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Ammonia emission from sandy loam soil amended with manure compost and urea

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Abstract

Urea is a renowned nitrogen (N) fertilizer widely used in plant N nutrition owing to its high N concentration (46%). The effect of the N application rate on ammonia (NH_3) emission into the environment and soil properties is yet to be unraveled. The rate of NH_3 emission from sandy loam soil amended with manure compost (T1: 5000 kg ha^{-1}) and urea at different application rates (100, 200, and 400 kg N ha^{-1} designated as T2, T3, and T4, respectively) with 3 replications was evaluated in an incubation experiment. Ammonia emission was rapid at the early stage of the experiment followed by an equilibrium decrease that tends toward zero at the end of the incubation. Ammonia emissions of 16.50, 52.15, and 75% of applied N in T2, T3, and T4 were observed on day 49. Ammonia emission increased linearly ($y = 0.7823x - 32.169$, $R^2 = 0.95^{**}$) in response to N application rates. T1 conserves more NH_4^+ (20.79 mg kg^{-1}) in the soil, followed by T2 (11.8 mg kg^{-1}) and T3 (11.7 mg kg^{-1}). T2 and T3 reduced the soil pH to optimal for microbial activities and nutrient availability, while T4 promoted soil acidity. A balanced combination of compost and urea mitigates NH_3 volatilization and improves soil fertility. In conclusion, applying compost (5000 kg ha^{-1}) with urea at 100 kg N ha^{-1} or 200 kg N ha^{-1} is recommended for NH_3 volatilization mitigation, nitrification inhibition, and efficient NH_4^+ retention in the soil.

Keywords: Urea, Manure compost, Ammonia emission, Sandy loam soil

Introduction

The rapid soil nutrient degradation and the necessity to meet the world's growing population's nutritional needs resulted in the excessive use of chemical fertilizer. Volatilization of ammonia (NH_3) from mineral nitrogen (N) fertilizer accounts for 19–20% of the total NH_3 released into the atmosphere [45]. Generally, agriculture is reported to be responsible for 80–95% of total NH_3 emissions to the atmosphere [48] thereby, causing soil health problems and adverse effects on the environment. Besides, it causes eutrophication and acidification of the soil and water environment [39]. Ammonia emission into the atmosphere is the second source of N_2O, contributing to global warming and ozone depletion in the stratosphere [22]. Moreover, the application of a high dosage of urea to the soil gives rise to the emission of CO_2 coupled with NH_3 [10]. As earlier reported, N loss after the addition of urea may be more than 50% of applied N [36, 43]. Several basic factors that influence NH_3 volatilization are methods of fertilizer application, the cultivation system, soil type, soil pH as well as soil thermal and moisture conditions [25, 28]. Urea application methods are key factors that influence NH_3 emission either by increase or decrease. Urea granules are often broadcast on the soil surface or are introduced under the soil by an appropriate agrotech method. However, placing urea at the soil surface increases the risk of NH_3 volatilization. The implication of the co-application of compost and urea is an attempt to delay urea hydrolysis, which minimizes the formation of NH_3 and carbonic acid in the soil. Given the need to increase N use efficiency by crops and reduction of environmental impact, there is a search for strategies that allow an increase in the efficiency of the fertilization

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process. The use of compost is considered a promising strategy to improve N utilization. Compost is a value-added product used in the farming system that could optimize N fertilizer usage whose demand is now on the increase worldwide. The production of compost using unwanted agricultural materials is a sustainable technology that improves plant nutrition and food security [20]. Over decades the addition of compost or manure has been reported to increase soil nutrient availability and increase crop yield [46]. However, there is a dearth of information on its combined use with urea in mitigating NH_3 volatilization. This study aims at providing (i) recommendations on the quantity of urea that should be added to the soil at the prevalent cropping period in summer to mitigate NH_3 volatilization and improve soil health. (ii) Developing a strategy that minimizes N loss via NH_3 volatilization using a fixed rate of compost in combination with different rates of urea. (iii) Estimating compost and urea's complementary effect on selected soil properties.

