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EFFECTS OF RICE HUSK BIOCHAR CHARRED AT DIFFERENT TIME ON SOIL CHEMICAL PROPERTIES, RICE GROWTH AND YIELD

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ABSTRACT

Sustainable rice production in Sub-Saharan Africa especially in Nigeria faces serious constraints due to soil infertility. Recycling of rice residues through biochar production and applying it to the soil could be a possible approach to address the soil fertility constraints facing rice production. A pot experiment was conducted at Imo State University to investigate the effect of rice husk biochar on some selected soil chemical properties, growth and yield of rice. Four treatments evaluated in the pot experiment include rice husk biochar charred at 250^oC for 60, 90 and 120 minutes together with control (no amendment). The treatments were replicated three times and laid out in completely randomized design (CRD). The soils in the pots were both treated with basal dose NPK (15:15:15) at 200kgha^{-1} while biochar was applied at the rate of 10tha^{-1} to the amendment soils. Application of biochar in this experiment appreciably increased the soil pH, available phosphorus, OC, TN, exchangeable cations, CEC and available silicon in biochar treated pots compare to control pots. The degree of soil improvement was proportional to the charring time. The rice husk charred for 120 minutes (RHB120) showed the highest effect on most of the soil chemical properties evaluated. Biochar amendment was found not to have much influence on the rice agronomical parameters except grain weight in which the highest value was found in soil treated with RHB120 (12.5gpot^{-1}). Therefore, converting rice husk to biochar and applying it to the soil can improve soil fertility status and yield of rice in Nigeria.

Keywords: Rice Husk Biochar, Soil Chemical Properties, Rice Growth, Rice Yield

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INTRODUCTION

Rice (Oryza sativa L.) is the third most produced crop in the world after sugarcane and corn. This is because for over half of the world population, rice is the primary staple food, with Asia, sub-Saharan Africa and South America being the largest consumer of rice (Muthayya, Sugimoto, Montgomery and Maberly (2014); World Rice Production 2021/2022). The annual global production of rice amounts to over 759.6 million tonnes (FAO. 2018) with Asian countries accounting for 90% of the world total rice production (Muthayya et al. 2012). Other non-Asia countries including Brazil, the United States, Cambodia and Nigeria, account for 5% of the rice produced globally (World Rice Production 2021/2022). In Africa, rice is the fastest growing staple food and its total cereal production raised steadily from 9.3% in 1961 to 15.2% in 2007 (IRRI, 2013). However, only 54% of the rice consumption is supplied locally and the region still imports over 40% of its rice need (FAO, 2018). Nevertheless, in the past few years, Nigeria has been the largest rice producing country in Africa. Since 1980, rice production in Nigeria has risen from 1,090,000 tonnes (IRRI, 1991) to about 9,000,000 tonnes in 2021 (Orjiude, 2022). Although the potential for local rice production in Africa is enormous which include favourable production cost, the rice sector still suffers from inefficiencies related to low productivity, a factor strongly controlled by soil related issues.

Frequent use of inorganic fertilizer and total removal of crop residue from agricultural lands have negative effect on soil organic carbon accumulation in particular and on soil fertility at large. Biochar application to the agricultural lands may help in replenishing the fertility of agricultural lands. Biochar is a carbon-rich solid produced by the pyrolyzation of biomass (feedstock) at a relatively low temperature (100 to 700°C) under anoxic conditions. Biochar when added to soils serves as a means to sequester carbon (C) and maintain or improve soil functions (Kajiura, Wagai and Hayashi, 2015). Biochar addition to soil also can produce changes in the soil's chemical and physical properties including nutrient availability, CEC, pH, soil strength and moisture holding capacity (Lehmann and Joseph, 2009). Chan,Van-Zwieten, Meszaros, Downie and Joseph (2008) concluded that the chemical changes in soil after biochar application reflects the properties of the biochar being applied. Several research studies have found that biochar addition to soil increases total C (Van Zwieten et al 2010), total N, pH, CEC, available P, and exchangeable cations (e.g. Ca, Mg, Na, and K) in soil (Chan et al 2008). Similarly, Major, Rondon, Molina, Riha and Lehmann (2010) found that biochar addition increases available Ca, Mg and pH in soil.

The frequent use of inorganic fertilizers for a prolonged period could cause deterioration of the surface soil characteristics and affect the availability and uptake of nutrients by the plants (Kerenhap, Tniagarajan and Kumar, 2007). To minimize these hazards, the use of naturally occurring materials such as rice husk biochar is a better alternate This is because the world annual production of rice husk and rice bran are 120 and 76 million tonnes respectively (Bodie, Micciche, Atungulu and Ricke, 2019). The objective of the study is to determine the effect of rice husk biochar on some soil chemical properties, growth and rice yield.

