that climate change is real (IPCC, 2007), there is an urgent need to protect soils from an increasingly uncertain climate (Cumaravel, Santhi, Kumar, & Mansour, 2011). Guyana has abundant rice residues, producing approximately 122,311.90 MT of rice husk annually (Guyana Energy Agency, 2014). These residues could be a valuable resource for the production of biochar to increase soil fertility (Milla, Rivera, Huang, Chien, & Wang, 2013). Rice husk contains high percentage of potassium and silicon, nutrients that have a great potential for amending soils (Lehmann, Czimczik, Laird, & Sohi, 2009).

The benefits derived from the addition of biochar may vary from soil to soil. However, the following effects have been seen in experiments: a) rice husk biochar increases soil pH, thereby increasing available phosphorous, b) increased water holding capacity especially for sandy soil (Milla et al., 2013), c) improvement of crop yield for acidic soil (Lehmann, et al., 2003; Rondon, Lehmann, Ramirez, & Hurtado, 2007), d) single applications of biochar can provide beneficial effects over several growing seasons (Steiner et al., 2007) and e) increased levels of magnesium (Mg) and exchangeable potassium (K) (Food and Technology Centre, 2001). According to Smith (2013), biochar is rich in nitrogen, phosphorus, potassium and other trace elements, and can release these nutrients slowly over time. Biochar's porous structure also helps in nutrient and water retention, especially in marginal sandy soils. There is need to highlight the agronomic properties and the effects of rice husk biochar on crop growth and to promote the use of biochar by farmers, especially on marginal soils.

This study seeks to examine the effects of rice husk biochar as a soil amendment on Tabela Sand (Soil Unit 800) under shade house conditions. Rice husk biochar was applied at four rates to determine their effects on the growth on pak

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choy (*Brassica rapa*). This study hypothesized that rice husk biochar could act as a soil amendment, enhancing the growth of pak choy by retaining the nutrients of inorganic fertilizers and thus improve the soil's physical and chemical properties. The general objective was to evaluate the effects of rice husk biochar on soil quality and crop growth under shade house conditions. It is hoped that the results of this study may help to determine the most effective rate of application of biochar for the improvement of soil quality and crop growth.

2. Materials and Method

The experiment was conducted at the National Agricultural Research and Extension Institute located at Mon Repos, East Coast Demerara, Guyana (W 0383228; N 0750522). The average temperatures in the shade house during the period under study was 32°C compared to 30°C on the outside. The roof of the building was covered with ultra violet plastic and a layer of black shade mesh and the sides were covered with white shade netting.

Soil

Tabela sand (Guyana Soil Series Unit 800) was used in this experiment. Soil from the 0-15 cm depth was collected from NAREI research station located at Kairuni (W 0363493; N 0681469). 88 kg of the air-dried soil was weighed and placed into each box. The initial pH of the soil used in the study was 4.61 and the electrical conductivity was zero. This soil type is poor in cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and anions (HCO_3^-, Cl^-, SO_4^{2-} and SO_4^{2-}), thus having a very low electrical conductivity. The soil texture is sand with a particle distribution of sand 94.60%, silt 1.35%, and clay 2.05%.

Biochar

The rice husk was collected from a waste stockpile in the vicinity of a rice mill located at Mahaica, East Coast of Demerara. Biochar was produced from rice husk in a kiln constructed by the Faculty of Agriculture, University of Guyana. The rice husk was placed in the kiln and heated by wood, for approximately six hours and allowed to cool for 48 hours. The conversion of rice husk to biochar was 42.7%. The biochar moisture content was measured by oven drying a sub sample of 9 g at 105 °C for 24 hours. The bulk density was determined by filling a 10 ml tube with dry grounded biochar. The tube was capped, tapped to a constant volume, and weighed. Bulk density was calculated by dividing the weight of the dry sample by the volume of the packed materials.

