



Research article

Effects of rice husk biochar in minimizing ammonia volatilization from urea fertilizer applied under waterlogged condition

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Abstract: Rapid ammonia volatilization from surface applied urea in waterlogged condition is one of the drawbacks as it leads to poor nitrogen use efficiency by plants. Thus, a laboratory scale closed dynamic air flow system was carried out in this study to assess the effect of rice husk biochar on ammonia volatilization, soil exchangeable ammonium and available nitrate in comparison to the urea without additives under waterlogged conditions. The study conducted consists of 6 treatments, soil alone (T0), soil + 175 kg ha⁻¹ urea (T1), soil + 175 kg ha⁻¹ urea + 5 t ha⁻¹ rice husk biochar (T2), soil + 175 kg ha⁻¹ urea + 10 t ha⁻¹ rice husk biochar (T3), soil + 175 kg ha⁻¹ urea + 15 t ha⁻¹ rice husk biochar (T4) and soil + 175 kg ha⁻¹ urea + 20 t ha⁻¹ rice husk biochar (T5). T2, T3, T4, and T5 significantly minimized ammonia volatilization by 23.8%–34.5% compared to T1. However, only T2, T3, and T4 had significantly retained more soil exchangeable ammonium by 14%–43% compared to urea without biochar (T1). Additionally, soil available nitrate was lower in all treatments except T1. This clearly gives an idea that rice husk biochar minimize ammonia volatilization, retaining more ammonium and slowing down the conversion of ammonium to nitrate under waterlogged environment. Mixing urea with rice husk biochar at rate of 5 t ha⁻¹ and 10 t ha⁻¹ offers a significant advantage over urea alone. The mixture successfully increased formation of ammonium ions in soil over ammonia. Additionally, it has retained more ammonium and nitrate ions in the soil. Hence, biochar amended soil with urea is a promising approach to minimize ammonia loss and increase plant N use efficiency and uptakes.

Keywords: ammonia volatilization; biochar; urea; acidic soil; ammonium; nitrate

1. Introduction

Nitrogen (N) is one of the primary essential plant nutrients for both crop growth and serves as a key element for environmental sustainability. It is required in a large amount and remains as a critical nutrient supplement throughout a plant lifecycle. Due to this, agricultural field needs additional N fertilizer application to increase the crop growth and yield production. However, rapid volatilization of ammonia (NH_3) from applied N fertilizers creates drawback to agricultural sectors [1,2], especially, surface applied urea fertilizer [3], where its efficacy constantly reduces. Upon application, urea hydrolyses in water and urease triggers NH_3 loss [4]. The conversion of NH_3 to ammonium ions (NH_4^+) speeds up during hydrolysis process. It is also known that high amount of NH_4^+ ions in soil without good retention can lead to N loss [5]. The retention of NH_4^+ ions in soil depends on many factors such as clay content, organic matter, irrigation and precipitation. These factors always varies and unable to retain the NH_4^+ in soil for plant uptake [4]. The NH_3 volatilization causes poor N use efficiency by agricultural crops and simultaneously increases the air pollution. Not only that, to overcome the N loss and increase the agricultural crop N uptake, farmers tend to apply excessive N which creates environmental problem and it is costly.

In order to minimize NH_3 loss, biochar can be used as one of the possible option. Biochar, namely biomass-derived charcoal is highly aromatic substance that has been thermally decomposed under charring condition [6]. Biochar is usually being produced in a small scale using low-cost modified stoves or kilns or through large-scale, cost-intensive production [7]. Agricultural waste such as rice husk can be utilized to produce biochar. Annual production of rice husk exceeds 926, 886 tonnes [8]. The rice husk is always being bulked and burned in landfill which creates hazardous environment. Hence, exploitation of rice husk to biochar can be a promising approach to minimize waste and increase agronomical benefits. Biochar is categorized as highly porous, usually alkaline and exhibit large surface area. Large surface of area of biochar helps in binding anions and cations which directly increase cation exchange capacity (CEC) [9]. Studies have shown that biochar adsorb NH_4^+ ion predominantly by cation exchange and extended biochar potential as a nutrient-retaining additive which can work synergistically with chemical fertilizers [10]. Increase in CEC aids soil fertility as nutrients remained attached to soil. This might increases the urea-N retention and reduces the total fertilizer requirement in biochar-amended agricultural soil.

Studies had shown a complex biochar and soil interaction with respect to nutrient retention. Previous research demonstrated that biochar comes in different properties based on feedstock, charring condition and activation. This is in agreement with Spokas et al. [11] who stated that different source of biochar materials and charring temperature influenced the biochar properties that in turn increased soil fertility and nutrient retention. Further Clough et al. [12] stated that NH_4^+ and NO_3^- adsorption depends on the temperature and feedstock material used for biochar production. Wheat straw biochar charred at 350–550 °C tested in paddy field had increased soil total N [13]. The *Eucalyptus marginata* biochar had increased the sorption of NH_4^+ and NO_3^- effectively [14]. Jones et al. [15] reported that wood trunks biochar pyrolyzed at 450 °C minimize NH_3 loss and increased NH_4^+ retention in soil. However, crop residue and manure biochar had shown negative effect on NH_4^+ and NO_3^- retention in the soil, but increased soil available P [16]. These suggest that the capability of biochar in nutrient retention varies. There is also scarcity of information on different types of feedstock biochar such as rice husk biochar in amending soil fertility by preventing urea-N loss either in rice, cash crop or other agricultural field. Generally, the urea volatilization is rapid in

waterlogged soil such as rice field. Lin et al. [17] stated that the NH_3 volatilization occurs rapidly at a rate of 60%–80% of the total urea fertilizer applied. The NH_3 volatilization from applied urea in waterlogged soils needs to be minimized. Therefore, this study was carried out to determine the effect of mixing urea with rice husk biochar on NH_3 volatilization, soil exchangeable NH_4^+ and available nitrate (NO_3^-) contents, compared with applied urea without additives under waterlogged condition depicts the actual rice field conditions.

