International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 20 (2017) pp. 10426-10432

Biochar as a carrier for Nitrogen plant Nutrition: 3. Effect of Enriched Biochar on Rice (*Oryza sativa L.*) Yield and Soil Qualities

W. H. Utomo[1], T. Islami[2] and, E. Wisnubroto[3] and H. T. Soelistyari[3]

[1] *International Research Centre for Management of Degraded and Mining Land, University Brawijaya, Malang, Indonesia.*
[2] *Research Centre for Tubers and Root Crops, University Brawijaya, Malang, Indonesia,*
[3] *University Tribhuwana Tunggadewi, Malang, Indonesia.*

Corresponding author: W.H. Utomo,
[1]Orcid: 0000-0002-7502-7940 & Scopus Author ID: 6507144030

Abstract

A lot of studies have proven that biochar is a good soil amendment. With its high Cation Exchange Capacity (CEC), it was hypothesized that biochar can be used as the carrier of nitrogen plant nutrient. A study was conducted to investigated the effect of nitrogen enriched biochar on the growth of rice *(Oriza sativa L.)*. The experiment was carried out in a greenhouse with the treatment of enriched biochar (2 enriched materials and 2 types of biochar feedstuffs), and the rice was planted on several soil acidity. There was 21 treatments combination which arranged in a Fully Randomized Design with 3 replications. Measurements were done for rice growth, rice yield, and some soil chemical properties, i.e. soil organic carbon and nitrogen content, soil pH, and Cation Exchange Capacity. The experimental results show that biochar was a good carrier for nitrogen plant nutrition. The growth and yield of rice planted in enriched biochar soil was as good as the rice growing in urea treated soil, even it had a higher yield. Nitrogen enriched biochar increased the fertilizer efficiency. Ammonium is a better enriched material for biochar than nitrate.

Keywords: fertilizer efficiency, soil amendments, soil pH, SOM, CEC

INTRODUCTION

Since the discovery of black high soil fertility in Amazon River basin, biochar has attracted attention of many scientist [1, 2]. In spite of its controversy, science has now proven that biochar is the future, not only for soil amendment [3], but also for climate mitigation [4]. Biochar is rich in relative stable organic carbon compound, so that it is believed that, unlike the conventional organic compound, its effect lasting yor years [5].

The prospect of biochar for improving of rice growth has been discussed by Haefele [6]. Asai *et al.* [7] applied biochar upland rice production in Northern Laos. Reichenauer *et al*. [8] showed that application of biochar in tsunami-affected paddy fields in Sri Lanka, increased the grain yield from less than 4 t ha^{-1} for the control treatment to more than 5 t ha^{-1} for the biochar treatment. Masulili *et al*. [9, 10] used biochar in acid soil of West Kalimantan, Indonesia. The effect of biochar application on methane gas emission from paddy field has investigated by Dong *et al.*[11].

The improvement of crop growth and increasing plant yield with biochar application is believed to be caused by the improvement of soil fertility status. Biochar application has been shown able to increase pH of acid soil [9], increasing cation exchange capacity of the soil [12], improvement of soil physical properties [7, 13] and indeed increasing soil organic content.

With its high cation exchange capacity, it is believed that biochar application to a soil will increase the efficiency of fertilizer application, especially nitrogen and potassium. Widowati *et al*. [14] studied the effect of biochar on the release and loss of nitrogen from urea fertilizer. They showed that the loss of nitrogen in biochar applied soil was lower compared to that of non biochar treated soil. Dong *et al*. [15] demonstrated that biochar application could enhance the nitrogen retention in waterlogged paddy rice. The increase of nitrogen fertilization efficiency has been shown by Widowati *et al.* [16].

Those phenomena lead to the hypothesis that biochar can be used as the carrier of some elements of plant nutrition, especially nitrogen. Taghizadeh-Toosi, *et al*.[17] demonstrated that nitrogen in ammonium enriched biochar was bio-available. Jassal *et al*.[18] used nitrate to enriched biochar. Wisnubroto *et al*. [19] studied the release of nitrogen from enriched biochar, and the result showed that, in submerged condition, ammonium enriched biochar was relatively better. Based on the above consideration, the study discussed here was aimed to investigate the effect of ammonium and nitrate enriched biochar on the growth and yield of rice. The changes in soil qualities due to the application of these enriched biochar were also studied.