Materials and method

Soil sampling, preparation, and characterization

The soil used in this study was sampled at 15 cm depth from Miyang-myeon, Anseong-si (36° 58′N, 127°13′E), Gyeonggi-do, Republic of Korea. The soil samples were air-dried and screened through a 2 mm sieve in preparation for the initial soil characterization and incubation experiment. The soil textural class was determined by the hydrometer method [19]. The electrical conductivity and pH of the soil were measured at a ratio of 1:5 (soil to water) [38] using a pH and conductivity meter (Orion star A214 and A215, respectively). The total N was determined using the Kjeldahl method [6]. Exchangeable cations (K, Ca, and Mg) were extracted by 1 N ammonium acetate [26] and analyzed on inductively coupled plasma–optical emission spectrometry (ICP–OES). Available P was extracted following the Lancaster method [30] and analyzed on an ultraviolet–visible spectrophotometer (UV–VIS spectrophotometer). The soil organic matter was determined by the modified Walkley and black method [33].

Sources and characterization of the amendments

The urea (46% N) and compost are commercial products purchased from Namhae chemical, Yeosusandan -ro, Yeosu-si, Jeollanam-do, and Jugjubilyo Yesnalgeoleum Yuna, Seodond-daero, Samjuk -myeon, Anseong -si, Gyeonggi-do, Republic of Korea, respectively. The compost consisted of pig manure, poultry manure, cattle dung manure, sawdust, and microorganism product combined at 20, 20, 20, 38, and 2%, respectively. The compost was oven-dried at 60^0C for 24 h and allowed to cool down in a desiccator before grinding in preparation for analysis. The pH and the EC of the compost were measured in a ratio 1: 10 (compost: water) using a pH and conductivity meter, respectively. The total nitrogen content of the compost was determined using the Kjeldahl method (Bremmer et al. 1996). The organic matter content was estimated using the loss on ignition method [49], while the organic carbon content was estimated from the organic matter content by calculation (%TOC = OM/1.724).

Experimental setup and design

The incubation experiment was performed in the laboratory of Agricultural Chemistry, Hankyong National University, Anseong, at room temperature (25 ℃). The experiment was laid out in a complete randomized design consisting of 4 treatments with 3 replications. The compost was applied to all the samples at the rate of 1.92 g chamber^{-1} (equivalent to 5000 kg ha^{-1}). Urea was applied at different rates (83.6, 167.2, and 334.4) mg chamber^{-1}, these rates are equivalent to 100, 200, and 400 kg N ha^{-1}, respectively. Therefore, the treatments evaluated are as follows:

T1: 500 g soil + 5000 kg ha^{-1} compost.
T2: 500 g soil + 5000 kg ha^{-1} compost + 100 kg N ha^{-1}
T3: 500 g soil + 5000 kg ha^{-1} compost + 200 kg N ha^{-1}
T4: 500 g soil + 5000 kg ha^{-1} compost + 400 kg N ha^{-1}

In this study, T1 is the control, without urea. Compost was thoroughly mixed with soil (500 g) samples in all the treatments, T1 was brought to 60% field capacity with ordinary distilled water while the mixture of urea and distilled water was used to bring the rest treatments to 60% field capacity. Urea was dissolved in water before application into the soil to give room for even distribution of fertilizer and minimize N loss via NH_3 emission [8].

Ammonia volatilization measurements, soil analysis, and calculations

The dynamic chamber method was employed for NH_3 volatilization collection. The NH_3 collection device (Fig. 1) includes a soil incubating jar with an air inlet opening by the side to allow air exchange within the soil chamber. It also consisted of another jar that contained 30 mL of 0.05 mol/L H_2SO_4 for NH_3 gas trapping, this jar was stopped and fitted with an inlet and outlet pipe. The outlet pipe was connected to the airflow meter while the inlet pipe was connected to the soil chamber. The airflow meter was also connected to the vacuum pump. The basic principle behind the NH_3 volatilization collection device is for the vacuum to serve as a power source. Here, the NH_3 in the soil chamber is replaced by air while the evaporated air enters the absorption jar together with