2. Materials and methods

2.1. Soil sampling, preparation and characterization

The soil used in this study was sampled at 30 cm of depth from an uncultivated land in Agro Techno Park of Universiti Malaysia Kelantan Jeli Campus, Malaysia (5.6955 latitude and 101.8389 longitudes) which has not been cultivated since 2007. The collected soil samples was air-dried, crushed and sieved to pass through a 2 mm sieve for initial soil characterization. Soil pH was measured in a ratio of 1:10 (soil:water) by using a digital pH meter [18]. Organic matter content, ash content, and total organic carbon (C) were determined by using loss-on ignition method [19]. The total N was determined by using Kjeldahl method [20]. Double acid method described by Mehlich [21] was used to extract soil available P and exchangeable cations (Ca, Mg, K, Na), after which the cations were determined by using an Atomic Absorption Spectrophotometer (AAS) (Analyst 800, Perkin Elmer, Norwalk, USA) while soil available P was determined by using molybdenum blue method [22]. The developed blue colour was analyzed by a UV-VIS spectrophotometer (Thermo Scientific Genesys 20, USA) at 882 nm wavelengths. Soil cation exchange capacity (CEC) was determined by ammonium acetate leaching method [23]. The exchangeable acidity and exchangeable Al^{3+} were determined by acid base titration method described by Rowell [24]. The method described by Keeney and Nelson [25] was used to extract exchangeable NH_4^+ and available NO_3^- , after which the ions were determined via steam distillation [19].

2.2. Characterization of rice husk

Rice husk collected from Pasir Puteh Rice Mill was analyzed for pH [18] and total N [20]. Single dry ashing method [19] was used to extract nutrients from rice husk for analysis of Ca, Mg, Na, P, and K. The content of Ca, Mg, Na, and K were determined by using an AAS (Analyst 800, Perkin Elmer, Norwalk, USA), meanwhile total P content was determined by using molybdenum blue method [16] after which the blue colour developed was analyzed by using a UV-VIS Spectrophotometer (Thermo Scientific Genesys 20, USA) [22]. Organic matter, ash content, exchangeable NH_4^+ and available NO_3^- , and CEC were determined by using the aforementioned methods in soil characterization section.

2.3. Biochar production, activation and characterization

Two cylindrical kiln, 200 L with removable chimney caps and air tight 110 L drum was constructed for biochar production. Rice husk was bulked inside the 110 L and closed before placed in the middle of 200 L drum, where the fire was kindled starting from the bottom of the drum. The

burning time was 4–6 hours with temperature ranging from 300–400 °C and left for cooling for 12 hours. Later, the pile of biochar sample was spread out for cooling. After that, activation was carried out by soaking biochar in a 5% chicken slurry solution, also known as chicken litter waste, for 7 days. Then biochar was dried and stored in a big container for further use. Activation of biochar with chicken slurry was crucial to further increase the nutrient content, alter the surface area and increases the pore size [26]. The analysis conducted for biochar characterization is similar to those of aforementioned characterizations of soil and rice husk. Additionally, microanalysis through Scanning Electron Microscopy-attached with Energy Dispersive X-ray Spectroscopy analysis (SEM-EDX JEOL JSM- 6400) was carried out to analyze surface morphology of rice husk biochar.

2.4. Ammonia volatilization study

For laboratory scale NH_3 volatilization study, the actual amount of urea applied was 0.97 g, scaled down from the 175 kg ha^{-1} application rate. The rice husk biochar actual application for 100 g of soil, scaled down from 5, 10, 15, and 20 t ha^{-1} was 0.28 g, 0.55 g, 0.83 g, and 1.11 g, respectively. The treatments evaluated were as follows:

T0: 100g soil only;

T1: 100g soil + 175 kg ha^{-1} urea;

T2: 100g soil + 175 kg ha^{-1} urea + 5 t ha^{-1} rice husk biochar;

T3: 100g soil + 175 kg ha^{-1} urea + 10 t ha^{-1} rice husk biochar;

T4: 100g soil + 175 kg ha^{-1} urea + 15 t ha^{-1} rice husk biochar;

T5: 100g soil + 175 kg ha^{-1} urea + 20 t ha^{-1} rice husk biochar.

Soil, urea and biochar were mixed well before it was deposited into 250 mL conical flask after which water was added to create a waterlogged condition. The water level was maintained 3 cm above the soil throughout the study. This set up was done to depict the waterlogged condition in actual rice field. The system was set to be closed dynamic air flow system and the NH_3 loss from urea was measured daily [27–29]. The system includes a 250 mL conical flask exchange chamber containing soil mixture and a trap 250 mL conical flask chamber containing 75 mL of boric acid which were stoppered and fit with inlet/outlet pipes. The inlet of the chamber containing the water was connected with an aquarium air pump and outlet was connected with pipe tubing to the trap containing boric acid solution. Air was passed through the chambers at a rate of 2.75 $\text{L}^{-1} \text{min}^{-1}$ chamber⁻¹. This setup was done to create soil aeration and trap NH_3 loss *via* volatilization process. The released NH_3 was captured in the trapping solution containing 75 mL of boric acid with colour indicator. The incubation chambers Boric acid-indicator traps were replaced every 24 h and back titrated with 0.01 M HCl, to estimate the NH_3 released. Measurement was continued until the loss declined to 1% of the N added with urea [30]. After the ammonia volatilization was evaluated, the soil samples were used for pH, exchangeable NH_4^+ and available NO_3^- determinations.

