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

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**Key words**: Rice straw biomass, biochar production, soil chemical properties, N dynamics.

**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 NH$_4^+$–N and NO$_3^-$–N concentrations in rice soil under intermittent wetting-drying and continuous flooding were examined. The results showed that, the rice straw-derived biochar produced was neutral in pH and the cation exchange capacity 37 cmol kg $^{-1}$. Application of biochar, reduces the NH$_4^+$–N and NO$_3^-$–N concentrations in soil irrespective of moisture conditions. Such effect was more pronounced on NH$_4^+$–N and NO$_3^-$–N concentrations under flooding condition and intermittent wetting&drying condition, respectively. Increasing the rate of rice straw derived biochar application rate had significantly decreased both the NH$_4^+$–N and NO$_3^-$–N concentrations in soil. The resulted rice yield from T3 (30 g biochar per kg-1 dry soil) was the highest and significant difference compared to other treatments. The biochar 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 undecomposed 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-biochar 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 biochar 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 HNO₃–HClO₄–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 NaHCO₃ 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 biochar production.

<table>
<thead>
<tr>
<th>Element</th>
<th>Total C (%)</th>
<th>Total N</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>40.9</td>
<td>0.11</td>
<td>1.21</td>
<td>0.65</td>
<td>0.16</td>
<td>0.14</td>
</tr>
</tbody>
</table>

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 H₂SO₄ 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.

<table>
<thead>
<tr>
<th>pH</th>
<th>EC (dS m⁻¹)</th>
<th>Cations (meq L⁻¹)</th>
<th>Anions (meq L⁻¹)</th>
<th>Particles size %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ca²⁺  Mg²⁺  Na⁺  K⁺  Cl⁻</td>
<td>HCO₃⁻  CO₃²⁻  SO₄²⁻</td>
<td>Sand  Silt  Clay</td>
</tr>
<tr>
<td>7.70</td>
<td>1.63</td>
<td>2.68  1.60  3.72  2.68  3.77</td>
<td>2.18  3.65  2.57  12.0  33.9  54.1</td>
<td></td>
</tr>
</tbody>
</table>

Pot experiment

There were three treatments as follow:

T₁ – Recommended NPK chemical fertilizer
T₂ – Rice straw-biochar (@15 g kg⁻¹ dry soil)
T₃ – 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 biochar. The recommended N fertilizer was applied in three equal splits during the cultivation period. Phosphorus as P₂O₅ 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 biochar on rice dry weight (g) accumulation at harvesting stage.

<table>
<thead>
<tr>
<th>Amendments</th>
<th>Flooding Conditions</th>
<th>Wetting&amp; Drying Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shoots</td>
<td>Roots</td>
</tr>
<tr>
<td>NPK chemical fertilizer (T1)</td>
<td>49.1a</td>
<td>15.2a</td>
</tr>
<tr>
<td>Rice straw-biochar (15 g kg⁻¹ dry soil) (T2)</td>
<td>54.2a</td>
<td>16.1a</td>
</tr>
<tr>
<td>Rice straw-biochar (30 g kg⁻¹ dry soil) (T3)</td>
<td>55.3a</td>
<td>15.3a</td>
</tr>
</tbody>
</table>

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 NH₄⁺–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 biochar on rice yield and its components.

<table>
<thead>
<tr>
<th>Amendments</th>
<th>Flooding Conditions</th>
<th>Wetting&amp; Drying Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Panicle s/ hill</td>
<td>Spikelet / panicle weight (g)</td>
</tr>
<tr>
<td></td>
<td>1000-grain weight (g)</td>
<td>Yield (g pot⁻¹)</td>
</tr>
<tr>
<td>NPK chemical fertilizer</td>
<td>7.5c</td>
<td>120b</td>
</tr>
<tr>
<td>Rice straw-biochar (15 g kg⁻¹ dry soil)</td>
<td>9.3b</td>
<td>126b</td>
</tr>
<tr>
<td>Rice straw-biochar (30 g kg⁻¹ dry soil)</td>
<td>11.5a</td>
<td>130a</td>
</tr>
<tr>
<td>NPK chemical fertilizer</td>
<td>6.9c</td>
<td>115b</td>
</tr>
<tr>
<td>Rice straw-biochar (15 g kg⁻¹ dry soil)</td>
<td>8.1b</td>
<td>121ab</td>
</tr>
<tr>
<td>Rice straw-biochar (30 g kg⁻¹ dry soil)</td>
<td>9.5a</td>
<td>127a</td>
</tr>
</tbody>
</table>

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-biochar after rice harvesting.

<table>
<thead>
<tr>
<th>Amendments</th>
<th>Flooding Conditions</th>
<th>Wetting&amp; Drying Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil pH (7.5±0.1b)</td>
<td>Total N (%) (2.01±0.04b)</td>
</tr>
<tr>
<td>NPK chemical fertilizer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice straw-biochar (15 g kg⁻¹ dry soil)</td>
<td>7.6±0.8b</td>
<td>2.18±0.01a</td>
</tr>
<tr>
<td>Rice straw-biochar (30 g kg⁻¹ dry soil)</td>
<td>7.7±0.2ab</td>
<td>2.51±0.01a</td>
</tr>
</tbody>
</table>

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

Results and Discussion

Rice-straw biochar 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 biochar 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 biochar application has shown to increase rice productively mainly by improving physical and chemical properties of the soil (Asai et al., 2009). In addition, after biochar is applied into soil, it can adsorb more nutrients and organic matter Accardi et al.,(2002).

Effect of biochar on soil properties

Results describing some selected soil chemical characterization at the end of the experiment are presented in (Table 5). Rice-straw biochar 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 biochar 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 biochar 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 biochar 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 biochar on selected soil properties and rice yield. The results showed that the biochar has positive effect on soil organic carbon, total N and decreased NH₄⁺–N and NO₃⁻–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


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