Influence of Rice Husk Biochar Application and Irrigation Water Salinity on Growth and Nitrogen Use Efficiency by Wheat

Maher E. Saleh[1]; Amal H. Mahmoud[2] and Khamis A. Rateb[2]
[1]Dep, of Soil and Water Science, Faculty of Agriculture, Alexandria University p, c,: 21545 El-Shatby, Alexandria
[2]Saline and Sodic Soils Res. Lab, Institute of Soil, Water and Environment Res., Agricultural Research Center, Bakous, Alexandria, Egypt.

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ABSTRACT

Biochar plays various roles in improving soil fertility, productivity, water use efficiency and reducing the environmental pollution coming from open field burning of crop residues. Greenhouse experiment was conducted to study the effect of rice husk (RH) and rice husk biochar (RHB) application (30 ton ha^{-1}) as soil amendments on yield of wheat plants and nitrogen use efficiency under the irrigation water of different salinity levels (0.75, 5 and 10 dSm^{-1}). Under the irrigation by fresh water, addition of RH to soil increased grain and straw yield by 60 and 33.3% over those obtained in non amended soil while added RHB increased the two parameters by 10.4 and 2.5%, respectively. Less increases in grain and straw yield of RH treated pots were obtained under the irrigation by saline water. The effect of water salinity on N uptake by wheat plants was non significant while RH significantly increased N uptake comparing with RHB. Both sodium and potassium increased only in wheat straw with increasing water salinity and with the addition of RH and RHB. After harvest, under all salinity levels of irrigation water, mineral N in soil significantly increased in RHB- treated soil by 35.3 to 50.4% over those amounts in non treated soils which reflect an important role for biochar in facilitating additional surfaces for N adsorption and reducing N loss against leaching and assimilation. Further studies are needed to explore the role of biochar application under the conditions of water and/or soil salinity as well as to investigate the mechanisms by which biochar maintains applied N in available form for the next growing seasons.

Key words: Biochar, rice husk, wheat, nitrogen, salinity, N use efficiency.

INTRODUCTION

It is predicted that global food production needs will be double in order to meet the needs of a growing world population by 2050 (Tilman *et al.*, 2001 and 2002). Soil and water resources for agricultural production in Egypt are not cope the rapid population growth for several reasons such as water sacristy, soil salinity, and poor fertility of the recently reclaimed soils. On the other hand, agricultural soils in Egypt are classified as dry land which is defined by high aridity index, high organic matter depletion rates and accelerating rate of soil salinization (FAO, 2001). Most of recent and future newly reclaimed soils arise in areas irrigated with saline water or in sandy-textured areas characterized by very low fertility levels(Hamdy and AbdelHafez, 1994), therefore, looking fore technologies to use saline water in irrigation of moderately and salinity tolerant crops such as graminaceous crops and apply soil amendments can improve soil fertility in one hand, on the other hand, will help in increasing the soil horizontal expansion and enroll marginal lands into the productive areas.