MATERIALS AND METHODS

1. Biochar production and enrichment

Biochar production and enrichment were done at the bio-energy Laboratory University Tribhuwana Tunggadewi, Malang, Indonesia, from March to May 2016. Green house experiment and laboratory analysis were carried out from June 2016 to March 2017 at the University of Brawijaya, Malang, Indonesia..

Two materials, namely: (i) poultry litter (PL), and (ii) corncobs (CC), were used as the feedstuffs. Biochar was produced with the method used by Masulili *et al*.[9] at a temperature of 300^0 C Two nitrogen sources were used to enrich biochar, i.e. ammonium sulfate, and nitric acid. The enrichment of biochar with ammonium sulfate was done by modification of the Taghizadeh-Tossi *et al.* [17]] technique, and the enrichment of biochar with nitrate nitrogen was done by the modification of Jassal *et al.* [18] method. The detail biochar production and enrichment techniques has been explain in detail by Wisnubroto *et al.*[19].

2. Green house experiment

Rice was grown in three soil types with different acidity (acid, neutral, and calcareous soil). The soil was taken from Pontianak, West Kalimantan; the neutral soil from Malang, East Java and the calcareous soil from Kupang, East Nusa Tenggara. Some properties of the soils and biochar used in this experiment are presented in Table 1.

Table 1: Some properties of soils and biochar used in the experiment

Soil	Soil properties					
	pH	Carbon (%)	Nitrogen (%)	Cation Exchange Capacity (cmol/kg)	Sand (%)	Clay (%)
Acid	4.32	0.90	0.11	6.47	55.45	11.28
Neutral	6.46	1.30	0.13	14.96	24.35	34.20
Calcareous	7.52	1.32	0.12	12.28	32.15	24.35
PLbiochar	7.95	28.45	0.02	15.50	-	-
PLbiocharNH_4^+	7.40	27.95	3.70	14.50	-	-
PLbiocharNO_3^-	7.55	29.05	3.40	14.95	-	-
CCbiochar	8.14	47.06	0.00	14.75	-	-
CCbiocharNH_4^+	7.65	48.04	3.50	16.55	-	-
CCbiocharNO_3^-	7.70	45.37	3.40	15.70	-	

There were 21 treatment combinations (3 soil types with 7 biochar treatments), and these treatment combinations were arranged in fully randomized design (FRD) with 3 replications.

The soil was air dried, after which it was passed through a 2.0 mm diameter sieve. The soil was then packed into plastic polybag of about 40 cm diameter and 50 cm height. Two of twenty day old rice seedlings, Ciherang variety, were planted on this polybag. All treatments were given 50 kg K_2O/ha, and 72 kg P_2O_5/ha (area based) in the form of Potassium Chloride (KCl) and Super Phosphate 36 (SP 36). Non biochar and biochar treated soils were given 150 kg N/ha. This nitrogen was given 3 times, i.e.: 1/3 rate at planting; 1/3 at 30 days after planting, and 1/3 at 60 days after planting. During experiment the soil was submerged with de-ionized water at height of about 5 cm.

Measurement was done for plant height (in cm), number of tillers, dry biomass (in g/pot), grain yield (in g/pot) and nitrogen uptake (in g/pot). After harvesting, soil sample was taken for soil qualities analysis. Soil quality was performed by its pH, Cation Exchange Capacity (CEC), and Carbon (C) and Nitrogen (N) content.

Soil pH was determined in H_2O solution (1:2.5 ratios) and read with a pH meter (Jenway 3305). Soil organic matter content was determined with wet oxidation of the Walkley and Black method [20]. The Kjeldhal method [21] was employed for total soil-nitrogen determination. Determination of CEC was done by extracting the soil with 1M NH_4Oac (buffered at pH 7.0), and the total NH_4^+ adsorbed was determined with Kjeldahl distillation.

