Preparation and nutrient release kinetics of enriched biochar-based NPK fertilizers and agronomic effectiveness in direct seeded rice

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Abstract

In present study, two enriched biochar-based fertilizers were prepared having fertilizer grade of 6-6-4 N-P₂O₅-K₂O by intercalation of NPK fertilizers mixture solution as EB-1 and additional humic acid and seaweed extract as EB-2. In laboratory, batch experiment were done to compare nutrients (NH₄⁺, NO₃⁻, P and K⁺) release patterns of developed fertilizers along with conventional fertilizers. Enriched biochar fertilizers (EB) demonstrated much slower release pattern of NH₄⁺, P and K⁺, however NO₃⁻ release was similar over conventional fertilizers. The cumulative release of N in EB fertilizers was similar to conventional fertilizer, however significantly less of P and K were released during the period of 72 hrs. The field response study of enriched fertilizers EB-2 revealed 29.5, 11.5 and 22.9% higher apparent use efficiency than conventional fertilizer. The slow nutrients release behaviour of EB fertilizers implies reduced losses and enhanced NUE as reflected by higher apparent recovery of N, P and K.

Introduction

Nutrient use efficiency (NUE) is a vital concept for assessing farming system which is greatly dependent on fertilizer management as well as soil- plant-water relationships. The nutrient use is mainly used to increase the crop performance by providing optimum nourishment while minimizing nutrient losses from the field and supporting sustainability by contributing to soil quality components. Use efficiency of nitrogenous fertilizers is around 30-40 %, phosphate fertilizers are 15-20 %, potassic fertilizers is 50-60 % and micronutrient is 1-2 % (Singh et al. 2014). Among the different approaches initiated to increase the nutrient use efficiency; control release fertilizer may be a novel environment-friendly approach. Control-release fertilizers delays the availability of nutrients after application for plant uptake and use, or which extends the nutrient availability to the plant for significantly longer period compared to the conventional fertilizers and thereby enhance nutrient use efficiency. Biochar prepared from agricultural wastes *viz.*, rice straw and husk may be utilized as a suitable matrix to prepare control release fertilizers (Singh et al. 2020; Chaturvedi et al. 2021). It will not only enhance NUE but also improve soil health and crop yield with most economic management of agro-wastes.

Biochar is a product of the pyrolysis of organic materials such as wood, rice husk, rice straw, leaves, grasses, crop residues and manure as a stable, recalcitrant organic carbon-rich amendment to improve soil bio-physiological and chemical properties (Lehmann et al., 2006). Biochar has a porous structure, huge surface area, a large number of functional groups, and plentiful mineral elements, that benefit loading of fertilizer nutrients and availability of heavy metals in the soil (Dong et al. 2019; Liu et al. 2019). Presence of surface functional groups on biochar strongly adsorbs various nutrient ions, including NH₄⁺, NO₃⁻, P and K⁺ ions (Kimetu 2010; Mizuta et al. 2004). This promotes to load nutrients on biochar and reduce their losses (Singh et al. 2020; O'Connor et al. 2018). Sorption by the biochar is the primary reason for reduced mean cumulative leaching of nitrate and nitrite in biochar-amended soil (Mukherjee et al. 2014). Therefore, application of biochar as a soil amendment or slow-release fertilizer could make farming more productive by compensating for acidity, improving organic carbon, water retention and nutrient availability and bring more area under agriculture (Fryda and Visser 2015).

Despite the positive impacts of biochar in agricultural systems, it is usually very expensive to apply mainly due to the high cost of collecting feedstock as well as the high costs of pyrolysis plants. Biochar itself does not contain enough nutrients for crop growth (Yaung et al. 2016). To utilize biochar in agriculture comfortably, it can be enriched with chemical fertilizers. This can curtail cost and make it relative to that of conventional chemical fertilizers. Compared to conventional chemical fertilizers, biochar enriched fertilizers have been shown to increase crop yields, nutrient use efficiency, plenty of beneficial microorganisms, and lower soil greenhouse gas emissions (Joseph et al. 2013; Qian et al. 2014; Zheng et al. 2017; Yao et al. 2015; Blackwell et al. 2015). Sole application of biochar reduced grain yield (Asai