Biochar is a term denotes black carbon formed by the pyrolysis of biomass, i.e., by heating biomass under oxygen-free environment (Lehmann *et a*l., 2006 and Jho *et al.*, 2010). It is one of stable soil amendments and its incorporation in soils, influences soil structure, texture, porosity, particle size distribution and density.The molecular structure of biochar shows a high degree of chemical and microbial stability. One of the key physical properties of biochar is their highly porous structure and large surface area which beneficially reflected on micro-organisms such as mycorrhizae and bacteria, and influences the binding of important nutritive cations and anions. This binding can enhance the availability of macro-nutrients such as N and P (Liang *et al.* 2006 and Chan and Xu 2009). Biochar is resistant to decay and can therefore occupy a significant proportion of the soil carbon fraction aided by its potential for a prolonged life within the soil (Dai *et al.* 2005). It is suggested that biochar applications to soil can increase agricultural productivity and its incorporation into soils can enhance plant growth (Lehmann *et al.* 2003; Yamato *et al.* 2006; Steiner *et al.* 2007; Kimetu *et al.* 2008; Blackwell *et al.* 2009). Depending on the amount of biochar added, significant improvements in crop productivity were achieved ranging from 20% to 220% (Lehmann and Rondon 2005). One of the key roles of biochar comes from its chemical properties; elevated cation exchange capacity (CEC) is due to increases in charge density per unit surface of biochar. Therefore, High CEC reduces the mobility of cationic nutrients and heavy metals (Hua *et al.* 2009). Ammonium leaching from greenhouse biochar experiment was reduced by about 60% (Major *et al.* 2009) and other studies confirmed that biochar can act as an absorber reducing NO_3-N leaching and increasing N use efficiency (Steiner *et al.* 2008). In Egypt, there is about 30–35 million ton of agricultural wastes are generated annually. El-Mashad *et al.* (2003) stated that about 19.733 and 13.577 million metric ton of plant and animal residues, respectively, are generated annually. Only 20% are used in organic fertilizer and fodder production (Ministry of Environmental Affairs, 2009) and the rest of waste amount is needed to précised management. The objectives of this study therefore were to use rice husk biocher as an attempt for (1) controlling fertilizer nitrogen loss and thereafter increasing the bioavailability of N to grown crops and (2) testing its role in reducing vulnerable effects of irrigation water salinity on plant growth.

MATERIALS AND METHODS

Preparation and Characterization of Biochar

Rice husk had come from the same soil used in the experiment where after harvesting the rice from the field, we brought it for rice milling to get the husk. Separate amounts of Rice husk were then put into aluminum sheet envelops and completely closed with making few small holes. The envelops were transferred to muffle furnace and the rice husk was then heated to a temperature of 450°C. The time heeded to reach the temperature was 15min then left on 450 °C for another 15 min. After cooling to ambient temperature, the rice husk was collected and stored in closed plastic jars for using it as a soil amendment. Part of biochar was ground to pass through 0.5 mm sieve and the moisture content was measured by oven drying using a sub sample of 5 g at a temperature of 80 °C for 24 hours. Elemental analysis (N, P, K, Fe, Mn, Zn and Cu) of rice husk and rice husk biochar were done using dry ashing method according to Jones and Case (1990) and the measurement of metals was done by ICP (Thermo model 6000 Series). Total organic carbon was determined using rapid dichromate oxidation method or Walkley-Black procedure (Tiessen and Moir, 1993).

Experimental setup

Greenhouse experiments were setup in Soil Salinity and Alkalinity Research Laboratory, Bakous, Alexandria, Egypt, to study the effect of rice husk biochar application on wheat growth and yield and to explore its role in nitrogen fertilizer use efficiency in comparison with rice husk application. Soil samples were collected from depths up to 30 cm from clay loam lacustrine soil in Abis in Northwestern Nile Delta, Egypt, then dried, ground, and passed through 4 mm sieve. The soil sample was analyzed to their chemical properties by the methods described by Page (1982) and reported in Table (1). Forty kg of soil was then transferred in a plastic pot with 30-cm diameter. The treatments of soil amendments used were:

1. No soil amendment as control, 9 pots
2. Rice husk (30 ton ha^{-1}), 9 pots
3. Rice husk biochar (30 ton ha^{-1}), 9 pots