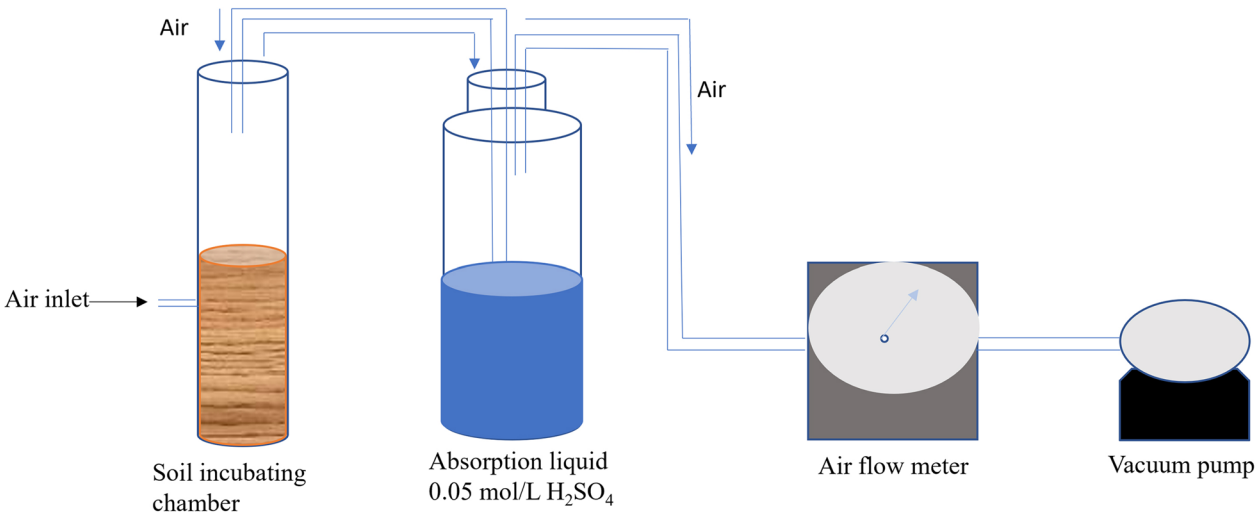

Fig. 1 Ammonia collection device

the pumping airflow. This device ensures aeration and traps NH_3 loss through the volatilization process. The NH_3 gas was sampled for one hour per sampling period with an airflow of 2 L min^{-1}. Ammonia volatilization was monitored consecutively for the first 5 days and continued every week till day 49 after treatment application. The gas trapped in 0.05 mol/L H_2SO_4 at each sampling time was analyzed calorimetrically on a UV-spectrophotometer using the nesslerization method. Briefly, an aliquot of 5 ml of the NH_3 trapped in 0.05 mol/L H_2SO_4 was pipetted into a test tube followed by the addition of 200µml of the ammonia color reagent (nesslerization reagent) [3]. The mixture was shaken vigorously on a vortex shaker and left for 15 min to enhance coloration at room temperature. Absorbance was thereafter read on a UV–VIS spectrophotometer at 425 nm. The NH_3 emission was calculated using the equation below, [41]

$$ER = Q\,(C_e - C_i)\,W_m T_{std} P_a \Big/ 10^6 V_m T_a P_{std} \times 10^3$$

Where, ER: emission rate (mg min^{-1}). Q: Air flow rate into the chamber (L min^{-1}). C_e: gas concentration of air leaving the chamber (mg kg^{-1}). C_i: gas concentration of air entering the chamber (mg kg^{-1}). W_m: Molecular weight of the gas (g mol^{-1}). V_m: molar volume at standard temperature (0 °C) and pressure (101.325 kPa), 22.4 l mol^{-1}. T_{std}: standard temperature, 273.15 K. T_a: temperature of the sample air, K (273.15 + sample air ℃). P_{std}: standard pressure, 101.325 kPa. $P_{a:}$ local barometric pressure, kPa.

At the termination of the incubation experiment, soil samples were collected from each chamber, prepared, and analyzed for soil pH, EC, and organic matter following the procedures mentioned above. Soil NH_4^+–N and NO_3^-–N were extracted by 2 M KCL and their concentrations were determined on UV–VIS spectrophotometer using indophenol-blue and brucine methods, respectively [51]. Thereafter NH_4^+ and NO_3^- were estimated by calculation.

Statistical analysis

The data obtained in this study were subjected to one-way analysis of variance (ANOVA) using Genstat10.3.00 software (VSN international limited) and means were separated by Duncan multiple range tests ($F \leq 0.05$).

Results

Experimental soil and compost characteristics

The selected properties of the soil and the compost are represented in Tables 1 and 2, respectively. The soil showed a sandy loam texture. It is alkaline in nature with a pH of 7.40, EC 0.4 dSm^{-1}, TN (0.08%), P (620.09 $mgkg^{-1}$), OM (11gkg^{-1}), 1.54, 2.60 and 1.50 $cmolkg^{-1}$ of K, Ca and Mg respectively (Table 1). The compost is also alkaline in nature (pH 7.36) with an EC level of 23.76 dSm^{-1} The compost has a high organic matter (623 gkg^{-1}), total carbon (361 gkg^{-1}), and TN concentration of 22 g kg^{-1} which resulted in a moderate C: N ratio (Table 2).