et al. 2009) due to the insufficient supply of nitrogen thus, augmenting biochar with fertilizer nutrients makes biochar composite suitable for plant growth and yield (Si et al. 2018) and heavy metal adsorption (Zhao et al. 2016). Due to the farming and ecological applications, enriched biochar fertilizers have received growing attention. Recent studies suggest that biochar-based fertilizers delay the release of nutrients in the soil displaying a slow-release effect (Chaturvedi et al. 2021). Enrichment of soil with biochar-based fertilizer adjust the soil pH, reduce the bulk density, improve soil aeration and water permeability and retention to increase the crops yield (Gao et al. 2012; O'Connor et al. 2018). Addition of enriched biochar in soil as a carrier of nutrients is enormous. Moreover, it could guide nutrient release in sustained manner and extended period due to its micro porous structure and extensive surface area (Ghezzehei et al. 2014; Singh et al. 2020). Collectively, these characteristics makes biochar-based fertilizer a novel approach that could reduce losses, increase nutrient bioavailability, mitigate GHG emission, improve soil health and consequently crop growth and biomass yield.

Materials And Methods

Synthesis and chemical characterization of biochar and enriched biochar-based fertilizers

Synthesis of the biochar-based NPK fertilizer entailed three consecutive steps: (1) pyrolysis of rice husk for the production of the biochar for fertilizer carrier; (2) impregnation of the biochar with nutrient solution; and (3) granulation or prilling. The rice husk, a readily available low cost biowaste was obtained from Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (28.97°N, 79.41°E). Pyrolysis of prepared feedstock was carried out in rotary type reactor under oxygen-limited conditions at temperature of 450°C (Mandal et al., 2018), aiming to produce small pores and preserve oxygen-functional groups (Al-Wabel et al., 2013; Keiluweit et al., 2010; Lawrinenko and Laird, 2015; Yuan et al., 2014). An NPK nutrient solution was prepared by dissolving 12-32-16 NPK (IFFCO) + Urea + MOP mixture in distilled water. Prepared biochar was ground in disc mill using 60 mesh sieves after grinding and added to prepared NPK solution (NPK (12-32-16) fertilizer (200 kg) + Urea (80 kg) + MOP (20 kg) in ratio 7:3 to produce enriched biochar; EB-1 and additionally humic acid and seaweed extract was added for enriched biochar; EB-2. Both EB-1 and EB-2 had 6-6-4 N-P₂O₅-K₂O fertilizer grade. The developed fertilizers were characterized for their properties and nutrient release kinetics.

Determination of nutrient release patterns

Batch experiment was conducted IFS laboratory with soil sample, Conventional fertilizer mix (N-P-K 12-32-16 + Urea + MOP), EB-1 and EB-2. Leachates of nutrient enriched biochar were collected through batch experiment for 36 h at 0 min, 15 min, 30 min, 1 h, 3 h, 6 h, 9 h, 15 h, 24 h and 36 h and NPK content in those leachates were determined as ammonium (NH₄⁺), nitrate (NO₃⁻), phosphorus (P) and potassium (K).

Ammonium (NH₄⁺)

For determination of release pattern of NH₄⁺ from conventional fertilizers mix, EB-1 and EB-2 batch experiment was followed. These three fertilizers were taken in 10 conical flasks for each sample on 1g N content basis. After that 10 g of soil sample from experimental field was added to each flask and 30 mL of water also added to each flask. At predetermined time intervals selected flasks samples were filtrated in 100 mL volumetric flask and after collecting filtrate filled the volumetric flask up to 100 mL. After collecting all the filtrates at all predetermined time intervals. Modified kjeldhal method was followed to determine NH₄⁺ content in samples. Calculated NH₄⁺ content (ppm) in samples from recorded readings were plotted in graph against time intervals to get NH₄⁺ released pattern of these three fertilizers. Both the cumulative and instantaneous concentration graph at predetermined time intervals were drawn.

Nitrate (NO₃⁻)

After determination of NH₄⁺ content of the samples, 0.2 g of Devarda's alloy was added to the samples and again Modified kjeldhal method was followed to determine NO₃⁻ content in samples. Calculated NO₃⁻ content (ppm) in samples from recorded readings were plotted in graph against time intervals to get NO₃⁻ released pattern of these three fertilizers. Both the cumulative and instantaneous concentration graph at predetermined time intervals were drawn.