The seeds of wheat plants (Sakha 104 local cultivar) were emerged after adding third of N, all of P_2O_5 and K_2O by rates 60, 70 and 120 kg ha^{-1} in the form of ammonium sulfate, single super phosphate and potassium sulfate, respectively. Two thirds of N fertilizer was applied after 45 and 65 days of plant emergence. The plants were irrigated by fresh water has electrical conductivity of 0.75 dSm^{-1} (S0) till 40 day of emergence then the pots were splitted into three groups irrigated by S0 and two levels of saline water had sodium chloride salinity equivalent to 5 dSm^{-1} (S1) and 10 dSm^{-1} (S2) dSm^{-1}. All treatments were carried out in triplicate and statistically designed using split plots. At harvest, total weight of plants and the yield of grains and straw were recorded. Also, plant height, and number of spikes were measured. After oven drying of plants (at 70°C for 48 hours), total nitrogen content in grains and straw of wheat was determined by Kjeldahl digestion and distillation method (Jones and Case, 1990), Sub samples of grains and straw were dry ashed at 500 °C for 6 hours and Na and K were determined using Inductively coupled plasma ICP-AES (ICAP Thermo model 6000 Series). Selection of the dry ashing method for elemental analysis for macro and micronutrients is considered safe and effective method to prepare biochar for ICP-AES analysis comparing with the wet digestion methods using the strong inorganic acids (Enders and Lehmann, 2010). Top 20-cm soil samples were withdrawn using soil tube to extract and distillate the remaining available nitrogen by 2.0 M KCl solution (Keeney and Nelson. 1982; Bremner and Mulvaney, 1982). Statistical analysis for all measured parameters was done using Costat software (Costat, 1985).

Table 1: Selected characteristics of rice husk (RH), rice husk biochar (RHB) and soil used in the study.

	Total OC	Total SiO_2	Total N	Total P	Total K	Total Fe	Total Mn	Total Zn	Total Cu
	%					mg kg⁻			
RH	27.90	25.81	1.19	0.40	0.62	233.40	78.60	41.60	16.00
RHB	36.60	72.10	0.52	0.54	0.88	248.20	90.60	50.00	17.60

					DTPA-extractable micronutrients, $mgkg^{-1}$			
Soil	EC, dSm^{-1}	pH	OC, %	min. N, $mgkg^{-1}$	Fe	Mn	Zn	Cu
	6.23	7.81	2.90	104.60	3.17	2.93	2.58	0.14

RESULTS AND DISCUSSION

Yield and yield components

The results in Table (2) showed that grain and straw yield were highly affected by the application of both RH and RHB in all salinity treatments. Under non saline conditions (S0), RH addition increased grain and straw yield by about 60 and 33.3% whereas RHB application increased it by about 10.4 and 2.5%, respectively. RH addition also increased the yield of grain (by 23.5 and 13.7%) and straw (by 17.1 and 3.9%) under the two salinity levels (S1 and S2) of irrigation water, respectively. RHB application only increased grain yield by about 17.3% and decreased straw yield by 3.3% in the pots irrigated with S1 water comparing with RHB non treated pots. In S2-irrigated soils, RHB addition led to decrease both grain and straw yield by 2.9 and 4.74%, respectively. These findings are agreed with the results obtained by Zwieten *et al.* (2010) when applied papermill biochar to wheat plants grown in calcareous soils under greenhouse conditions. They found that application of biochar increased the soybean biomass but reduced wheat and radish biomass. It is observed that application of RHB increased the plant height and decreased the number of spikes per plant in all water salinity treatments comparing with RH. On the other hand, in acid-sulfate soils, application of RHB improved the growth of rice plants and gave the highest number of tillers (Masulili *et al.* 2010). It is speculated that the slightly increase in grain and straw yield as a result of RHB in Abis soil may be due to alkaline properties of the biochar, therefore its application to acid soils increases soil pH which reflects improvement in nutrients availability and reducing Al toxicity. In contrast to the negative impact of alkaline pH of RHB, the improvement in the yield and yield components accompanied to applied RH and RHB may be attributed to their high content in silicon which is considered essential nutrient to wheat and other graminaceous crops (Mahmoud, 2009).