Ammonia volatilization

Daily ammonia (NH_3) volatilization from each treatment for 49 days of incubation is presented in Fig. 2a. Ammonia volatilization occurred rapidly at the inception of the experiment in each urea treatment. Ammonia emission was highest on day 4 in T2 while T3 and T4 peaked on

Table 1 Basic properties of the experimental soil

Parameter	Units	Values
pH (1:5)		7.40
EC	dSm^{-1}	0.42
TN	gkg^{-1}	0.80
P	$mgkg^{-1}$	620.09
OM	gkg^{-1}	11.00
NH_4^+	$mgkg^{-1}$	41.56
NO_3^-	$mgkg^{-1}$	449.80
K	$cmolkg^{-1}$	1.54
Ca	$cmolkg^{-1}$	2.60
Mg	$cmolkg^{-1}$	1.50
Textural class		Sandy loam

Table 2 Selected properties of the compost

Parameter	Units	Values
pH		7.36
EC	dSm^{-1}	23.76
OM	gkg^{-1}	623.00
TC	gkg^{-1}	361.00
TN	gkg^{-1}	22.00
C: N ratio		16.41

day 3. At the maximum level, the daily NH_3 volatilization measured was 0.6, 5.2, and 9.2 kg NH_3 ha^{-1} for T2, T3, and T4, respectively. However, Samples treated with compost alone (T1) showed no significant ($P < 0.05$) NH_3 loss until day 2 after treatment application with the maximum NH_3 loss (0.4 kg NH_3 ha^{-1}) on day 4. Compared to T4, T2 and T3 were observed to reduce NH_3 volatilization by 58.04% and 22.38%, respectively. Overall, active NH_3 volatilization in all treatments occurred between day 1 and day 14 followed by an equilibrium decrease that tends toward zero till the end of the incubation experiment (Fig. 2a).

Cumulative NH_3 emission increased steadily and peaked at day 7 in all the treatments. Cumulative emission amounts of 0.88, 2.45, 11.66, and 33.41 kg NH_3 ha^{-1} after 7 days were observed in T1, T2, T3, and T4, respectively (Fig. 2b). Overall, on day 49, the total amount of NH_3 emission (9.23 kg NH_3 ha^{-1}) was observed in soils treated with compost alone while, the total 16.50 kg NH_3 ha^{-1}, 104.3 kg NH_3 ha^{-1} and 298.12 kg NH_3 ha^{-1} were volatilized at the urea application rates of 100 kg N ha^{-1} (T2), 200 kg N ha^{-1} (T3), and 400 kg ha^{-1} (T2), respectively (Table 3). These values are equivalent to 16.50, 52.15, and 74.5% of applied N at the equivalent 100 kg N ha^{-1} (T2), 200 kg N ha^{-1} (T3), and 400 kg ha^{-1}(T4), respectively (Table 3). This showed that NH_3 loss was significantly minimized in T1, T2, and T3. As shown in Fig. 2c, NH_3 lost through volatilization increased markedly giving a linear equation ($y = 0.7823x - 32.169$, $R^2 = 0.95^{**}$), indicating that NH_3 emission increased with an increase in N application rate.

Soil $NH4^+$, NO_3^-, pH, EC, and organic matter.

