

Using Soil Water to Control Ammonia Emission from Acid Soils with and Without Chicken Litter Biochar

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Abstract

Although urea use in agriculture is on the increase, increase in pH at soil microsite due to urea hydrolysis which causes ammonia emission can reduce N use efficiency. Among the interventions used to mitigate ammonia loss include urease inhibitors, clinoptilolite zeolite, coated urea, and biochar but with little attention to the use of soil water levels to control ammonia volatilization. The objective of this study was to determine the effects of soil water levels on ammonia volatilization from soils with and without chicken litter biochar. Dry soils with and without chicken litter biochar were subjected to 0%, 25%, 50%, 75%, 100%, and 125% soil water. There was no urea hydrolysis in the soil without water. Chicken litter biochar as soil amendment effectively mitigated ammonia loss at 1% to 32% and 80% to 115% field capacity. However, urea used on soil only showed lower ammonia loss at 33% to 79% and 116% to 125% field capacity compared with the soils with chicken litter biochar. At 50% field capacity ammonia loss was high in soils with and without chicken litter biochar. Although chicken litter biochar is reputed for improving soil chemical properties, water levels in this present study affected soil chemical properties differently. Fifty percent field capacity, significantly reduced soil chemical properties. These findings suggest that timely application of urea at the right field capacity can mitigate ammonia emission. Therefore, whether soils are amended with or without chicken litter biochar, urea application should be avoided at 50% field capacity especially in irrigated crops.

Keywords: ammonia volatilization, chicken litter biochar, soil water, urea hydrolysis

1. Introduction

The ever-increasing human population has caused increased use of nitrogen fertilizers in agriculture (Gellings & Parmenter, 2016). Although ammonium nitrate and ammonium sulphate are used in agriculture, granular urea is the most used chemical fertilizer. For example, approximately 190 million tons of urea is used yearly out of which 80% is used in food production (Zhang et al., 2015). Urea is popular in developing countries because of its high nitrogen content and easy transportation (Glibert et al., 2006). However, increase in pH at soil microsite due to urea hydrolysis can accelerate ammonia emission. Urea-N loss through ammonia volatilization causes low N use efficiency (Sommer et al., 2004; Jensen et al., 2011; Martins et al., 2015). Ammonia volatilization from urea occurs when urea is hydrolysed by water to produce ammonium carbonate [$\text{NH}_2\text{CONH}_2 + 2\text{H}_2\text{O} - (\text{NH}_4)_2\text{CO}_3$]. Afterwards, ammonium carbonate decomposes to produce ammonia, carbon dioxide, and water (Palanivell et al., 2017). Nitrogen loss through ammonia volatilization does not only cause economic loss to farmers but it also causes environmental pollution and human lung failure (Bremner, 1995).

Although the literature is replete with information on ammonia volatilization from organic and mineral fertilizers (Sommer & Hutchings, 2001; Sommer et al., 2004), the increasing use of urea due to high nitrogen demanding cultivars used in production agriculture has compelled researchers to come out with more effective means of mitigating ammonia volatilization. One of the approaches being adopted is the use of urease inhibitors to retard urea hydrolysis (Jia et al., 2015; Abalos et al., 2012; Francisco et al., 2011). Although, this approach decreases NH_4^+ concentration in soil solution (Gill et al., 1999), the building up of NH_4^+ in soils without it being timely used by crops will result in higher NH_4^+ concentration in the soil solution. Higher concentration of NH_4^+ in soil solution could also increase soil OH^- ions such that the ions could re-react with NH_4^+ to produce ammonia and H_2O (Jia et al., 2015). The ammonia produced could be emitted into the environment regardless of urease inhibitors. Ahmed et al. (2010) and Palanivell et al. (2016) also used Clinoptilolite zeolite to mitigate ammonia volatilization from aerobic and anaerobic soil with urea, besides improving soil chemical properties. However, accessibility of good Clinoptilolite zeolite even for research purposes has been an issue. Another invention is coating urea with humic acids which had been reported to significantly minimize Urea-N loss through ammonia volatilization (Ahmed et al. 2010). The afore-stated innovations are good but they are expensive for farmers to adopt.

In recent times, some researchers are using organic amendments to control ammonia loss but among the organic amendments, biochars are preferred because they also improve soil CEC, texture, cations, and anions. Biochars are able to minimize ammonia volatilization because of their high surface charges. These charges which enable sorption of ammonium ions from being converted to ammonia (Rondon et al., 2006). Palanivell et al. (2017) used chicken litter biochar to reduce ammonia emission from a tropical acid soil (Typic Paleudults). However, there is a dearth of information on how soil water levels affect ammonia volatilization from tropical acid soils with chicken litter biochar and urea. If soil water minimize ammonia volatilization, it could be used as a cheaper method to improve nitrogen use efficiency in agriculture. Therefore, this study seeks to address the following research questions: (1) will soil water affect ammonia volatilization from soils with and without chicken litter biochar? and (2) what will be the suitable amount of soil water that could minimize ammonia volatilization from soils with and without chicken litter biochar? The objective of this study was to determine the effects of soil water levels on ammonia volatilization from soils with and without chicken litter biochar.

2. Materials and Methods

Typic Paleudults (Nyalau Series) soil was taken at 0 to 25 cm depth in a secondary forest of Universiti Putra Malaysia Bintulu Campus, Sarawak, Malaysia (latitude $3^\circ 12' 14.5''$ N and longitude $113^\circ 4' 16.0''$ E). Afterwards, the soil was air dried and ground to pass a 5 mm sieve for pot trial and some were further sieved to pass a 2 mm sieve for selected chemical and physical properties analyses before and after incubation study (Table 1).

Soil pH was determined in a ratio of 1:2.5 (soil: distilled water) using a digital pH meter (Peech et al., 1965). Soil total C was calculated as 58% of the organic matter using the loss of weight on ignition method (Cheftez et al., 1996). Cation exchange capacity (CEC) of the soil was determined using the leaching method (Cottenie, 1980) followed by steam distillation (Bremner, 1965). Exchangeable cations were extracted with 1 M NH_4OAc using the leaching method (Cottenie, 1980) after which, the cations were determined using Atomic Absorption Spectrometer (AAAnalyst 800, PERKIN Elmer Instruments, Norwalk, CT). Total N was determined using Kjeldhal method (Tan, 2005) whereas NO_3^- and NH_4^+ were determined using Keeney & Nelson (1982) method. Total P and K were extracted using aqua regia method and thereafter, total P was determined using Spectrophotometer after blue colour was developed using the Blue Method (Murphy & Riley, 1962). Total K was determined using Atomic Absorption Spectrometry (AAAnalyst 800, Perkin Elmer Instrument, Norwalk, CT). Soil exchangeable acidity, H^+ , and Al^{3+} were determined using acid-base titration method (Rowell, 1994). These chemical analyses were repeated after the incubation study. The results of the initial soil chemical properties (Table 1) are similar those of Palanivell et al. (2017).