Phosphorus (P)

For determination of release pattern of P from conventional fertilizers mix, EB-1 and EB-2 batch experiment was followed. These three fertilizers were taken in 10 conical flasks for each sample on 0.1 g P₂O₅ content basis. After that 10 g of soil sample from experimental field was added to each flask and 30ml of water also added to each flask. At predetermined time intervals selected flasks samples were filtrated in 100 mL volumetric flask and after collecting filtrate filled the volumetric flask up to 100 mL. After collecting all the filtrates at all predetermined time intervals, ammonium molybdate and potassium antimony react method was followed to determine P content in samples. Calculated P content (ppm) in samples from recorded readings were plotted in graph against time intervals to get P released pattern of these three fertilizers. Both the cumulative and instantaneous concentration graph at predetermined time intervals were drawn.

Potassium (K)

For determination of release pattern of K from conventional fertilizers mix, EB-1 and EB-2 batch experiment was followed. These three fertilizers were taken in 10 conical flasks for each sample on 0.1 g K₂O content basis. After that 10 g of soil sample from experimental field was added to each flask and 30 mL of water also added to each flask. At predetermined time intervals selected flasks samples were filtrated in 100 mL volumetric flask and after collecting filtrate filled the volumetric flask up to 100 mL. After collecting all the filtrates at all predetermined time intervals, Flame emission spectrophotometry method was followed to determine K⁺ content in samples. Calculated K content (ppm) in samples from recorded readings were plotted in graph against time intervals to get K released pattern of these three fertilizers. Both the cumulative and instantaneous concentration graph at predetermined time intervals were drawn.

Evaluation of the Nutrient-use efficiency

A field experiment was initiated during rainy season of 2018 at N.E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand to evaluate the effect of enriched biochar-based fertilizers on nutrient-use efficiency in direct seeded rice (DSR). Rice variety "HKR-47" was used for present study. The soil of experimental site was sandy loam in texture with bulk density of 1.44 Mg/m³. The soil was neutral (pH 7.2) in reaction, medium in soil organic carbon (0.65 %), low in available nitrogen (149.6 kg/ha), high in available phosphorus (26.9 kg/ha) and potassium (281.1 kg/ha). The moisture content of the site at field capacity and permanent wilting point was 20 and 8 %, respectively.

The experiment had eight treatments applied at 3 rates with 3 fertilizer source *i.e.* 100 % RDF (120 kg N, 60 kg P₂O₅, 40 kg K₂O / ha) through conventional fertilizers (T1); 75% (T2), 100% (T3) and 125% (T4) RDF through enriched biochar based fertilizer EB-1 for basal application + urea enriched biochar (UEB-1) containing biochar + urea (1:1) for top dressing of N; 75 % (T5), 100 % (T6) and 125 % (T7) RDF through enriched biochar based fertilizer EB-2 for basal application + urea enriched biochar (UEB-2) containing biochar + urea (1:1) + seaweed + humic acid for top dressing and no fertilizer application (T8) replicated thrice laid out in randomized block design. The recommended fertilizer dose (RDF) was 120 kg N + 60 kg P₂O₅ + 40 kg K₂O per ha. half dose of N and full dose of P and K were applied through

conventional fertilizers mix as basal and rest half of N was applied in two equal splits at 30 and 60 DAS as top dressing through urea for treatment T1. Whereas for treatments T2, T3 and T4, half dose of N and full dose of P and K were applied through EB-1 as basal and rest half of N was applied in two equal splits at 30 and 60 DAS as top dressing through UEB-1. For treatments T5, T6 and T7, half dose of N and full dose of P and K were applied through EB-2 as basal and rest half of N was applied in two equal splits at 30 and 60 DAS through UEB-2 as top dressing. For evaluating nutrient-use efficiency of enriched biochar-based fertilizers apparent nutrient recovery (%) was determined using following formulae:

$$\text{Apparent Nitrogen recovery (\%)} = \frac{\text{Total N uptake in nutrient applied plot} - \text{Total N uptake in no nutrient applied plot}}{\text{Amount of Nitrogen applied}} \times 100 \quad (1)$$

$$\text{Apparent Phosphorus recovery (\%)} = \frac{\text{Total P uptake in nutrient applied plot} - \text{Total P uptake in no nutrient applied plot}}{\text{Amount of Phosphorus applied}} \times 100 \quad (2)$$

$$\text{Apparent Potassium recovery (\%)} = \frac{\text{Total K uptake in nutrient applied plot} - \text{Total K uptake in no nutrient applied plot}}{\text{Amount of Potassium applied}} \times 100 \quad (3)$$