MATERIALS AND METHOD

Soil and Biochar Preparation

The top soil used for this experiment (0 - 20cm) was collected from a paddy soil at Ibura, Agbogu community in Okigwe North area in Imo State Nigeria (5^{o}18’34”N; 7^{o}15’26”E). The soil was homogenized, air-dried, crushed and passed through a 2 mm sieve before filling the plastic pots with the soil. The selected soil properties analyzed are presented in Table 1. Commercial rice husk was used for this experiment. The rice husk was first air-dried and grounded using a modified hand blender powered by petrol engine. Prior to the insertion of rice husk feedstock, the biochar machine was first heated for 10 minutes. 500g of grounded rice husk was inserted into a modified gas biochar kiln desiged and fabricated by Nwawuike I. M. Rice husk feedstock was pyrolyzed at 250^{o}C for 60, 90 and 120 minutes respectively with an intermittent rotation using the rotatory device inserted at the side of the machine. The rotation ensures homogenity of the inserted feedstock while charring. Prior to the application of biochar to the soil, the produced biochar was analyzed for its chemical composition (Table 1).

Pot Experiment Procedure

The pot experiment was conducted from February to May 2022 at the experimental greenhouse in the faculty of Agriculture Teaching and Research Farm, Imo State University, Nigeria (5^{o}30’28”N; 7^{o}02’26”). The size of the plastic pots used was 18cm in diameter and 17cm in height. The pots were filled with 2kg of soil and amended with 10g pot^{-1} rice husk biochar (at the rate of 10 t ha^{-1}). The pots were fertilized with a basal dose of NPK (15:15:15) fertilizer at the rate of 200 kg ha^{-1} (0.2g pot^{-1}) at transplanting only. The control pot had no biochar treatment. The pots were arranged in a completely randomized design (CRD) with three replications. All the pots were irrigated with deionized water up to 5cm above the soil level. Transplanting was done the following day after allowing the watered pots to stay overnight. Rice seedlings gotten from ADP Owerri were planted one per pot. The average temperature during the experiment was 27°C with minimum of 23°C and maximum of 32°C while the relative humidity was in the range of 63 - 80% during the experimental period.

Crop Growth and Yield Parameters

Forty five (45) days after transplanting, the plant height was measured and the tiller numbers counted. Three months after the transplanting date, the above ground biomass (shoot) of the plants were harvested and air-dried in the greenhouse. Two weeks after, the grains were separated from the shoot, inserted into a paper bag and oven dried at 60°C until a constant weight was reached. The root was also harvested, washed thoroughly with deionized water and oven dried at 60°C in paper bags until a constant weight was gained.

Laboratory Analyses

The soil from each pot was air-dried, homogenized and passed through a 2mm sieve to remove any visible roots in the soil before laboratory analysis. Soil pH was determined in distilled water using a soil/liquid ratio of 1:2.5. After stirring for 30 minutes, the pH values were read using a glass electrode (McLean, 1982). Available phosphorus was determined by the Bray 2 method (Page, Miller and Keeney, 1982). Total nitrogen was determined by macro kjeldahl method (Bremner and Mulvaney, 1982) using $CuSO_4/Na_2SO_4$ catalyst mixture. The ammonia (NH_3) from digestion was distilled with 45% NaOH into 2.5% boric acid and determined by titrating with 0.05N HCl. The organic carbon was determined using Walkley and Black dichromate method (Nelson and Sommer, 1982). This method involves the oxidation of soil OM with potassium dichromate ($K_2Cr_2O_7$) using concentrated H_2SO_4. Percentage OC was then found by titrating the oxidized soil OM with 1N $Fe(NH_4)_2\ SO_4$ solution. Organic matter was then calculated by multiplying the value for OC by the conventional “Van Bemmelen factor” of 1.724 which is based on the assumption that soil OM contains 58% C. The soil samples were leached with 1N NH_4OAC, after which potassium and sodium in the extract determined by flame photometry (Kundsen, Peterson and Pratt, 1982) and calcium and magnesium by EDTA method (Lanyon and Heald, 1984). Exchangeable acidity was determined titrimetrically with 0.05N NaOH using 1NKCl extract (Mehlich, 1982). The CEC of the soil was obtained by leaching the sieved soil with 1N neutral (pH 7) ammonium acetate saturated method following titration with 0.1N NaOH (Chapman, 1965). Silicon was extracted from soil samples using 0.5 M acetic acid extraction procedure as outlined by Korndorfer and Lepsch (2001). The Si in the soil sample extracts was determined by Molybdenum Blue Colorimetry (MBC) procedure (Hallmark, Wilding, and Smeck 1982).