Table 1. Selected chemical properties of *Typic Paleudults* (Bekenu Series) soil before ammonia volatilization study

Properties	Values	Properties	Values
pH in water	4.9 ± 0.04		..... cmol kg ⁻¹
	..... % .....	Available K	1.01 ± 0.12
Total carbon	1.25 ± 0.10	Total K	3.30a ± 1.14
Total N	0.05 ± 0.007	CEC	4.58 ± 0.10
	..... mg kg ⁻¹	Exchangeable Acidity	1.32 ± 0.07
Available NO ₃ ⁻	1.05 ± 0.35	Exchangeable Al ³⁺	1.24 ± 0.05
Exchangeable NH ₄ ⁺	1.58 ± 0.18	Exchangeable H ⁺	0.08 ± 0.02
Available P	2.84 ± 0.64	Exchangeable Cu ²⁺	0.0119 ± 0.0006
Total P	64.80 ± 4.64	Exchangeable Mn ²⁺	0.27 ± 0.07
		Exchangeable Fe ²⁺	0.16 ± 0.01
		Exchangeable Zn ²⁺	0.0068 ± 0.0008
		Exchangeable Na ⁺	5.25 ± 0.39
		Exchangeable Ca ²⁺	26.39 ± 2.76
		Exchangeable Mg ²⁺	5.27 ± 0.93

2.1 Chemical Properties of Chicken Litter Biochar

The Black Earth Products chicken litter biochar used in this study was imported from Australia. Chemical properties of the chicken litter biochar (Table 2) are consistent with Australia Certified Organic Standard, 2010. (Table 1).

Table 2. Selected chemical properties of BlackEarth chicken litter biochar

Macro Nutrients		Micro nutrients			
pH	8.5	Av. Particle size	0.5 -2 mm		
.....%	.....	.....	mg kg ⁻¹		
Total Carbon	63.7	Silicon	2.3	Magnesium oxide	6.7
Fixed Carbon	61.2	Aluminium	1.5	Arsenic	2.1
Nitrogen	2.8	Potassium oxide	16.3	Cadmium	0.7
Phosphate	2.6	Boron	62	Chromium	9.6
Potassium	3.9	Copper	167	Mercury	0.06
Calcium	5.9	Manganese	1130	Nickel	14
Sulphur	0.59	Zinc	856	Lead	12
Ash content	23.7				

Source: Black Earth Company in North of Bendigo Victoria, Australia

Amount of the chicken litter biochar used was 5 t ha⁻¹ (Maru et al., 2015) and this was scaled down according to the treatments evaluated (Table 3). The amount of urea used in this study was based on the recommendation of MADA (2015) and this was scaled down based on the requirement of rice plants hill (Table 2) (Palanivell et al., 2017).

Table 3. Amounts of soil, chicken litter biochar, urea, and moisture levels used in the incubation study

Treatments	Soils	Chicken litter Biochar	Urea	Level of water per +soil field capacity
	g			%
T1	1000	20	1.32	0
T2	1000	20	1.32	25
T3	1000	20	1.32	50
T4	1000	20	1.32	75
T5	1000	20	1.32	100
T6	1000	20	1.32	125
T7	1000	0	1.32	0
T8	1000	0	1.32	25
T9	1000	0	1.32	50
T10	1000	0	1.32	75
T11	1000	0	1.32	100
T12	1000	0	1.32	125

2.2 Ammonia Volatilization Setup

Before setting up the ammonia volatilization study, soil was oven dried in an oven at 105 °C until constant weight was attained. This was done to remove hygroscopic water of the soil. Plastic containers were filled with 1 kg soil based on the soil's bulk density (1.16 g cm⁻³). Rates of the chicken litter biochar and amount of urea recommended by Maru et al. (2015) and MADA (2015), respectively were scaled down based on the requirement of the rice plants (Table 2). Ammonia volatilization was measured using a closed dynamic air flow system (Siva et al., 1999; Ahmed et al., 2006; Palanivell et al., 2017) with modification. The system consisted of air pumps which were connected to plastic containers with treatments using polyethene tubes (Figure 1). The incubation chambers were maintained at room temperature. Air was passed through the closed system at a rate of 3.5 L⁻¹ min⁻¹ chamber⁻¹. This rate of airflow which is equivalent to 8.5 volume exchanges min⁻¹, was maintained throughout the incubation study using a Gilmont flow meter (Gilmont Instrument, Great Neck, NY, USA). The outlet of each container was connected to a conical flask with 75 mL boric acid solution using a polyethene tube. In the conventional method, only one conical flask with 75 mL boric acid solution is used but in this present study, three conical flasks connected in series using polyethene tubes were used (Figure 1). This modification is essential because the ammonia captured in the 75 mL of boric acid solution in only one conical flask requires accurate trapping of ammonia to avoid underestimation of this gas. Our preliminary trials revealed that excess ammonia got lost when only one conical flask with 75 mL boric acid solution was used due to saturation of the boric acid over 24 hours. Moreover, it was hard to know if the boric acid had captured enough ammonia for it to be changed within the 24 hours. However, with the three-capturing conical flasks with the boric acid solution in series, avoidance of the underestimation of ammonia loss was possible (Figure 1) as excess ammonia were captured in the boric acid solutions of the second and third conical flasks. This means that, with this new approach of using 3 sets of conical flasks each with 75 mL boric acid solution, all of the ammonia released within 24 hours were captured. The captured ammonia was back titrated with 0.01 M HCl to estimate the daily percentages of the ammonia released from urea. Measurements were continued until the ammonia loss declined to 1 % of the N added from urea (Ahmed et al., 2006). Thereafter, the ammonia volatilization study was stopped, and the soil samples were processed and analysed using standard procedures outlined earlier.

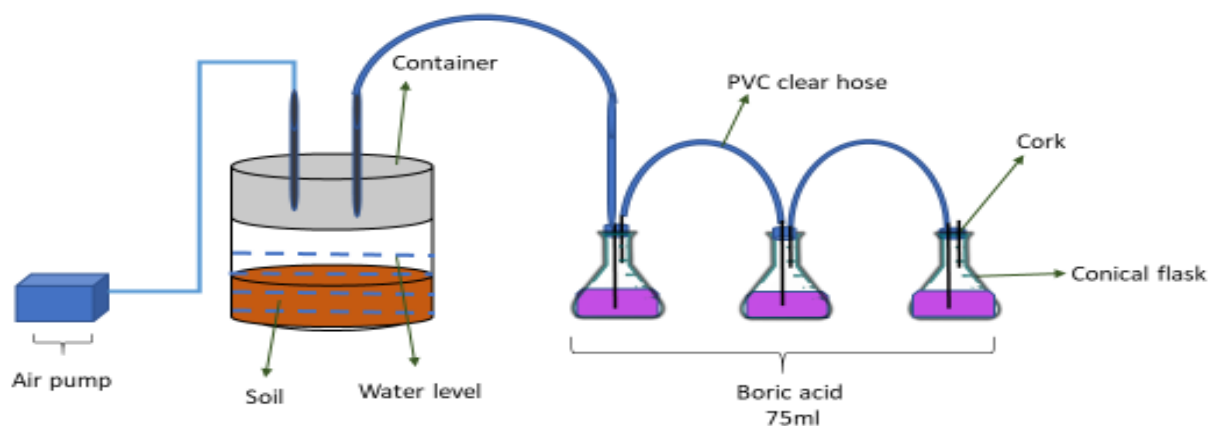


Figure 1. Close-dynamic air flow system (Siva et al., 1999; Ahmed et al., 2006) with modification

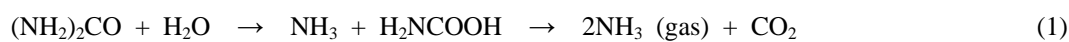
2.3 Statistical Analysis

Analysis of variance (ANOVA) was used to detect significant differences among treatments whereas Tukey's HSD test was used to compare treatment means using Statistical Analysis System version 9.2 (SAS, 2008).