2.5. Statistical analysis

The experiments were arranged in a completely randomized design with three replicates. An independent t-test was conducted by using SPSS software version 24.0 (SPSS Inc, US) to compare the significant difference between non-activated biochar and activated biochar. The effect of different rates of rice husk biochar addition was subjected to one-way analysis of variance (ANOVA).

Significant differences among treatments were separated by Tukey's HSD test and considered significant at $P \leq 0.05$. Statistical analysis for all the data was performed using SPSS software version 24.0 (SPSS Inc, US).

3. Results and discussion

3.1. Characteristics of soil

The selected physical and chemical properties of soil used are summarized in Table 1. The soil showed: sandy-clay-loam texture, pH 5.5, N (0.07%), NH_4^+ (89 ppm) and NO_3^- (30 ppm). Acidic soil slows down the mineralization process which causes lower N content in the soil. Khalil et al. [31] reported that acidic soil causes N immobilization and reduces N mineralization. The low soil available P (0.385 ppm) was the result of high exchangeable Al ($1.14 \text{ cmol}_c \text{ kg}^{-1}$), and Fe ($0.091 \text{ cmol}_c \text{ kg}^{-1}$) and low pH. Generally, all tropical soils in Malaysia have relatively low soil available P, due to its immobilization as oxides Al and Fe. Exchangeable K, Ca, Mg, and Na were found to be low in the soil (Table 1). This might be due to incapability of the soil to retain and hold nutrients effectively because of low CEC ($5.4 \text{ cmol}_c \text{ kg}^{-1}$). The CEC readily influences the nutrient availability, soil pH, and soil structure stability. Low soil CEC indicates the lower the negative charge and the lesser the cations that can be held on the surface of the soil. The CEC of the soil used in this study was low, however the soil organic matter was relatively high.

Table 1. Selected physico-chemical properties of the soil used in this experiment.

Property	Value obtained
pH	5.5
Electrical conductivity (EC) (dS m^{-1})	0.022
Texture	Sandy Clay Loam
Soil organic matter (%)	6.24
Total organic C (%)	3.62
Ash content (%)	6.4
Cation exchange capacity (CEC) ($\text{cmol}_c \text{ kg}^{-1}$)	5.4
Ammonium (ppm)	89
Nitrate (ppm)	30
Total N (%)	0.07
Available P (ppm)	0.385
Exchangeable K ($\text{cmol}_c \text{ kg}^{-1}$)	0.084
Exchangeable Ca ($\text{cmol}_c \text{ kg}^{-1}$)	0.10
Exchangeable Mg ($\text{cmol}_c \text{ kg}^{-1}$)	0.082
Exchangeable Na ($\text{cmol}_c \text{ kg}^{-1}$)	0.024
Exchangeable Fe ($\text{cmol}_c \text{ kg}^{-1}$)	0.091
Exchangeable acidity ($\text{cmol}_c \text{ kg}^{-1}$)	0.7
Exchangeable Al ($\text{cmol}_c \text{ kg}^{-1}$)	1.14

3.2. Surface morphology and selected physico-chemical properties of rice husk biochar

The surface morphological characteristics of rice husk biochar before activation and after activation are shown in Figure 1 and Figure 2, respectively. The porosity and surface area of biochar is influenced by the temperature, heating rate, burning hours, and activation method [26,32]. The rice husk biochar showed porous structure and large surface area [33], which is useful in binding ions [34]. After activation, most of the empty pores of rice husk biochar were compacted with nutrients and there were some pores that were still free (Figure 2). The unbounded free pores are useful for further nutrient adsorption in the soil and potentially NH_3 produced by soil applied urea from being volatilized. The rice husk biochar inherent nutrients and externally adsorbed nutrients will be released slowly, preventing an immediate loss in the environment.

In addition, the rice husk biochar also had higher CEC which was $66.6 \text{ cmol kg}^{-1}$ (Table 2). The CEC of biochar depends on the types of feedstock used. Van Zwieten et al. [35] and Carrier et al. [36] stated that paper mill waste biochar has lower CEC than sugarcane bagasse biochar. The difference in CEC was observed because feedstock with higher ash content can produce biochar with a higher CEC [37]. Besides, the low temperature pyrolysed biochars at $400 \text{ }^\circ\text{C}$ also increase the CEC value [38]. With this property, rice husk biochar produced at the temperature ranging from 300 to $400 \text{ }^\circ\text{C}$ has higher affinity to adsorb more ions onto its surface. Major et al. [39] stated that CEC, surface area, and nutrients content interlinked together in improving soil fertility. Xie et al. [40] stated that production temperature more than $500 \text{ }^\circ\text{C}$ increases the biochar structure aromaticity, which enhances resistance to microbial decomposition. Resistance to microbial degradation causes impediments in N mineralization. According to Deenik et al. [41] and Spokas et al. [42], biochar produced at temperature higher than $500 \text{ }^\circ\text{C}$, contributed to the N immobilization which could inhibit plant growth.

