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Impact of rice-straw biochar on some selected soil properties and rice (*Oryza sativa* L.) grain yield

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Abstract

Biochar is a co-product of pyrolysis of rice straw biomass, its qualities vary according to pyrolysis conditions but it mainly contains phosphorus and potassium. The carbon (C) content in biochar is stable, so it can be applied to soils which enlarging the C sink. In the present investigation, a biochar was produced from rice straw residue, characterized and its effect on rice grain yield, pH, soil organic carbon, total N and changes in NH4+–N and NO3-–N concentrations in rice soil under intermittent wetting-drying and continuous flooding were examined. The results showed that, the rice straw-derived biochair produced was neutral in pH and the cation exchange capacity 37 cmol kg -1. Application of biochar, reduces the NH4+–N and NO3-–N concentrations in soil irrespective of moisture conditions. Such effect was more pronounced on NH4+–N and NO3-–N concentrations under flooding condition and intermittent wetting&drying condition, respectively. Increasing the rate of rice straw derived biochair application rate had significantly decreased both the NH4+–N and NO3-–N concentrations in soil. The resulted rice yield from T3 (30 g biochair per kg-1 dry soil) was the highest and significant difference compared to other treatments. The biochair application significantly enhanced the total soil N, soil organic carbon and soil pH under both flooding and wetting&drying conditions.

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Introduction

Although rice straw residue constitutes an enormous resource, actual residue management practices in rice-based systems have various negative side effects and contribute to global warming. Egypt, with a long history of agricultural development, currently faces an urgent problem of significant carbon (C) loss from agricultural paddy soils due to the intensive cropping system used for food production. Direct incorporation of rice straw into paddy soil has long been promoted by the Egyptian government to conserve soil nutrients and organic carbon content. Although this management practice helps to improve soil fertility, it only results in a slight increase in soil organic carbon and in the process creates significant increase in methane (CH_4) which released to the atmosphere Chidthaisong and Watanabe, (1997). In intensive Egyptian agricultural systems, where 2–3 crops are grown each year, the time for rice straw residue incorporation and decomposition is very short, so un-decomposed remains and decomposition products often disrupt soil preparation, crop establishment, and early crop growth. Therefore, rice straw residue burning is still widely practiced, contributing to air pollution, human health problems, and substantial nutrient losses Tipayarom and Kim Oanh, (2007); Gustafsson *et al*., (2009).

Biochar is an organic material produced via the pyrolysis of C-based biomass and is best described as a (soil conditioner). Biochar is a kind of carbonized organic matter; black carbon, which more stable relative to other soil organic matter forms Lehmann (2007). Formation of rice straw-based biochar technology appears to be a promising method to address the problem of reductions in soil nutrients and C storage, and increased Green House Gases (GHGs) emissions associated with rice straw application Lou *et al*., (2007). Biochar is a term generally used for the plant biomass derived materials contained within the black carbon. The unique characteristics of the Biochar are its effectiveness in retaining most nutrients and keeping them available to plants than other organic matter (e.g. leaf litter, compost and manures. The chemical structure of charcoal is characterized with poly-condensed aromatic groups, providing prolonged biological and chemical stability that sustains the resistance towards microbial degradation; it also provides, after partial oxidation, the highest nutrients retention. The large negative surface charge of biochar could directly retain positively charged nutrients and decrease nutrients leaching (Liang *et al*., 2006). Lehmann (2007) reported that biochar is biologically stable; the benefit of higher cation exchange capacity (CEC) may be obtained without the risk of contributing to seasonal flushes of NO_3^-. In the context of nutrient availability, the impact of biochar addition on pH may be important (Steiner *et al*., 2007).

Biochar is a unique substance, retaining exchangeable and therefore plant available nutrients in the soil and offering the possibility of improving crop yields while decreasing environmental pollution by nitrogen. However, most studies on biochar as a soil amendment concentrated on extensive production systems, on crops other than rice. Therefore, the objective of this research was to produce characterization and determine the effect of rice-straw biochar on some selected paddy soil properties and rice grain yield.