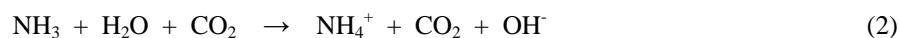
3. Results and Discussion

3.1 Water Levels on Ammonia Volatilization from Soils with Chicken Litter Biochar

Urea reacts with soil water to produce unstable carbamic acid after which this acid decomposes to form ammonia and carbon dioxide (Equation 1) (Fan & Mackenzie, 1993). However, there was no ammonia emission from T1 (Figures 2, 3, and 4) because of negligible amount of soil water as the soil was oven dried at 105 °C.



For T2, there was urea hydrolysis resulting in ammonia loss at 25% soil water and ammonia volatilization from this treatment was lower than that of T3 (50% soil water) (Figures 2, 3, and 4) because of the lower soil water. In T3, ammonia volatilization increased significantly (Figures 2, 3, and 4) because there was enough soil water to hydrolyze urea to produce unstable carbamic acid ($\text{NH}_3 + \text{H}_2\text{NCOOH}$) (Palanivell et al., 2017; Havlin et al. 1999) but not enough water to further convert carbamic acid to ammonium (NH_4^+) and carbon dioxide (CO_2) hence, the higher ammonia emission from T3 (Equations 1 and 2).



The total amounts of the ammonia emitted for 41 days further indicate that the ammonia loss from T3 was significantly higher than those of T1, T2, T4, T5, and T6 (Figure 3). At 75% and 100% soil water respectively, ammonia emissions from T4 and T5 were lower than that of T3 because of extra soil water to hydrolyze most of urea to NH_4^+ (equation 2). The soil water might have diluted the concentration of NH_4^+ in solution to minimize ammonia emission (Madrini et al., 2016).

The daily ammonia volatilization from T6 started on day 3 and this loss was similar to those reported by Palanivell et al. (2016) because urea hydrolysis is rapid in waterlogged soils. The waterlogged condition might have limited nitrification (conversion of NH_4^+ to NO_3^-) in T6 due to limited oxygen. As a result, higher NH_4^+ concentration in soil solution favours ammonification that is, reaction of NH_4^+ with OH^- to produce NH_3 and H_2O thereby causing the earlier ammonia emission from T6 (Figure 2). Ammonia loss from T6 (125% soil water) was higher than those of T4 and T5 at 75% and 100% soil water, respectively, because production of OH^- in waterlogged condition is higher due to complete urea hydrolysis. In complete urea hydrolysis, one mole of urea consumes two moles of H^+ ions from soil water to produce two moles of OH^- (Liyanage et al., 2015). Thereafter, the hydroxyl ions react with NH_4^+ to produce ammonia and water (Equation 3) (Palanivell et al., 2017; Havlin et al., 1999).



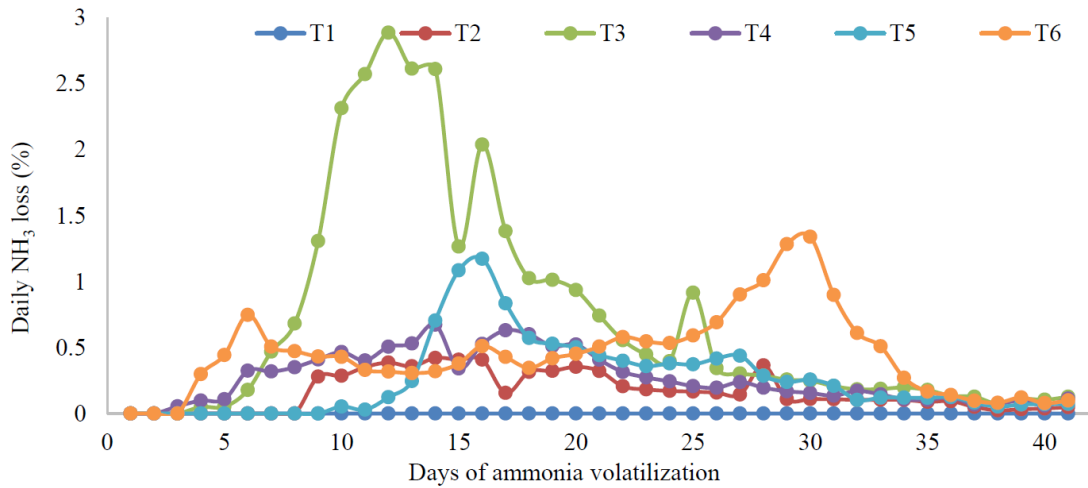


Figure 2. Water levels on daily ammonia volatilization from soil with chicken litter biochar

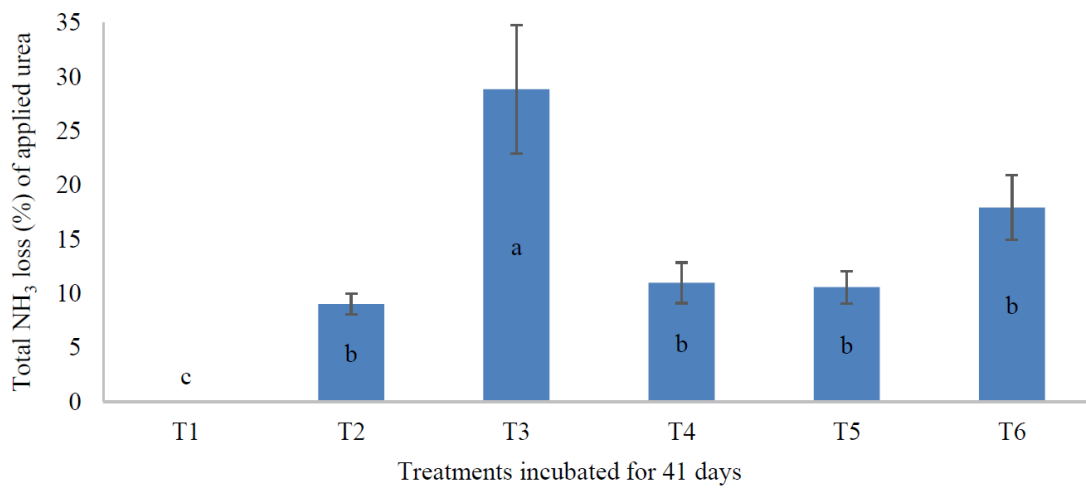


Figure 3. Water levels on total ammonia volatilization from soil with chicken litter biochar