The treatment effect on NH_4^+ was significant ($P < 0.001$) among treatments and highest in chambers with compost (20.79 mg kg^{-1}) followed by compost with urea treatments at 100 kg N kg^{-1} (11.8 mg kg^{-1}) and 200 kg N kg^{-1} (11.7 mg kg^{-1}). There was no significant ($P < 0.05$) difference between the NH_4^+ content of T2 and T3. The least values of NH_4^+ were recorded in soils treated with compost and urea at 400 kg N ha^{-1} (T4) (Fig. 3a). Conversely, on day 49, the NO_3^- concentrations in the soil across the treatments followed a reversed pattern compared to the observation in NH_4^+ concentrations. The concentrations of NO_3^- followed the order 400 kg N ha^{-1} > 200 kg N ha^{-1} > 100 kg N ha^{-1} > 0 kg N ha^{-1}. Soil available NO_3^- increased with an increase in N rate application (Fig. 3b). The effect of the sole application of compost and its combination with urea at different rates was highly significant ($P < 0.05$) on the soil pH and EC values of the soil at day 49. Soil treated with 400 kg N ha^{-1} had the least pH value (5.71) and highest EC (2.61dS m^{-1}) value while the soil treated with compost had the highest pH value (7.18) and least EC values (0.45 dS m^{-1}) (Fig. 4a and b). At the end of incubation, EC values of co-application of compost and urea treatment at 400 kg N ha^{-1} were found to be 36% greater than that of compost only, 24% greater than compost and urea at 100 kg N ha^{-1} and 13% greater than compost and urea at 200 kg N ha^{-1} (Fig. 4b). Moreover, NH_3 emission was proportional to an increment in EC level in all treatments while pH was inversely related to cumulative NH_3 emission after 49 days of incubation (Fig. 4a and b). Although, there was no significant ($P < 0.05$) difference in the mean values recorded in the OM content of compost treatment only (12.33 g kg^{-1}) and compost plus urea (12.24 g kg^{-1}) at 400 kg ha^{-1}, soil treated with compost and urea at 100 kg N ha^{-1} had the highest values (13.21 g kg^{-1}) followed by compost plus urea at 200 kg N ha^{-1} (12.77 g kg^{-1}) (Fig. 4c).

Discussion

The use of urea fertilizer is indispensable in the farming system; however, it has been suspected to be a potential contributor to the emission of NH_3 into the environment. Our study investigated the effect of compost and urea on NH_3 volatilization, soil pH, EC, NH_4^+, NO_3^-, and soil organic matter (SOM) at the prevalent cropping temperature (25 ℃) during summer. Ammonia volatilization