To investigate the efficiency of nitrogen application, the unfertilized rice was planted for each soil with no nitrogen fertilizers (called as the control rice), and then efficiency of nitrogen fertilizer application was calculated by equation:

$$\text{Neff} = \frac{\text{Total N uptake of treated rice} - \text{Total N uptake of control rice}}{\text{applied N}} X\ 100\ \%$$

Two ways analysis of variant (ANOVA) was performed for data analysis, and if there was a significant different further analysis was done with Least Significant Different (LSD) at the probability of 5%

RESULTS AND DISCUSSION

1. Rice growth

Until 30 days after planting (dap), plant height of rice planted on nitrogen enriched biochar did not significantly different with that of planted on non-biochar soil. At 45 days after planting, biochar application increased plant height on acid soil. At 75 dap, however, plant height of rice planted on nitrogen enriched biochar on all soil was higher compared to that of planted on non-biochar treated soil.

At 45 days after planting, plant height on non-biochar acid coil was only 29.3 cm, significantly lower compared to the other treatments. Different phenomenon was observed at 75 days after planting; in all soil, plant height of rice planted on non-biochar treated soil were lower compared to that planted on biochar treated soil. Looking in detail, There was a tendency that rice planted in ammonium enriched biochar treated soil possessed a higher plant height compared to that of planted in nitrate enriched biochar treated soil.

Table 2: Effect of nitrogen enriched biochar on plant height and tiller numbers of rice planted in soils with different acidity

Treatment		Plant height (cm)			Dry biomass (g/pot)
Soil	Biochar	30 dap*)	45 dap	75 dap	at harvest
Acid	Non biochar	22.5	29.3 a	80.7 a	43.25 a
	PLbiochar	25.3	39.6 b	81.9 a	43.64 a
	PLbiochar NH_4^+	25.2	40.3 b	89.7 c	62.60 c
	PLbiochar NO_3^-	26.1	38.6 b	85.7 abc	51.36 a
	CCbiochar	24.2	39.5 b	85.4 ab	45.70 a
	CCbiochar NH_4^+	25.3	42.1 b	87.4 abc	63.55 c
	CCbiochar NO_3^-	24.2	40.2 b	88.4 bc	50.36 ab
Neutral	Non biochar	26.2	42.6 b	83.7 abc	53.40 bc
	PLbiochar	27.5	41.8 b	85.6 ab	61.35 c
	PLbiochar NH_4^+	25.2	42.6 b	91.9 c	69.46 d
	PLbiochar NO_3^-	26.4	41.4 b	89.7 c	67.85 d
	CCbiochar	26.2	41.5 b	86.4 ab	62.26 cd
	CCbiochar NH_4^+	26.2	42.5 b	92.0 c	67.40 d
	CCbiochar NO_3^-	25.5	41.4 b	89.6 c	65.75 c
Calcareous	Non biochar	23.2	40.6 b	84.6 abc	40.60 a
	PLbiochar	25.4	40.4 b	83.7 abc	49.45 ab
	PLbiochar NH_4^+	26.8	41.2 b	90.6 c	63.44 cd
	PLbiochar NO_3^-	24.2	39.7 b	85.8 abc	60.20 cd
	CCbiochar	25.4	41.5 b	89.4 bc	60.46 cd
	CCbiochar NH_4^+	25.4	41.3 b	88.8 abc	68.36 d
	CCbiochar NO_3^-	23.4 NS	40.7 b	85.2 abc	57.25 bc

*) dap: days after planting

Means followed by the same letters is the same column are not significantly different (p=0.05); NS: Non significant

The results in Table 2 also show that, compared to non biochar treatment, application of nitrogen enriched biochar significantly increased rice dry biomass. Rice planted in non-biochar treated soil had a lower dry biomass compared to that of planted in biochar treated soil. Dry biomass (excluded grain yield) of rice planted in non-biochar soil varied from 40 g/pot (acid and calcareous soils) to 57.40 g/pot (neutral soil). The dry biomass increased (with biochar application) in acid and calcareous soil was higher compared to that of rice planted in neutral soil.