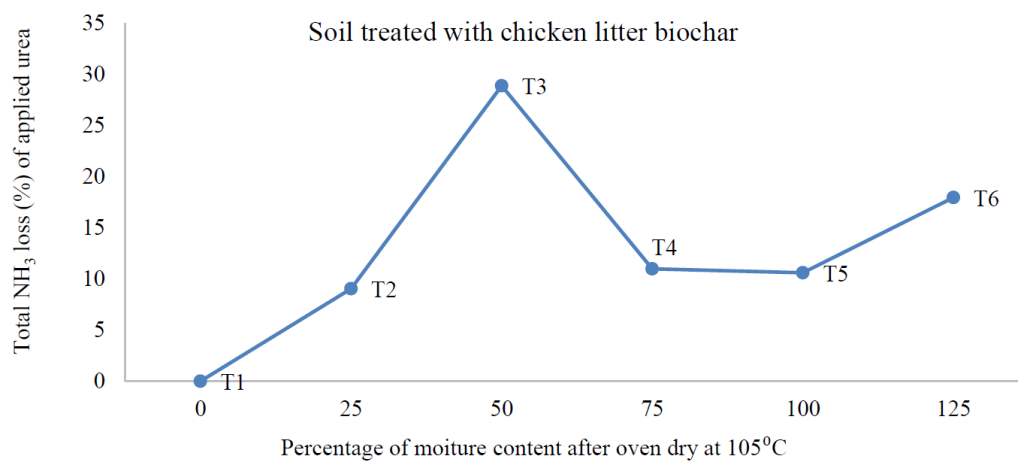


Figure 4. Soil water levels on total ammonia volatilization

3.2 Water Levels on Ammonia Volatilization from Soils without Chicken Litter Biochar

There was no ammonia volatilization from T7 because of the absence of soil water to hydrolyze urea (Palanivell

et al., 2016) and this finding is also consistent with that of T1 (Figure 2). This indicates that, with or without organic amendments, soil without water will not cause ammonia volatilization. At 25% soil water (T8), urea hydrolysis caused ammonia loss and this finding is consistent with that of soil with chicken litter biochar (T2) (Figures 5, 6, and 7). Furthermore, 50% soil water (T9) cause higher loss of ammonia (Figure 6). This observation also corroborates with that of T3 (soil with chicken litter biochar and 50% soil water) (Figure 3). As soil water increased to 75% (T10), ammonia loss significantly decreased because of nitrification of ammonium to nitrate, thus resulting in decrease of NH_4^+ concentration in the soil solution. As soil water increased to 100% field capacity (T11), ammonia loss increased because all the soil pores were field with water and this prevented biological oxidation of NH_4^+ to nitrate. However, at 125% soil water (T12), ammonia loss decreased. Total ammonia loss after 41 days of this study showed that, the emission of ammonia from T9 was similar to that of T11 but significantly higher than those of T7, T8, T10, and T12 (Figure 6). The highest ammonia volatilization from soil without chicken litter biochar occurred at 50% soil water (Figure 7). This result is similar to that of T3 (soil with chicken litter biochar) (Figure 3).

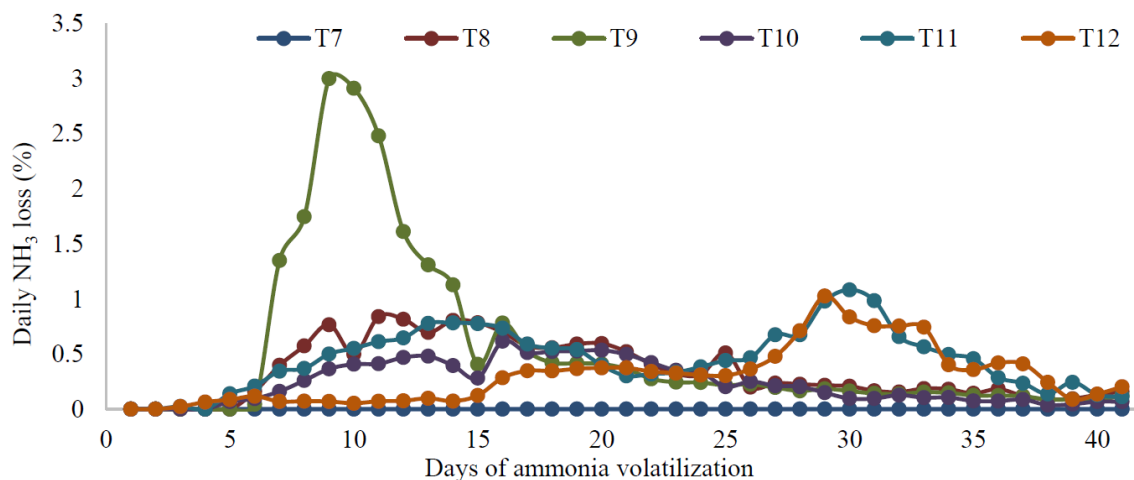


Figure 5. Soil water contents on daily ammonia volatilization from soil without chicken litter biochar.

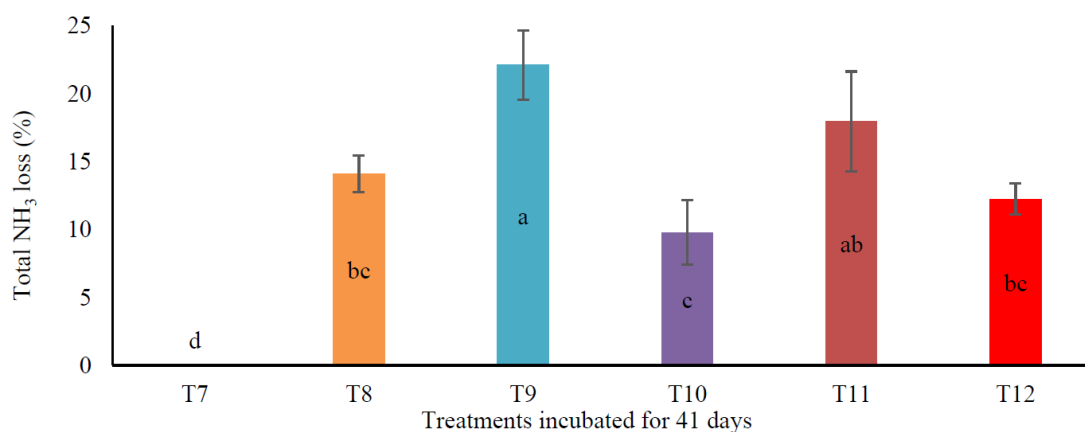


Figure 6. Water contents on total ammonia volatilization from soil without chicken litter biochar