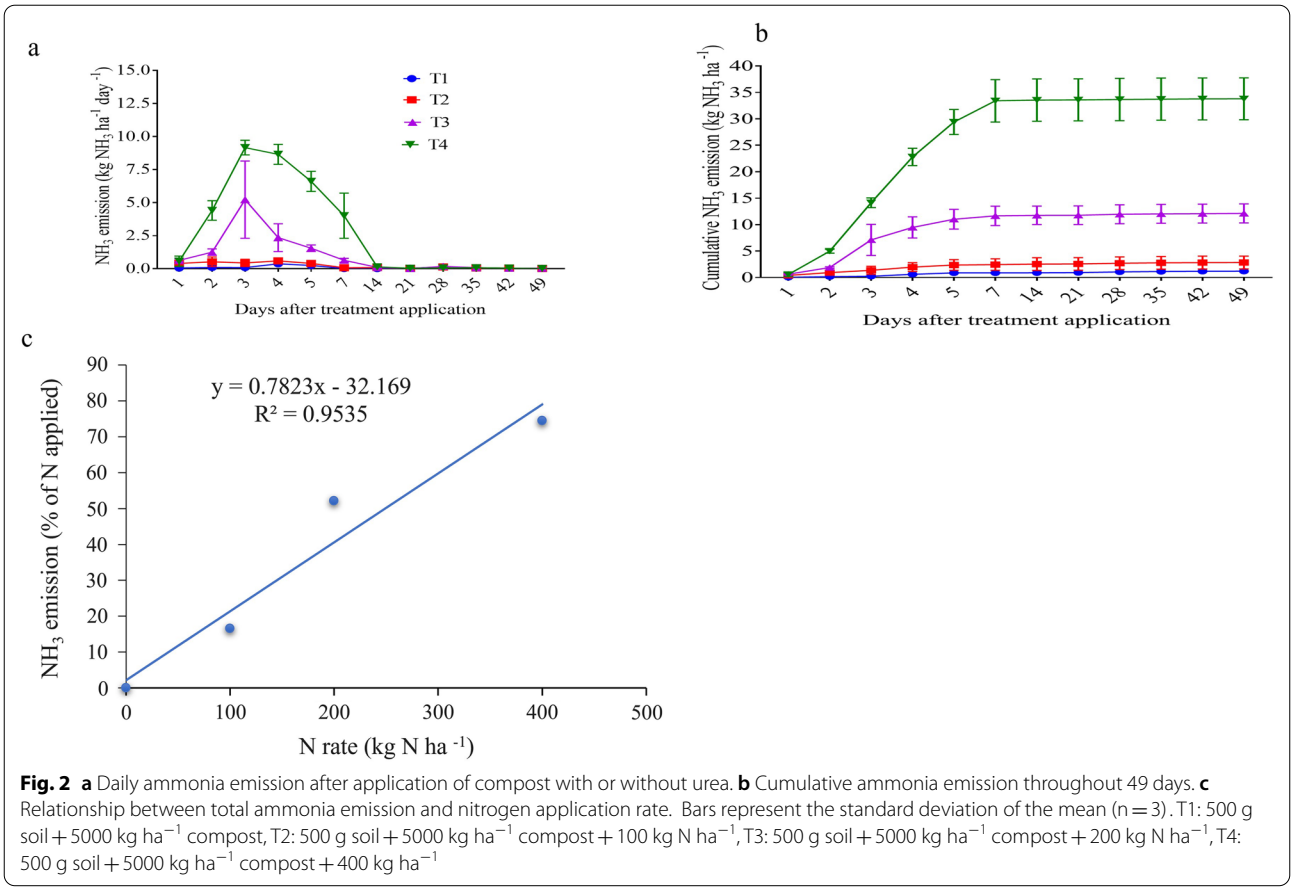

Fig. 2 **a** Daily ammonia emission after application of compost with or without urea. **b** Cumulative ammonia emission throughout 49 days. **c** Relationship between total ammonia emission and nitrogen application rate. Bars represent the standard deviation of the mean (n = 3). T1: 500 g soil + 5000 kg ha^{-1} compost, T2: 500 g soil + 5000 kg ha^{-1} compost + 100 kg N ha^{-1}, T3: 500 g soil + 5000 kg ha^{-1} compost + 200 kg N ha^{-1}, T4: 500 g soil + 5000 kg ha^{-1} compost + 400 kg ha^{-1}

Table 3 Rate of ammonia emission from the soil

Treatment	Amount of urea applied (kg N ha^{-1})	Total NH_3 emission (kg NH_3 ha^{-1})	Ammonia emission rate (% of N applied)
T1	0	9.23 ± 0.41^{d}	0
T2	100	16.50 ± 0.81^{c}	16.50
T3	200	104.3 ± 4.11^{b}	52.15
T4	400	298.12 ± 12.28^{a}	74.53

Mean values with different letters along the column differ statistically at $P < 0.05$. Data represent the mean (n = 3). The standard deviation of the means is shown in parentheses. T1: 500 g soil + 5000 kg ha^{-1} compost. T2: 500 g soil + 5000 kg ha^{-1} compost + 100 kg N ha^{-1}. T3: 500 g soil + 5000 kg ha^{-1} compost + 200 kg N ha^{-1}. T4: 500 g soil + 5000 kg ha^{-1} compost + 400 kg N ha^{-1}

was very rapid at the early stage of the experiment which indicated the hydrolysis reaction of dissolved urea with water to form ammonium ions (NH_4^+). This effect could be accrued to the intrinsic characteristics of urea which rapidly hydrolyses when applied to the soil as urease enzymes change the urea to carbonate [4]. Furthermore, our observation that active NH_3 emission among treatments occurs within the first 14 days after treatment addition attests to the fact that it takes a shorter period for urea to be hydrolyzed after application into the soil [34]. After the 14 days of active volatilization, there was equilibrium in the NH_3 volatilization rate which tends towards zero at the end of the experiment. This result corroborates the findings of Ferguson et al. [18] who reported stabilization in NH_3 volatilization after 12 to 16 days of fertilization addition. The retardation in the NH_3 emission rate toward the end of the incubation experiment could also be attributed to the gradual dryness of the soil surface resulting from aeration by the air pump as NH_3 emission loss decreases where there is insufficient soil moisture. Reduction in NH_3 volatilization due to insufficient soil moisture for chemical reactions has been reported by early researchers [8, 9, 37, 40].