The improvement of rice growth with application of nitrogen enriched biochar as shown in Table 2 indicated that the addition of ammonium and nitrate in biochar was able to increase the effectiveness of nitrogen fertilization. This phenomenon proven that biochar was able to adsorb both the negative (NO_3^-) and positive (NH_4^+) charge..The mechanism by which biochar adsorb NH_4^+ can be easily explain because biochar is negative rich compound (see Table 1). The adsorption of NO_3^- by biochar is more complicated phenomenon. One of the explanation has been proposed by Jassal *et al*.[18].

Looking in detail the result in Table 2, it can be concluded that biochar enriched with ammonium had a better effect compared to the biochar enriched with nitrate. This is reasonable, because the negative charge of biochar would adsorb $NH4^+$, but not NO_3^-, hence the loss of nitrogen from ammonium enriched biochar would be less. The ability of biochar to reduce nitrogen leaching could be originated from the high of cation exchange capacity of biochar treated soil (see Table 5). The increase of cation exchange capacity of a soil treated with biochar has also proven by many workers [9, 12].

The result presented in Table 3 show that the number of tillers and productive tillers of rice applied with nitrogen enriched biochar were higher compared to the non-biochar rice.

If there was no biochar application (non biochar treatment), the experimental result presented in Table 3 show that rice planted in neutral soil grew better compared to that of planted on acid or calcareous soil. In neutral soil, the number of tiller acid soil, application of biochar significantly increased the number of tillers was 21.1 tillers/pot. This is significantly higher than that of in acid soil (10.5 tillers/pot) and in calcareous soil (17.2 tillers/pot).

The experimental results presented in Table 3 also show that rice planted in nitrogen enriched biochar soil yielded a higher grain yield compared to that of planted on non biochar treated soil. There was a tendency that, in each soil acidity group, rice grown in ammonium enriched biochar treated soil grows better than the rice grown in nitrate enriched biochar. The rice in ammonium enriched biochar produced a higher number of tillers, productive tillers compared to the rice grown in biochar or nitrate enriched biochar. Furthermore, the grain yield of rice planted in ammonium enriched biochar was higher than that of planted in nitrate enriched biochar.

Table 3: Effect of nitrogen enriched biochar on tiller number and grain yield of rice planted in soil with different acidity

Treatment		number of tillers/pot	productive tillers/pot	grain yield
Soil	Biochar	70 dap	at harvest	(g/pot)
Acid	Non biochar	10.5 a	5.7 a	27.27 a
	PLbiochar	20.3 bcd	16.3 bcde	31.78 ab
	PLbiochar NH_4^+	20.2 bcd	17.6 bcde	38.80 c
	PLbiochar NO_3^-	23.1 cd	15.3 bcd	31.65 ab
	CCbiochar	19.2 bc	17.2 bcde	33.47 abc
	CCbiochar NH_4^+	20.3 bcd	17.8 c	39.45cd
	CCbiochar NO_3^-	18.2 bc	13.7 bcd	30.27 ab
Neutral	Non biochar	21.2 bcd	15.2 bcd	37.65 bcd
	PLbiochar	22.5 cd	19.3 ef	43.65 e
	PLbiochar NH_4^+	23.2 c d	19.6 ef	47.25 ef
	PLbiochar NO_3^-	24.4 d	18.8 de	46.35 ef
	CCbiochar	23.2 cd	18.6 de	40.37 de
	CCbiochar NH_4^+	23.2 cd	19.5 e	49.35 f
	CCbiochar NO_3^-	22.5 cd	18.6 de	48.64 f
Calcareous	Non biochar	17.2 b	15.3 bcd	31.72 ab
	PLbiochar	21.4 bc	23.7 f	33.46 abc
	PLbiochar NH_4^+	23.8 cd	16.6 bcde	45.37 e
	PLbiochar NO_3^-	22.2 bcd	15.3 bcd	40.60 d
	CCbiochar	24.4 d	15.2 bcd	39.35 cd
	CCbiochar NH_4^+	24.4 d	20.5 ef	46.46 ef
	CCbiochar NO_3^-	18.4 bc	13.9 bc	35.38 bcd

*) dap : days after planting

Means followed by the same letters is the same column are not significantly different ($p=0.05$)

The better growth and grain yield of rice planted in biochar treated soil was also thought to be caused by the improvement of soil properties. In acid soil biochar application significantly increased soil pH (see Table 5). It has been widely understood that the increase of soil pH in acid soil will reduce the negative effect of some toxic element, especially Al [22]. The increase in soil pH with biochar application has also been shown by many workers as has been discussed by Chintala *et al*.[9,23]. On calcareous soil, on the other hand, application of nitrogen enriched biochar tends to decrease soil pH (Table 5). This process has beneficial effect because it will increase the availability of phosphorus.