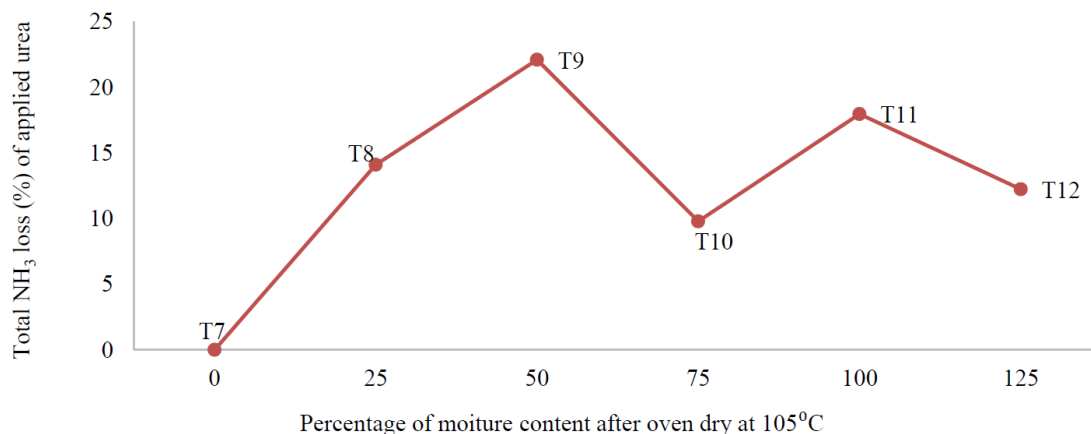


Figure 7. Soil water contents on total ammonia volatilization

3.3 Water Content on Ammonia Volatilization from Soils with and Without Chicken Litter Biochar

The fact that there were no ammonia emissions from T1 (Soil + biochar + urea + no soil water) and T7 (Soil + urea + no soil water) (Figures 8, 9, and 10) soils suggest that without soil water, there will be no ammonia volatilization regardless of the presence of chicken litter biochar and urea. However, when the soils of T2 and T8 were moistened with water to 25% field capacity, ammonia volatilization occurred although the amounts emitted were similar they were lower than those of T3 and T9 (Figure 9). These results confirm that of Al-Kanani et al. (1991) who reported that, at low soil water, both urea hydrolysis and ammonia volatilization are slow. The chicken litter biochar did not significantly reduce ammonia loss compared with soil without chicken litter biochar (Figure 9).

Results in Figure 9 show that the total ammonia loss from T3 was similar to that of T9 but significantly higher than those of T1, T2, T4, T5, T6, T7, T8, T10, T11, and T12. Also, the total ammonia loss from T9 was similar to that of T6, T8, and T10 but significantly higher than those of T1, T2, T4, T5, T7, T11, and T12 (Figure 9). Soil water affected NH₄⁺ concentrations in the soil solution and at 50% soil water, the concentration of NH₄⁺ was high thus, resulting in higher ammonia losses (Cameron et al., 2013). Increasing soil water increases rates of urea hydrolysis and ammonia production from urea (Cameron et al., 2013). Seventy-five percent soil water and above resulted in lower ammonia losses because there was significant amount of water to dilute the concentrations of NH₄⁺ in soil solution (Cameron et al., 2013). As shown in Figure 10, chicken litter biochar as soil amendment only minimized ammonia volatilization at 1% to 32% and 80% to 115% field capacity due to higher sorption of ammonia onto the surfaces of the chicken litter biochar (Asada et al., 2002; Clough and Condron, 2010). This further indicates that sorption of ammonia by chicken litter biochar (Jia et al., 2015) is lower at 33% to 79% and above 116% field capacity.

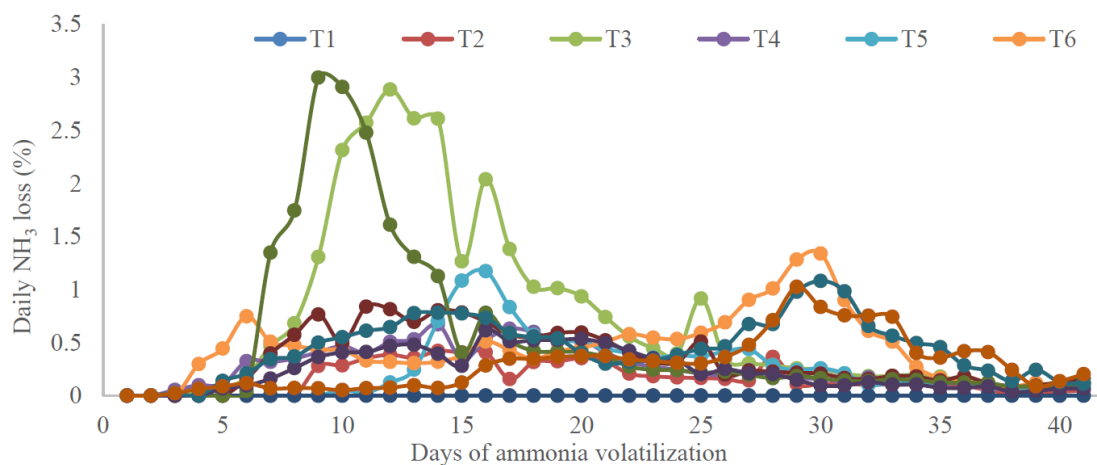


Figure 8. Water levels on daily ammonia volatilization from soils with and without chicken litter biochar

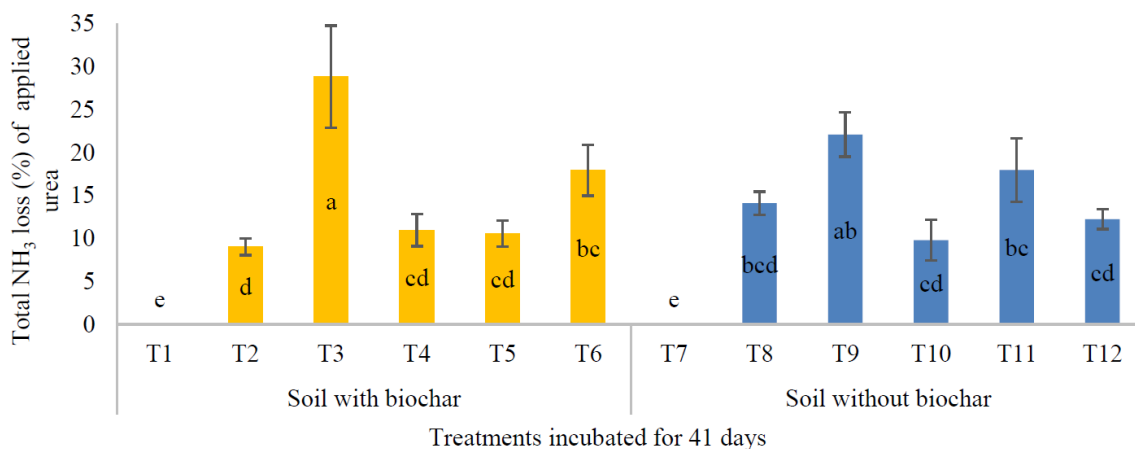


Figure 9. Water levels on total ammonia volatilization from soils with and without chicken litter biochar