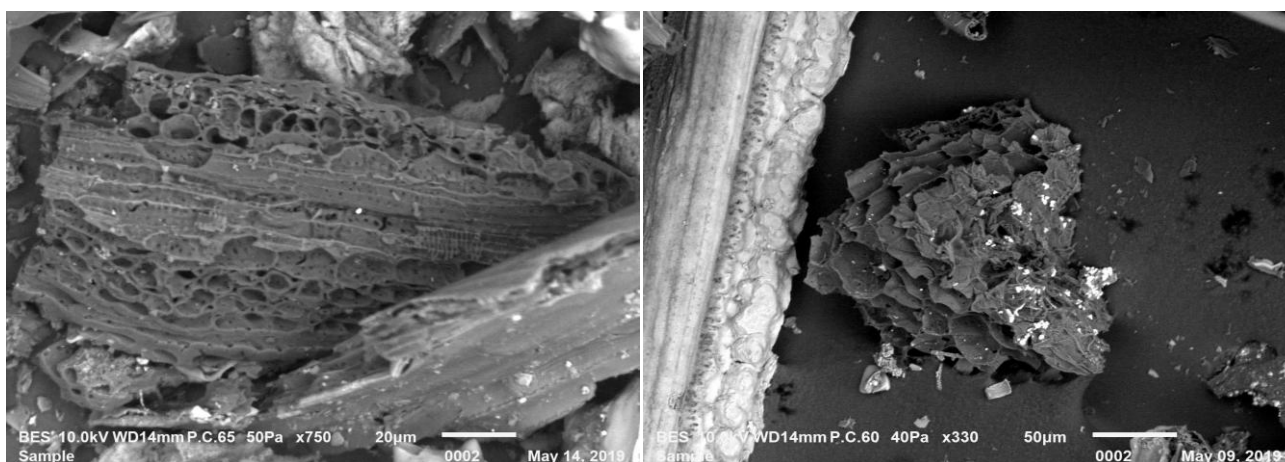


Figure 1. Rice husk biochar surface before activation at 750x and 330x magnification under SEM.

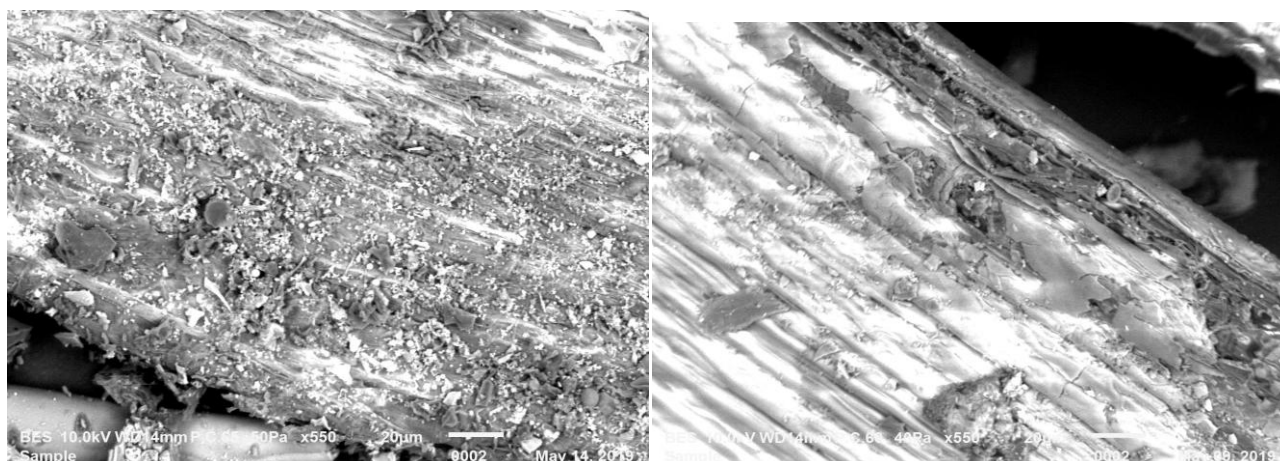


Figure 2. Rice husk biochar surface after activation at 550x magnification under SEM.

Rice husk biochar total N absorption was increased by almost 18% compared to before activation (Table 2). Exchangeable Ca and Na also showed increment after the activation. There was also an increase of available P after activation which accounted for 37%. This shows that the structure and surface of the rice husk biochar generated in this experiment captured nutrients from the chicken slurry activation. The pH of rice husk biochar was alkaline (9.1) and favorable to increase and modify the pH of the soil which will reduce the practice of liming at a certain level of biochar application rate [43]. Wang et al. [44] stated that wheat straw biochar significantly reduces the soil acidity in tea garden soil. This indicates that rice husk biochar packed with nutrient can act as one of the organic amendments to reduce liming process, increase soil fertility, decrease NH_3 volatilization and enhance plant growth.

Table 2. Selected physico-chemical properties of non-activated and activated rice husk biochar.

Property	Non-activated rice husk biochar	Activated rice husk biochar
pH (water)	8.0 ± 0.03^a	9.1 ± 0.05^b
CEC ($\text{cmol}_c \text{kg}^{-1}$)	65.5 ± 0.06^a	66.6 ± 0.05^b
Total N (%)	0.28 ± 0.005^a	0.33 ± 0.017^b
Available P (%)	10.4 ± 0.23^a	14.3 ± 0.06^b
Exchangeable Ca ($\text{cmol}_c \text{kg}^{-1}$)	86.1 ± 0.05^a	1048 ± 2.30^b
Exchangeable Mg ($\text{cmol}_c \text{kg}^{-1}$)	734.8 ± 0.5^a	508 ± 0.04^b
Exchangeable K ($\text{cmol}_c \text{kg}^{-1}$)	5686 ± 1.15^a	4925 ± 2.89^b
Exchangeable Na ($\text{cmol}_c \text{kg}^{-1}$)	121.4 ± 0.35^a	256 ± 3.46^a

Note: Means between columns with different letters indicate significant difference between non-activated and activated rice husk biochar by independent t-test $P \leq 0.05$. Columns represent the mean values \pm SE.