Materials and methods

Rice straw-biochair production

Rice straw (*Oryza sativa*) was collected from rice research and training center experimental farm, Sakha, Kafr El-Sheikh, Egypt. Some chemical characterization of collected rice straw is shown in Table (1). First, rice straw was dried at 60 C° for 24 hours to less than 10% moisture content, and then cut to a particle size of 2 cm. For pyrolysis, the samples were placed in a tubular furnace equipped with a corundum tube (32 mm diameter x 700 mm length) with a N_2 purge (flow rate @ 1 L/minute) to ensure an O_2-free atmosphere. Heat treatments were performed in temperature varied from 300 -700 C°. The heating rate was adjusted to be 7 C°/ minute. Each temperature was maintained for 1 to 5 hours before cooling to ambient temperature. The yield of the obtained rice straw char was recorded, milled to pass a 0.25 mm-sieve and subjected to the following measurement, ash content, volatile matter, total C, total N, H, and O. The biochar properties were characterized for total organic C and N with an Elementar CNS Analyser (German Elementar Company, 2003). The pH of the biochair was measured using mixture of 1:5: water suspension with a pH meter. Total ash content was determined using 720 C° ignition in a muffle furnace for 3 hour, and the mineral element content was determined by digestion with HNO_3–$HClO_4$–HF mixture, finally elemental analysis determined by atomic adsorption spectroscopy. The cation exchange capacity (CEC) was measured using 1.0 M ammonium acetate (at pH 7) according to method of Rayment and Higginson, (1992). Available phosphorus (P) was extracted by placing 1.0 g sample in 20 mL of 0.50 M $NaHCO_3$ solution for 30 minutes. Extracts were then filtered and analyzed using the Molybdate method (Kuo, 1996).

Table 1. Mean values of elements of rice straw used for biochair production.

Element	Total C	Total N	K	Ca	Mg	Na
Composition (%)	40.9	0.11	1.21	0.65	0.16	0.14

Characterization of experimental soil

The soil used in the pot experiments was collected from rice research and training center experimental farm, Sakha, Kafr El-Sheikh, Egypt. Soil samples were air-dried, and then sieved by 2-mm stainless steel sieve. The pH and EC of samples were measured (using 1:5 ratio with distilled water) by pH-meter and the electrical conductivity meter, respectively. Complex metric EDTA titration was employed for determining Ca^{++} and Mg^{++} simultaneously and individually Sparks, (1996). Sodium and potassium was determined using flame photometer. Carbonate and bicarbonate were determined by titration with H_2SO_4 while silver nitrate was used to determine chloride (Sparks 1996). Particle size distribution was analyzed according to Gee and Bauder, (1996). Some selected soil properties are shown in Table (2).

Table 2. Some selected soil properties of the experimental site.

p H	*EC*	*Cations (meq L^{-1})*				*Anions (meq L^{-1})*				*Particles size %*		
	(dS m^{-1})	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SO_4^{2-}	Sand	Silt	Clay
7.70	1.63	2.68	1.60	3.72	2.68	3.77	2.18	3.65	2.57	12.0	33.9	54.1

Pot experiment

There were three treatments as follow:

T_1 – Recomended NPK chemical fertilizer

T_2 – Rice straw-biochar (@15 g kg^{-1} dry soil)

T_3 – Rice straw-biochar (@30 g kg^{-1} dry soil)

T1, T2 and T3 treatment was carried out under both wetting-drying cycles and continuous flooding as regular management. The treatment was replicated four times. Soil passes the through 2 mm sieve, fill 8 kg dry soil and mixing well with biochair. The recommended N fertilizer was applied in three equal splits during the cultivation period. Phosphorus as P_2O_5 and K as KCl were applied as a basal dose to all pots at the rate of 8 g m^{-2} in one dose just before transplanting. Two of seedlings of three weeks- rice cultivar (Sakha 102) were transplanted into each pot with five replicates. Regular management is carried out for rice growth.

Table 3. Effect of rice-straw biochair on rice dry weight (g) accumulation at harvesting stage.