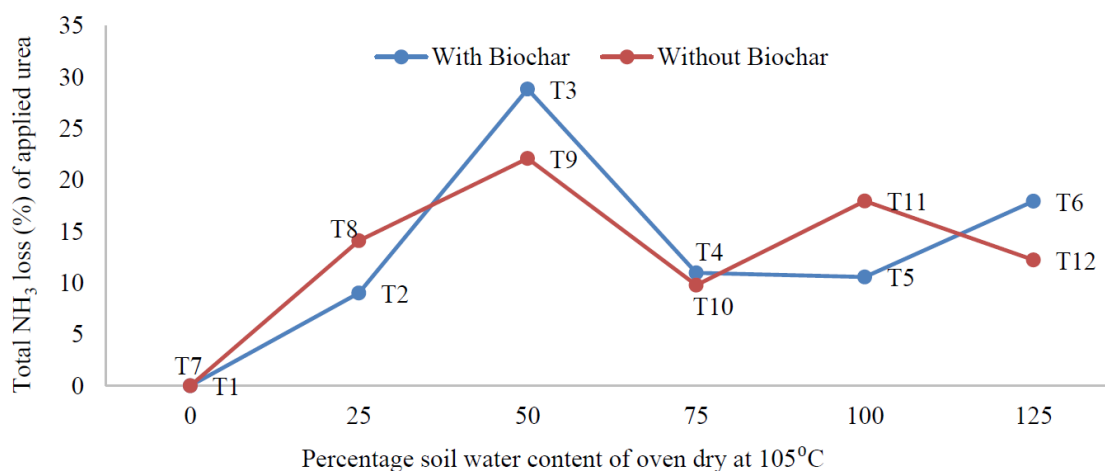


Figure 10. Soil water content on total ammonia volatilization

3.4 Water Levels on Selected Chemical Properties of Soils with Chicken Litter Biochar

Soil pH in water and KCl of T3, T4, T5, and T6 were not significantly different but higher than those of T1 and T2 (Table 4). The soil pH of T2 was higher than that of T1 (Table 4). Although soils with T1, T2, T3, T4, T5, and T6 were amended with the same amount of chicken litter biochar, the pH of T1 was significantly lower pH because T1 soil had no soil water to initiate urea hydrolysis ($\text{NH}_3 + \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{NH}_4^+ + \text{CO}_2 + \text{OH}^-$) (Palanivell et al., 2017; Sommer et al., 2004). This further explains why in T1, ammonia was not released throughout the incubation study. In T2, the soil pH was higher than that of T1 because soil water at 25% enabled some of the urea to hydrolyze (Sommer et al., 2004) to produce some OH⁻ to increase the soil pH. Soil pH of T3 was similar to those of T4, T5, and T6 because the soil water with T3, T4, T5, and T6 were enough to hydrolyze most of urea to produce similar amount of OH⁻. The soil total acidity and exchangeable H⁺ of T1 were lower than those of T2, T3, T4, T5, and T6 but exchangeable Al³⁺ was negligible in T2, T3, T4, T5, and T6 (Table 4). The soil total C of T1 was not different from those of T3 and T6 but significantly higher than those of T2, T4, and T5. Soil CEC of T1 was significantly higher than that of T6 (Table 4) due to absence of water in T1 and chicken litter biochar was only activated when the soil samples were solubilized for analysis. This indicates that for biochars to be active in soils, they need soil water to reduce Al³⁺ in soil solution.

Exchangeable NH₄⁺ of T4, T5, and T6 were not different but higher than those of T3, T2, and T1 (Table 5) because the ammonium ions increased with increasing soil water (Table 5). Available NO₃⁻ of T5 was significantly higher than those of T1, T2, T3, T4, and T6 (Table 5). Soil water did not affect total P, total N, exchangeable Na, and Cu availability (Tables 4 and 5). Soil total K of T1 and T2 were not different but higher than those of T3, T4, T5, and T6. Exchangeable K of T4, T5, and T6 were lower because of K dissolution in the

soil. Generally, the soil exchangeable cations of T1 were higher compared with those of T2, T3, T4, T5, and T6 (treatments with soil water) because of no water.

Table 4. Water levels on selected chemical properties of soil with chicken litter biochar

Treatments	pH in KCl	pH in water	Total C	CEC	Total acidity	Exchangeable	Exchangeable	Exchangeable	Total P
						Al ³⁺	H ⁺	K	
			%	.....cmol kg ⁻¹			mg kg ⁻¹		
T1	3.8c ± 0.11	5.98c ± 0.04	4.45a ± 0.19	6.03a ± 0.3	0.2b ± 0.01	0.06a ± 0.01	0.14b ± 0.01	2.2a ± 0.11	0.12a ± 0.09
T2	4.66b ± 0.15	6.48b ± 0.02	2.36d ± 0.04	5.03ab ± 0.43	0.38a ± 0.05	0	0.38a ± 0.05	1.83a ± 0.09	0.39a ± 0.03
T3	5.22a ± 0.06	6.46b ± 0.11	3.56abc ± 0.08	4.63ab ± 0.58	0.33ab ± 0.04	0	0.33a ± 0.04	1.42b ± 0.09	0.49a ± 0.16
T4	5.5a ± 0.16	6.86a ± 0.01	2.59cd ± 0.14	5.97a ± 0.33	0.42a ± 0.01	0	0.42a ± 0.01	1.21b ± 0.06	0.25a ± 0.1
T5	5.65a ± 0.02	7.04a ± 0.02	2.71bcd ± 0.39	4.53ab ± 0.3	0.37a ± 0.02	0	0.37a ± 0.02	1.21b ± 0.05	0.099a ± 0.07
T6	5.67a ± 0.01	6.95a ± 0.003	3.87ab ± 0.39	3.73b ± 0.47	0.42a ± 0.02	0	0.42a ± 0.02	1.07b ± 0.04	0.115a ± 0.098

Note: Different letter within a row indicate significant difference between the means of three replicates ± standard error using Turkey's test at $p \leq 0.05$.

Table 5. Water levels on selected chemical properties of soil with chicken litter biochar

TRT	Total N	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable
		NH ₄ ⁺	NO ₃ ⁻	Mg	Fe	Na	Ca	Cu	Mn
		%	.....mg kg ⁻¹.....		.....cmol kg ⁻¹				
T1	0.39a±0.07	16.11d±0.7	6.30bc±1	0.69b±0.04	0.02a±0.0002	0.623a±0.06	0.93d±0.05	7.56a±0.8	0.04b±0.002
T2	0.29a±0.02	56.04c±3.31	5.37bc±0.9	0.92a±0.04	0.012abc±0.0004	0.55a±0.06	1.63c±0.03	9.86a±0.56	0.056a±0.002
T3	0.25a±0.04	90.6b±3.5	6.77b±0.23	0.92a±0.06	0.013abc±0.002	0.58a±0.02	1.87bc±0.1	11.2a±0.82	0.043b±0.001
T4	0.28a±0.05	113.9a±4.7	5.83bc±0.23	0.85ab±0.05	0.011bc±0.0004	0.52a±0.03	2.04abc±0.1	9.02a±1.03	0.036b±0.003
T5	0.27a±0.02	117.5a±3.8	9.57a±0.62	0.85ab±0.04	0.0096c±0.002	0.65a±0.17	2.16ab±0.12	7.55a±0.96	0.043b±0.002
T6	0.2a±0.04	113.2a±2.63	4.67c±0.47	0.96a±0.03	0.016ab±0.003	0.4a±0.06	2.40a±0.17	8.71a±0.69	0.06a±0.001

Note: Different letter within a row indicate significant difference between the means of three replicates ± standard error using Turkey's test at $p \leq 0.05$.