3.3. Effect of rice biochar on minimizing ammonia volatilization

The daily volatilization rate of NH_3 from urea fertilizer over a period of 29 days incubation is presented on Figure 3. The NH_3 loss in T2 and T3 started at day 6, meanwhile T4 and T5 started at day 5. As for the T0, there was no activity of NH_3 loss while for T1, the loss started on the 3rd day. In a study by Omar et al. [3], NH_3 loss was delayed for 3–6 days during incubation study. The

maximum NH_3 loss for T1 occurred on the day 6, meanwhile T2 and T4 NH_3 loss peaked up at day 12 and 13, respectively. Figure 3 shows that T3 increased NH_3 loss in the first 11 days but suddenly there was a decrease of NH_3 loss at day 12, and then the loss increased back on day 13. Afterwards, the NH_3 loss declined gradually until it ceased to be lesser than 1% of the N added as urea. The decrease of NH_3 loss on day 12 might be due to the rapid drying of soil surface due to aeration given by the air pump. The NH_3 loss decreased when soil moisture was not sufficient for chemical reaction and it increased at day 13 upon addition of the water. This observation is consistent with a study conducted by Palanivell et al. [45]. The fluctuation in NH_3 loss during the period of incubation study was a result of reaction between urea and soil in forming NH_4^+ over NH_3 .

All the treatments with rice husk biochar (T2, T3, T4, and T5) had significantly minimized NH_3 loss compared to urea without additives (T1) (Table 3). The total amounts of NH_3 lost at the end of the incubation period as a percentage of urea-N added were 0, 44.52, 29.18, 29.44, 33.92, and 32.84% for T0, T1, T2, T3, T4, and T5, respectively. Noticeably, T2 was significantly effective in minimizing NH_3 loss over T1. Despite of the application rate, rice husk biochar had successfully reduced the percentage of NH_3 loss. However, biochar at 5 t ha^{-1} and 10 t ha^{-1} minimized NH_3 loss even more effectively than 15 t ha^{-1} and 20 t ha^{-1} . Lower application rate of biochar can act as one of the cost effective option because farmers can achieve the goal of minimizing N loss with lesser amount of biochar application. It also has been proven that higher rate of biochar can inhibit the plant growth performance [46]. Besides, the rice husk biochar with higher porosity increases the soil volume and alters the soil texture to be more porous. Lehmann and Joseph [47] stated that application of biochar alters the physical nature of soil such as structure, surface area, and pore size which will have direct impact on plant growth. The soil fertility increased following the application of biochar to the soil. Biochar increased the retention of N in soil by minimizing NH_3 loss. It also was proven to overcome the soil mineral depletion, especially N in waterlogged soils [48]. The N which is easily volatilized [49] can be minimized by the application of biochar since biochar act as slow release fertilizer [50].

Rice husk biochar can naturally lower the acidity of soil and can reduce the necessity of liming. All the treatments with biochar had improved the pH of soil (Table 3). This is consistent with other study that also used crop residue biochar and concluded the soil pH increment related to acid buffering capacity by biochar [51]. The increase in soil pH is also related to the release of organic anions from rice husk biochar, where organic anions undergo decarboxylation and consume proton. Rukshana et al. [52] also reported that anions released from organic material amendment increases soil pH. Additionally, Tang and Yu [53] and Xu et al. [54] stated that organic anions and other negatively charged functional groups present in organic matter can react with H^+ ions. Biochar addition increased soil pH and on the whole can improve the growth performance of the plants [7]. Soil pH needs an utmost consideration because crop vary in their tolerance to acidity and nutrient needs different optimal pH ranges to be successfully utilized by the respective plants [55]. It is well known that NH_3 volatilization speeds up in soil with higher pH. The soil pH (5.5) used in this study was found to delay the NH_3 loss and increase the formation of NH_4^+ ion (Table 4) because urea hydrolyses slowly in acidic soil, except T0 [56]. In previous studies, it has been reported that NH_3 loss speeds up in soil upon addition of alkaline biochar [57]. Contrastingly rice husk biochar used in this study minimized the NH_3 losses. Dougherty [58] stated that NH_3 volatilization significantly reduced with the addition of biochar mostly because of the NH_3 adsorption at the oxygen containing

surface functional group or biochar micropores. Studies also have shown that pH increase with biochar is usually not high enough to enhance NH_3 volatilization [59].