Amendments	Flooding Conditions			Wetting& Drying Conditions		
	Shoots	Roots	Total	Shoots	Roots	Total
NPK chemical fertilizer (**T1**)	49.1a	15.2a	64.3a	38.5a	13.7a	52.2a
Rice straw-biochar (15 g kg^{-1} dry soil) (**T2**)	54.2a	16.1a	70.3a	36.7a	14.7a	51.4a
Rice straw-biochar (30 g kg^{-1} dry soil) (**T3**)	55.3a	15.3a	70.6a	35.8a	14.18a	49.9a

Means within a column followed by the different letters are significantly different at the 0.05 probability level.

Soil analysis

Soil samples were taken to measure ammonium-N and nitrate-N concentrations after rice harvesting. A 10 g sub-sample was then weighed and extracted using 50 ml of 2 M KCl solution before being filtered. The filtered solution was then analyzed calorimetrically for $NO3^{-}$–N and NH_4^{+}–N concentrations using an Auto Ion analyzer Model AAII, Brant+Luebbe, Germany (Anonymous, 1974; Litchfield, 1967; Varley, 1966). Sub soil sample was ground to pass a 0.15 mm sieve for C and N analysis using the same method as for biochar analysis.

Table 4. Effect of rice-straw biochair on rice yield and its components.

Amendments	Panicles/ hill	Spikelet / panicle	1000-grain weight (g)	Yield (g pot^{-1})	Yield increases over NPK treatment
	Flooding Conditions				
NPK chemical fertilizer	7.5c	120b	24.0a	23.5b	-
Rice straw-biochar (15 g kg^{-1} dry soil)	9.3b	126b	24.3a	26.5b	12.7%
Rice straw-biochar (30 g kg^{-1} dry soil)	11.5a	130a	24.4a	35.1a	49.3%
	Wetting& Drying Conditions				
NPK chemical fertilizer	6.9c	115b	23.5a	22.1b	-
Rice straw-biochar (15 g kg^{-1} dry soil)	8.1b	121ab	23.1a	25.1b	13.5%
Rice straw-biochar (30 g kg^{-1} dry soil)	9.5a	127a	24.3a	30.3a	37.1%

Means within a column followed by the different letters are significantly different at the 0.05 probability level.

Statistical analysis

The collected data were statistically analyzed using ANOVA at first, then the homogeneity of variances was tested using multiple comparison tests with Tukey-Kramer method at ($p < 0.05$) using KyPlot software packages (Kyenslab Inc., Tokyo, Japan).

Table 5. Some selected chemical properties of soil amending with chemical fertilizers and rice straw-biochair after rice harvesting.

Amendments	*Flooding Conditions*			*Wetting& Drying Conditions*		
	Soil pH	Total N (%)	Soil organic carbon (%)	Soil pH	Total N (%)	Soil organic carbon (%)
NPK chemical fertilizer	7.5±0.1b	2.01±0.04b	22.2±1.2b	7.1±0.1b	1.98±0.03b	23.1±1.2b
Rice straw-biochar (15 g kg^{-1} dry soil)	7.6±0.8b	2.18±0.01a	26.1±1.3b	7.5±0.09a	2.01±0.1a	27.8±1.4b
Rice straw-biochar (30 g kg^{-1} dry soil)	7.7±0.2ab	2.51±0.01a	34.8±1.5a	7.8±0.1a	2.3±0.1a	38.9±1.3a

Means within a column followed by the different letters are significantly different at the 0.05 probability level.

Results and Discussion

Rice-straw biochair properties

Biochar was produced from the rice straw was characterized and the obtained results showed that the pH of biochar has pH 7.97) It contained ash 29%, carbon 88%, hydrogen 3.30%, nitrogen 1.60%, oxygen 1.40%, volatile matter 22.3%, yield 40.3%, phosphorus 529 mg kg^{-1} and CEC of 30 cmol kg^{-1}.

