Growth of aerobic rice in the presence of biochar as soil amendment: short-term effects in a clayey Rhodic Ferralsol in the Brazilian savannah (Cerrado)

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Abstract
Increasing yields in aerobic rice systems (ARS) is a challenge in the Brazilian savannah (BS), where rice is grown under unfavourable conditions characterised by well drained and low fertile soils. Management options that could increase soil water availability and nitrogen (N) use efficiency would probably lead to higher grain yields in ARS. One promising option under consideration is the use of 'biochar', a by-product of charcoal made of hardwood, as a soil amendment. Biochar is high in resistant (pyrogenic) carbon (70 to 80% of the material), which influences some processes in soil, depending on the amount applied and its interaction with the soil properties. Yet there are no conclusive field studies that quantify the effect of hardwood biochar application on grain yield of ARS in the BS. Here, we report single season effects of biochar application coupled with N fertilisation on aerobic rice growth and grain yield in a clayey Rhodic Ferralsol in the BS. At 72 days after sowing, leaf area index and total shoot dry matter of aerobic rice was negatively related to biochar rates above 16 Mg/ha. This effect might be related to changes in soil properties due biochar application, such as increased soil nitrate availability.We found that biochar applications did not influence grain yield. The effect of N fertilisation on yield followed a quadratic pattern, with an optimal N rate of around 46 kg/ha to achieve a grain yield above 3 Mg/ha, regardless of biochar application. The trends will guide future research.

Key Words
Oryza sativa, yield, pyrogenic carbon, nitrogen, Oxisol.

Introduction
Aerobic rice based cropping systems (ARS) are typically rain fed, where rice is grown on well drained soils. Less demand for labor, mechanization and water are important advantages of this system. Disadvantages of ARS include high weed pressure, water limitation due to rainfall variability, and low soil nutrient availability (Fageria 2001). A suggested strategy to improve soil fertility is the application of 'biochar'as soil amendment. Pieces of charcoal smaller than 8 mm are a by-product of charcoal production readily available in the Brazilian savannah (BS). An otherwise worthless by-product, which we refer to as 'biochar', can be recycled as a soil amendment. Biochar is high in resistant (pyrogenic) carbon (70 to 80% of the material). Adding large amounts of biochar might increase soil mineralization or immobilization of nitrogen (N) immediately after biochar application in soil. Given the potential for co-limitations, the interactions between N fertilisation and biochar application are particularly relevant. Some of the effects of hardwood biochar on soil chemical properties in a Ferralsol have been reported (Lehmann et al. 2003, Steiner et al. 2007). However, there are still no conclusive field studies that quantify the effect of hardwood biochar application on grain yield of ARS in the BS. The objective of this paper was to report on the short-term effects of biochar application and its interaction with N fertilisation on aerobic rice growth and grain yield in a clayey Rhodic Ferralsol in the BS.

Methods
Study location and experimental design
An experimental field was established on June 9, 2009, in a clayey Rodhic Ferralsol at the National Rice and Beans Research Centre ('Embrapa Arroz e Feijão'), in Santo Antonio de Goiás, Goiás, Brazil (16°29'17 "S and 49°17'57 "W). Experimental plots were arranged in four replications, with nitrogen (0, 30, 60 and 90 kg/ha) and biochar (0, 8, 16, 32 Mg/ha), each applied in four rates. Each plot had an area of 28 m^2. Plots were located under a centre pivot; a total of 78 mm of water via irrigation was applied throughout the

growing season (from November 2009 to February 2010). Total rainfall during the growing season was 855 mm, and average temperature was 24 °C. Biochar was incorporated into soil at 0-20 cm layer using a harrow, six months prior to sowing rice (June 9, 2009). Following a crop of common beans (*Phaseolus vulgaris*), aerobic rice, cultivar 'Primavera', was sown on November 3, 2009, in seven 10 m-rows in each plot with row spacing of 40 cm, at a plant density of 100 seeds/m. The crop was harvested on February 22, 2010. Rates of 120 kg/ha of P and 60 kg/ha of K were applied to all plots and incorporated in soil together with the rice seeds. Rates of nitrogen (urea) were divided in two applications: 50% at sowing incorporated in soil together with rice seeds, and 50% at 33 days after sowing, as topdressing.

