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RESEARCH

Effects of Biochar Based N Fertilizer Application on Ammonia Volatilization from a Rice Growing Soil: A Laboratory Scale Closed Chamber Study

M.K.N.W. Jayarathna¹, R.S. Dharmakeerthi^{2*} and A.D. Igalavithana³

¹Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, 20400, Sri Lanka ²Department of Soil Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, 20400, Sri Lanka ³Future Industries Institute, University of South Australia, Mawson Lakes Campus, Mawson Lakes, 5095, SA, Australia

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Jayarathna, M.K.N.W. (D) https://orcid.org/0000-0002-2538-4237



ABSTRACT

Ammonia Volatilization (AV) in rice growing soils is one of the major pathways to lower the use efficiency of added nitrogen (N) fertilizers. Direct broadcasting of urea facilitates AV by increasing the substrate availability. Urea intercalated biochar (BC_U) can be a novel approach that could improve N use efficiency and reduce AV in paddy cultivation. Therefore, a laboratory experiment was conducted to quantify the effect of BC_U pellets on AV losses and N dynamics in a rice growing Entisol. We determined the changes in soil urease activity (UA) and pH buffer capacity (pHBC) after application of BC_U to soil under flooded or saturated conditions. Treatments were zero application of N (control), urea (U) and BC_U pellets added at a rate of 23 mg N kg soil⁻¹. Under saturated conditions, significantly higher NH4⁺ concentration in soil solution was observed in urea added soils and the highest NO₃⁻ was observed in U. Under flooded conditions, a significantly higher NH₄⁺ was in U and NO₃⁻ was not affected by urea application. In general, AV losses were very small under the investigated experimental conditions and it varied from 0 to 2.72 % of added urea. Under saturated conditions, AV was significantly (p<0.05) higher in U (2.72 %) and BC_U (1.21 %) than in the Control (0%). Under flooded conditions, only U showed a significant AV (2.42 %; p<0.05). The pH buffer capacity (11-12 mmols kg⁻¹ pH⁻¹) and urease activity (6.3 - 8.5 μ g NH₄⁺-N g⁻¹ hr⁻¹) did not significantly changed (p>0.05) by N treatments. Although there was a small AV loss (<3 %) after N application, it could be further reduced by application of urea as BC_U and/or maintaining a flood water layer for few days after N application.

*Corresponding author- dharmakeerthirs@agri.pdn.ac.lk

INTRODUCTION

Nitrogen loss as ammonia (NH₃) volatilization (AV) in rice growing soils contributes to reducing the use efficiency of added N fertilizers (Buresh et al., 2008). It has been observed that about 18-20 % of added N is lost as AV in non-flooded soil (Ernst and Massey, 1960) and 20-50 % loss in flooded rice paddies (Mikkelsen et al., 1978, De Datta et al., 1991). Broadcasting of ammonia and amide fertilizers into flood water or to puddled saturate soil leads to the accumulation of NH₄+ ions in the surface water layers and encourage the AV (Sommer et al., 2004). In rice growing soils, the maximum NH₃ flux can be varied widely from 45 to 400 g N ha⁻¹ h⁻¹ (Hayashi et al., 2006, Cao et al., 2013).

Primary factors that influence AV in flooded soils are flood water pH, flood water NH₄+-N of concentration, depth floodwater. temperature and wind speed (Jayaweera and Mikkelsen, 1991). The overall effect of pH, alkalinity and NH4+-N concentration or aqueous NH₃ concentration in floodwater is considered as the AV potential, while actual AV loss rates are further determined by environmental factors such as temperature, wind speed, and rainfall conditions (Vlek and Craswell, 1981, Macnack et al., 2013). Changes in soil pH are directly proportional to the AV loss from flooded soils (Zhenghu and Honglang, 2000). However, for fertilized acidic soils AV is not economically serious unless the soil surface pH rises above 7.5 (Ferguson et al., 1984). Moreover, soil pH buffer capacity is a critical factor that determines the pH changes in soils (Nelson and Su, 2010) and thereby indirectly affects to the AV. At high pH and high initial NH₃ concentrations, the dominant factor controlling the AV reaction is the buffer capacity of the soil (Avnimelech and Laher, 1977).