Prior to pyrolysis, the original biomass were analyzed for its chemical composition (Table 2). The biochar yield was calculated as the proportion of the weight of product to the original material. Ash content determination was conducted according to the American Society for Testing and Materials D1752-84. The ash content was thus determined by measuring the weight loss that follows the combustion of about 1g of biochar in a crucible at 750^oC after 3 hours. The pH of biochar was measured in 1:20 w/v biochar water extracts using pH meter. Rice husk biochar was digested by nitric and perchloric acid (Kalra, Maynard and Radford, 1988) and then the extract were used to measure elements (C, N, P, Ca, Mg, Na and K) according to the standard methods. Carbon was determined using Walkley and Black dichromate method (Nelson and Sommer, 1982). Nitrogen was determined by macro kjeldahl method (Bremner and Mulvaney, 1982). Phosphorous was determined by the Bray 11 method (Page *et al*., 1982). Sodium and potassium were determined by flame photometry (Kundsen *et al*., 1982) and calcium and magnesium by EDTA method (Lanyon and Heald, 1984).

Data Analyses

SPSS version 25 was used for Analysis of Variance (ANOVA) at $P < 0.05$. The mean differences were compared using Tukey's HSD test at $P < 0.05$.

RESULTS AND DISCUSSION

Characteristics of the Initial soil used for the experiment

The initial soil physicochemical properties before the addition of biochar treatment are shown in Table 1. The soil is brown in colour and has sandy clay loam texture. The soil has moderate sand (590 g kg^{-1}), low clay (142.0 g kg^{-1}) and silt (268.0 g kg^{-1}) fractions. It is acidic (4.6). Organic carbon (12.1 g kg^{-1}) and phosphorous (15.8 mg kg^{-1}) were relatively medium. The values of exchangeable bases (Ca, Mg, Na and K) of the soil used in the experiments ranges from high to medium with high exchangeable acidity (Table 1). The CEC of the soils were of medium range (Esu, 1991).

Chemical composition of the produced biochar used for the pot experiment

Table 2 shows the chemical composition of the pyrolyzed biochars. Biochar yield was reduced with increasing charring time. In general, the nutrient content of the produced biochar increased with increasing charring time. The produced biochars had higher pH values (5.9, 6.6 and 6.8 at 60, 90 and 120 minutes charring time) when compared with the pH of the soil used. This pH values found in the produced biochar could be attributed to high ash content in the produced biochar (Gaskin, Steiner, Harris, Das and Bibens, 2008). Biochar with high ash content can provide more mineral nutrients such as K, Ca, Na and Mg which increase pH values (Wu et al, 2012). The total N contents decreased as the charring time increases while total C, P, K, Ca and Mg contents of the produced biochars showed an increasing trend. Silicon increased with increase in Charring time. The increase obtained from silicon with increasing charring time might be as a result of a change in the form of silica relative to the time of charring (Nwajiaku, Sato, Tokunari, Kitano and Masunaga, 2018).

The Effect of biochar on crop growth and yield performance

Table 3 shows the effect of rice husk biochar on rice growth and yield components. The plant height, tiller number and shoot biomass showed no significant difference ($P < 0.05$) among the treatments while the root biomass and grain yield differ significantly. The results from the pot experiment showed that the plants treated with RHB120 gave the highest plant height (95.6cmpot^{-1}), tiller number (10.0), shoot biomass (13.5gpot^{-1}) and grain weight (12.5gpot^{-1}). The high values obtained from RHB120 might be because RHB120 is rich in plant nutrients (Alburquerque et al. 2014). Despite that RHB120 had high values in almost all the growth and yield components, its root biomass was the lowest (5.0 g pot^{-1}) when compared to control (10.5 g pot^{-1}). The low root biomass obtained from biochar amended soils is because of the biochar's ability to retain nutrient to improve plant growth thus, limiting the need for root elongation. (Nigussie, Kissi, Misganaw, and Ambaw, 2012).