Results And Discussion

Characteristics of biochar and enriched biochar (EB-1 and EB-2)

The surface morphology of biochar derived from rice husk is primarily performed by SEM and showed a highly porous structure with smooth and tight. The porous tubular morphology of rice husk biochar (RHB) favour it to store/reserve the nutrients and slow release to soil system (Fig. 1a&b). The properties of rice husk biochar (RHB) and EB-1 & 2 prepared are shown in Table 1. The RHB had pH value of 9.1, cation exchange capacity of 27 cmol/kg, EC of 1.55 ds/m and bulk density of 0.22 g/cc whereas, EB-1 and EB-2 had pH of 8.07 and 7.6 and EC of 0.15 and 0.17 ds/m and CEC of 17 and 21 cmol/kg, respectively. Proximate and elemental analysis representing the recalcitrance and stability of biochar relates the qualitative traits of resultant biochar (Table 1). These results are common for biochar from different feedstock's produced at low temperature (Chaturvedi et al., 2021; Shaheen et al., 2019).

Kinetics of NPK release

Ammonium (NH₄⁺) release pattern

Ammonium (NH₄⁺) release from conventional fertilizers mix (NPK 12-32-16 + Urea + MOP) reached its peak around 30 min after starting the batch experiment, whereas the peak NH₄⁺ releases from both the enriched biochar fertilizers (EB-1 and EB-2) were noticed around 6 h after starting the batch experiment (Fig.2a&b). Ammonium (NH₄⁺) released from conventional fertilizers mix at significantly faster rate compared to both of the enriched biochar based fertilizers. From the conventional fertilizers mix around 78.90 % of NH₄⁺ released within 1 h but that same amounts of NH₄⁺ (81.11 % and 81.78 %) were released from both of EB-1 and EB-2 respectively at 24 h after starting the experiment. This slow release of NH₄⁺ might be due to the fact that hydrogen bonding and electrostatic interactions between the oxygen containing functional group (carboxyl and keto group) of biochar and NH₄⁺, slowed the release rate of NH₄⁺ from enriched biochar based fertilizers (Wen et al., 2017). Under pyrolysis temperature of 200 to 400 °C, the feedstock was carbonized incompletely, so numerous oxygen functional groups were remaining in biochar, which could provide abundant negative potential charges for the adsorption of NH₄⁺, owing to hydrogen bonding and electrostatic

interactions (Cai et al., 2016). In the present study, NH_4^+ released from the conventional fertilizers mix at the logarithmic rate *i.e.* released at faster rate with shorter time interval up to 1 h, after that release rate with increase in time interval were less and at the end of the experiment (36 h) around 96 % of NH_4^+ was released. In case of NH_4^+ releases from the EB-1 and EB-2, initial release rates were at par with conventional fertilizers mix but after that NH_4^+ released at slow and steady rate with time. Between the times interval 1 h to 15 h both the enriched biochar based fertilizers released around 54-55 % of total NH_4^+ . At the end of the experiment (36 h) total NH_4^+ released from both of the enriched biochar fertilizers were at par with conventional fertilizers mix. There was no significant difference in NH_4^+ release pattern for both of EB-1 and EB-2. Similarly, rapid release of urea was recorded with RHB-450 and most of the urea released for 2900 min and thereafter get plateau whereas in case RSB-450, increasing release trend was recorded upto 3600 min (Singh et al., 2020). Liu et al (2019) reported release from the urea loaded biochar and bentonite composites to follow similar trend. Swelling and swelling of biochar with the absorption of moisture lead to the release nutrient particles intercalated nutrient particles into the cavities of biochar.

Nitrate (NO_3^-) release pattern

Nitrate (NO_3^-) nitrogen released from both EB-1 and EB-2 was more as compared to the conventional fertilizers mix (Fig. 3a&b). It was due to less nitrate content in conventional fertilizers mix because of this conventional fertilizers mix contented most of the nitrogen in ammoniacal (NH_4^+) form. Though enriched biochar based fertilizers were enriched with that same fertilizers composition, there might be chance to convert NH_4^+ to NO_3^- due to reaction with biochar matrix. There was no significant difference in NO_3^- release pattern for EB-1 and EB-2. Similar release pattern was reported by Gwenzi et al (2017) for biochar based slow-release fertilizer (BSRF).