Ammonium N concentration in flood water is affected by the N management practices such as the source of the N, time of application and the method of application (Jantalia et al., 2012, Das et al., 2015). Soils with high urease activity (UA) can convert added urea into NH_{4^+} -N at a faster rate and increase the flood water NH_{4^+} concentration leading to high AV loss (Bouldin et al., 1991). In tropical flooded rice soil, surface soil is having the highest UA followed by subsurface soil and flood water and also it varies with the crop growth stage (Pattanik et al., 1999). The depth of flood water affects mainly by dilution effect on NH_{4^+} -N concentration and it is an inversely proportional to the AV rate (Freney et al., 1988, Jayaweera and Mikkelsen, 1991). Temperature can influence the magnitude of NH_3 loss by increasing soil urease activity, influencing $NH_{4^+(aq)}/NH_{3(g)}$ equilibrium and resulting a high amount of ammoniacal N in gaseous form (Li et al., 2022).

Source of N, timing of application and method of application are the most important fertilizer management decisions that affect NH₃ losses (Jayaweera and Mikkelson, 1991). Different strategies have been suggested to reduce the AV from added N. Deep placement, use of slow-release fertilizers, and urease inhibitors can control the release of NH4+ ions from N source to flood water and soil solution (Wang et al., 2019, Chen et al., 2021, Li et al., 2022). The application of synthetic slow-release urea fertilizer has reduced the AV from paddy grown soils by 35-40 % compared to the conventional urea application under field conditions (Liu et al., 2020). Biochar (BC) based slow-release fertilizer is a novel technology that can be used to improve N use efficiency (Jayarathna et al., 2021; Wang et al., 2022). In many studies BC has been used as a substrate to regulate the N release from urea and the pattern of release of adsorbed urea in BC has synchronized better with the plant uptake of N and reduces the losses (Manikandan and Subramanian, 2013; Chunxue et al., 2015; González et al., 2015; Rose et al., 2016).

Ammonia volatilization has been studied both under field conditions (Feng et al., 2017; Sun et al., 2019) and laboratory conditions (Huang et al., 2017; Palanivell et al., 2017; Ali et al., 2018). The net result of pH, alkalinity and NH₄+-N concentration on the dynamics of aqueous NH₃ in the floodwater or soil solution can be considered as the AV potential, while actual AV loss rates will further be determined by environmental factors such as temperature, wind speed, and rainfall conditions (Vlek and Craswell, 1981). Hence, the results obtained by chamber methods could often be biased with regard to the absolute quantity of the measured fluxes because the air exchange in the chambers generally do not match the ambient wind speed and turbulence conditions (Pachaloski et al., 2008). In order to minimize such errors, closed-dynamic air chamber systems have been used under laboratory conditions (Yang et al., 2018).

Although the application of urea intercalated biochar (BC_U) is a low cost and effective method to enhance the use efficiency of N fertilizers, the effects on AV and underlying mechanisms have not been studied so far under eco-physiological conditions in Sri Lanka. Neither any research has been published to study specific effects of locally produced BC_U on enzyme activities, pH changes and nitrogen dynamics in rice growing soils. Therefore, the present study was conducted based on the hypothesis that the application of BC_U could change the NH₃ volatilization losses significantly in lowland rice fields. In order to test the hypothesis, we conducted a closed chamber experiment (1) to quantify the effect of locally produced BC_U on AV losses and N dynamics in paddy growing Entisol and (2) to determine the changes in soil urease activity (UA) and pH buffer capacity (pHBC) after the application of BC_U into that soil.

METHODOLOGY

A soil (Typic Endoaquents) sample of about 10 kg was collected from the surface layer (0-15 cm depth) of a rice cultivating land in Kurunegala (7°31'54" N 80°26'08" E). After removing the stubble and other visible organic residues it was air dried and sieved using a 2mm sieve. Soil was initially characterized for soil texture (Sheldric and Wang, 1993), pH (Brown, 1943), cation exchange capacity (Sumner and Miller, 1996), organic carbon content (Walkley and Black, 1934), total N (Bremner, 1965), pH buffer capacity (Liyanage et al., 2012), urease activity (Sahrawat, 1980), and available P and K after extracting with Melich III extraction (Mehlich, 1984) and determined by UV visible spectrophotometer (Shimadzu UV-1900i, Japan) and flame photometer (Jenway PFP7, UK) respectively.