The Effect of biochar on soil chemical properties after harvest

Table 4 shows that soil pH was significantly lower in the non-amended soils (control) than in the biochar amended soils. The pH was highest in RHB120 (6.3) and lowest in control (4.9). The pH increases due to biochar application (Yuan, Xu, Wang and Li, 2011). Liang *et al.,* (2006) also showed a significant increase in soil pH as a result of biochar application. The biochar amendment significantly improved the organic carbon compared to control. Soil amended with RHB90 gave the highest OC (19.9 g kg^{-1}), with control (10.5 g kg^{-1}) having the lowest value even lower than OC of the initial soil (12.1 g kg^{-1}) (Table 1 and 4). The increase of organic carbon in the biochar amended soils could be as a result of the high amount of organic carbon in the biochar. High organic carbon in the biochar amended soils suggests that the organic carbon of the biochar is recalcitrant (Kuzyakov, Bogomolova and Glaser, 2014). The soil CEC was significantly influenced by biochar application. The soil with RHB120 gave the highest CEC (10.3 Cmol kg^{-1}) compared to soil with no biochar amendment (5.95 Cmol kg^{-1}) (Table 3). CEC increase was in proportion with the biochar charring time. However, the inherent characteristics of biochar, such as high porosity and surface area could be responsible for high CEC in biochar amended soils (Meena et al, 2014). High organic carbon and CEC in soils amended by biochar were similarly reported by a number of authors (Nigussie et al. 2012 and Lehmann et al, 2011).

Exchangeable cations were significantly ($P< 0.05$) influenced by the addition of rice husk biochar relative to soil with no biochar amendment. The exchangeable Ca, Mg, K and Na ranges from 3.0 to 5.8 Cmol kg^{-1}, 0.80 to 2.80 Cmol kg^{-1}, 0.17 to 0.36 Cmol kg^{-1} and 0.16 to 0.31Cmol kg^{-1} respectively. The maximum values for Ca (5.8 Cmol kg^{-1}), Mg (2.80 Cmol kg^{-1}), K (0.36 Cmol kg^{-1}) and Na (0.31Cmol kg^{-1}) were found in the pots treated with RHB120 except for Na whose maximum value was on pots with RHB90. The results obtained from this study confirmed that biochar application could improve the status of soil exchangeable cation capacity, especially Ca and Mg, which was in accordance with the results of Jien and Wang 2013, who posit that original nutrients in biochar supplied the exchangeable cations in soils. Exchangeable acidity showed significant effect ($P< 0.05$), with the biochar treated soil having lower exchangeable acidity (Al and H). The highest and the lowest values of Al (0.78cmolkg^{-1} and 0.22cmolkg^{-1}) and H (1.82comlkg^{-1} and 0.87comlkg^{-1}) were found in control and RHB120 (Table 4). Recent studies exposes the liming effect of biochar, adsorption properties and the surface adsorption and co-precipitation of Al with silicate particles to fix Al in soil (Qian, Chen and Hu, 2013 and Zhao, Coles, Kong and Wu, 2015). Similarly, these results are consistent with several reports suggesting that biochar application has potential to decrease Al toxicity in soil (Qian, Chen and Chen, M, 2016 and Xiao, Chen, Chen, Zhu and Schnoor, 2018).

The results on Table 4 also show that application of rice husk biochar significantly ($P < 0.05$) increased the amount of nitrogen in soil. The Total N ranges from 0.88 to 1.53gkg^{-1}, with the highest value (1.58gkg^{-1}) found in RHB60 treated pot while the unamended pot gave the lowest value (0.88gkg^{-1}) (Table 4).Total N in the produced biochar decreases with increase in charring time. However, an increase was observed when it was added to the soil. This is because the use of biochar especially the sewage biochar could increase the usability of nitrogen in soil (Yoo, Kim, Chen and Kim, 2014). Although, Xu, Shao and Sun (2013) concluded that after adding biochar to the soil, it increases the speed of nitrogen deformation in short term; however, for a long term stay, the biochar in the soil increases nitrogen utilization by de-immobilizing nitrogen. Dong et al. (2015) argued that biochars can release nutrients into soil when they are added to the soil and can release significant amounts of elements such as nitrogen.

Soil available phosphorus showed progressive increase with charring time of biochar. The avail. P values range from 13.20 to 23.57 mg kg^{-1} with its maximum (23.57 mg kg^{-1}) and minimum (13.20 mg kg^{-1}) on pots treated with RHB120 and no biochar amended pots (control) respectively. The high available P found in the RHB amended pots might be as a result of the type and chemical composition of the biochar used for the experiment. The biochar type used for this study has a high amount of total phosphorus. Therefore, a much greater increase of soil available P was induced by incorporating the biochar into the soil (Table 4). This finding is consistent with (Liu et al. 2017 and Cui et al. 2011) who found that biochar addition can improve P availability in soil. Thus, improvement of soil available P might be due to an additional P element in biomass used as raw material for biochar production and due to P mobilization, which previously was immobilized by Al^{3+}, Fe^{2+}/F^{e3+} under acidic condition (Li et al. 2016).