Rice dry weight, yield and its components

Table 3 shows the dry weight production accumulation at harvesting. There was no significant difference observed between the treatments in the dry weight. Rice yield and its attributers of biochair treated rice are all higher than those of the recommended NPK (Table 4). Among the treatments, T3 has the highest rice grain yield; it had increased the rice grain yield by 12.7-49.3% under T3 compared to T1 with respecting wetting&drying condition and flooding conditions. The main reason of yield increases could be mainly attributed to increase the panicles/ hill and spikelet/panicle. Rice straw biochair application has shown to increase rice productively mainly by improving physical and chemical properties of the soil (Asai *et al.*, 2009). In addition, after biochair is applied into soil, it can adsorb more nutrients and organic matter Accardi *et al.*,(2002).

Effect of biochair on soil properties

Results describing some selected soil chemical characterization at the end of the experiment are presented in (Table 5). Rice-straw biochair application resulted in soil increases pH, soil organic carbon and total N under both under wetting&drying and flooding regime. Under flooding conditions, total N increased 8.45% and 24.8% under treatment T2, T3, respectively compared to recommend NPK (T1). Similarly, soil organic carbon was enhanced by 17.5% and 56.7% under T2 compared to T1 treatment. Such effect was more pronounced under intermittent wetting and drying condition. The biochair plays an important role in changing chemical and physical soil properties, facilitating rice growth and therefore increasing the yield (Lehmann *et al.,* 2003, 2006). The biochar amendment applied can increase N availability to crops (Chan *et al*., 2008) and therefore high levels of soil organic carbon accumulation can enhance N efficiency and increases rice production Liang *et al*., (2006); Pan *et al*., (2009).

Effect of biochair on NH_4^+-N and NO_3^-–N dynamics

Effect of rice-straw biochar on NH_4^+–N (mg kg^{-1}) concentrations of rice paddy soil under different water regime is shown in Figure 1. The mineral NH_4^+–N and NO_3^-–N concentrations was increased up to tillering stage and thereafter showed a declining trend at harvesting stage. Increases of biochar application rate markedly decreased the NH_4^+–N concentrations under both flooding and intermittent wetting drying conditions. Irrespective of biochar treatments, the NH_4^+–N content was significantly higher in soil under submerged condition than under intermittent wetting and drying condition. During the rice crop growth, the NH_4^+–N concentrations was found decreased both under submerged condition and intermittent wetting &drying conditions. NO_3^-–N concentrations was also influenced by the moisture regime and biochar application (Figure 2). NO_3^-–N concentrations at tillering stage and harvesting growth stages, was relatively higher in soil under intermittent wetting drying cycles than that under flooding condition. The application of biochair resulted in significant decrease in NO_3^-–N concentrations under the two water regimes; however, the reduction was greater at higher level of biochar (T3) treatment. This effect was more pronounced under flooding condition than the intermittent wetting and drying condition. The reduction of NO_3^-–N concentration could be attributed to rice uptake. As the chemistry of flooding soil differs from that of upland, the N dynamics also changed accordingly. The submerged soil appears to be an ideal medium for both aerobic and anaerobic N fixation, especially in the presence of rice plants. Nitrogen occurs in rice soil as organic-N, NH_4^+, molecular N_2, NO_3^- and NO_2. The transformation that they undergo is largely microbial introversions regulated by the soil physical and chemical characterization Sahrawat (2005). In flooding soil, the main transformations are the accumulation of NH_4^+–N, de-nitrification and N fixation, depending upon nature and content of OM, Eh, pH and soil temperature. The mineralization of organic N in flooding soil stops at the NH_4^+ stage because of the lack of oxygen to carry the process via NO_2 to NO_3. Therefore, NH_4^+–N accelerates under flooding conditions. Whereas, in soil under intermittent wetting&drying cycles, aeration causes active nitrification to take place, resulting in more NO_3^-–N accumulation Ghoneim *et al*., (2012). The addition of biochar to soil significantly reduces the concentrations of soil NH_4^+–N and NO_3^-–N, mainly due to electrostatic adsorption of nutrients on biochar particles. In addition, biochar was can adsorb large amounts of NH_4^+ which may have lowered the NH_4^+–N concentrations in soil (Steiner *et al.,* 2007). However, it should be noted that immobilization potential associated with biochar additions to soil would be greatly limited by the recalcitrant nature of biochar (DeLuca and Aplet, 2007). The reduction in N availability could be due to greater immobilization in biochar amended soil since the biochar used in the experiment had a high C/N ratio. Biochar application to agricultural soils of tropics has been reported to either reduce N availability (Lehmann *et al*., 2003, 2006) or increases N uptake (Steiner *et al*., 2007).