It has been shown in Table 4 that, after harvesting the rice, the soil applied with ammonium enriched biochar had a higher nitrogen content compared to that of applied with nitrate enriched biochar. Thus, together with the results presented in Table 6, it can be concluded that ammonium is a better enriched material for biochar. As has been discussed before, ammonium is a cation (positive charge). With a high cation exchange capacity of biochar[12] (see also the result in Tables 1 and 5), these ammonium ion will be better adsorbed by the soil. Then it will reduce nitrogen lost due to leaching and denitrification.

2. Soil Qualities

The enrichment of biochar with ammonium sulfate did not influence its ability to increase soil carbon content (Table 4) and soil CEC (Table 5). The results presented in Table 4 show that in all soil, non biochar soil possessed a lower soil carbon compared to that of biochar treated soil. Soil carbon for all biochar treated soil was not significantly different.

Table 4: Effect of N-enrichment biochar application on carbon and nitrogen content of soils with different acidity after harvesting rice

Treatments	C (%)			Total nitrogen		
	Acid soil	Neutral soil	Calcareous soil	Acid soil	Neutral soil	Calcareous soil
Non biochar	0.92 a	1.30 a	1.37 a	0.09 a	0.11 ab	0.09 a
PLbiochar	1.33b	1.62 b	1.86 b	0.11 ab	0.10 a	0.10 a
PLbiochar-NH_4^+	1.35 b	1.65 b	1.84 b	0.14 b	0.14 b	0.14 c
PLbiochar-NO_3^-	1.29 b	1.66 b	1.78 b	0.12 b	0.12 a	0.11 ab
Ccbiochar	1.45 b	1.74 b	1.78 g	0.11 ab	0.11 ab	0.09 a
CCbiochar-NH_4^+	1.56 b	1.79 b	1.88 g	0.13 a	0.14 b	0.13 bc
CCbiochar-NO_3^-	1.55 b	1.76 b	1.87 g	0.12 b	0.12 ab	0.11ab

*) means followed by the same letters for the same characteristics is not significantly different (p = 0.05)

The result presented in Table 4 also showed that total nitrogen content of soil treated with biochar tend to be higher compared to that of non biochar soil. This phenomenon indicated that biochar is able to decrease soil nitrogen loss due to leaching. Furthermore, the result in Table 4 show that nitrogen content of soil with ammonium enriched biochar tend to be higher compared to that of applied with nitrate enriched biochar. This result indicated that ammonium is better basic materials for nitrogen enrichment of biochar. This phenomenon is not surprising. Ammonium which possesses positive charge will be easily adsorbed by the negative charge of biochar.

Application of biochar significantly increased pH of acid and neutral soil (Table 5). The effect of biochar application on pH of calcareous soil, on the other hand, did not significantly different. Enrichment biochar with ammonium sulfate and nitrate acid did not significantly influence its ability to increase soil pH.

Table 5: Effect of N-enrichment biochar application on soil pH and cation exchange capacity (CEC) of soils with different acidity after harvesting rice

Treatments	pH			CEC (cmol kg^{-1})		
	Acid soil	Neutral soil	Calcareous soil	Acid soil	Neutral soil	Calcareous soil
Non biochar	4.62 a	6.62 a	7.54 a	6.35 a	15.43 a	13.35 a
PLbiochar	5.66 b	7.24 b	7.84ab	7.44 b	15.22 ab	14.25 ab
PLbiochar-NH_4^+	5.48 b	6.90 ab	7.66 ab	7.35 b	15.90 ab	14.34bc
PLbiochar-NO_3^-	5.87 b	7.05 ab	7.80 ab	7.35 b	16.45 bc	14.26 ab
CCbiochar	5.85 b	7.45 b	8.05 b	7.48 b	17.38 c	15.90d
CCbiochar-NH_4^+	5.68 b	6.94 ab	7.62 ab	7.82 b	17.24 bc	15.28 cd
CCbiochar-NO_3^-	5.65 b	7.08 ab	7.65 ab	7.60 b	16.55 bc	15.45 d