Biochar amendments significantly ($P < 0.05$) increased the available Si concentration in the soil used for this study (Table 4). The increase ranges from 22.4 to 37.4mgkg^{-1} with its maximum

($37.4 mgkg^{-1}$) and minimum ($20.4 mgkg^{-1}$) on pots treated with RHB120 and no biochar amended pots respectively. This finding is consistent with some previous studies that used biochar from rice residue (Houben, Sonnet and Cornelis, 2014; Li et al. 2018 and Wang, Xiao and Chen, 2018) and wollastonite (Tavakkoli, Lyons, English and Guppy, 2011; Haynes, Belyaeva, and Kingston, 2013 and Babu, Tubana, Paye, Kanke and Datnoff, 2016). The more pronounced available Si increase under the rice husk biochar amendments compared to non-rice husk biochar amendment (control) is explained by higher Si concentrations in the pyrolyzed feedstock (Table 2).

CONCLUSION

The findings in this study show the beneficial effect of rice husk biochar as an organic amendment for sustainable agriculture. Incorporating rice husk biochar assisted in improving soil chemical properties such as pH, Avail. P, OC, Exch Ca, Mg, K and Na together with CEC and Avail. Si. The effect of the rice husk biochar on soil chemical properties were proportional to the biochar charring time Therefore, using rice husk biochar charred for 120 minutes (RHB120) stands as the best biochar compared to RHB90 and RHB60 for improvement in soil chemical properties and rice yield. Long term field studies are therefore needed to determine the optimum charring time of rice husk biochar for improved soil chemical properties and resultant increase in rice yield.

REFERENCES

Alburquerque, J.A., Calero, J.M., Barrón, V., Torrent, J., del Campillo, M.C., Gallardo, A. & Villar, R. (2014). Effects of Biochars Produced from Different Feedstocks on Soil Properties and Sunflower Growth. *Journal of Plant Nutrition and Soil Science*, 177, 16-25.

Babu, T., Tubana, B., Paye, W., Kanke Y. & Datnoff. L. (2016). Establishing soil silicon test procedure and critical silicon level for rice in Louisiana soils. *Communication in Soil Science Plant Analysis*, 47, 1578 –1597.

Bodie, A. R., Micciche, A. C., Atungulu, G. G. & Ricke, S. C. (2019). Current trends of rice milling byproducts for agricultural applications and alternative food production systems. Frontiers in Sustainable *Food Systems*, 3(47), 1–13.

Bremner, J. M. & Mulvananey, C. S. (1982). Total nitrogen. In Page *et al*. (ed.) Methods of Soil Analysis Part 2. Agron. Monogr. 9. ASA and ASSA, Madison, W.I. pp. 595 – 624.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. & Joseph, S. (2008). Agronomic Values of Green waste Biochar as a Soil Amendment. *Soil Research*, 45, 629-634.

Chapman, H.D. (1965). Cation Exchange Capacity in method of Soil Analysis Part II, Agronomy No.9, Black, C.A. (ed) Am.Soc. of Agronomy Medison, Wisoconsin pp.891-901.

Cui, H. J., Wang, M. K., Fu M. L. & Ci, E. (2011). Enhancing phosphorus availability in phosphorus-fertilized zones by reducing phosphate adsorbed on ferrihydrite using rice straw-derived biochar. *Journal of Soils and Sediment*,, 11, 1135–1141.

Dong, D., Feng, Q., McGrouther, K., Yang, M., Wang, H. & Wu, W. (2015). Effects of biochar amendment on rice growth and nitrogen retention in a waterlogged paddy field. *Journal of Soils and Sediment*, 15, 153–162. https://doi.org/10.1007/s11368-014-0984-3

Esu, I. E. (1991). Detailed soil survey of NIHORT farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

Food and Agriculture Organization of the United Nations (2018). Rice market monitor, Volume XXI Issue No. 1. Accessed December 2022.

Gaskin, J. W., Steiner C., Harris K, Das K. C. & Bibens B. (2008). Effect of low temperature pyrolysis conditions on biochar for agricultural use. *Transactions of the ASABE, 51*(6): *2061-2069. doi: 10.13031/2013.25409*.

Hallmark, C.T., Wilding, L.P. & Smeck, N.E. (1982). Silicon. In: "Methods of Soil Analysis" No. 9, Part 2. (A.L. Page, R.H. Miller, D.R. Keeney, eds.). American Society of Agronomy, Incorporation, Soil Science Society of America, Inc. Publisher, Madison, USA, pp. 263–273 .

