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BIOCHAR ADDITION COUPLED WITH NITROGEN FERTILIZATION IMPROVES SOIL FERTILITY, NITROGEN USE EFFICIENCY AND RICE YIELD

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Abstract

Excessive use of nitrogen (N) fertilizer harms the environment, lowers N use efficiency and affects soil health. Biochar can substitute partially N fertilizer and benefit crop production. A field experiment was conducted to investigate the effect of biochar along with N fertilization on the growth and yield of rice (cv. BRRI dhan89), N use efficiency and soil properties. The treatments were T_0 (Control), T_1 (100% RDN), T_2 (100% RDN + 2 t ha^{-1} biochar), T_3 (75% RDN + 2 t ha^{-1} biochar), and T_4 (50% RDN + 2 t ha^{-1} biochar); RDN means recommended dose of nitrogen. The experiment was laid out in a randomized complete block design (RCBD) with four replications. Results showed that there was a significant positive effect of biochar and N fertilization on rice crop. The significantly highest plant height (103 cm), tillers (13.8), SPAD value (37.8), 1000-grain weight (25.2 g), straw yield (5.93 t ha^{-1}) and grain yield (5.7 t ha^{-1}) were recorded in T_2 treatment which was statistically similar with T_1 and T_3 treatments. The combined application of biochar and N fertilizer increased agronomic efficiency by 5.8% and apparent N recovery by 13.6% in T_3 treatment compared to sole application of RDN fertilizer (T_1). Moreover, the physico-chemical properties of post-harvest soils were significantly improved. Hence, the combined application of biochar and N fertilizer can be practiced to improve soil health, N use efficiency and rice productivity.

Keywords: BRRI dhan89, Soil health, SPAD value, Straw yield, Thousand-grain weight

1. Introduction

In Bangladesh, declining soil quality and nutrient loss have been the main constraints to rising agricultural productivity and food security. In addition to these issues, farmers are under tremendous pressure to boost crop yields, which exacerbates due to geometric population rise and climate change. Nitrogen is main deficient element in this country's soil and consequently, farmers use huge urea fertilizer to obtain higher crop yield. So, judicial N management is important for achieving sustainable soil health and crop yield. Excessive use of N fertilizer can harm the soil health such as soil acidification, soil organic matter content decline, bulk density increment, mineralization decline (Karimi *et al.,* 2023). Soil fertility declines and environmental degradation occurs due to unbalanced use of N fertilizer. Excessive use of N fertilizer can harm the soil health such as soil acidification, soil organic matter content decline, bulk density increment, mineralization decline (Karimi *et al.,* 2023). The government subsidizes N fertilizer. It is also apparent that the fertilizer subsidy does not guarantee balanced use of N fertilizer. Among the three types of rice, N fertilizer consumption is the highest in boro rice, because this high yielding crop receives the greatest inputs (Hossain *et al.,* 2012; FRG, 2018).

Excessive N inputs in intensive agricultural ecosystems have resulted in decreased N use efficiency (NUE). However, N undergoes several transformations in the soil and crop environments that result in loss of the N through leaching, denitrification, NH_3 volatilization, surface runoff, N_2O emissions that cannot be taken up by the crop via the hydrosphere, atmosphere, and soil (Brady *et al.,* 2008). Hence, despite intensive cropping with modern crop varieties and the use of mostly chemical fertilizers, N use efficiency is declining in Bangladesh (Rahman *et al.,* 2021). Better management techniques can reduce N fertilizer inputs, improve storage of soil N, and enhance N use efficiency. Thus, it becomes requisite to look into sustainable methods of optimizing crop production potential and regulating soil N through inorganic fertilizer along with organic sources. Applying biochar in this situation might be a way to knock a balance between the health of the soil and the amount of N fertilizer used. Biochar is a carbon-rich product from pyrolysis of biomass at relatively high temperature (400-600^{0}C) such as wood, crop residues, and manure (Lehmann and Joseph, 2015). Its (biochar) physiochemical properties such high surface area, high surface charge, high porosity, high water holding capacity, high pH, high nutrient exchange capacity etc. make it ideal for use as a soil conditioner and carbon sequester. Biochar enhances the physicochemical characteristics of soil, lowers soil acidity, raises cation exchange capacity (CEC), strengthens soil aggregates, holds onto nutrients, and influences the dynamics of water infiltration in various types of soil (Bouqbis *et al.,* 2016). Several studies have demonstrated the beneficial effects of applying biochar on soil N level, crop N uptake, and fertilizer N use efficiency. However, the degree, timing, and type of biochar application, along with the characteristics of the soil, are all highly related to these effects (Fiorentino *et al.,* 2019). On the other hand, biochar can adsorb N and other nutrients in the soil, reduce N leaching loss and NH_3 volatilization (Fiorentino *et al.,* 2019), and enhance crop N uptake and N use efficiency (Huang *et al.,* 2018) because of its porosity, high cation exchange capacity, and rich functional groups. Rice is the dominant crop covering about 75% cultivable area in Bangladesh. The situation dictates the need of improving N use efficiency is of utmost importance for smallholder. Application of biochar which is a stable source of organic matter and plant nutrients could play a good role in sustenance of soil quality and crop productivity. Considering the above-mentioned situation, the present study was undertaken to investigate the potentiality of biochar along with N fertilization for increasing rice yield, N use efficiency and soil quality.