The increase in NH_3 volatilization following the increase in the N rate observed in this study corroborates previous studies [11, 24]. The highest total NH_3 (298.12 kg N ha^{-1}) volatilized from T4 compared to other treatments suggests that the rate of urea application is one of the key factors that influence NH_3 volatilization. Besides, the alkalinity of the soil used in this experiment is a vital reason for 75% N loss in T4 as the

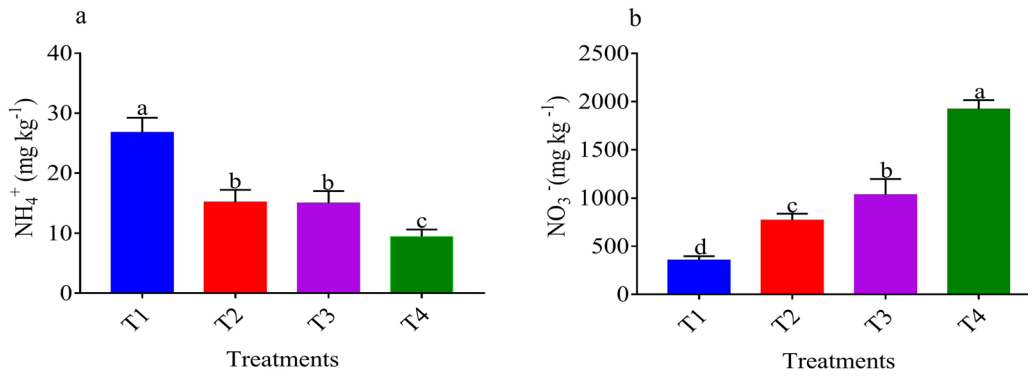

Fig. 3 Effect of compost application with or without urea on soil NH_4^+ (mg kg^{-1}) and NO_3^- (mg kg^{-1}) after 49 days of incubation. Bars with the same letters are not statistically different at $P < 0.05$. Bars represent the standard deviation of the mean (n = 3). T1: 500 g soil + 5000 kg ha^{-1} compost, T2: 500 g soil + 5000 kg ha^{-1} compost + 100 kg N ha^{-1}, T3: 500 g soil + 5000 kg ha^{-1} compost + 200 kg N ha^{-1}, T4: 500 g soil + 5000 kg ha^{-1} compost + 400 kg ha^{-1}