Haynes, R. J., Belyaeva, O. N. & Kingston, G. (2013). Evaluation of industrial wastes as sources of fertilizer silicon using chemical extractions and plant uptake. *Journal Plant Nutrition Soil Science*, 176, 238-248.

Houben, D., Sonnet, P. & Cornelis, J.T. (2014). Biochar from Miscanthus: A potential silicon fertilizer. *Plant and Soil, l* 374, 871–882.

International Rice Research Institute (1991). Rice Germplasm: Collecting, Preservation and Uses. Los Banos, Phillippines. Retrieved March 30, 1991. *http://www.knowledgebank.irri.org/rkb/rice-milling.*

International Rice Research Institute (2013). Rice Knowledge Bank. Loa Banos, Philippines. Retrieved March 29, 2013. *http://www.knowledgebank.irri.org/rkb/rice-milling.*

Jien, S. H. & Wang, C. S. (2013). Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena*, *110*, 225–233.

Kajiura M., Wagai R. & Hayashi K. (2015).Optimal thermolysis conditions for soil carbon storage on plant residue burning: modeling the trade-off between thermal decomposition and subsequent biodegradation. *Journal of Environmental Quality*, *44*, 228 - 235.

Kalra, Y.P., Maynard, D.G. & Radford, F.G. (1988). Microwave digestion of tree foliage for multi-element analysis. *Canadian Journal of Forest Resource*, *19*, 981-985.

Kerenhap, W., Tniagarajan, V. & Kumar, V. (2007). Biochemical and Bioassay studies on the influence of different, organic manures on the growth of Mulberry variety V. and Silkworm (Bombyx mori L.) *Caspian Journal of Environmental Sci*ences, *5*(1), 51 - 56.

Korndorfer, G. H. & Lepsch (2001). Effect of silicon on plant growth and crop yield. In: Datnoff LE, Snyder GH, Korndorfer GH (eds). Silicon in agriculture. Studies in plant science, 8 Elsevier Amsterdam, pp 133 -147.

Kundsen, D., Peterson, G. A. & Pratt, P. F. (1982). Lithium, sodium and potassium, In A.L. Page *et al* (ed.). Methods of Soil Analysis Part 1 Agron. 9. ASA and SSA Madison, W.I. pp. 241– 262.

Kuzyakov, Y., Bogomolova, I. & Glaser, B. (2014). Biochar stability in soil: decomposition during eight years and transformation as assessed by compound-specific 14C analysis. *Soil Biology and Biochemistry*, 70, 229–236.

Lanyon, L. E. & Heald, W. R. (1984). Magnesium, calcium, strontium, and barium. In A.L. Page (ed.). Methods of Soil Analysis Part 2. Agron. Mongr. 9. ASA and SSA, Madison, W.I. pp. 247– 262.

Lehmann, J. & Joseph, S. (2009). Biochar for environmental management: An introduction. In. J. Lehmann and S. Joseph (eds.), Biochar for Environmental Management: Science and Technology. Earthscan Publ., London.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C. & Crowley, D. (2011). Biochar effects on soil biota: A review. *Soil Biology and Biochemistry, 43,*1812 - 1836.

Li, H., Ye, X., Geng, Z., Zhou, H., Guo, X., Zhang Y., Zhao, H. & Wang G. (2016). The influence of biochar type on long-term stabilization for Cd and Cu in contaminated paddy soils. *Journal of Hazardous Materials, 304*, 40 - 48.

Li, Z., Delvaux, B., Yans, J., Dufour, N., Houben, D. & Cornelis, J. T. (2018). Phytolith-rich biochar increases cotton biomass and silicon-mineralomass in a highly weathered soil. *Journal of Plant Nutrition and Soil Sciences, 181*, 537–546.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., Skjemstad, J. O., Thies, J., Luizão, F. J., Petersen, J., & Neves, E. G. (2006). Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal*, *70*(5), 1719-1730. https://doi.org/10.2136/sssaj2005.0383

Liu, J., Zhu, J., Zhang, P., Han, L., Reynolds, O. L., Zeng, R.,.... Gurr, G.M. (2017). Silicon supplementation alters the composition of herbivore induced plant volatiles and enhances attraction of parasitoids to infested rice plants. *Frontiers in Plant Science, 8*, 1265.

Major, J., Rondon, M., Molina, D., Riha, S.J. & Lehmann, J. (2010) Maize Yield and Nutrition during 4 Years after Biochar Application to a Colombian Savanna Oxisol. *Plant and Soil*, 333, 117-128.