Biochar properties
The source of the biochar was charcoal produced from plantation timber (*Eucalyptus* sp.) by slow pyrolysis at around 400-550 °C. It was milled to pass 2 mm sieve before soil application. Chemical analysis showed that 1 Mg of biochar contained around 770 kg of carbon, 3 kg of nitrogen, 0.005 kg of phosphorous, 0.06 kg of potassium, 0.6 kg of calcium, and 0.3 kg of magnesium. This accounts for 81% of the biochar mass.

Plant and soil sampling and measurements
Yield (weight of grains dried to 13% moisture) was determined from an area of 2.4 m^2 (two rows of three meters) at 110 days after sowing (DAS). Harvest index was calculated as the ratio between weight of dried grains and weight of total shoot dry matter (including grains) at 110 DAS. Spikelet fertility was calculated as the ratio between the number of full grains and total number of grains per spikelet. At 72 DAS, the leaf area index (LAI) and total shoot dry matter (TDM) were determined using plants collected from a 50 cm row (area of 0.2 m^2) in each plot. Leaf area of ten tillers was measured using Li-Cor (Inc. Lincoln, NE, EUA). Total number of tillers in 50 cm row was counted and used to calculate LAI. All plants in 50 cm row were dried in an oven at 75 °C during 48 hours and weighted to determine TDM. Soil moisture, ammonium and nitrate availability were measured frequently throughout the growing season in the 0-10 cm soil layer. Three sub-samples were collected to get a 30 g soil sample in each plot. Around 10 g of soil was weighed before and after drying in an oven for 24 hours under 45ºC. Soil moisture (cm^3/cm^3) was calculated by considering the soil bulk density (g/cm^3) determined in each plot. Nitrate and ammonium (mg/kg) were extracted from soil samples by shaking 20 g of soil with 60 mL of 1M KCl for 60 minutes (Mulvaney 1996).

Data analysis
We adopted generalized linear mixed models that account for spatial autocorrelation among plots, by including rows and columns (coordinates of plots) as random effects. Linear and quadratic functions were fitted to investigate effects of nitrogen (N), biochar (char) and its interactions (N*char), here treated as fixed effects. Analyses were performed using the SAS/STAT Mixed procedure (SAS Institute Inc. 2010).

Results

Effects on plant growth and soil properties
At 72 days after sowing (DAS) rice, rates of biochar (char) above 16 Mg/ha tended to negatively affect leaf area index (LAI) and total shoot dry matter (TDM) (Figure 1). The influence of biochar on LAI and TDM showed a quadratic trend. Predicted LAI (m^2/m^2) varied from 4.4 (16 Mg char) to 3.6 (32 Mg char), whereas predicted TDM (Mg/ha) varied from 6 (16 Mg char; 90 kg N) to 3 (32 Mg char; 0 kg N).

The fitted function for the average soil nitrate availability ($Y = 0.5002$ char $+ 0.3357$ N $+ 43.85$) showed that soil nitrate availability (mg/kg) in the 0-10 cm soil layer increased linearly ($p \leq 0.0001$) with biochar application. On the other hand, there was no effect of biochar on the average soil ammonium availability, which was linearly increased ($p \leq 0.05$) with N application ($Y = 0.06349$ N $+ 16.83$). Throughout the growing season of aerobic rice, soil moisture was up to 0.03 cm^3/cm^3 higher in treatments with 16 and 32 Mg/ha biochar than in treatments without biochar application (Figure 2).