Closed chamber experiment

The closed chamber system was prepared based on the method described by Mandal et al. (2019) with slight modifications. Nine glass bottles of 500 ml (Diameter 7cm x height 12cm) were filled with 200 g of air-dried and 2-mm sieved soil, and well puddled with excess water. Height of the soil inside the bottle was 0.05m after puddling. A RhizonFlex[®] soil solution sampler with a pore diameter of about 0.12-0.18 µm was inserted horizontally at 0.04 m below the soil surface. Then soil was allowed to pre-incubate for two weeks under saturated conditions without standing water. Another set of similarly prepared soil in glass bottles were flooded with 1cm of standing water and pre-incubate for two weeks. At the end of the pre-incubation period, three N treatments were imposed to soils in the two sets of bottles; zero application of N (Control), and 23 mg of N supplied as urea (U) or urea intercalated BC (BC_U). A locally produced BC_U pellets using the method described by Jayarathna et al. (2021) was used for the study. All the treatments were replicated three times and arranged according to a complete randomized design and kept on laboratory benches under ambient light and temperature (27±2°C) over a two-week period.

Lids of the glass bottles were kept air-tight throughout the incubation period. In the lid of the glass bottle, there were one inlet and two outlets. The inlet was connected to an air pump (BOUY 9900) and a flow rate of ≈ 0.1 L min⁻¹ was maintained continuously throughout the 2-week period. One outlet was connected to a fixed RhizonFlex® and the other to a conical flask with 25 ml of 4% boric acid to trap NH₃ gas. The trapped NH₃ samples were collected at 1, 2, 3, 4, 5, 7, 9, 11 and 14 days after fertilizer application (DAF). Then the collected samples were titrated with 0.01M HCl acid and reacted NH₃ amount was calculated using stoichiometry. About 20 ml of pore water was sucked out through RhizonFlex[®] from each pot using a syringe at the same time and analyzed for NH4+ -N concentration (Markus et al., 1985) and NO₃- -N concentration (Bremner et al., 1965) and pH (Hanna Instruments HI 2020, USA). Each time when pore water was removed, a similar

amount of distilled water was inserted via inlet opening on the lid using a syringe.

A subsample of treated soil collected from the incubation study at the beginning (0 DAF) and at 14 DAF were air dried and soil pH buffer capacity (Liyanage et al., 2012) and urease activity (Sahrawat, 1980) were measured. Briefly, pH buffer capacity of the soil was measured in 1:5 soil-solution suspensions by adding 0.22M Ca(OH)₂ aliquots at the rates of 0.5, 1, 2 ml or 0.1M HCl at the rates of 0.5, 1, 2 ml at a time to 10 g of soil. The pH change in the soil suspension was measured using a pH electrode (Hanna Instruments HI 2020, USA). Amount of acid/alkali added (mmols kg soil⁻¹) was plotted against the pH and the slope of the linear fit was used as the buffer capacity and expressed in mmols kg soil⁻¹ unit pH⁻¹. Urease activity was determined by treating 10 g of soil with 500 μ g urea-N ml⁻¹ solution and incubating at 37°C for 4h. After the incubation the samples were extracted with 2M KCl containing 100 μ g Ag₂SO₄ ml⁻¹ and the NH₄⁺ concentrations were measured (Markus et al., 1985) and expressed in mg NH₄+- released g soil⁻¹ hour⁻¹.

Statistical Analysis

Univariate ANOVA was conducted using SPSS software (IBM Corp.2012) for UA and pHBC and treatment means were separated using LSD at a p<0.05 significance. Repeated measures analysis was conducted using SPSS software (IBM Corp., 2012) on ammonia volatilization, pH, NO₃--N, and NH₄+-N concentrations. In brief, the N treatments were used as the between subject effects and time as the within subject variable. When the sphericity was detected from the Mauchly's test, the Greenhouse-Geisser correction was used to test the significance in variables. In instances where time × treatment interaction effect was significant the Bonferroni correction was employed prior to mean separation. Statistical analyses were conducted for flooded and saturated soils separately.