McLean, E.O. (1982). Soil pH and lime requirements. In: methods of Soil Analyses Part II, Page, A. L., R. A. Miller, D.R. Keeney (eds). Chemical and Microbial Properties. American Society of Agron. Medison Wiscosin, U.S.A. pp 199-220.

Meena, V.D., Dotaniya, M.L., Coumar, V., Rajendiran, S., Kundu, S. & A.S. Rao, A. S. (2014). A case for silicon fertilization to improve crop yields in tropical soils. *Proceedings of National Academy of Sciences, India Section B: Biological Sciences, 84*, 505–518.

Mehlich, A. (1976). New buffer method for rapid estimation of exchangeable acidity and lime requirement. *Communications in Soil Science Plant Anaysis, 7*(7), 637 – 652.

Muthayya, S., Hall, J. Bagriansky, J. Sugimoto, J. Gundry, D., Matthias, D.,... Maberly, G. (2012). Rice Fortification an emerging opportunity to contribute to the elimination of vitamin and mineral deficiency worldwide. *Food and Nutrition Bulletin, 33*, 296 - 307.

Muthayya, S., Sugimoto, J. D., Montgomery, S. & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences*, *1324*(1), 7-14.

Nelson, D. W. & Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. Methods of soil Analysis. Part 2. Chemical and Microbiological Properties. ASA, Madison, WI pp. 359 – 580.

Nigussie, A., Kissi, E., Misganaw, M. & Ambaw, G. (2012). Effect of Biochar Application on Soil Properties and Nutrient Uptake on Lettuces (Lactuca sativa) Grown in Chromium Polluted Soils. *Americian-Eurasian Journal of Agriculture and Environmental Science*, 369-376.

Nwajiaku, I. M, Sato, K., Tokunari, T., Kitano, S. & Masunaga, T. (2018). Improvement of Rice Husk Residue Silicon Availability for Replenishing Available Silicon in Paddy Soil. *International Journal of Plant and Soil Science, 24*(2), 1-11.

Orjiude, A. (2022). Rice Production Hits Nine MT in 2021. Punch Newspaper, January 19.

Page, A. L., Miller, R. H. & Keeney, D. R. (1982). Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. ASA, Madison pp. 539 – 579.

Qian, L., Chen, B. & Chen, M. Novel (2016). Alleviation mechanisms of aluminum phytotoxicity via released biosilicon from rice straw derived biochars . *Scientific Report,* 6(1), 29346.

Qian, L., Chen, B. & Hu, D. (2013). Effective alleviation of aluminum phytotoxicity by manure-derived biochar. *Environmental Science and Technology*, *47*(6), 2737–2745.

Tavakkoli E., Lyons G., English P. & Guppy C. N. (2011). Silicon nutrition of rice is affected by soil pH, weathering and silicon fertilisation. *Journal of Plant Nutrition and Soil Sci*ence, *174*,437 - 446.

van Zwieten L., Kimber S., Morris S., Downie A., Berger E., Rust J., & Scheer C. (2010). Influence of biochars on flux of N2O and CO2 from Ferrosol. *Australian Journal of Soil Research 48*, 555-568. https://doi.org/10.1071/SR10004

Wang, Y., Xiao, X. & Chen, B. (2018). Biochar impacts on soil silicon dissolution kinetics and their interaction mechanism. *Science Report*, 1, 1 - 11.

World Rice Production 2021/2022. Global Rice Production. Retrieved on April 9, 2023. *www.worldagriculturalproduction.com/crops/rice.*

Wu, W., Yang, M., Feng, Q., McGrouther, K., Wang, H., Lu, H. & Chen, Y. (2012). Chemical Characterization of Rice Straw-Derived Biochar for Soil Amendment. *Biomass and Bioenergy*, *47*, 268-276.

Xiao, X., Chen, B., Chen, Z., Zhu, L. & Schnoor, J. L. (2018). Insight into multiple and multilevel structures of biochars and their potential environmental applications: a critical review. *Environmental Science and Technology*, *52*, 5027–5047.

Xu, G., Shao, H. B. & Sun, J.N. (2013). What is more important for enhancing nutrient bioavailability with biochar application into a sandy soil: direct or indirect mechanism. *Ecological Engineering*., 52, 119-124.

Yoo, G. Y., Kim, H. J., Chen, J.J. & Kim Y. S. (2014). Effects of biochar addition on nitrogen leaching and soil structure following fertilizer application to rice paddy soil. *Soil Science Society of America Journal*, 78, 852-860.