2. Materials and Methods

2.1 Experimental site

The experiment was conducted in the research field of the Soil Science Department of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur. The experimental farm belongs to Salna series and has been classified as Shallow Red Brown Terrace soil and inceptisol as USDA classification system (FAO and UNDP, 1988). The soil is under the agro-ecological zone of Madhupur Tract (AEZ 28) and acidic in nature. The physico-chemical properties of experimental soil are presented in Table 1. Chemical analysis was done following the methods as outlined by Page *et al.* (1982). The experimental site is located at 24.09° N latitude and 90.26° E longitudes with an elevation of 8.2 m from sea level. The experimental site experiences subtropical humid climate.

Table 1. Physico-chemical properties of the experimental soil and biochar

Parameters	Soil	Biochar
Soil moisture content	24 %	-
Bulk density	1.49 g cm^{-3}	-
Soil texture	Silt loam	-
Soil pH	5.94	7.56
Cation exchange capacity (CEC)	12.3 cmol kg^{-1}	16 cmol kg^{-1}
Organic carbon (OC)	0.88 %	41.3 %
Total Nitrogen (N)	0.09 %	0.50 %
Available P	7.45 ppm	0.13 %
Exchangeable K	0.27 me%	1.90 %
Available S	11.3 ppm	0.50 %

2.2 Experiment set up

The experiment was carried out in a Randomized Complete Block Design (RCBD) with five treatments and four replications. The treatment combinations were as: T_0= Control (without fertilizer and biochar); T_1= 100% RDN (recommended dose of nitrogen); T_2=

100% RDN + 2 t ha^{-1} biochar; T_3= 75% RDN + 2 t ha^{-1} biochar; T_4= 50% RDN + 2 t ha^{-1} biochar. The boro Rice variety BRRI dhan89 was used as the test crop. Biochar was prepared from rice husk (collected from rice mill) using the modified biochar preparation stove developed by the Department of Soil Science, BSMRAU. Characterization of biochar was performed using standard methods. The characteristics of biochar are shown in Table 1. Along with the biochar, fertilizers such as urea for N, triple superphosphate (TSP) for P, muriate of potash (MoP) for K and gypsum for S were calculated as prescribed by Bangladesh Agricultural Research Council (FRG, 2018). Thirty days' old seedlings were transplanted on 01 February 2023 and the crop was harvested on 05 May 2023. The urea for N was applied as top dressing in three equal splits at 15, 30, and 45 days after transplanting (DAT) and other fertilizers applied as basal. All the intercultural operations were performed as per standard methods and procedures. Five hills of rice were selected randomly for different data collection such as plant height (cm), number of tillers per hill, SPAD value at maximum tillering stage, panicle length (cm), 1000 grain weight (g), straw yield (t ha^{-1}) and grain yield (t ha^{-1}).