3.5 Water Levels on Selected Chemical Properties of Soils without Chicken Litter Biochar

pH in water and KCl of soil without chicken litter biochar increased with increasing soil water. The highest soil pH occurred in T11 and T12 (Table 6) because of their higher soil water which effectively hydrolyzed urea to produce OH⁻ (Xu et al. 2006). This explains why soil pH increases with urea hydrolysis. Total acidity and exchangeable Al³⁺ of T7 were higher than those of T8, T9, T10, T11, and T12 (Table 6), suggesting that soil water plays an important role in controlling soil acidity (Cheng et al., 2008). The total soil acidity and Al³⁺ of T7 were higher than those of T9, T10, T11, and T12 because there was no urea hydrolysis in T7. These observations demonstrates that urea hydrolysis can minimize soil exchangeable Al³⁺ (Table 6). The findings also suggest that the affinity of ammonia for H⁺ produced during Al and Fe hydrolysis is higher than H⁺ from water molecules. The exchangeable H⁺ of T9, T10, T11, and T12 were not different but significantly higher than those of T2 and T1 (Table 6). Exchangeable NH₄⁺ of T11 and T10 were not different from those of T8, T9, T10, and T12 but significantly higher than that of T7 (Table 7) however, this ion increased with increasing soil water (Table 7).

The available NO₃⁻ of T8 and T9 were similar but higher than those of T7, T10, T11, and T12 (Table 7). Total C of T11 was not significantly different from those of T7, 9, and T12 but higher than that of T8. Soil CEC of T7 was significantly higher than those of T11 and T12 (Table 5). However, soil total K, P, and N, and soil exchangeable Mg, Na, and Cu of T7, T8, T9, T10, T11, and T12 were similar (Tables 6 and 7). These results were similar to those of the soils with chicken litter biochar thus, indicating that, variations among treatments were due to the differences in soil water as the soil water affected the chemical reactions of the treatments with soil.

Table 6. Water levels on selected chemical properties of soil without chicken litter biochar.

TRT	pH in KCl	pH in water	Total C	CEC	Total acidity	Exchangeable Al ³⁺	Exchangeable H ⁺	Exchangeable K	Total P
									... mg kg ⁻¹ ...
									.....cmol kg ⁻¹
T7	3.62d ± 0.02	4.54d ± 0.09	2.32ab ± 1	6.9a ± 0.42	1.17a ± 0.01	0.86a ± 0.02	0.3c ± 0.03	0.62ab ± 0.04	0.045a ± 0.04
T8	4.21c ± 0.02	6.04c ± 0.04	3.09b ± 0.39	6.17ab ± 0.19	0.57b ± 0.03	0.22b ± 0.01	0.35bc ± 0.02	0.58b ± 0.03	0.073a ± 0.05
T9	4.40c ± 0.09	6.27bc ± 0.07	2.32ab ± 1	6.73ab ± 0.54	0.53b ± 0.03	0	0.53a ± 0.03	0.73ab ± 0.01	0.09a ± 0.05
T10	4.75b ± 0.02	6.56ab ± 0.07	1.55b ± 0.39	7.03a ± 0.44	0.46b ± 0.04	0	0.46ab ± 0.04	0.71ab ± 0.07	0.16a ± 0.06
T11	4.84ab ± 0.05	6.61a ± 0.06	3.09a ± 0.39	4.27b ± 0.64	0.48b ± 0.01	0	0.48a ± 0.01	0.73ab ± 0.03	0.041a ± 0.04
T12	5.05a ± 0.03	6.83a ± 0.09	2.36ab ± 0.04	4.37b ± 0.48	0.47b ± 0.03	0	0.47a ± 0.03	0.82a ± 0.03	0.12a ± 0.07

Note: Different letter within a row indicate significant difference between the means of three replicates ± standard error using Turkey's test at $p \leq 0.05$.

Table 7. Water levels on selected chemical properties of soil without chicken litter biochar.

TRT	Total N	Exchangeable NH ₄ ⁺	Exchangeable NO ₃ ⁻	Exchangeable Mg	Exchangeable Fe	Exchangeable Na	Exchangeable Ca	Exchangeable Cu	Exchangeable Mn
									.....mg kg ⁻¹
									.....Cmol kg ⁻¹
									%
T7	0.23a±0.01	8.87b±1.68	6.07bc±0.47	0.39a±0.005	0.08a±0.004	0.26a±0.02	1.6b±0.08	8.71a±0.56	0.053a±0.001
T8	0.16a±0.03	41.1ab±13.1	25.69a±2.23	0.41a±0.02	0.015bc±0.002	0.23a±0.03	1.7b±0.11	9.13a±0.96	0.042abc±0.003
T9	0.11a±0.03	50.2ab±19.1	21.25a±1.17	0.39a±0.02	0.01c±0.0005	0.24a±0.01	1.67b±0.03	10.39a±0.36	0.04c±0.002
T10	0.10a±0.02	83.6a±15.1	12.61b±2.02	0.36a±0.005	0.01c±0.0005	0.18a±0.01	1.78ab±0.01	8.60a±0.46	0.04bc±0.003
T11	0.14a±1	96.9a±16.77	5.18c±0.66	0.37a±0.03	0.009c±0.0004	0.23a±0.001	1.79ab±0.05	9.76a±0.66	0.043abc±0.002
T12	0.18a±0.06	64.91ab±17.8	10.74bc±0.23	0.4a±0.007	0.02b±0.001	0.25a±0.02	2.01a±0.02	8.4a±0.56	0.052ab±0.002

Note: Different letter within a row indicate significant difference between the means of three replicates ± standard error using Turkey's test at $p \leq 0.05$.

3.6 Water Levels on Selected Chemical Properties of Soils with and Without Chicken Litter Biochar

Generally, the pH in water and KCl were higher in the soils with chicken litter biochar than those without this amendment (Table 8) because of the liming effect of the chicken litter biochar (Xu et al., 2006). The carboxylic-COOH and phenolic-OH groups of the chicken litter biochar further increased the concentration of OH⁻ in soil solution besides those which were produced during urea hydrolysis (Xu et al., 2006). Total acidity, exchangeable Al³⁺, H⁺, NH₄⁺, and Ca increased with increasing soil water in the soils with and without chicken litter biochar (Tables 8 and 9) because chicken litter biochar has the ability to reduce soil exchangeable acidity (Van Zwieten et al., 2009) due to its higher carboxylic and phenolic contents. These functional groups have higher affinity for Al³⁺ and Fe³⁺. Although Al³⁺ can be minimized during urea hydrolysis, the addition of chicken litter biochar is responsible for the further decrease in soil acid (Van Zwieten et al., 2009).

Total C of T1 was significantly higher than those of T2, T4, T5, T7, T8, T9, T10, T11, and T12 (Table 8). Soils with chicken litter biochar showed higher soil carbon than the soils without chicken litter biochar because of recalcitrant carbon content of chicken litter biochar (Gaskin *et al.*, 2008; Lehmann, 2007; Rebecca, 2007). Soil total P, exchangeable NH₄⁺, Ca, Cu, and Mn did not increase significantly in the soils with chicken litter biochar compared with the soils without chicken litter biochar (Table 9). However, exchangeable K, Mg, and Na were generally increased in the soils with chicken litter biochar (Tables 8 and 9) whereas available NO₃⁻ and exchangeable Fe were significantly higher in the soils without chicken litter biochar than those with chicken litter biochar (Table 9). These differences were because the complex and heterogeneous chemical composition of chicken litter biochar increased the soil's chemical properties. Functional groups such as hydroxyl -OH, amino-NH₂, ketone -OR, ester -(C=O)OR, nitro -NO₂, aldehyde -(C=O)H, carboxyl -(C=O)OH on the outer surface of the graphene sheets of chicken litter biochar (Harris, 1997; Harris and Tsang, 1997) enabled this organic amendment to act as electron donor and electron acceptor (Amonette & Joseph, 2009) to improve soil chemical properties.