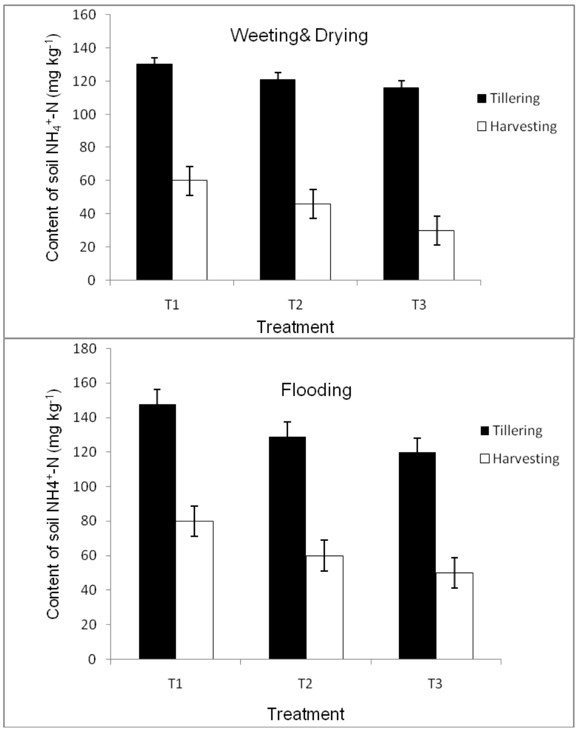

Fig. 1. Effect of rice-straw biochar on NH4+–N concentrations (mg kg-1) of soil at different rice growth stage. Vertical bars represent Standard Error (SE, n=4).

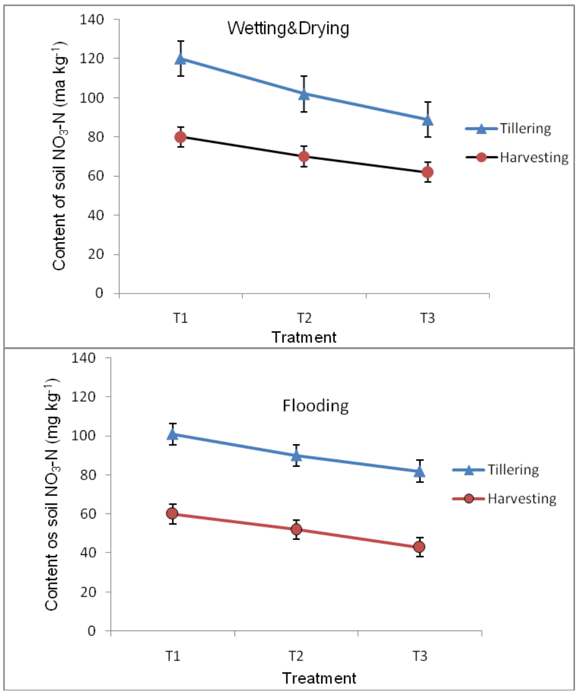

Fig. 2. Effect of rice-straw biochar on NO3-–N soil concentrations (mg kg-1) at different rice growth stage. Vertical bars represent Standard Error (SE, n=4).

Conclusion

The objectives of this study were to determine the effect of rice-straw derived biochair on selected soil properties and rice yield. The results showed that the biochar has positive effect on soil organic carbon, total N and decreased NH_4^+–N and NO_3^-–N concentrations. It is suggest that, the use of rice straw as the initial material for biochar production will result in a large amounts of rice straw being removed from rice fields. The long term effect of rice-straw derived biochar amendment for rice production need further study to identify the most cost effective and environmental friendly management practices for rice culture.

References

Accardi-dey A, Gschwend PM. 2002. Assessing the aspects of phosphate adsorption by charcoal. Soil Science Society of America Proceeding, **24**, 340-346.

Anonymous. 1974. *Technician Auto-analyzer* II, Technician Industrial Systems. Tarrytown, NY, 10591.