2.3 Nutrient analysis of the soil and plant samples

The collected soil and plant samples (grain and straw) from each plot were dried in an oven at 70^{0}C for 48 hr until a constant weight was gained and ground by a grinding machine The soil and plant samples were analyzed for relevant parameters in the laboratory following the standard methodologies. Rice straw and grain samples were analyzed for N concentrations using Kjeldahl method as described by Jackson (1958). Nitrogen uptake in grain and straw was calculated by multiplying N content with the respective straw and grain yield per hector (ha). Total N content in straw and grain samples was used for calculating N use efficiency according to Guarda *et al.* (2004). The different efficiencies of nitrogen were derived using the following formula:

$$\text{Agronomic efficiency}\left(\text{kg kg}^{-1}\right) = \frac{\text{Grain yield of fertilized plot }\left(\text{kg ha}^{-1}\right)\text{ - Grain yield of control plot (kg ha}^{-1}\text{)}}{\text{Applied N (kg ha}^{-1}\text{)}}$$

$$\text{Apparent N recovery (\%)} = \frac{\text{N uptake from fertilized plot }\left(\text{kg ha}^{-1}\right)\text{ - N uptake from control plot }\left(\text{kg ha}^{-1}\right)}{\text{Applied N }\left(\text{kg ha}^{-1}\right)}\text{x100}$$

2.4 Statistical analysis

Experimental data were analyzed statistically with the help of statistical software STATISTIX 10. The mean differences of the treatments were obtained from least significant difference (LSD) test at 5% level of probability for the interpretation of results.

3. Results and Discussion

3.1 Effects of biochar and nitrogen on the growth and yield of rice

The effect on the growth and yield of BRRI dhan89 rice is presented in Table 2. There was a significant difference in plant height, tillers per hill and SPAD value under different treatment combinations. At maximum tillering stage the highest SPAD value (37.8) was recorded in T_2 treatment which was statistically similar with the T_1 treatment (37.6) and T_3 treatment (37.1). Whereas, the lowest plant height (85.5 cm), number of tillers per hill (8.25) and SPAD value (30.6) were observed in T_0 (control) treatment. Current findings are in line with the findings of Ning *et al.* (2022), Ali *et al.* (2021) and Zhang *et al.* (2015) who reported that biochar application in combination of N fertilizer had significant positive influence on plant height and tillers per hill of rice as compared to the control. Higher SPAD value in N and biochar treatments could be attributed to the higher amount of N uptake by plants, more greenness (chlorophyll) of leaf, higher photosynthesis and N nutrition status (Li *et al.* 2020; Ali *et al.,* 2020a).

Table 2. Growth, yield components and yield of rice as influenced by biochar and nitrogen fertilizer

Treatments	Plant height (cm)	Tillers per hill (no.)	SPAD value	Tillers per hill	1000-grain weight (g)	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})
T_0	85.5	8.3	30.6	7.3	21.2	3.28	3.11
T_1	100.8	13.0	37.6	11.8	24.9	5.92	5.67
T_2	102.3	13.8	37.8	12.8	25.2	5.93	5.70
T_3	100.8	13.0	37.1	11.8	24.9	5.92	5.59
T_4	96.3	10.8	34.6	9.8	23.4	5.10	4.70
$LSD_{(0.05)}$	2.1	0.9	2.2	1.4	0.4	0.14	0.20
CV (%)	1.40	5.21	3.95	8.22	1.00	1.74	2.61

Results presented in Table 2 shows that the number of tillers per hill, 1000- grain weight, straw yield and grain yield of rice were significantly influenced by different treatment combinations of urea-N and biochar. The higher number of tillers per hill (12.8), 1000- grain weight (25.2 g), straw yield (5.93 t ha^{-1}) and grain yield (5.70 t ha^{-1}) were observed in T_2 treatment which was statistically similar with the T_1 treatment (26.0 cm, 11.8, 24.9 g, 5.92 t ha^{-1} and 5.67 t ha^{-1} respectively) and T_3 treatment (26.0 cm, 11.8, 24.9 g, 5.92 t ha^{-1} and 5.59 t ha^{-1}, respectively). On the other hand, the lowest number of tillers per hill (7.3), 1000- grain weight (21.2 g), straw yield (3.28 t ha^{-1}) and grain yield (3.11 t ha^{-1}) were observed in T_0

(control) treatment. Furthermore, the highest straw yield increase (80.8%) and grain yield increase (83.2%) over the control was found in T_2 treatment and the lowest increase (55.5% and 51.1%, respectively) was noted in T_4 treatment (Table 2). Results of the present study demonstrate a significant role of biochar in combination with urea-N fertilizer which could reduce 25% N fertilizer without hampering the number of tillers per hill, 1000- grain weight, straw yield and grain yield of rice. The higher grain yield in T_2 treatment might be ascribed by the greater influence of plant growth and yield contributing characters.