*) means followed by the same letters for the same characteristics is not significantly different (p = 0.05)

Table 6: Effect of nitrogen enriched biochar on the N-fertilization efficiency of rice planted in soil with different acidity

Treatment		N in vegetative part	N in grain yield	Total N uptake	N Fertilizer Efficiency
Soil	N rate	(g/pot)	(g/pot)	(g/pot)	(%)
Acid	Non biochar	52.76	50.01	102.77	24.18 ab
	CCbiochar NH_4^+	78.80	58.45	137.15	40.34 cd
	CC biochar NO_3^-	62.65	47.52	110.17	25.65 ab
Neutral	Non biochar	61.41	54.59	116.00	26.77 ab
	CCbiochar NH_4^+	80.20	76.48	156.92	46.24 d
	CC biochar NO_3^-	82.18	73.23	155.41	46.71 d
Calcareous	Non biochar	50.75	49.48	100.23	19.09 a
	CCbiochar NH_4^+	82.03	72.01	154.04	46.88 d
	CC biochar NO_3^-	72.13	54.83	126.96	32.57 bc

*) means followed by the same letters for the same characteristics is not significantly different (p = 0.05)

Except in acid soil, enriched biochar possessed higher nitrogen fertilization efficiency compared with the conventional nitrogen fertilizer (Table 6). Furthermore, the results in Table 6 show that biochar enriched with ammonium had a higher nitrogen fertilizer efficiency compared that of enriched with nitrate.

CONCLUSION

The experimental results discussed above had shown that biochar was a good carrier for nitrogen plant nutrition. The growth and yield of rice planted in enriched biochar soil was as good as the rice growing in urea treated soil; even it had a higher yield. There was a tendency that biochar enriched with ammonium sulfate relatively better compared to that of enriched with nitrate acid. The rice yield of rice planted in ammonium enriched biochar was higher than that of planted on nitrate enriched biochar. The application of nitrogen enriched biochar increased the fertilizer efficiency. Ammonium is a better enriched material for biochar than nitrate.

ACKNOWLEDGEMENT

This research was funded by Directorate General for Research and Development Strengthening, Indonesian Ministry of Research, Technology and Higher Education, under Strategic National Research Scheme, with Contract No.063/SP2H/LT/DPRM/IV/2017, SPK No.460.161.

REFERENCES

[1] Sombroek, W. G. 1966. A reconnaissance of the soils of the Brazilian Amazon region. Centre for Agricultural Publications and Documentation, Wageningen. 292 pp

[2] Lehmann, J. and S.Joseph. 2009. Biochar for Environmental Management: Introduction. *In* Lehman, J. and Joseph (ed). Biochar for Environmental Management: Science and Technology. Earth scan, London. pp 1-12.

[3] Woolf, D. 2008. Biochar as a soil amendment: A review of the environmental implications. [Online] :http://orgprints.org/13268/01/Biochar_as_a_soil_amendment_-_a_review.pdf. [Accessed 25 October 2008].

[4] Woolf, D.,J.E. Amonete, F.A. Street-Perrott, J. Lehmann and S. Joseph. 2010. Sustainable biochar to mitigate global climate change. Nature Communications 1, Article number: 56. 47 pp

[5] Downie, A., P. Munroe and A. Crosky. 2009. Characteristics of biochar- physical and structural properties. *In:*Lehmann J and Joseph S (Eds.). Biochar for Environmental Management: Science and Technology. Earth scan, London. Pp 13-29

[6] Haefele, S.M, C. Knoblauch, M. Gummert, Y. Konboon and S. Koyama. 2008. Black carbon (biochar) in rice-based systems: Characteristics and opportunities. *In:* Woods, W.I., Teixeira, W.G., Lehmann, J., Steiner, C., Prins, A.W.and Rebellatods, L. (Eds.). Amazon dark earths: Wim Soembrok's vision (pp 445-463. Amsterdam: Springer .