3. Procedure

Soil Analysis

Before planting the soil was thoroughly mixed using spades and a composite sample was taken following an eight star pattern. The samples were mixed and a 0.5 kg sub-sample drawn for laboratory analysis. Soil properties evaluated included particle size analysis, bulk density, pH, EC, exchangeable acidity, organic carbon, Ca, Mg, K, Na, P, Cu, Mn, Fe, and Zn. After the first crop cycle a soil probe was used to take a soil sample from each plant box and same analyses were repeated. A sub-sample of the biochar was taken and analysed for the same parameters. Physical and chemical soil analysis was performed by the Guyana Sugar Corporation Central Laboratory. Soil bulk density was determined using the core method (NAREI, 2008).

Soil water holding capacity was determined following the procedure utilized by (Yu et al., 2013) to establish each sample's water holding capacity. Soil pH was determined in 1:2.5 ratio of soil to water using 10 g of soil. The mixture was stirred for ten minutes and allowed to stand for 30 minutes; the pH of the mixture was measured using a pH meter. The same mixture used for measuring the pH was then filtered and an electrical conductivity meter was used to measure the electrical conductivity (NAREI, 2008). Soil cation exchange capacity (CEC) was calculated by adding the exchangeable cations (Ca, Mg, K, Na) and the exchangeable acidity values.

Organic carbon was determined by Walkey and Black method, total N by Kjeldhal method, available P was extracted by Bray -1 method. K, Ca, Mg, Na, Cu, Mn, Fe and Zn were extracted using 1 molar ammonium acetate and measured using Atomic Absorption Spectrophotometer at Guyana Sugar Corporation, Central Laboratory.

3.1. Experimental Design

A shade house experiment was set up to study the effect of rice husk biochar on the growth of Pak Choy White (Tropical Type). Plants were grown in boxes of dimension 71 cm x 71 cm. The boxes were lined with fine mesh to prevent soil loss and 88 kg of soil was placed in each box. Calcium carbonate was added to each box based on the soil analyses to improve soil pH for optimum nutrient uptake. Inorganic fertilizers (urea, triple super phosphate and muriate of potash) were added to each box based on recommendations elaborated for pak choy cultivation in NAREI's Farmer Manual. Precaution was taken to ensure homogeneity of soil and amendment mixes. No subsequent limestone or fertilizers were added to the soil. In biochar treatments, the fertilizers were dissolved in water and the biochar added to the mixture and allowed to soak for three days. After three days this was thoroughly mixed with the soil in the boxes.

Pak choy seeds were sown in seedlings trays and transplanted three weeks after sowing for both crop cycles. Plant spacing used was 20 cm between plants and 20 cm between rows. Plants were watered once daily. Plants were harvested 31 days after transplanting for both cycles, and measurements were done for: plant height, number of leaves, leave area index and plant biomass.

Biochar application rates used were:

(1) No biochar, (control)
(2) Rice husk biochar, 5 t/ha
(3) Rice husk biochar, 25 t/ha

(4) Rice husk biochar, 50 t/ha

The treatments were arranged randomly within boxes with four replications.

3.2. Data Analysis

Analysis of Variance (ANOVA) was performed to assess the significant differences among treatments, using the general linear model (GLM) procedure of Statistix Version 9. Means separation was done using least significant difference (LSD) tested by All-pairwise Comparisons at P = 0.05. Pearson correlation analysis was also performed using Statistix Version 9 in order to analyse the relationship between selected variables.