Nitrogen, potassium and sodium uptake

The percentage of N, K and Na in grains and straw of wheat plants grown under different conditions of soil amendments and water salinity are presented in Table (3). Nitrogen uptake by both grains and straw of wheat plants showed no significant change with salinity increases in irrigation water in non-amended pots. Application of rice husk (RH) increased N contents in both plant grains and straw by significant amounts comparing with the effects of applied rice husk biochar (RHB). The increases included the plants irrigated with saline water in the RH-treated soils. On the other hand, in the RHB-treated soil, there was an increase in grains N contents reached to 18, 6.0 and 24.1 % in the pots irrigated with S0, S1 and S2 waters, respectively (Table 3) whereas the N increase of 19.7% in straw was observed in plants irrigated only with fresh water. It is suggested that the N increase in plant tissues was related partially to the N content in the amendments (see Table 1) and to their high content from silicon. Silicon application enhanced N, P and K uptake by barley, rice and wheat plants as stated by Liang *et al.* (1996), Chen *et al.* (2002) and Hanafy *et al.* (2008), respectively, under saline soil conditions

Sodium percent in wheat straw in RHB treatments was greater than RH and non- amended soil samples under all irrigation water salinity levels. These results reflect a higher content of Na in RHB and RH, and subsequent corresponded higher Na uptake, comparing to non amended soils. RHB was more beneficial in potassium uptake only under fresh irrigation water conditions where K content in grains increased by about 35% more than in those grown on non-amended soil. The Analysis of variance for the effects of water salinity and soil amendments and their interaction on yield and N, Na and K uptake by wheat plants are summarized in Table (4). In this table, regardless the type of soil amendment, application of intermediate saline water (5 dSm^{-1}) significantly increased grain yield and potassium uptake by straw while the straw yield was decreased. Also, sodium in grains and straw was increased as water salinity increased. With respect to soil amendments, regardless of water salinity, application of RH significantly enhanced both grains and straw yields as well as the N, Na and K contents in grains and straw comparing with RHB.

Table 2: Effect of RH and RHB application on the yield and yield components of wheat plants irrigated with different levels of saline water.

Soil amendment	Water Salinity	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})	Plant height (cm)	Spike no per pot^{-1}
Null	S0	2.99	8.45	82.67	34.67
	S1	3.67	8.65	74.33	38.33
	S2	3.83	8.66	78.00	34.67
RH	S0	4.79	11.27	84.67	42.33
	S1	4.79	10.13	80.00	37.33
	S2	4.36	8.99	78.67	38.33
RHB	S0	3.30	8.66	85.67	32.33
	S1	4.30	8.36	81.33	35.33
	S2	3.72	8.25	81.00	31.00

Table 3: Effect of RH and RHB application on N, K and Na contents in wheat plants irrigated with different levels of saline water.

Soil amendment	Water Salinity	N, %		Na, %		K, %	
		in grains	in straw	in grains	in straw	in grains	in straw
Null	S0	1.14	1.17	0.07	0.21	0.45	1.93
	S1	1.14	1.42	0.13	0.56	0.47	2.67
	S2	1.23	1.16	0.12	1.30	0.46	1.80
RH	S0	1.24	1.38	0.12	0.27	0.48	2.43
	S1	1.26	1.49	0.10	0.62	0.46	2.77
	S2	1.37	1.44	0.16	1.33	0.53	2.43
RHB	S0	1.16	1.40	0.07	0.33	0.45	2.60
	S1	1.13	1.28	0.11	1.06	0.44	2.27
	S2	1.20	1.19	0.14	1.34	0.45	1.90

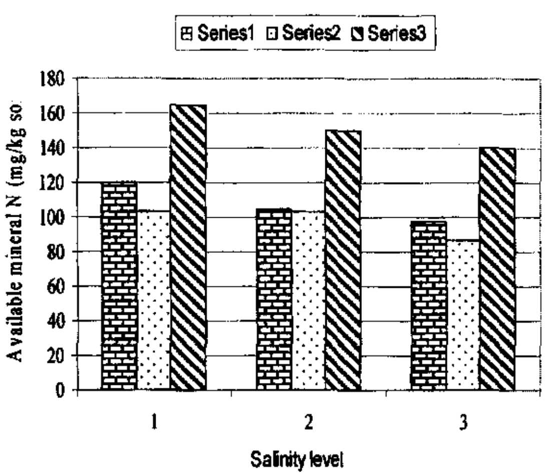
Table 4: Analysis of variance (ANOVA) of the effects of soil amendments application and irrigation water salinity on wheat yield and plant uptake of N, Na and K.