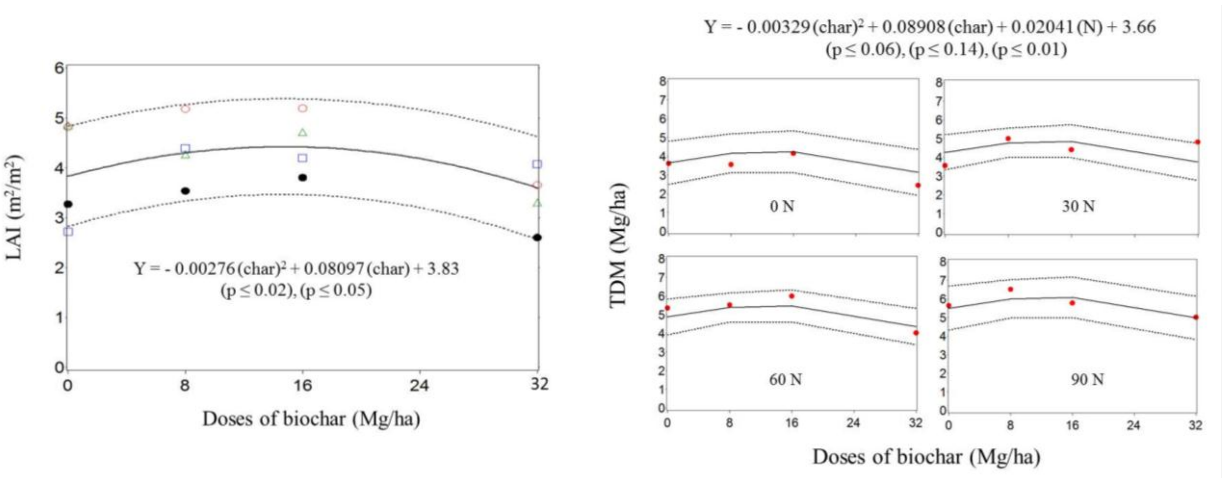

Figure 1. (*Right*) influence of biochar rates (0, 8, 16, 32 Mg/ha) on leaf area index (LAI) of aerobic rice cultivated under different nitrogen rates (●0, □30, △60, ○90 kg/ha); and (*left*) influence of biochar (char) and nitrogen (N) rates on total shoot dry matter (TDM) of aerobic rice in a clayey Rhodic Ferralsol in the Brazilian savannah, at 72 days after sowing rice, growing season 2009/2010. Black lines indicate the fitted function. Dotted lines correspond to respective 95% confidence bands. Values between brackets are nominal significance values corresponding to hypothesis tests on linear or quadratic effects.

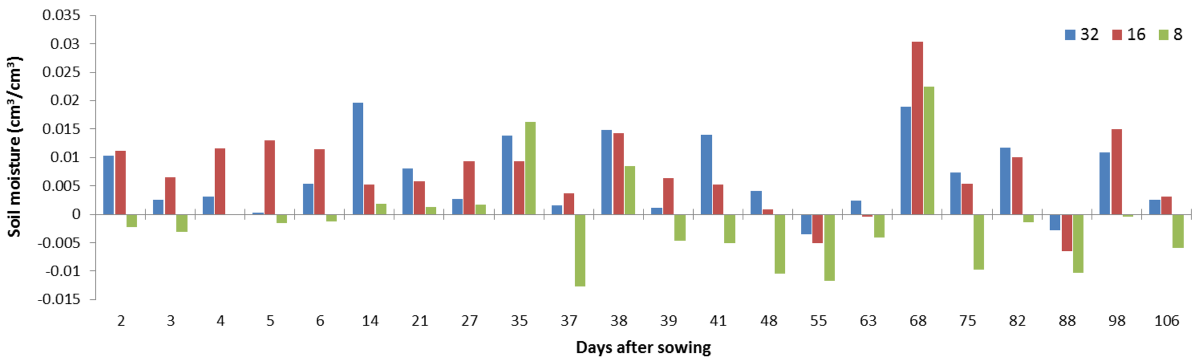

Figure 2. Difference in soil moisture (cm^3/cm^3) between treatments with biochar (8, 16, 32 Mg/ha) and control (without biochar) in a clayey Rhodic Ferralsol in the Brazilian savannah, throughout a growing season of aerobic rice, summer 2009/2010.

Effects on grain yield and yield components

There was no effect of biochar on grain yield of aerobic rice. Rates of nitrogen (N) above 60 kg/ha tended to negatively affect grain yield (Figure 3-*right*), even though the higher the rate of N, the higher the total shoot dry matter (TDM) at 72 days after sowing (Figure 1-*left*). Based on the fitted function for grain yield, optimal rate of N would be around 46 kg/ha we to achieve a grain yield above 3 Mg/ha, regardless biochar application. Predicted grain yield (Mg/ha) varied from 3 (60 kg N) to 2 (0 kg N).