Present findings are in line with the findings of previous studies where significant positive influence on tillers, 1000- grain weight, straw yield and grain yield (Ali *et al.,* 2020b; Ali *et al.* 2020b; Ning *et al.* 2022) was reported where biochar was applied in combination with N fertilizer as compared to the control treatment.

3.2 Effects of biochar and N fertilizer on N use efficiency (NUE) of rice

A significant difference was observed in N concentration of rice straw and rice grain under different treatment combinations (Table 3). The highest N content in straw (0.590%) and grain (1.20%) was found in T_2 treatment which was statistically similar with the T_1 treatment (0.578% and 1.195% respectively) and T_3 treatment (0.572% and 1.193% respectively). The lowest N content in straw (0.388%) and grain (01.008%) was observed in T_0 treatment. This finding indicates that biochar application along with N fertilizer could reduce 25% N fertilizer without hampering the N content of rice straw and grain (Table 4). Current findings are in line with Ning *et al.* (2022) who reported that N fertilizer along with biochar increased N uptake by rice plants compared to control treatment.

In the light of agronomic efficiency of rice, the significantly highest agronomic efficiency was observed in T_3 treatment (Table 4). In case of T_3 treatment, the application of biochar along with N fertilizer increased 5.83% agronomic efficiency compared to sole application of 100% recommended dose of N fertilizer (T_1) and increased 25.65% agronomic efficiency compared to control. Similarly, the significantly highest apparent N recovery was observed in the treatment T_3 where biochar application along with N fertilizer increased 13.56% N recovery compared to sole application of 100% recommended dose of N fertilizer (T_1) and increased 58.45% apparent N recovery compared to control.

Table 3. Nitrogen concentration and N use efficiency of rice

Treatments	N conc. in straw (%)	N conc. in grain (%)	Agronomic efficiency (kg kg^{-1})	Apparent N recovery (%)
T_0	0.388c	1.01c	-	-
T_1	0.578a	1.20a	19.8b	44.9b
T_2	0.590a	1.20a	20.1b	46.0b
T_3	0.572a	1.19a	25.7a	58.5a
T_4	0.440b	1.10b	24.5a	46.5b
$LSD_{(0.05)}$	0.05	0.09	2.4	3.9
CV (%)	5.62	6.24	6.63	4.98

T_0: Control, T_1: 100% RDN, T_2: 100% RDN + 2 t ha^{-1} Biochar, T_3: 75% RDN + 2 t ha^{-1} Biochar, T_4: 50% RDN + 2 t ha^{-1} Biochar. Values in a column having similar letter (s) do not differ significantly as per LSD at 5% level of significance. The data for plant height and number of tillers per hill was recorded at 60 DAT and SPAD value at maximum tillering stage.

Results from current study revealed highest growth and yield in T_2 treatment but highest N use efficiency noted in T_3 treatment due to biochar could play a better role in stabilizing grain yield and N uptake of rice plant in case of N shortage. In current study, increase in agronomic efficiency and apparent N recovery through the co-application of biochar and N fertilizer supports the importance of using a stable nutrient-retaining substance such as biochar for nutrient retention and bioavailability. Application of biochar mostly improved N fertilizer use efficiency through positive and additive effects. Present findings line with the findings of Sarma *et al.* (2018), Oladele *et al.* (2019) and Ning *et al.* (2022) where they reported that the significant positive influence of biochar application in combination with N fertilizer on agronomic efficiency and apparent N recovery of rice plants compared to control plants and sole application of N fertilizer.