RESULTS AND DISCUSSION

Soil had sandy loam texture with low levels of organic carbon (OC) and total N contents

(Table 1). Acidic pH and very low EC indicated that the soil was not affected by salinity or sodicity. Plant available P and K contents were less than critical levels and CEC of the soil was also less than 5.0 cmol₊/kg suggesting very low fertility status of the used soil.

Changes in available forms of N in soil solution under saturated conditions

Soil solution NH₄+-N concentrations changed significantly (p<0.05) with DAF while it did not vary significantly (p>0.05) among the treatments throughout the incubation period (Figure 1a). But N added treatments maintained a higher NH₄+-N levels than the control treatment. Soil solution NO₃--N concentrations significantly varied (p<0.05) among the treatments throughout the incubation period (Figure 1b). The mean NO₃--N levels in pore water were significantly higher (p<0.05) in urea added treatment when compared to control treatment and this increase was about 60%. Overall, the trend in changing NH4+-N concentrations indicated a gradual decrease up to 5 DAF (from 32 to 7 mg/L) and increase again until 9 DAF before decrease thereafter (Figure 1a). In contrast, NO₃--N levels showed an increase in first few days where it peaked at 3DAF in U and at 5 DAF in control and, BC_U. Then it gradually decreased up to 9 DAF and either increased (BC_U) or remained unchanged (control and U) up to 14 DAF (Figure 1b).

Trends in NH₄⁺-N and NO₃⁻-N levels in pore water, i.e. decrease in NH₄⁺-N while increasing NO₃-N, suggest an increase in rate of nitrification during the first 3-5 DAF in saturated soil that could have contributed to the reduction of availability of NH₄⁺ ions. Jiang et al. (2015) has reported that ammoniaoxidizing archaea (AOA) are dominating nitrification activity in acidic paddy soils at pH 5.6 and nitrification activity was stimulated by urea fertilization accompanied by a significant increase of AOA. Moreover, NH₄⁺ can be ammonia volatilization removed via (Watanabe et al., 2009) and utilized by microorganisms (Geisseler et al., 2010) during this period and could have also been responsible for the decrease in NH_{4}^{+} concentrations in the pore water.

There is a two days delay in reaching to the peak of the NO₃--N levels in Control and BC_U when compared to U (Figure 1b). Low NH₄+-N concentrations in soil solution could reduce the rate of nitrification (Saharawat, 2008) delaying the peak NO₃-N concentrations. It has been reported that urea-N release is slower in BC_U when compared to that of urea (Manikandan and Subramanian 2013. Jayarathna et al., 2021) that could have limited the NH₄+ availability and retard the nitrification.

Changes in available forms of N in soil solution under flooded conditions

Under flooded conditions, $NH_4^{+}-N$ levels are significantly changed (p<0.05) within DAFs and not significantly different (p>0.05) among treatments. But, application of urea has increased the soil solution $NH_4^{+}-N$ concentration in U compared to other treatments (Figure 2a). Urea is highly water soluble and the flood water can instantly dissolve urea and dilute their concentration in the flood water. Therefore, the rate of urea hydrolysis could have decreased more under flood water condition than in the saturated conditions. Also, BC_U release urea at a slower rate to the solution compared to urea (Jayarathne et al., 2021). Thus, higher the dissolved urea concentration in the soil solution, the faster can be the urea hydrolysis by urease enzyme releasing NH₄⁺ ions to soil solution (Anand and Patey, 2018).