Factors	Grain yield (g/pot)	Straw yield (g/pot)	Nitrogen (%)		Sodium (%)		Potassium (%)	
			grains	straw	grains	straw	grains	straw
Water salinity (dS/m)								
0.75	35.520 b	90.922 a	1.179 a	0.335 a	0.089 b	0.27 c	0.46 ab	2.322 b
5	40.857 a	86.921 ab	1.176 a	0.400 a	0.116 a	0.747 b	0.456 b	2.567 a
10	38.213 ab	82.953 b	1.268 a	0.352 a	0.139 a	1.323 a	0480 a	2.044 c
LSD (0.05)	4.6268	7.069	0.1005	0.0496	0.0256	0.1212	0.0217	0.1648
Amendments								
null	33.599 b	82.512 b	1.170 b	0.332 a	0.109 a	0.69 b	0.458 b	2.133 b
rice husk	44.713 a	97.342 a	1.288 a	0.397 a	0.126 a	0.739 b	0.489 a	2.544 a
rice husk biochar	36.280 b	80.942 b	1.164 b	0.378 a	0.109 a	0.911 a	0.449 b	2.256 b
LSD (0.05)	3.833	13.998	0.079	0.0675	0.0315	0.1493	0.0101	0.2487
Significance								
salinity	ns	ns	ns	ns	**	***	ns	***
amendments	**	ns	*	ns	ns	*	***	*
interaction	ns	ns	ns	**	ns	*	ns	***

Available N in soil

After plant harvest, the results of available mineral nitrogen ($NH_4^+ + NO_3^-$) in the top soil (0-20cm) showed that application of RHB saved more N in soil comparing to RH- and non-amended soils (Fig. 1) where about 35.3, 45.2 and 50.4% of mineral N in soils irrigated by S0, S1 and S2 water salinity, respectively, were remained in soil more than those occurred in corresponded non-amended soils. In contrast, concentrations of N in RH-amended soil were less than those in non-amended one with all corresponded salinity levels of water (Fig. 1) by about 15.0, 2.5 and 8.5%. In a study of nitrogen adsorption on biochar of *Acacia dealbata*, Gonzalez *et al.* (2010) found that significant amounts of NH_4^+ were adsorbed in soil at different values of pH and suggested that biochar application eventually avoid N leaching process in soil and simultaneously promoting its slow release to plants. On the other hand, in a study on N use efficiency using labeled isotopic ^{15}N of maize after biochar additions to a temperate soil, Guerena *et al.* (2010) showed that maize stove biochar significantly increased grain yield and decreased N losses via leaching.

These results indicate that RHB application should be extended to the next growth seasons to explain its role in mineral fertilizer nitrogen conservation to the followed crops and its subsequent impact on crop production economies. Further studies are needed to explore the role of different biochar sources as soil amendment for saline soils in arid areas.



Fig, 1: Soil mineral N (NH_4^++NO_3^-) as a results of RH and RHB application to wheat grown on soil irrigated with different water salinity.

CONCLUSION

The recalcitrant nature of rice husk biochar proposes it as a long-term soil amendment. Its surface properties can help in improvement of soil fertility and productivity. The current study confirmed that the RHB can act as N absorber and reduces its leaching and subsequently increases N use efficiency.The sorption capacity of RHB toward the applied N fertilizer in the form of $NH_4^+$and maintaining high levels of N availability in soil is considered as an important economic point. In other wards, RHB saved a significant percents of applied N against the losses and still in mineral available forms. These benefits of applied biochar extended to wheat plants irrigated by saline water. Further studies are urgently needed to understand the mechanisms of retention and release of N by biochar applied to soils under alkaline conditions.