3.3 Physico-chemical properties of post-harvest soils

Results presented in Table 4 shows that all physico-chemical properties of post-harvest soil except bulk density was significantly ($p<0.05$) changed under different treatment combinations. Overall, the higher bulk density was observed where biochar was not applied such as in T_0 treatment (1.52 g cm^{-3}) which was comparatively lower than the T_2 (1.45 g cm^{-3}), T_3 (1.45 g cm^{-3}) and T_4 (1.44 g cm^{-3}) treatments where 2 t ha^{-1} biochar was applied along with N fertilizer which probably due to the less dense and highly porous nature of rice husk biochar which could minimize soil compaction and increase volume of soil and ultimately decrease bulk density of soil. Findings from current study are corroborated by Randolph *et al.* (2017), who reported similar results with reduced bulk density upon combined application of biochar and N fertilizer. Significantly ($p<0.05$) the highest pH (6.01), OC (0.92 %) and CEC (13.2 me%) were recorded in T_4 treatment where 2 t ha^{-1} biochar was applied along with N fertilizers and the lowest results showing 5.89, 0.87 % and 12.0 me%, respectively. According to Sarma *et al.* (2018), the presence of ash and cations in biochar helped to increase the pH. Ali *et al.* (2021) and Oladele *et al.* (2019) reported that biochar application along with nitrogen fertilizer increased soil OC and CEC due to its high carbon content and surface area respectively. Significantly ($p<0.05$) the highest N (0.13 %) in T_2 treatment and P (12.0 ppm), K (0.33 me%) and S (13.9 ppm) in T_4 treatment were recorded and the lowest results showing 0.08 %, 6.9 ppm, 0.23 me% and 10.3 ppm, respectively in T_0 treatment. The findings of Oladele *et al.* (2019) and Randolph *et al.* (2017) are in align with our study.

Table 4. Effects of biochar and N fertilization on post-harvest soil properties

Treatments	Bulk density (g cm^{-3})	pH	OC (%)	CEC (me%)	Total N (%)	Available P (ppm)	Exchangeable K (me%)	Available S (ppm)
T_0	1.52	5.90	0.87	12.0	0.08	6.9	0.23	10.3
T_1	1.46	5.89	0.89	13.0	0.12	10.6	0.31	12.7
T_2	1.45	5.99	0.91	13.2	0.13	11.6	0.31	13.4
T_3	1.45	6.00	0.91	13.2	0.12	11.9	0.32	13.4
T_4	1.44	6.01	0.92	13.2	0.10	12.0	0.33	13.9
$LSD_{(0.05)}$	0.12	0.02	0.01	0.3	0.01	0.7	0.02	0.7
CV (%)	5.38	0.20	0.73	1.44	7.96	4.35	3.76	3.43

T_0: Control, T_1: 100% RDN + without Biochar, T_2: 100% RDN + 2 t ha^{-1} Biochar, T_3: 75% RDN + 2 t ha^{-1} Biochar, T_4: 50% RDN + 2 t ha^{-1} Biochar. Values having similar letter (s) do not differ significantly whereas values with dissimilar letter (s) differ significantly as per LSD at 5% level of significant.

4. Conclusions

Biochar and nitrogen (N) fertilization had significant positive influence on rice growth and yield compared to control. About 25% urea-N saving is possible if biochar is used. Biochar and N fertilization had significant positive effect on agronomic efficiency and apparent N recovery of rice. The 5.83% t agronomic efficiency and 13.6% N recovery is possible with the application of 75% RDN + 2 t ha^{-1} biochar compared to sole application of recommended dose of N fertilizer. Application of biochar plus RDN improved soil quality including organic carbon content and nutrient availability in comparison with the results of sole application of chemical fertilizers.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

References

Ali, I., He, L., Ullah, S., Quan, Z., Wei, S. et al. 2020a. Biochar addition coupled with nitrogen fertilization impacts on soil quality, crop productivity, and nitrogen uptake under double-cropping system. *Food Energy Secur.* 9:208.

Ali, I., Ullah, S., He, L., Zhao, Q. and Iqbal, A., et al. 2020b. Combined application of biochar and nitrogen fertilizer improves rice yield, microbial activity and N-metabolism in a pot experiment. *PeerJ.* 8:10311.

Ali, I., Zhao, Q., Wu, K., Ullah, S., Iqbal, A., et al. 2021. Biochar in combination with nitrogen fertilizer is a technique: to enhance physiological and morphological traits of rice (*Oryza sativa* L.) by improving soil physio-biochemical properties. *J. Pt. Grt. Reg.* 41:2406–2420.

Angst, T.E. and Sohi, S.P. 2013. Establishing release dynamics for plant nutrients from biochar. Gcb Bioer. 5, 221-226.