The NO₃⁻⁻N concentrations in soil solution also significantly changed (p<0.05) within DAFs and not significantly different (p>0.05) among treatments during the incubation period (Figure 2b). Overall, it has a sharp decline from 1 DAF (15.6 mg L⁻¹) to day 2 DAF (8.4 mg L⁻¹) and has maintained lower levels less than 10 mg L⁻¹ up to 14DAF. It can be due to the denitrification which is favoured under flooded conditions (Yang et al., 2017, Katyal et al., 1988)

Table 1. Initial Characterization of soil presented as mean±SE (n=3)

Property	Soil
pH (1:5 water)	5.82 ± 0.02
EC (1:5 water) (μS/cm)	33.70 ±0.75
CEC (cmols+/kg)	4.60 ±0.57
OC (g/kg)	13.38 ±0.08
Total N (g/kg)	1.20 ± 0.40
Available P (mg/kg)	1.24 ±0.05
Available K (mg/kg)	55.63 ±0.79
Texture	Sandy loam (USDA)
	(Sand 81.6%, Silt1.4%, Clay17.0%)



Figure 1. Variation in (a) NH₄⁺ -N and (b) NO₃⁻ -N concentration of the pore water with days after fertilization under saturated conditions. Vertical bars at each data point are ±SE (n=3).



Figure 2. Variation in (a) NH₄⁺ -N and (b) NO₃⁻ -N concentration of the pore water with days after fertilization under flooded conditions. Vertical bars at each data point are ±SE (n=3).

Effects on Ammonia Volatilization

Under saturated conditions an ammonia flux was observed only in N added treatments and the interaction effect of DAF into treatment was significant (p<0.05). At the 1 DAF and 2 DAF, the emission was significantly higher (p=0.07) in U than in control and the emission of BC_U is not significantly different from the other two treatments (p>0.05). Thereafter, no significant AV was observed in any treatment. The percentage loss of added N as AV was very small under the experimental conditions used and it varied from 0 to 3 % of added N. Under saturated conditions, AV was significantly higher (2.72 %; p<0.05) in U and BC_U (1.21 %; p<0.05) than in Contral (0 %). Under flooded conditions only U had a significant AV (2.42%; p<0.05) and the emission of BC_U has suppressed (Figure 3b). Any loss of N due to AV was observed only in Urea added treatments and even that is within three days application. Soon after urea after its application the pH in the soil solution increases significantly and then decrease (Sherlock et al, 1987, Christianson et al., 1993). The increase in pH could enhance AV in urea added treatments immediately after their application but decrease as pH decreases to values less than 8 (Ventura and Yoshida, 1977). The pH in the soil solution were lower than 8 (Figure 4), although there could have been higher pH levels for brief period. On the other hand, AV is affected by the combination effects of NH4+ concentration and pH of the solution and urease activity in addition to other climatic factors (Jayaweera and Mikkelsen, 1991).

These observations in AV can be a cumulative effect of various factors. Application of Urea triggers the AV by increasing the NH_{4^+} availability and it depends on the urea hydrolysis rate (Jones et al., 2013). Higher the NH₄⁺ ions present, higher the AV (Jayaweera and Mikkelson, 1991). Soil UA has not significantly changed with the application of either urea or BC_U (Tabel 2). Jiao et al. (2005) has observed that application of polymer coated urea has inhibited the soil urease activity by regulating the rate of urea release. But when comparing the nutrient releasing pattern, BC_U may not strictly regulate the urea availability (Jayarathna et al., 2021). Moreover, Fan et al. (2011) suggests that, the composition of BC_U, soil temperature, and soil type are main factors to dominate AV from slow-release fertilizers.

In comparison to other studies, very low AV values has recorded in this study. It could be due to the relatively low N application rate (23 mg of N per kg soil) used which could have limited the NH₄⁺ ion concentration in the pore water. Hayashi et al. (2006) has observed a maximum peak at DAF 3 with 30 g N ha⁻¹ h⁻¹ under field conditions in a Japanese acidic rice soil (pH 5.7) under low urea application rates (30 kg N ha⁻¹). Also, Ernst and Massey (1960) have observed 20 % cumulative AV loss of added N, top dressed as urea (113 kg N ha-1) in saturated soil. He et al. (2014) has reported that a seasonal AV loss of 13 % of added N (318 kg N ha⁻¹) from flooded rice soils which peaked at 1 to 3 days after fertilization and then decrease within 10 days. Moreover, the pore water pH was also at near neutral level that retarded the NH₄⁺ dissociation in water. Also,

there can be other N transformation processes than AV, which are more significant in this system. For example, NH_{4^+} ions can be subjected to nitrification in the surface oxidized layer and its subsequent denitrification in the reduced layer (Katyal et al., 1988). Dubey (1968) has reported the nitrification rate is higher under saturated conditions than flooded conditions in a sandy loam soil by 75 %, 33 % and 24 % in 2,4 and 8 weeks, respectively. Immobilization also could affect the AV by decreasing the pore water NH₄⁺ ion concentration at short durations (Ventura and Yoshida, 1977, Ponnamperuma, 1972) like in our study.