Yuan, J., Xu, R., Wang, N. & Li J. (2011). Amendment of acid soils with crop residues and biochars. *Pedosphere*, 21, 302–308.

Zhao, R., Coles, N., Kong, Z. & Wu, J. (2015). Effects of aged and fresh biochars on soil acidity under different incubation conditions. *Soil Tillage Research*, 146, 133–138.

APPENDICES

Table 1. Physicochemical Properties of the soil used for the pot experiment

Soil Parameters	Values
Particle size distribution	
Sand (g kg^{-1})	590.0
Silt (g kg^{-1})	142.0
Clay (g kg^{-1})	268.0
Textural class	**Sandy clay loam**
Soil pH	4.6
Available Phosphorus (mg kg^{-1})	15.8
Available Silicon (mg kg^{-1})	25.2
Total nitrogen (%)	0.106
Organic Carbon (g kg-^{1})	12.1
Exchangeable cations	
Calcium (Cmol kg^{-1})	3.6 /
Magnesium (Cmol kg^{-1})	1.2
Potassium (Cmol kg^{-1})	0.218
Sodium (Cmol kg^{-1})	0.202
Cation exchange capacity (CEC) (Cmol kg^{-1})	6.9
Exchangeable acidity	
Hydrogen ion (Cmol kg^{-1})	1.68
Aluminium ion (Cmol kg^{-1})	0.58

Table 2: The chemical composition of the produced biochar used for the experiment

Parameters	**RHB (60 minutes charring)**	**RHB (90 minutes charring)**	**RHB (120 minutes charring)**
Biochar yield (%)	79.4	63.2	51.4
Ash content (%)	27.0	32.0	35.0
pH (H_2O)	5.9	6.6	6.8
Total C (g kg^{-1})	168.0	169.6	181.4
Total P (g kg^{-1})	15.2	16.4	16.8
Total N (g kg^{-1})	8.9	7.7	6.9
Total Ca (g kg^{-1})	6.9	7.3	7.9
Total K (g kg^{-1})	9.1	10.4	10.6
Total Mg (g kg^{-1})	4.1	4.6	4.8
Total Si (g kg^{-1})	69.20	75.80	88.40

Note: RHB = Rice husk biochar

Table 3. Effect of biochar on crop growth and yield performance

Treatments	Plant height	Tiller number	Shoot biomass	Root biomass	Grain weight
	(cm pot^{-1})			(g pot^{-1})	
Control	91.7a	9.0a	13.3a	10.5a	9.4ab
RHB60	87.3a	9.0a	13.4a	5.4c	7.2b
RHB90	83.2a	8.0a	11.6a	8.3b	8.5b
RHB120	95.6a	10.0a	13.5a	5.0c	12.5a
CV%	10.5	25.5	28.0	19.6	32.9

Note: RHB90= Rice husk biochar charred at 250^{o}C for 60 minutes, RHB90= Rice husk biochar charred at 250^{o}C for 90 minutes and RHB120= Rice husk biochar charred at 250^{o}C for 120 minutes. The different alphabet in a column showed statistical difference ($p < 0.05$).

Table 4: Soil chemical composition after harvest

Treatments	pH (H_2O)	Avail. P	Total N	**OC**	Exchangeable bases				Exchangeable acidity		CEC	Avail. SiO_2
		Mg kg^{-1}			Ca	Mg	K	Na	H^+	Al^{3+}		
				g kg^{-1}		Cmol kg^{-1}			Cmol kg^{-1}		Cmol kg^{-1}	mg kg^{-1}
Control	4.9c	13.20d	0.88d	10.5d	3.0d	0.80c	0.17dc	0.16a	1.82a	0.78a	5.95d	20.4d
RHB60	5.7b	19.40c	1.53a	16.4b	4.8c	2.20b	0.22c	0.29a	1.34b	0.42b	8.95c	29.3c
RHB90	5.7b	22.07b	1.22b	19.9a	5.2b	2.80a	0.32b	0.31a	1.12c	0.32c	9.82b	35.1b
RHB120	6.3a	23.57a	1.18c	14.4c	5.8a	2.80a	0.36a	0.22a	0.87d	0.22d	10.30a	37.4a
CV%	9.3	21.1	16.0	23.9	23.3	39.8	30.5	38.5	1.1	51.3	20.2	22.4

Note: RHB90= Rice husk biochar charred at 250°C for 60 minutes, RHB90= Rice husk biochar charred at 250°C for 90 minutes and RHB120= Rice husk biochar charred at 250°C for 120 minutes. The different alphabet in a column showed statistical difference ($p < 0.05$).