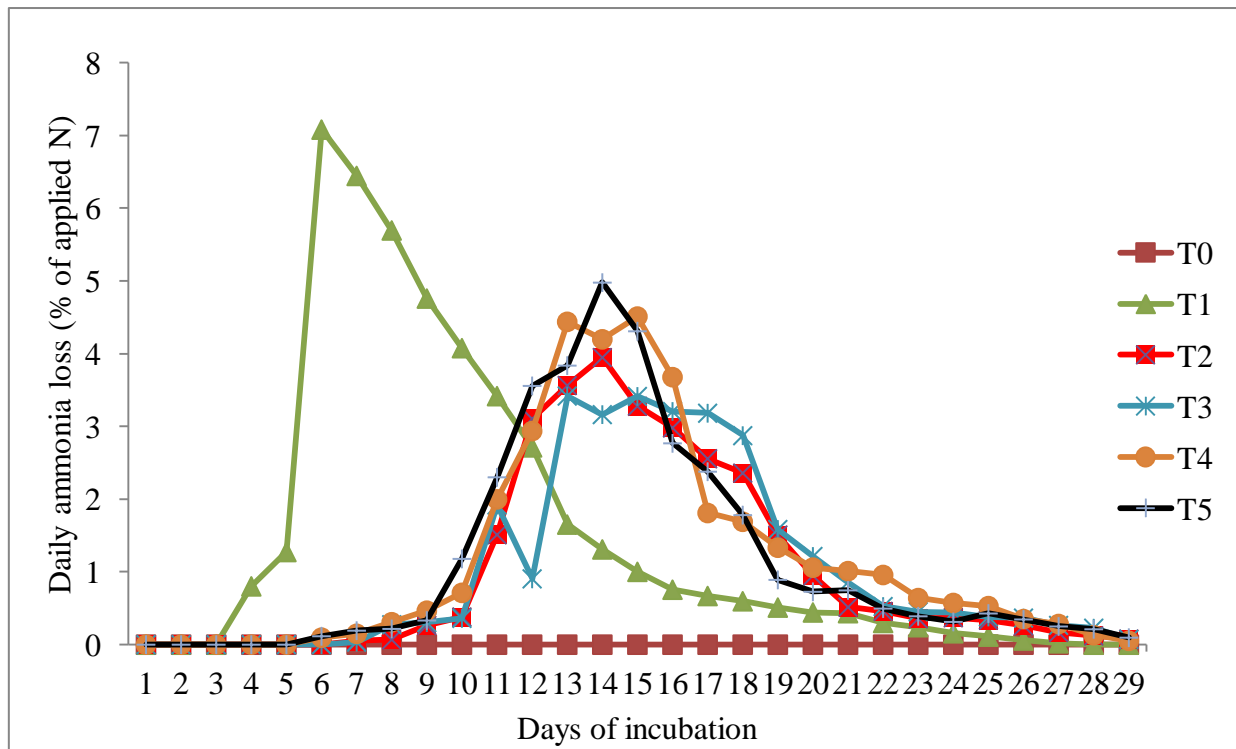


Figure 3. Ammonia volatilization over 29 days of incubation under waterlogged condition.

Table 3. Total ammonia loss and soil pH after incubation study under waterlogged conditions.

Treatment	Total NH_3 loss (%)	Soil pH (water)
T0	0.00 ± 0.00^a	5.52 ± 0.06^a
T1	44.52 ± 0.95^d	6.27 ± 0.12^b
T2	29.18 ± 0.03^b	7.94 ± 0.03^c
T3	29.44 ± 0.06^{bc}	7.97 ± 0.01^c
T4	33.92 ± 0.40^c	7.92 ± 0.03^c
T5	32.84 ± 0.30^{bc}	7.94 ± 0.02^c

Note: Mean values within column with different letter(s) indicate significant difference between treatments by Tukey's test at $P \leq 0.05$. Columns represent the mean values \pm SE.

Biochar had been proven in many studies to efficiently sorb nutrients from the soil. In the present study, T2, T3, and T4 had shown a significant NH_4^+ retention in soil over T0 and T1 (Table 4). T2 and T3 had retained highest amount of NH_4^+ by 74% and 81% respectively over T1, followed by T4 and T5 which was 49% and 31%. This clearly gives an idea that rice husk biochar increased the formation of NH_4^+ ions over NH_3 . Biochar readily adsorb NH_4^+ to its surface due to abundance of negatively charged sites [60]. Another reason for the higher retention of NH_4^+ could be associated to the higher CEC of rice husk biochar ($66.6 \text{ cmol}_c \text{ kg}^{-1}$) which absorbs the ions and release it slowly. This was in agreement with Omar et al. [3]. Besides, the adsorption capacity of rice husk biochar had increased the presence of NH_4^+ ions in the soil.

Table 4. Rice husk biochar effectiveness in retaining NH_4^+ and NO_3^- .

Treatment	NH_4^+ (ppm)	NO_3^- (ppm)
T0	106.67 ± 12.01 ^a	14.67 ± 5.49 ^a
T1	256.67 ± 29.63 ^b	56.00 ± 4.62 ^c
T2	447.67 ± 3.33 ^{cd}	33.33 ± 2.33 ^b
T3	464.33 ± 26.30 ^d	39.67 ± 2.33 ^{bc}
T4	383.33 ± 31.80 ^{cd}	44.33 ± 6.17 ^{bc}
T5	335.00 ± 27.84 ^{bc}	50.00 ± 4.93 ^{bc}

Note: Mean values within column with different letter(s) indicate significant difference between treatments by Tukey's test at $P \leq 0.05$. Columns represent the mean values ± SE.

4. Conclusions

The result of this study suggests that mixing urea with rice husk biochar at rate of 5 t ha^{-1} and 10 t ha^{-1} offers a significant advantage over urea alone. The mixture successfully increased formation of NH_4^+ ions in soil over NH_3 as well as soil retention of NH_4^+ and NO_3^- ions. The findings in this present study suggest that urea can be properly managed if it is applied with rice husk biochar. Field application of our findings is currently being evaluated in our ongoing field experiment.

Acknowledgement

The authors would like to thank Malaysia Ministry of Education and Malaysia Ministry of Finance for financial assistance and Universiti Malaysia Kelantan Jeli Campus for providing research facilities. This research was supported by grants from the Malaysia Fundamental Research Grant Scheme (FRGS) (Grant. No.: R/FRGS/A0700/01459A/002/2018/00563); UMK-MOF Social Enterprise Program (R/MOF/A07.00/01397A/007/2020/00721); and High-impact Entrepreneurship Program in 2019 TUMKEI-MPC.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

1. He ZL, Calvert DV, Alva AK, et al. (2002) Clinoptilolite zeolite and cellulose amendments to reduce ammonia volatilization in a calcareous sandy soil. *Plant Soil* 247: 53–260.
2. Tang Z, Xu W, Zhou G, et al. (2018) Patterns of plant carbon, nitrogen, and phosphorus concentration in relation to productivity in China's terrestrial ecosystems. *Proc Natl Acad Sci* 115: 4033–4038.
3. Omar OL, Ahmed OH, Muhamad AN (2010) Minimizing ammonia volatilization in waterlogged soils through mixing of urea with zeolite and sago waste water. *Int J Phys Sci* 5: 2193–2197.
4. Fageria NK, DosSantos AB, Moraes MF (2010) Influence of urea and ammonium sulphate on soil acidity indices in lowland rice production. *Commun Soil Sci Plan* 41: 1565–1575.