The influence of N on spikelet fertility (SF) also followed a quadratic trend ($Y = -\ 0.00003\ N^2 + 0.00201\ N + 0.72$). Rates of N above 60 kg/ha tended ($p \leq 0.10$) to negatively affect SF. Predicted SF varied from 0.75 (30 kg N) to 0.65 (90 kg N).

There was, however, an interaction effect of biochar and N on harvest index (HI), meaning that the effect of biochar was dependent on the rate of N applied. The higher the rate of biochar applied, the more N was required to achieve the same HI (Figure 3-*left*). Predicted HI (Mg/Mg) varied from 0.44 (0 Mg char; 0 kg N) to 0.37 (32 Mg char; 0 kg N).

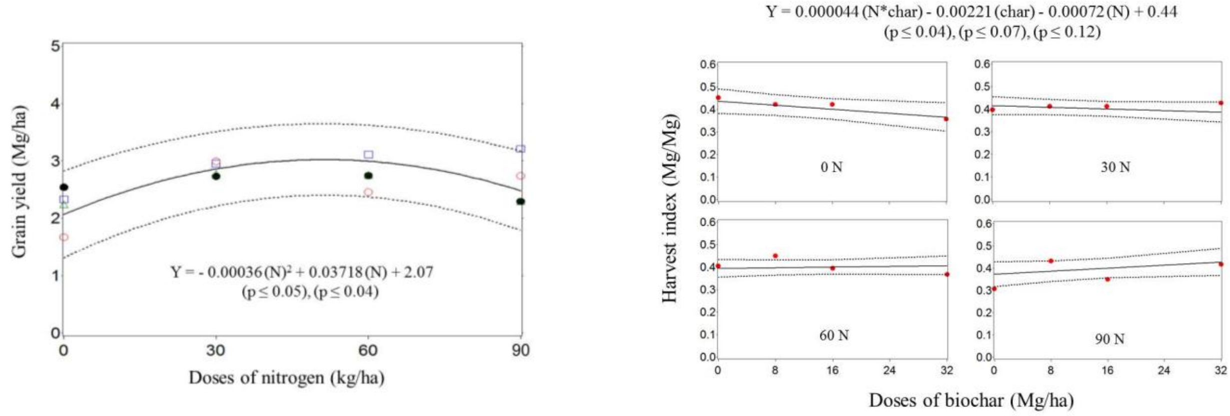

Figure 3. (*Right*) influence nitrogen rates (0, 30, 60, 90 kg/ha) on grain yield of aerobic rice cultivated under different biochar rates (●0, □8, △16, ○32 Mg/ha); and (*left*) influence biochar (char) and nitrogen (N) rates and its interaction (N*char) on harvest index of aerobic rice in a clayey Rhodic Ferralsol in the Brazilian savannah, growing season 2009/2010. Black lines indicate the fitted function. Dotted lines correspond to respective 95% confidence bands. Values between brackets are nominal significance values corresponding to hypothesis tests on linear or quadratic effects.

Conclusions

At 72 days after sowing aerobic rice, leaf area index (LAI) and total shoot dry matter (TDM) were negatively affected by biochar rates above16 Mg/ha. The negative effect of biochar on LAI and TDM might be related to changes in soil properties due biochar application, such as increased soil nitrate availability. Since nitrate can be easily lost via N_2O emissions under anaerobic conditions, and that biochar rates above 16 Mg/ha led to high soil moisture throughout the growing season of rice, the negative effect of biochar on LAI and TDM might be related to decreased soil N availability. There was no effect of biochar application on grain yield. The effect of N fertilisation on yield followed a quadratic pattern. The optimal rate of N was around 46 kg/ha to achieve a grain yield above 3 Mg/ha. The negative effect of N rates above 60 kg/ha on grain yield might be related to the lower carbohydrate remobilisation capacity of modern aerobic rice cultivars, such as ‘Primavera’, than traditional upland varieties (Pinheiro et al. 2006). Increases in TDM beyond a certain threshold could result in yield penalties. The consistently lower grain yield, harvest index, TDM and LAI of the high biochar treatment (32 Mg/ha), without N fertilisation, require further investigation.We will study effects of biochar and N and its interactions in following growing seasons of aerobic rice in the same experimental field and in areas under less favorable conditions (sandy soil, only rain fed) in the Brazilian savannah.

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