The pore water pH has remained at near neutral levels and not significantly changed (p>0.05) throughout the incubation period (Figure 4) and not significantly different among treatments as well. After the two weeks of preincubation period, the pH of the soil

could have increased to near neutral level. Neutral to acidic soils (pH 5.0-7.0) are not much susceptible for AV as alkaline soils (Overrein and Moe, 1967). Watanabe et al. (2009) has observed that in acidic rice soils the pH of the flood water has ranged from 6.1-9.7 under field conditions and they have reported 10-15% AV loss of applied N within two weeks where flood water pH was 7.7 at the time of measurement. Moreover, during urea hydrolysis NH₄⁺ and OH ⁻ ions are produced and fast urea degradation will accelerate the accumulation of NH4+ and OHwhich could increase soil pH and stimulate NH₃ emissions (Gao et al., 2022). In the studied soil the UA was very low (Table 2) and rapid pH changes were not observed during the incubation period. Further, nitrification of NH₄⁺ over time releases NO₃⁻ and H⁺ which could gradually reduce soil pH (Curtin et al., 2020).



Figure 3. Variation in ammonia volatilization (g N/kg of soil/day) in different treatments with days after fertilization under two moisture regimes; (a) saturated, (b) flooded. Vertical bars at each data point are ±SE (n=3).



Figure4. Variation in pH of the pore water in different treatments with days after fertilization under two moisture regimes (a) saturated, (b) flooded. Vertical bars at each data point are ±SE (n=3).

submerged irrigation In systems, the incorporated NH₄⁺ is diffused upward from the anaerobic layer to the aerobic layer, where oxidized N species diffuse downward from the oxidized layers to the reduced layers (Hanif et al., 1987). When more NH_{4^+} ions come to the oxidized layers, the flood water layer acts as a barrier there. The NH4⁺ ions dissolve in the flood water layer and the dilution will discourage the volatilization (Jayaweera and Mikkelson, 1991, Li et al., 2008). Also, the slow fluctuations in temperature in flood water also retard the volatilization of NH₃ (Freney et al., 1988) compared to AV from the bare soil surface. But, under saturated conditions it is more oxidized than the flooded soil. As there is no any flood water layer, it directly supports to the removal of ammonium ions via volatilization (Ventura and Yoshida, 1977). It has been observed that the N use efficiency was almost 64% under continuous flooded conditions while it was only 26% in alternate flooded conditions (Hanif et al., 1987). Zhao et al. (2010) has compared the traditional flooding with the system of rice intensification (SRI) where, the average AV loss during the rice growth stage under SRI was 22% high, suggesting that SRI paddy kept in a moist condition without standing water would enhance AV.

Effects on Soil Urease Activity

Soil urease activity ranged from 7.0 to 8.4 µg NH₄⁺ g⁻¹ soil h⁻¹ in the studied soil and had not been changed significantly (p>0.05) among treatments under both saturated and flooded conditions during the period of incubation (Table 2). While some studies have reported UA ranged from 8 to 32 μ g NH₄⁺ g⁻¹ soil h⁻¹ at 30°C in tropical paddy growing soils (Sahrawat, 1980) some others have observed much higher UA (198 - 346 μ g NH₄⁺ g⁻¹ soil h⁻ ¹) in paddy growing soils (Pattanik et al., 1999; Huang et al., 2017: Sahoo et al., 2017). With comparison to the reported values, the UA of the studied soil is very low probably due to differences in methodologies used and soil properties. Continuous application of BC_U could accumulate BC in soil and at higher levels of BC (20 Mg ha-1) can significantly reduce UA (Huang et al., 2017, Jing et al., 2020). However, application of BC_U adds only a very low quantity of BC (0.14 Mg ha⁻¹) to the soil which probably could not have been sufficient to change UA significantly in the studied soil. In the present study, under saturated and flooded conditions, the UA was more or less similar although Antil et al. (2006) has observed a decrease in urease activity at moisture levels above saturation. Generally, the UA is low in reduced soils than that of oxidized soils (Dharmakeerthi and Thenabadu, 1996). Therefore, it is worthy to monitor the redox potential as well in future studies to better understand the reasons for similar UA in soils that had two water regimes.