5. Ahmed OH, Yap CB, Muhamad AN (2010) Minimizing ammonia loss from urea through mixing with zeolite and acid sulphate soil. *Int J Phys Sci* 5: 2198–2202.
6. Ghorbani M, Amirahmadi E (2018) Effect of rice husk Biochar (RHB) on some of chemical properties of an acidic soil and the absorption of some nutrients. *J Appl Sci Environ Manage* 22: 313–317.
7. Abrol V, Sharma P (2019) Biochar—An imperative amendment for soil and the environment. (Intechopen Ebook PDF). Available from: <https://www.intechopen.com/books/biochar-an-imperative-amendment-for-soil-and-the-environment>.
8. Mansor AM, Theo WL, Lim JS, et al. (2018) Potential commercialisation of biocoke production in Malaysia—A best evidence review. *Renew Sust Energ Rev* 90: 636–649.
9. Laird DA, Fleming P, Davis DD, et al. (2010) Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma* 158: 443–449.
10. Ding Y, Liu YX, Wu WX, et al. (2010) Evaluation of biochar effects on nitrogen retention and leaching in multi-layered soil columns. *Water Air Soil Pollut* 213: 47–55.
11. Spokas KA, Novak JM, Venterea RT (2012) Biochar's role as an alternative N-fertilizer: ammonia capture. *Plant Soil* 350: 35–42.
12. Clough TJ, Condrón LM, Kammann C, et al. (2013) A review of biochar and soil nitrogen dynamics. *Agronomy* 3: 275–293.
13. Zhang A, Bian R, Pan G, et al. (2012) Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. *Field Crops Res* 127: 153–160.
14. Dempster DN, Gleeson DB, Solaiman ZI, et al. (2012) Decreased soil microbial biomass and nitrogen mineralisation with Eucalyptus biochar addition to a coarse textured soil. *Plant Soil* 354: 311–324.
15. Jones DL, Rousk J, Edwards-Jones G, et al. (2012) Biochar-mediated changes in soil quality and plant growth in a three year field trial. *Soil Biol Biochem* 45: 113–124.
16. Gao S, De Luca TH, Cleveland CC (2019) Biochar additions alter phosphorus and nitrogen availability in agricultural ecosystems: A meta-analysis. *Sci Total Environ* 654: 463–472.
17. De-Xi L, Xiao-Hui F, Feng H, et al. (2007) Ammonia volatilization and nitrogen utilization efficiency in response to urea application in rice fields of the Taihu Lake region, China. *Pedosphere* 17: 639–645.
18. Peech HM (1965) Hydrogen-ion activity. In: *Methods of soil analysis, part 2*, Black CA, Evans DD, Ensminger LE, et al. Madison, WI: American Society of Agronomy.
19. Tan KH (2005) *Soil sampling, preparation, and analysis* (2nd ed). Boca Raton, Florida, USA.
20. Bremner JM (1965) Organic forms of nitrogen. In: Black CA (ed.) *Methods of Soil Analysis. Agronomy* 9: 1238–1254.
21. Mehlich A (1953) Determination of P, Ca, Mg, K, Na and NH₄. Raleigh, North Carolina State University Soil Test Division.
22. Murphy J, Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. *Anal Chim Acta* 27: 31–36.
23. Cottenie A (1980) Soil testing and plant testing as a basis of fertilizer recommendation. *FAO Soils Bulletin* 38: 70–73.
24. Rowell DL (1994) *Soil science, methods and applications*. Longman Group UK Limited, 86–87.