[7] Asai, H., B.K. Samson, H.M. Stephan, K. Songyikhangsuthor, K. Homma, Y. Kiyono, Y.Inoue, T. ShiraiwaandT. Horie. 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.

[8] Reichenauer, T.G, S. Panamulla, S.Subasinghe and B. Wimmer. 2009. Soil amendments and cultivar selection can improve rice yield in salt-influenced (tsunami-affected) paddy fields in Sri Lanka. Environ. Geochem. Health, 31, 573–579.

[9] Masulili, A., W.H. Utomo.and Syekhfani, Ms. 2010. Rice husk biochar for rice based cropping system in acidic soils: The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. J. of Agric. Sci. (Canada) 2: 39-47

[10] Masulili, A., W.H. Utomo and E.I. Wisnubroto. 2015. Growing Rice (Oriza sativa L.) in the Sulphate Acid Soils of West Kalimantan, Indonesia. Int. J. Agric. Res., 11: 13-22

[11] Dong D., M. Yang, C. Wang, H.Wang, Y. Li, J. Luo, and W. Wu.2013. Responses of methane emissions and rice yield to applications of biochar and straw in a paddy field. J Soils Sediments 13:1450–1460

[12] Liang, B., J. Lehmann, J., D. Kinyangi, J. Grossman, B. O'Neill, J.O. Skjemstad, J. Thies, F.J. Luizao, J. Peterson, and E.G. Neves. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J.,70, 1719–1730

[13] Chan, K.Y., B.L. van Zwieten,I. Meszaros, D. Downie, D. and S. Joseph. 2007. Agronomic values of greenwaste biochars as a soil amendments. Australian Journal of Soil Research, 45, 437–444.

[14] Widowati, W.H. Utomo, L.A, Soehono and B. Guritno. 2011. Effect of biochar on the Release and Loss of Nitrogen from Urea Fertilization. J. Agric. Food. Tech., 1: 127-132

[15] Dong, D., Q. Feng, K. Mc Grouther and M. Yang. 2015. Effects of biochar amendment on rice growth and nitrogen retention in a waterlogged paddy field. J Soils Sediments, 15: 153.

[16] Widowati, W.H. Utomo, B. Guritno and L.A. Soehono. 2012. The Effect of Biochar on the Growth and N Fertilizer Requirement of Maize (Zea mays L.) in Green House Experiment. J. of Agric. Sci, (Canada), 4: 255-262

[17] Taghizadeh-Toosi, A., T.J. Clough, R.R. Sherlock and L.M. Condron. 2012. Biochar adsorbed ammonia is bioavailable. Plant and Soil, 350: 57-69.

[18] Jassal, R. S., M.S. Johnson, M. Molodovskaya, T.A. Black, A. Jollymore and K. Sveinson. 2015. Nitrogen enrichment potential of biochar in relation to pyrolysis temperature and feedstock quality. Journal of environmental management, 152: 140-144.

[19] Wisnubroto, E. I., W.H. Utomo and H.T. Soelistyari. 2017. Biochar as a Carrier for Nitrogen Plant Nutrition: 1. The Release of Nitrogen from Biochar Enriched with Ammonium Sulfate and Nitrate Acid. IJAER, Vol. 12: 1035-1942

[20] Soil Survey Laboratory Staff. 2011. Soil Survey laboratory Information Manual. Soil Survey Investigation Report No. 45, Version 2.0, NRS,USDA. Pp 245-251

[21] Bremner, J.M. and C.S. Mulvaney. 1982. Nitrogen-total. In: A.L. Page, R.H. Miller, D.R. Keeney, (Eds.), Methods of Soil Analyses, Part 2. Chemical and Mineralogical properties (pp. 595–624. Madison: American Society of Agronomy and Soil Science Society of America Inc.

[22] Tanaka, A. and S.A. Nasero. 1966. Aluminium toxicity of rice plant under water culture condition. Soil Science and Plant Nutrition, 12: 9-14

[23] Chintala, R., J. Mollinedo, T.E. Schumaker, D.D. Malo and J. Julson. 2014. Effect of biochar on chemical properties of acidic soil. Archive of Agronomy and Soil Science. 393-404.