Table 2. Mean soil urease activity and pH buffer capacity (\pm SD) of the treatments at the beginning (0 DAF) and at the end (14 DAF) of the incubation period under saturated and flooded conditions (n=3).

Treatme nt	Urease Activity (µg NH4+-N g ⁻¹ hr ⁻¹)			pH buffer capacity (mmls kg ⁻¹ pH ⁻¹)		
	ODAF	14DAF (Saturated)	14DAF (Flooded)	0DAF	14DAF (Saturated)	14DAF (Flooded)
Soil	8.40 a ±1.71	7.70a±0.99	8.40 a ±0.12	11.19 a ±0.18	11.39 a ±0.74	11.62 a ±0.46
Soil+ Urea	7.70 a ±1.05	5.60a±1.04	7.00 a±1.98	11.14 a±0.05	11.44 a±0.28	11.55 a ±0.48
Soil+ BC_U	8.40 a ±1.72	6.30a±0.98	8.40 a±3.43	11.36 a±0.15	11.32 a±0.17	11.97 a ±0.46
p value	0.87	0.32	0.78	0.52	0.96	0.61

Effects on Soil pH Buffer Capacity

The pHBC in tropical soils ranged from 9 to 27 mmols kg⁻¹pH⁻¹ (Palanivell et al., 2019; Lu et al., 2022). Comparatively, the studied soil has a medium pHBC. Soil pHBC also had not been changed significantly (p>0.05) among treatments under both saturated and flooded conditions (Table 2). The soil pHBC is governed by several mechanisms, mostly protonation/deprotonation of acidic groups on organic matter, oxides, and hydroxides and dissolution/precipitation of carbonates (Bloom, 2000) and positively correlated with soil organic carbon, clay content and exchangeable acidity (Aitken et al., 1990). Despite the moisture regime, the soil suspension valence, ionic strength, reaction time and biological processes greatly affected the pHBC of a soil (Wang et al., 2015). The application of urea does not significantly affect on pHBC (Curtin et al., 2020). But, application of organic matter such as crop residues and BC can improve soil pHBC (Latifah et al., 2018, Shi et al., 2017). Although the application of biochar at high rates (72 and 120 t ha⁻¹) had increased soil pHBC (70-120% increase) by increasing CEC (Xu et al., 2012), the addition of BC via BC_U is insignificant due to their low application rate (0.14 Mg ha⁻¹).

CONCLUSION

Ammonia volatilization from paddy growing soils is governed by multitude of factors. We studied the effects of source of N and water regime, on AV in a paddy growing Entisol of Sri Lanka while in a closed chamber laboratory experiment. The source of Ν (Urea intercalated BC and urea), did not significantly change the urease activity and pH buffer capacity in the studied rice growing Entisol. Under saturated conditions, significantly higher NH₄⁺ concentration in soil solution was observed in urea added soils and the highest NO₃- was observed in U applied soil. Under flooded conditions, a significantly higher NH₄+ was detected in U and NO₃⁻ was not affected by urea application. Very low (0-2.72%) but significant increase in AV after N application was observed during the first 2-3 DAF, but application of urea as BC_U can reduce AV by maintaining a lower pore-water NH4+-N concentration under both saturated and

flooded conditions. Urea application, as BC_U or otherwise, did not significantly increase pore water pH and maintained it bellow 7.2 minimizing the AV loss. Although there was a small AV loss (<3%) after N application, it could be further reduced by application of urea as a rice husk biochar-based BC_U and/or maintaining a flood water layer for few days after N application.

Future Directions

The experiment needs to be scaled up to test the hypothesis under field conditions. To better understand the underlying mechanisms for AV loss processes such as nitrification and denitrification should also be studied in rice growing soils of Sri Lanka.

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