Phosphorus (P) release pattern

In general, enriched biochar based fertilizers (EB-1 and EB-2) had consistently lower phosphorus release than the conventional fertilizers mix throughout the 36 hours monitoring period (Fig. 4a&b). Total phosphorus release was significantly lower for EB-1 and EB-2 than conventional fertilizers mix up to 9 h of starting of batch experiment and after that total releases were statistically at par. P release pattern for conventional fertilizers mix was characterized by general decline with time with its peak at 3 h after starting the experiment. The peak of P release pattern for both of the enriched biochar fertilizers were different. P release from EB-1 reached its peak around 6 h and from EB-2 reached its peak around 9 h after starting the experiment. Gwenzi et al. (2017) also found that in P release pattern the cumulative concentration of PO_4^{3-} released from biochar based slow release fertilizer (BSRF) was approximately half of that of commercial fertilizer Compound D during a 72 days' period of sequential leaching. In the present study, there was no significant difference in P release pattern for both of EB-1 and EB-2. The P in the matrix of biochar is slowly released due to physical protection of the biochar pores network (Dias et al., 2018). The water action removes aliphatic groups (hydrophobicity) on biochar surface, increasing its affinity for water (Das and Sarmah, 2015) interacting with hydrophilic groups resulting a swelling of the biochar coating making a new arrangement which finally controls the water movement inside and outside of the fertilizer (Dias et al., 2018). Till date, limited studies have evaluated nutrient release patterns of slow release NPK fertilizer using biochar as a nutrient carrier. Yao et al. (2013) used biochar to remove P from aqueous solution and concluded that P-laden biochar could possibly act as a slow-release fertilizer. It did not include other nutrients such as cations and highly soluble and mobile nutrients in its study. Moreover, a conventional chemical fertilizer was also not taken for comparison. Therefore, the present study focused to develop a biochar-based slow-release NPK fertilizer and evaluate its nutrient release pattern.

Potassium (K^+) release pattern

Peak K^+ releases from the conventional fertilizers mix as well as from the enriched biochar based fertilizers (EB-1 and EB-2) occurred at 1 h after starting the experiment but that for EB-1 was about 60.50 % and for EB-2 was about 44.22 % lower than that of conventional fertilizers mix (Fig. 5a&b). Overall cumulative concentration of K^+ released by both EB-1 and EB-2 were lower than that for conventional fertilizers mix up to 36 h of experiment. Similar result was reported by Gwenzi et al. (2017) that overall cumulative concentration of K^+ released by biochar based slow release fertilizer (BSRF) was 1.5 times lower than that of for commercial fertilizer Compound D and peak K^+ release was significantly lower for BSRF than that of Compound D. In the present study, there was no significant difference in K^+ release pattern for both of EB-1 and EB-2.

Evaluation of NH_4^+ , NO_3^- , PO_4^{3-} , and K release patterns confirmed the slow-release behavior of the biochar enriched fertilizers (Figs. 2-5). Nutrient release patterns of biochar enriched slow-release fertilizers were characterized by an initial high release in the first few observations mainly attributed to rapid diffusion and washout as also reported by Gwenzi et al. (2017). The release of PO_4^{3-} and K by enriched fertilizers was characterized by distinct multiple peaks suggesting a number of release mechanisms which was not the case with N. Moreover, the cumulative PO_4^{3-} and K releases of the enriched fertilizers (EB-1 & EB-2) were approximately half that of commercial fertilizer mix in period of study. The manifold mechanisms of nutrient release from biochar enriched fertilizers include pore diffusion, ion exchange on charged biochar surfaces of biochars, co-precipitation, complexation/ligand exchange, van der Waals/electrostatic forces, and p-cation interactions between solute ions and aromatic rings of biochar (Wang and Chen 2006; Berber-Mendoza et al., 2013). Moreover, the use of an adjuvants may enhance the slow-release behavior of the biochar-based fertilizers.