4. Results and Discussion

Effect of Biochar Application on Soil pH and EC Content

The statistical analysis revealed significant increases in pH among treatments due to the addition of biochar. The highest mean values of pH were observed in soils treated with 50t/ha, while the lowest values were recorded at the control (0 t/ha). There were increases in pH values of 2.1, 2.5 and 2.94 units at 5, 25 and 50 t/ha respectively. The increase in soil pH owing to the application of biochar was generally attributed to ash accretion as ash residues are generally dominated by carbonates of alkali and alkaline earth metals and considerable amounts of silica (Lehmann, Czimczik, Laird, & Sohi, 2009). In agreement with this, Khanna, Raison, & Falkiner (1994) and Arocena & Opio (2003), reported the capacity of ashes to neutralize acidic soil. Sukartono et al., (2011), also reported that the increase of soil pH following biochar application may be related to the alkaline nature of biochars. The pH of the rice husk biochar used for this experiment was 8.42. The high surface area and porous nature of biochar may be another reason for the increase in soil pH after application, by increasing the CEC of the soil (Nigussie et al., 2012; Filiberto & Gaunt, 2013). The Pearson correlation showed a strong positive ($P<0.001$; $r = 0.930$) correlation between soil pH and CEC. There were no significant increases in Ec, the mean value was 0.15 mmhos/cm across all treatments.

These results therefore indicate that rice husk biochar could be used as a substitution for lime materials to increase the pH of acidic soils. In agreement with this Masulili et al., (2010); Chen-Chi, Yu-Fang, Gwo-Shyong, & Zeng-Yei (2013), also reported use of rice husk biochar as a substitution for liming materials. Low soil pH can limit plant growth by modifying the dynamic of plant nutrients (Carter, et al., 2013), thus the addition of biochar could be particularly beneficial to the brown sands (800 soil series) that are widespread on the Linden Soesdyke Highway and the Intermediate Savannahs of Guyana.

Bulk Density

The bulk density of biochar is much lower than that of mineral soils, thus the application of biochar can decrease the bulk density of the soil (Gundale & DeLuca, 2006; Downie, Crosky & Munroe, 2009). The bulk density of the rice husk biochar used in the experiment was 0.3 g cm^{-3} and this was much lower than that of the Tabela Sand (1.35 g cm^{-3}). There was no significant differences in bulk density between the control (0 t/ha) and the addition of biochar at 5 t/ha. However, addition of biochar at 25 and 50 t/ha significantly reduced the bulk density of the soil compared to the control (0 t/ha) 61 days after application.

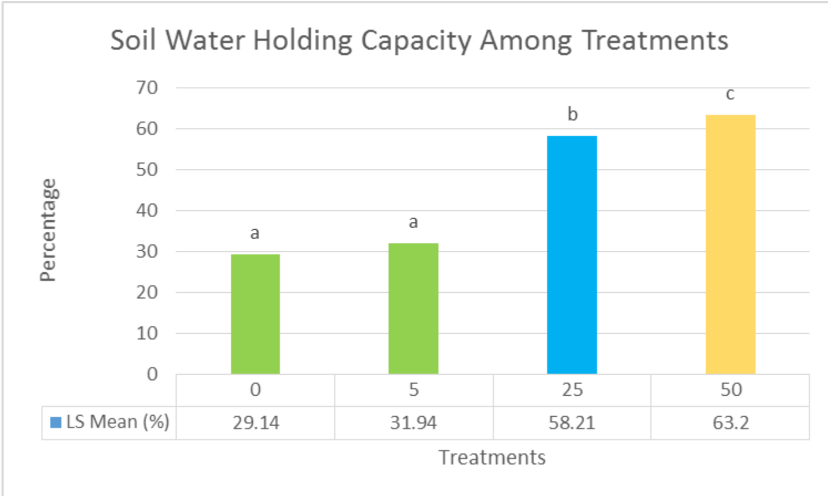
The bulk density reduced from 1.35 g cm^{-3} in the control (0 t/ha) to 1.01 and 1.00 cm^{-3} for 25 and 50 t/ha respectively. The decrease in soil bulk density with the organic soil amendment application in this experiment could be explained as being a result of the incorporation of the soil which has a relatively high bulk density (1.35 g cm^{-3}) with a lower density of organic soil amendment (0.3 g cm^{-3}). These results are consistent with work done by (Busscher et al., 2010; Mukherjee & Lal, 2013; Githinji, 2013).