25. Keeney DR, Nelson DW (1982) Nitrogen-Inorganic forms. In: Miller AL, Keeney DR (eds.) *Methods of Soil Analysis part 2: Chemical and microbiological properties*, American society of Agronomy, Madison, WI, 643–698.
26. Sakhiya AK, Anand A, Kaushal P (2020) Production, activation, and applications of biochar in recent times. Available from: <https://doi.org/10.1007/s42773-020-00047-1>.
27. Siva KB, Aminuddin H, Husni MHA, et al. (1999) Ammonia volatilization from urea as affected by tropical-based palm oil mill effluent (POME) and peat. *Commun Soil Sci Plant* 30: 785–804.
28. Ahmed OH, Aminuddin H, Husni MHA (2006a) Effects of urea, humic acid and phosphate interactions in fertilizer microsites on ammonia volatilization and soil ammonium and nitrate contents. *Int J Agric Res*: 25–31.
29. Ahmed OH, Aminuddin H, Husni MHA (2006b) Reducing ammonia loss from urea and improving soil-exchangeable ammonium retention through mixing triple superphosphate, humic acid and zeolite. *Soil Use Manage* 22: 315–319.
30. Ahmed OH, Husin A, Hanif AHM (2008) Ammonia volatilization and ammonium accumulation from urea mixed with zeolite and triple superphosphate. *Acta Agric Scand B Soil Plant Sci* 58: 182–186.
31. Khalil MI, Hossain MB, Schmidhalter U (2005) Carbon and nitrogen mineralization in different upland soils of the subtropics treated with organic materials. *Soil Biol Biochem* 37: 1507–1518.
32. Zabaniotou A, Stavropoulos G, Skoulou V (2008) Activated carbon from olive kernels in a two-stage process: Industrial improvement. *Bioresource* 99: 320–326.
33. Lua AC, Yang T, Guo J (2004) Effects of pyrolysis conditions on the properties of activated carbons prepared from pistachio-nut shells. *J Anal Appl Pyrolysis* 72: 279–287.
34. Schmidt HP, Pandit BH, Martinsen V, et al. (2015) Fourfold increase in pumpkin yield in response to low-dosage root zone application of urine-enhanced biochar to a fertile tropical soil. *Agriculture* 5: 723–741.
35. Van Zwieten L, Kimber S, Morris S, et al. (2010) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant Soil* 327: 235–246.
36. Carrier M, Hardie AG, Uras Ü, et al. (2012) Production of char from vacuum pyrolysis of South-African sugar cane bagasse and its characterization as activated carbon and biochar. *J Anal Appl Pyrolysis* 96: 24–32.
37. Yang F, Lee XQ, Wang B (2015) Characterization of biochars produced from seven biomasses grown in three different climate zones. *Chin J Geochem* 34: 592–600.
38. Tomczyk A, Sokołowska Z, Boguta P (2020) Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. *Rev Environ Sci Bio/Technol* 1–25.
39. Major J, Rondon M, Molina D, et al. (2010) Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant Soil* 333: 117–128.
40. Xie T, Sadasivam BY, Reddy KR, et al. (2016) Review of the effects of biochar amendment on soil properties and carbon sequestration. *J Hazard Toxic Radioact Waste* 20: 04015013.
41. Deenik JL, McClellan T, Uehara G, et al. (2010) Charcoal volatile matter content influences plant growth and soil nitrogen transformations. *Soil Sci Soc Am J* 74: 1259–1270.
42. Spokas KA, Novak JM, Stewart CE, et al. (2011) Qualitative analysis of volatile organic compounds on biochar. *Chemosphere* 85: 869–882.

43. Butterly CR, Bünemann EK, McNeill AM, et al. (2009) Carbon pulses but not phosphorus pulses are related to decreases in microbial biomass during repeated drying and rewetting of soils. *Soil Biol Biochem* 41: 1406–1416.
44. Wang L, Butterly CR, Wang Y, et al. (2014) Effect of crop residue biochar on soil acidity amelioration in strongly acidic tea garden soils. *Soil Use Manag* 30: 119–128.
45. Palanivell P, Ahmed OH, Majid ANM (2016) Minimizing ammonia volatilization from urea, improving lowland rice (cv. MR219) seed germination, plant growth variables, nutrient uptake, and nutrient recovery using clinoptilolite zeolite. *Arch Agron Soil Sci* 62: 708–724.
46. Gale NV, Sackett TE, Thomas SC (2016) Thermal treatment and leaching of biochar alleviates plant growth inhibition from mobile organic compounds. *PeerJ* 4: e2385.
47. Lehmann J, Joseph S (2015) Biochar for environmental management: An introduction. In: *Biochar for environmental management*, Routledge.
48. Si L, Xie Y, Ma Q, et al. (2018) The short-term effects of rice straw biochar, nitrogen and phosphorus fertilizer on rice yield and soil properties in a cold waterlogged paddy field. *Sustainability* 10: 537.
49. Cayuela ML, Sánchez-Monedero MA, Roig A, et al. (2013) Biochar and denitrification in soils: When, how much and why does biochar reduce N₂O emissions. *Sci Rep* 3: 17–32.
50. Ding Y, Liu Y, Liu S, et al. (2016) Biochar to improve soil fertility. A review. *Agron Sustain Dev* 36: 36.
51. Yuan JH, Xu RK (2011) The amelioration effects of low temperature biochar generated from nine crop residues on an acidic Ultisol. *Soil Use Manage* 27: 110–115.
52. Rukshana F, Butterly CR, Baldock JA, et al. (2011) Model organic compounds differ in their effects on pH changes of two soils differing in initial pH. *Biol Fertil Soils* 47: 51–62.
53. Tang C, Yu Q (1999) Impact of chemical composition of legume residues and initial soil pH on pH change of a soil after residue incorporation. *Plant Soil* 215: 29–38.
54. Xu JM, Tang C, Chen ZL (2006) The role of plant residues in pH change of acid soils differing in initial pH. *Soil Biol Biochem* 38: 709–719.
55. Goulding KWT (2016) Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. *Soil Use Manage* 32: 390–399.
56. Fan MX, Mackenzie AF (1993) Urea and phosphate interactions in fertilizer microsites: Ammonia volatilization and pH changes. *Soil Sci Soc Am J* 57: 839–845.
57. Sun X, Zhong T, Zhang L, et al. (2019) Reducing ammonia volatilization from paddy field with rice straw derived biochar. *Sci Total Environ* 660: 512–518.
58. Dougherty BW (2016) Biochar as a cover for dairy manure lagoons: reducing odor and gas emissions while capturing nutrients. (Doctoral dissertation), Oregon State University.
59. Kelly CN, Calderón FC, Acosta-Martínez V, et al. (2015) Switchgrass biochar effects on plant biomass and microbial dynamics in two soils from different regions. *Pedosphere* 25: 329–342.
60. Egene CE, VanPoucke R, Ok YS, et al. (2018) Impact of organic amendments (biochar, compost and peat) on Cd and Zn mobility and solubility in contaminated soil of the Campine region after three years. *Sci Total Environ* 626: 195–202.