Table 8. Water levels on selected chemical properties of soil with and without biochar

Treatments	pH in KCl	pH in water	Total C	CEC	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Total P	
					acidity	Al ³⁺	H ⁺	K		
			%	..... cmol kg ⁻¹.....				.....mg kg ⁻¹		
T1	3.8g ±0.11	5.98g ±0.04	4.45a ±0.19	6.03abcde ±0.3	0.2f ±0.01	0.06c ±0.01	0.14e ±0.01	2.2a ±0.11	0.12ab ±0.09	
T2	4.66de ±0.15	6.48de ±0.02	2.36cd ±0.04	5.03abcde ±0.43	0.38de ±0.05	0	0.38bcd ±0.05	1.83b ±0.09	0.39ab ±0.03	
T3	5.22bc ±0.06	6.46de ±0.11	3.56abc ±0.08	4.63bcde ±0.58	0.33ef ±0.04	0	0.33d ±0.04	1.42c ±0.09	0.49a ±0.16	
T4	5.5ab ±0.16	6.86a ±0.01	2.59bcd ±0.14	5.97abcde ±0.33	0.42cde ±0.01	0	0.42abcd ±0.01	1.21cd ±0.06	0.25ab ±0.1	
T5	5.65a ±0.02	7.04a ±0.02	2.71bcd ±0.39	4.53bcde ±0.3	0.37de ±0.02	0	0.37bcd ±0.02	1.21cd ±0.05	0.099ab ±0.07	
T6	5.67a ±0.01	6.95a ±0.003	3.87ab ±0.39	3.73e ±0.47	0.42cde ±0.02	0	0.42abcd ±0.02	1.07de ±0.04	0.115ab ±0.098	
T7	3.62g ±0.02	4.54h ±0.09	2.32cd ±1	6.9ab ±0.42	1.17a ±0.01	0.86a ±0.02	0.3d ±0.03	0.62f ±0.04	0.045b ±0.04	
T8	4.21f ±0.02	6.04fg ±0.04	3.09bc ±0.39	6.17abcde ±0.19	0.57b ±0.03	0.22b ±0.01	0.35bcd ±0.02	0.58f ±0.03	0.066ab ±0.05	
T9	4.40ef ±0.09	6.27ef ±0.07	2.32cd ±1	6.73abc ±0.54	0.53bc ±0.03	0	0.53a ±0.03	0.73f ±0.01	0.09ab ±0.05	
T10	4.75de ±0.02	6.56cd ±0.07	1.55d ±0.39	7.03a ±0.44	0.46bcde ±0.04	0	0.46abc ±0.04	0.71f ±0.07	0.16ab ±0.06	
T11	4.84cd ±0.05	6.61bcd ±0.06	3.09bc ±0.39	4.27de ±0.64	0.48bcd ±0.01	0	0.48ab ±0.01	0.73f ±0.03	0.041b ±0.04	
T12	5.05cd ±0.03	6.83abc ±0.09	2.36cd ±0.04	4.37cde ±0.48	0.47bcd ±0.03	0	0.47ab ±0.03	0.82ef ±0.03	0.12ab ±0.07	

Note: Different letter within a row indicate significant difference between the means of three replicates ± standard error using Turkey's test at $p \leq 0.05$.

Table 9. Water levels on selected chemical properties of soil with and without biochar

TRT	Total N	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable	Exchangeable
		NH ₄ ⁺	NO ₃ ⁻	Mg	Fe	Na	Ca	Cu	Mn
		.....%.....	..... mg kg ⁻¹.....	..... Cmol kg ⁻¹					
T1	0.39a±0.07	16.11de±0.7	6.30cd±1	0.69b±0.04	0.02bc±0.0002	0.623a±0.06	0.93e±0.05	7.56a±0.8	0.04bcd±0.002
T2	0.29ab±0.02	56.04bcde±3.31	5.37d±0.9	0.92a±0.04	0.012cd±0.0004	0.55ab±0.06	1.63cd±0.03	9.86a±0.56	0.056a±0.002
T3	0.25ab±0.04	90.6abc±3.5	6.77cd±0.23	0.92a±0.06	0.013cd±0.002	0.58a±0.02	1.87bcd±0.1	11.2a±0.82	0.043bcd±0.001
T4	0.28ab±0.05	113.9a±4.7	5.83cd±0.23	0.85ab±0.05	0.011cd±0.0004	0.52abc±0.03	2.04abc±0.1	9.02a±1.03	0.036d±0.003
T5	0.27ab±0.02	117.5a±3.8	9.57bcd±0.62	0.85ab±0.04	0.0096cd±0.002	0.65a±0.17	2.16ab±0.12	7.55a±0.96	0.043bcd±0.002
T6	0.2ab±0.04	113.2a±2.63	4.67d±0.47	0.96a±0.03	0.016bcd±0.003	0.4abcd±0.06	2.40a±0.17	8.71a±0.69	0.06a±0.001
T7	0.23ab±0.01	8.87e±1.68	6.07cd±0.47	0.39c±0.005	0.08a±0.004	0.26bcd±0.02	1.6d±0.08	8.71a±0.56	0.053ab±0.001
T8	0.16b±0.03	41.1cde±13.1	25.69a±2.23	0.414c±0.02	0.015bcd±0.002	0.23cd±0.03	1.7cd±0.11	9.13a±0.96	0.042bcd±0.003
T9	0.11b±0.03	50.2bcde±19.1	21.25a±1.17	0.39c±0.02	0.01cd±0.0005	0.24cd±0.01	1.67cd±0.03	10.39a±0.36	0.04d±0.002
T10	0.10b±0.02	83.6abc±15.1	12.61b±2.02	0.36c±0.005	0.01d±0.0005	0.18d±0.01	1.78bcd±0.01	8.60a±0.46	0.04cd±0.003
T11	0.14b±1	96.9ab±16.77	5.18d±0.66	0.37c±0.03	0.009d±0.0004	0.23cd±0.001	1.79bcd±0.05	9.76a±0.66	0.043bcd±0.002
T12	0.18b±0.06	64.91abcd±17.8	10.74bc±0.23	0.4c±0.007	0.02b±0.001	0.25bcd±0.02	2.01abcd±0.02	8.4a±0.56	0.052abc±0.002

Note: Different letter within a row indicate significant difference between the means of three replicates ± standard error using Turkey's test at $p \leq 0.05$.

4. Conclusion

There was no urea hydrolysis in the soil without water. Chicken litter biochar as soil amendment effectively mitigated ammonia loss at 1% to 32% and 80% to 115% field capacity. However, urea used on soil only showed lower ammonia loss at 33% to 79% and 116% to 125% field capacity compared with the soils with chicken litter biochar. At 50% field capacity, ammonia loss was high in soils with and without chicken litter biochar. Although chicken litter biochar is reputed for improving soil chemical properties, water levels in this present study affected soil chemical properties differently. Fifty percent field capacity, significantly reduced soil chemical properties. These findings suggest that timely application of urea at the right field capacity can mitigate ammonia emission. Therefore, whether soils are amended with or without chicken litter biochar, urea application should be avoided at 50% field capacity especially in irrigated crops.

Conflict of Interests

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

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