Bouqbis, L., Daoud, S., Koyro, H.W., Kammann, C.I. and Ainlhout, L.F.Z. 2016. Biochar from argan shells: production and characterization. *Int. J. Recycl. Org. Waste Agric.* 5:361-365.

Brady, N.C., Weil, R.R. and Weil, R.R. 2008. The nature and properties of soils. Upper Saddle River, NJ: Prentice Hall. 13, 662-710.

FAO and UNDP. 1988. Land Resources Appraisal of Bangladesh for Agricultural Development. Report No. 2. Agro-Ecological Regions of Bangladesh. United Nations Development Programme and Food and Agricultural Organization., Rome., Italy, 212-221.

Fiorentino, N., Sánchez-Monedero, M.A., Lehmann, J., Enders, A. and Fagnano, M., et al. 2019. Interactive priming of soil N transformations from combining biochar and urea inputs: A 15N isotope tracer study. *Soil Bio. Biochem.* 131:166-175.

FRG. 2018. Fertilizer Recommendation Guide. Soils. Pub. No. 41. Bangladesh Agricultural Research Council, Farmgate, Dhaka-1215.

Guarda, G., Padovan, S., Delogu, G. 2004. Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. *Eur. J. Agron.* 21:181-192.

Hossain, M.F., Elahi, S.F., White, S.K., Alam, Q.K. and Rother, J.A., et al. 2012. Nitrogen budgets for *boro* rice (*Oryza sativa* L.) fields in Bangladesh. *Field Crops Res.* 131:97-109.

Huang, M., Fan, L., Chen, J., Jiang, L. and Zou, Y. 2018. Continuous applications of biochar to rice: Effects on nitrogen uptake and utilization. *Sci. Rep.* 8:11461.

Jackson, M.L. 1958. Soil chemical analysis prentice Hall. Inc., Englewood Cliffs, NJ, 498, 183-204.

Karimi, S., Soltani, S. and Jasemi, K. 2023. Positive and Negative Impact of Nitrogen Fertilizer on Soil Properties and Nutrient Dynamic. *Asian J. Res. Agr. Forest.* 9:233-240.

Lehmann, J. and Joseph, S. 2015. Biochar for environmental management: an introduction. In Biochar for environmental management. Routledge.1, 1-13.

Li, J., Feng, Y., Wang, X., Peng, J. and Yang, D. et al. 2020. Stability and applicability of the leaf value model for variable nitrogen application based on SPAD value in rice. Plos One J. 15, 0233735.

Ning, C., Liu, R., Kuang, X., Chen, H. and Tian, J. et al. 2022. Nitrogen fertilizer reduction combined with biochar application maintain the yield and nitrogen supply of rice but improve the nitrogen use efficiency. *Agron.* 12:3039.

Oladele, S., Adeyemo, A., Awodun, M., Ajayi, A. and Fasina, A. 2019. Effects of biochar and nitrogen fertilizer on soil physicochemical properties, nitrogen use efficiency and upland rice (*Oryza sativa*) yield grown on an Alfisol in Southwestern Nigeria. *Int. J. Recyl. Org. Waste. Agricul.* 8:295-308.

Page, A.L., Miller, R.H. and Keeney, D.R., 1982. Methods of Soil Analysis. 2nd Edn, Amer. Soc. Agron., Madison, WI., USA.

Rahman, M.M., Biswas, J.C., Sutton, M.A., Drewer, J. and Adhya, T.K. 2021. Assessment of reactive nitrogen flows in Bangladesh's agriculture sector. *Sustain.* 14:272.

Randolph, P., Bansode, R.R., Hassan, O.A., Rehrah, D.J. and Ravella, R. 2017. Effect of biochars produced from solid organic municipal waste on soil quality parameters. *J. Environ. Manage.* 192:271-280.

Sarma, B., Gogoi, N., Bharali, M. and Mali, P. 2018. Field evaluation of soil and wheat responses to combined application of hardwood biochar and inorganic fertilizers in acidic sandy loam soil. *Exp. Agri.* 54:507-519.

Zhang, A.P., Liu, R.L., Gao,J., Zhang, Q.W. and Chen, Z. et al. 2015. Effects of biochar on rice yield and nitrogen use efficiency in the Ningxia Yellow River irrigation region. *J. Plant. Nutri. Ferti.* 21:1352-1360.