Research by Mukherjee & Lal (2013), suggested that the application of biochar can reduce soil bulk density because of the high porosity of biochar. When biochar is added to the soil it can significantly reduce the bulk density by increasing the pore volume. Githinji (2013), noted that by increasing the rate of biochar application bulk density was significantly reduced.

Water Holding Capacity

Water use efficiency will need to be substantially improved if we are going to use the sandy soils of the Soesdyke Linden Highway and the Intermediate Savannah for agricultural purposes since these soils are excessively drained. Recently, research has shown that the application of biochar has the potential to increase the water holding capacity of soils (Basso, Miguez, Laird, Horton, & Westgate, 2013). The rice husk used in this experiment has a water holding capacity of 55.61% that is enhanced by the pyrolysis process, resulting in 77.92% in water retention in rice husk biochar.

Sohi et al., (2009), hypothesized that the addition of biochar to soils may lead to increased levels of organic matter content. This may partially explain improved water retention. Also, changes in water holding capacity by soil amendment, was primarily due to the water holding capacity of the characteristics of the rice husk biochar itself. This was evident in the study, the highest rate of biochar application (50 t/ha) had the highest percentage of organic matter (3.59%) and recorded the greatest improvement in water retention. At this rate there was a 34.06% increase compared to the control. There were no significant differences between the unamended soil (control) and biochar applied at 5 t/ha. However, there was a significant increase of 29.07% in water retention at 25 t/ha as compared to the control. These findings are important because it establishes biochar as an effective medium for increasing water efficiency, runoff mitigation, and reducing agricultural pollution since these are excessively drained soils.



Means with the same letters do not differ significantly at P<0.05

Figure 1. Effect of biochar on soil water holding capacity

Effect of biochar on soil properties

In general, the application of rice husk biochar significantly improved the chemical properties of the soil. There was significant increase in soil pH, organic carbon content, organic matter, cation exchange capacity and a decrease in soluble Fe. The application of rice husk biochar also increased elemental plant nutrients N, P, K, Ca, Mg and Na for all treatments compared to the control. Similar results were reported by Glaser (1999), showed increases in effective cation exchange capacity, base saturation, available K, Ca, and Mg, total N, and available P in Oxisols amended with biochar.

The application of biochar to soil significantly increased the organic matter content of the soil compared to the control. There were significant differences among all the treatments, with the highest value reported at application rate of 50t/ha. The organic matter content improved as the rate of application increased. There was a 1.12, 2.07 and 3.62% increase in organic matter for application rates of 5, 25 and 50t/ha respectively compared to the control. Thus the rational for the use of rice husk biochar with a high organic matter content (61.06 %) in this experiment.

No clear difference existed between the soil organic matter in the first crop cycle and that of the second cycle, indicating no significant loss of soil organic matter during the period under study. In sandy, acidic soils as the one used in this study, organic matter plays a critical role because in addition to being a source of plant nutrition, it is a key source of negative charge, which is vital for helping the soil to adsorb cations in the soil solution (Ponamperuma, 1982). Zebarth et al., (1999), found similar results using organic waste at 45 t/ha on a sandy, infertile soil improved the organic matter content of the soil by 2% relative to the control.

Rice husk biochar (RHB) used in this experiment has a high cation exchange capacity (CEC), and with its high recalcitrance (Glaser, Lehmann, & Zech, 2002), it is rational that soil applied with the highest rate of biochar had the highest CEC. The significant increase in CEC of soils with the application of rice husk biochar would probably be due to the negative charge arising from the carboxyl groups of the organic matter (Masulil et al., 2010). An increase in soil CEC with the application of biochar has been shown by (Chan, et al., 2007; Sukartono et al., 2011; Cornelissen et al., 2013).