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الملخص العربي

تأثير إضافة البيوتشار وملوحة مياه الرى على نمو وكفاءة امتصاص النيتروجين بواسطة القمح

ماهر السيد صالح[١] ، أمل حسن محمود[٢] ، خميس عبد العزيز راتب[٢]
قسم علوم الأراضى والمياه – كلية الزراعة – جامعة الاسكندرية
معمل بحوث الأراضى الملحية والقلوية – معهد بحوث الأراضى والمياه والبيئة – مركز البحوث الزراعية – باكوس – الاسكندرية

يلعب البيوتشار (ناتج ثانوى من احتراق المخلفات النباتية في ظروف لاهوائية بغرض إنتاج الوقود الحيوى) أدوار عديدة فى تحسين خصوبة وإنتاجية التربة وفى رفع كفاءة استخدام مياه الرى وفى تقليل التلوث البيئي الناتج من حرق مخلفات المحاصيل فى الحقول المفتوحة. تم تنفيذ تجارب زراعية داخل الصوبة لدراسة تأثير إضافة كل من غلاف حبة الأرز (السرسة) وبيوتشار السرسة بمعدل ٣٠ طن للهكتار على محصول القمح (صنف سخا ١٠٤) وعلى كفاءة استخدام النيتروجين المضاف تحت ظروف الرى بمياه مالحة (التوصيل الكهربي لها ٠٠٧٦ ، ٥٠٠٠ ، ١٠٠٠٠ ديسيسيمنز/متر). وقد بينت النتائج أنه تحت ظروف الرى بالمياه العذبة أدت إضافة السرسة إلى زيادة كل من محصول الحبوب ومحصول القش بنسبة ٦٠ ، ٠ ، ٣٣ ، ٣% على التوالى مقارنة بالمحصول الناتج من الأرض غير المعاملة بالسرسة. بينما أدت إضافة بيوتشار السرسة إلى زيادة مناظرة نسبة ١٠٠٤ ، ٢٠٥%. ولم يؤثر الرى بالمياه المالحة على الزيادة المتحصل عليها فى المحصول نتيجة إضافة السرسة مقارنة بالمحصول الناتج من الأرض المعاملة ببيوتشار السرسة. لم يؤثر الرى بالمياه المالحة على امتصاص النيتروجين بواسطة النبات ولكن هذا الامتصاص زاد بدرجة معنوية نتيجة إضافة السرسة وبدرجة أقل نتيجة إضافة البيوتشار. زادت النسبة الممتصة من الصوديوم والبوتاسيوم فقط فى تبن القمح نتيجة الرى بالمياه المالحة ونتيجة اضافة السرسة والبيوتشار. كما أوضحت نتائج النيتروجين المعدني المتاح بالأرض بعد الحصاد حدوث زيادة كبيرة فى تركيز النيتروجين المعدنى فى الأرض المعاملة بالبيوتشار مقارنة بالمعاملات الأخرى فى كل مستويات الملوحة المختبرة لمياه الرى. وهذا يعكس دور هام للبيوتشار فى الحفاظ على مستويات مرتفعة من النيتروجين المتاح نتيجة تيسير أسطح إضافية للإدمصاص ومن ثم تقليل الفقد بالغسيل فى النيتروجين. وهناك حاجة الى مزيد من الدراسات والتجارب لتوضيح دور إضافة البيوتشار تحت ظروف ملوحة كل من مياه الرى والتربة ولبيان الآليات التى يحفظ بها البيوتشار النيتروجين فى الأرض فى صورة متاحة للنباتات النامية فى مواسم النمو التالية.