Asai H, Samson KB, Stephan MH, Songyikhangsuthor K, Homma K, Kiyono Y, Inoue, Y, Shiraiwa T, Horie T. 2009. Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Research **111**, 81-84.

Chan KY, Zwieten VL, Meszaros I, Dowine A, Joseph S. 2008. Using poultry litter biochars as soil amendments. Aust. J. Soil Research **46**, 437-444.

Chidthaisong A, Watanabe I. 1997. Methane formation and emission from flooded rice soil incorporated with 13C-labeled rice straw. Soil Biol Biochemistry **29**, 1173-1181.

DeLuca TH, Aplet GT. 2007. Charcoal and carbon storage in forest soils of the Rocky Mountain West. Front. Ecol. Environ **6**, 1-7.

Gee GW, Bauder JW. 1996. Particle Size Analysis, 3th Ed. In: Methods of soil Analysis. Part 1: Physical and Mineralogical Methods, S.S.S.A. and American Society of Agronomy, Madison, WI, 377-382.

Ghoneim AM, Ueno H, Asagi N, Takeshi W. 2012. Indirect ^{15}N isotope techniques for estimating N dynamics and N uptake by rice from poultry manure and sewage sludge. Asian Journal of Earth Sciences **5(2)**, 63-69.

Gustafsson Ö, Kruså M, Zencak Z, Sheesley RJ, Granat L, Engström E, Praveen PS, Rao PSP, Leck C, Rodhe H. 2009. Brown clouds over South Asia: biomass or fossil fuel combustion? Science **323**, 495-498.

Kuo S. 1996. Phosphorus. In: Sparks DL, editor. Methods of soil analysis: chemical methods. Part 3-chemical methods. Madison, Wis: ASA-CSSA-SSSA; 869-919.

Lehman J, Gaunt K, Rondon M. 2006. Biochar sequestration in terrestrial ecosystems – a review. Mitigat. Adapt. Strate. Global Change **11**, 403-427

Lehmann J, Kern DC, Glaser B, Woods WI. 2003. Biochar and carbon sequestration. In: Amazonian Dark Earths: Origin, Properties, Management. Kluwer Academic Publishers, Netherlands, 523.

Lehmann J. 2007. A handful of carbon. Nature, **447**, 143-144.

Liang B, Lehmann J, Solomon j, Kinyangi D, Grossman J, O'Neill J, Skjemstad B, Thies JO,

Luizão J, Petersen FJ, Neves J. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soci. America Journal **70,** 1719-1730.

Litchfield MH. (1967). The automated analysis of nitrite and nitrate in blood. Analyst **92**, 132-136.

Lou YS, Ren LX, Li ZP, Zhang TL, Inubushi K. 2007. Effect of rice residues on carbon dioxide and nitrous oxide emissions from a paddy soil of subtropical China. Water Air Soil Pollution **178**, 157-168.

Pan GX, Zhou P, Li ZP, Smith P, Li LQ, Qiu DS, Zhang XH, Xu XB, Shen SY, Chen, XM. 2009. Combined inorganic/organic fertilization enhances N efficiency and increases rice productivity through organic carbon accumulation in a rice paddy from the Tai Lake region, China. Agric. Ecos. Environ. **131**, 274-280.

Rayment GE, Higginson FR. 1992. Australian laboratory handbook of soil and water chemical methods. Inkata, Melbourne.

Sahrawat KL. 2005. Fertility and organic matter in submerged rice soil. Current Science, 88, 735-739.

Sparks DL. 1996. Methods of Soil Analysis. Part 3. Chemical Methods. SSSA Book Ser. 5. ASA and SSSA, Madison, WI, USA.

Steiner C, Teixeira W, Lehmann W, Nehls J, MacêDo T, Blum JLV, Zech WEH. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant and Soil **291,** 275-290.

Tipayarom D, Kim Oanh NT. 2007. Effects from open rice straw burning emission on air quality in the

Bangkok metropolitan region. Science Asia **33**, 339-345.

Varley JA. 1966. Automated method for the determination of nitrogen, phosphorus and potassium in plant material. Analyst **91**, 119-126.