Crop Yield

The use of charcoal was shown to increase soil fertility in the Amazonian Terra Preta soils, and increased crop yield has been recognised as a benefit of biochar application (Taylor, 2011). For both crop cycles of pak choy production, above ground biomass increased with biochar addition up to 25 t/ha. However, plant biomass was significantly reduced for all treatments, and for every parameter measured in the second crop cycle. In each cycle the lowest above ground biomass was from the control and the highest biomass was in the treatment with the application of biochar at 25 t/ha. The control (0 t/ha) and the treatment with the application of biochar at 50 t/ha did not differ significantly for both crop cycles. These results suggest that there appears to be an upper limit on the application of biochar and crop productivity.

The degree of biomass increased with biochar addition was maintained across both crop cycles. There was a 32.81% increase in biomass between the application of biochar at 25 t/ha and the control. The control recorded the lowest biomass in both crop cycles which suggests that the application of inorganic fertilizers alone could not sustain plant growth in marginal soils. Similar results were obtained by Islami, Guritno, Basuki, & Suryanto (2011), who reported cassava yields were greatly reduced when planted with inorganic fertilizers alone compared to using a combination of inorganic fertilizers and biochar on marginal soils in Indonesia.

In the second crop cycle all plants grown in treatments with application rates of 5 and 50 t/ha, and the control (no biochar) showed nitrogen deficiency. This clearly suggests that the beneficial effects of rice husk biochar in retaining residual nitrogen at these rates did not last beyond one cropping cycle. This results support findings by Carter et al., (2013), they found that the application of biochar to lettuce and cabbage on an acidic, sandy soil showed a significant increase in yield compared to the control in the first crop cycle but yields decreased significantly in the third cycle. The greatest yield was recorded in cycle one and the lowest in cycle three. The author suggested that the use of longer cropping cycles could benefit more from the addition of biochar. Saarnio et al., (2013), also reported that the effect of biochar could be short lasting, the application of wood biochar at 10 Mg/ha significantly increased the yield of pasture grass in the first crop cycle, but subsequent cycles had no significant differences.

To maintain sustained productivity, therefore, repeated addition of inorganic fertilizers may be necessary at the beginning of each crop cycle.

5. Conclusions

The results obtained in this study reveal that the addition of biochar to a marginal soil significantly improved the physical and chemical properties of the soil. There were significant increases in soil pH, organic carbon content, organic matter, water holding capacity, cation exchange capacity and exchangeable cations, decrease bulk density and available iron for all biochar amended treatments. The improvement in soil pH from added biochar has implications for marginal soils as it can help to reduce aluminium toxicity and increase availability of nutrients elements. Also, it reduces the quantities of limestone needed to neutralise aluminium toxicity on acidic soils such as Tabela Sand. The significant increase of Cation Exchange Capacity, nitrogen, calcium and phosphorous levels at 25 t/ha applied biochar correlated with significant increase of yields further enhancing the potential of biochar use for increased production.

For both cropping cycles increase in crop biomass correlated with increased application of biochar up to 25 t/ha. These results suggest an upper limit to the application of biochar on crop productivity. However, biomass was significantly reduced for all treatments, and for every parameter measured in the second crop cycle. These results clearly suggested that the beneficial effects of rice husk biochar on crop growth and yield did not last beyond one crop cycle. To maintain sustained productivity, therefore, repeated addition of inorganic fertilizers may be necessary since biochar is not a fertilizer but an amendment.

The application of rice husk biochar could be particularly beneficial to the brown sands (800 soil series) that are widespread on the Linden Soesdyke Highway and the Intermediate Savannahs of Guyana. These are marginal soils that must be amended in order to make them productive. The results showed that the application of rice husk biochar can be used to improve the soil quality of these soils and make sustainable use of available rice husk. In conclusion, the hypothesis that there are significant differences among treatments using rich husk biochar as a soil amendment has been supported, the application of biochar at 25 t/ha was most effective rate for crop production.

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