Apparent nutrient recovery (%) of N, P and K

Apparent nitrogen recovery was higher under application of 100 % fertility dose through EB-2 + UEB-2 which was 29.5 % more than application of conventional fertilizers at that same fertility dose (Table-2). Even application of EB-1 + UEB-1 at 75, 100 and 125 % fertility levels had lower apparent N recovery as compared to EB-2 + UEB-2 at similar fertility levels, respectively. However, application of both the enriched biochar fertilizers at all the fertility levels had more apparent N recovery as compared to application of 100 % fertility level through conventional fertilizers. More N uptake from enriched biochar sources might be the principle reason for their higher apparent recovery. Apparent P and K recovery was higher under application of 100 % fertility dose through EB-2 + UEB-2 of 29.39 % and 83.06 % of P and K respectively. Further, it was 11.5 % and 22.9 % more than application of conventional fertilizers at that same fertility dose (Table-2). Huang et al. (2013) reported that due to addition of biochar, agronomic nitrogen use efficiency was increased by 43 % over no biochar addition at 100 % fertility level. Slow release of nitrogen, phosphorus and potassium from NPK enriched biochar-based fertilizers is mainly attributed to their slower release kinetics, reduced losses and indirectly by enhanced availability of soil nutrients thereby higher apparent use efficiency of N, P and K under enriched biochar fertilizers application. Several studies have shown that biochar application enhanced the microbial activity including soil enzyme activity and soil respiration (Steiner et al., 2008), promote root colonization by arbuscular mycorrhiza (Elmer and Pignatello, 2011). These root exudates and enhanced microbial activities could further promote release of nutrients from insoluble soil nutrient pools. Therefore, biochar based slow-release fertilizers have several potential niche applications in crop production, horticulture, olericulture including environmental remediation.

Conclusions

Two novel enriched biochar-based fertilizers (EB-1 and EB-2) were developed with much slower nutrient release patterns as compared to that of conventional chemical fertilizers. The slow nutrients (NH_4^+ , P and K^+) release behavior

of EB fertilizers implies reduced loss of nutrients through leaching and hence increase crop nutrient use efficiency. Chemical characterization of EB fertilizers showed their potential niche applications in agriculture including environmental remediation demonstrating their potential superiority over conventional fertilizers mix.

Declarations

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Declaration of Competing Interest

All the authors declare that they have no known competing financial interests.

Compliance with ethical standards: Not applicable

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Author contribution: Arkaprava Roy: data collection, analysis, Sumit Chaturvedi: writing, reviewing, and editing, Suhita Pyne: designing the experiments, analysis, Shiv Vendra Singh: analysis, writing, Govindaraju Kasivelu: reviewing, and editing

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Tables

Table 1 Characterization of biochar and enriched biochar-based fertilizers

Biochar	Physicochemical properties											
	Physicochemical properties				Proximate analysis							
	pH	EC (dSm ⁻¹)	CEC (cmol/kg)	BD (g/cc)	MC (%)	VC (%)	Ash (%)	FC (%)	N (%)	P (%)	K (%)	S (%)
RHB	9.0	1.56	26.2	0.22	3.9	17.3	23.5	55.4	0.71	0.87	2.03	0.04
EB-1	8.07	0.15	17.0	-	-	-	-	43.4	6.0	6.0	4.0	-
EB-2	7.6	0.17	21.0	-	-	-	-	43.7	6.0	6.0	4.0	-

Table 2. Apparent nutrients recovery (%) of N, P and K under direct seeded rice.

Treatments		Apparent Nitrogen Recovery (%)	Apparent Phosphorus Recovery (%)	Apparent Potassium Recovery (%)
Source	Fertility level			
Conventional fertilizers	100 % RDF	38.52	17.86	60.17
EB-1 + UEB-1	75 % RDF	41.18	15.01	48.00
	100 % RDF	43.05	23.74	78.96
	125 % RDF	44.49	26.76	80.05
EB-2 + UEB-2	75 % RDF	46.52	19.79	64.28
	100 % RDF	49.91	29.39	83.06
	125 % RDF	47.39	28.36	81.54

EB-enriched biochar; UEB-Urea enriched biochar; RDF-recommended dose of fertilizer

Figures

Figure 1

1a&b shows the SEM images of biochar derived from of rice husk

Figure 2

Cumulative (a) and Instantaneous (b) concentrations of NH_4^+ released

Figure 3

Cumulative (a) and Instantaneous (b) concentrations of NO_3^- released

Figure 4

Cumulative (a) and Instantaneous (b) concentrations of P released

Figure 5

Cumulative (a) and Instantaneous (b) concentrations of K⁺ released