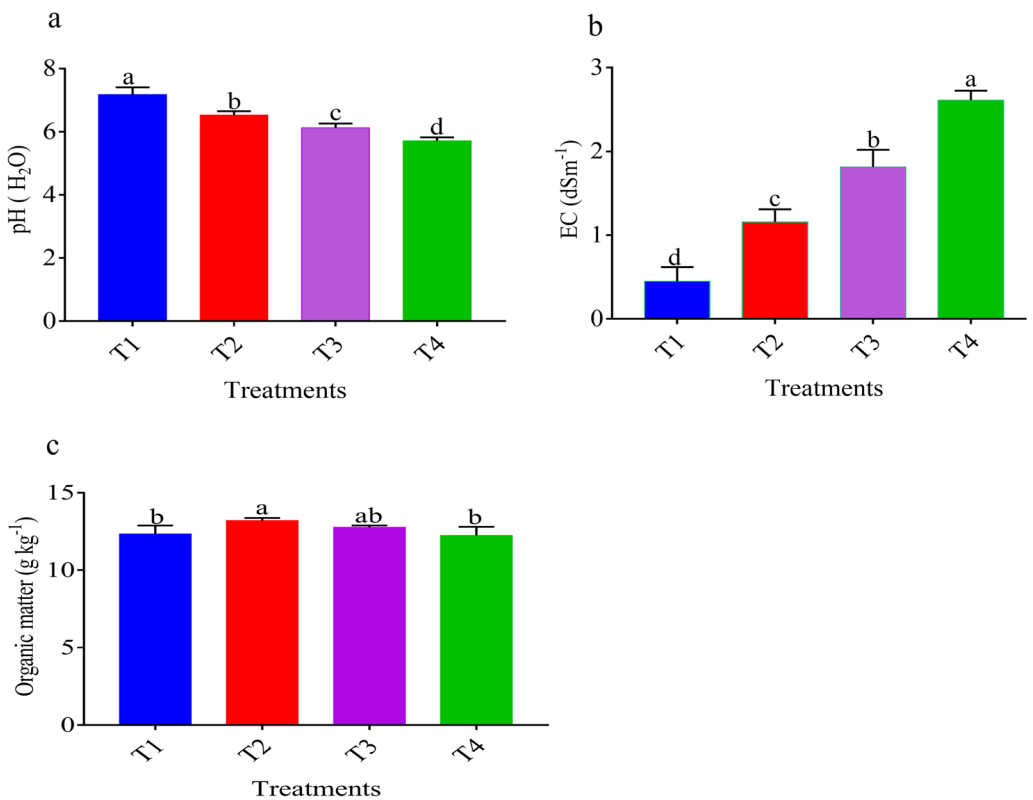

Fig. 4 Effect of compost application with or without urea on soil **a** pH **b** electrical conductivity (dSm^{-1}) and **c** organic matter content after 49 days of incubation. Bars with the same letters are not statistically different at $P < 0.05$. Bars represent the standard deviation of the mean (n = 3). T1: 500 g soil + 5000 kg ha^{-1} compost, T2: 500 g soil + 5000 kg ha^{-1} compost + 100 kg N ha^{-1}, T3: 500 g soil + 5000 kg ha^{-1} compost + 200 kg N ha^{-1}, T4: 500 g soil + 5000 kg ha^{-1} compost + 400 kg ha^{-1}

addition of urea changes the soil pH of the soil at the initial stage of application, therefore, aggravating the rate of hydrolysis thus increasing NH_3 emission into the atmosphere. This high N loss (75%) is inconsistent with most of the previous reports either in the laboratory (56% at 15 kg N ha^{-1}) [12], greenhouse (58% at 55 kg N ha^{-1}) [17] and field trial (47% at 56 kg N ha^{-1}) [14]. The discrepancy could be explained by the differences in the initial

soil pH, soil structure, soil buffer capacity, and the rate of N application. Although our study did not monitor the changes in pH across the incubation period, however, the pH of alkaline soil has been reported to be higher at the initial stage of N addition [42]. It is therefore evident that alkaline soil is likely to lose a larger percentage of N applied especially when N is added at a high rate such as 400 kg N ha^{-1}. Additionally, the highest NH_3 emission in T4 implies poor retention of NH_4^+ after hydrolysis thus escaping into the atmosphere. The effect of compost in delaying the emission of NH_3 in T2 and T3 was apparent compared to T4, as the NH_3 emission was observed to be low in T2 and T3 at the inception of the experiment. The Lower NH_3 emission rate in T1, T2, and T3 results from the effect of compost on the slow release of hydrolysable N from the organic matter of the compost [34]. Similarly, the reduced total emission observed in T2 and T3 could also be attributed to the ability of compost to adsorb NH_4^+ to its surface. Additionally, the porous and irregular morphological surface and large interface of the compost that serves as bio adsorbents for NH_4^+ adsorption could also account for the lower emission rate in T2 and T3. Jauberthies et al. [21] reported earlier that organic amendments' chemical composition is vital as they reflected organic fibers with a high external surface area which has the ability for NH_4^+ adsorption. Generally, one wouldn't have expected NH_3 volatilization from the control chambers (T1), however, the least total ammonia emission observed in the control chamber indicates that the organic matter (OM) in both the soil and the compost could contribute to NH_3 volatilization. Besides, ureolytic enzymes in compost could also trigger NH_3 volatilization [50]. In this study, the percentage of N loss increases with an increase in the application rate of the N fertilizer. This finding is supported by the report of Fan et al. [15] who observed NH_3 emissions increase to be proportionate with an increase in N applied. The amount of volatilization showed a positive relationship with the N application rate [27]. This confirms that it is not beneficial and cost-effective when urea is added to the crop beyond the recommendation rate. It should therefore be emphasized that the application of compost and urea should be at a recommended rate for effective N-use efficiency and sustainable agriculture.

Furthermore, among all the soil properties (such as SOM, pH, cation exchange capacity (CEC), and soil texture: [1, 16, 18, 35, 47] reported affecting NH_3 volatilization from the soil after urea application, non-appear to dominate or have consistent control on NH_3 volatilization from the soil [44]. Post-soil analysis was performed on day 49 to investigate the effect of urea on selected soil properties after the initial increase in soil pH following the application of N-based fertilizer into the soil. For example, on day 49, the soil pH in all the treatments decreases as the EC level increases. This implies that a higher amount of hydrogen ions in the soil enhanced the higher content of soluble salt which thus leads to a higher level of soil electrical conductivity (EC). Mohd-Aizat et al. [32] and Bruckner [7] also observed lower soil pH as an indication of a large number of hydrogen ions in the soil and vice versa. Electrical conductivity increases as does the cumulative NH_3 volatilization while pH decreases as cumulative NH_3 volatilization increase across all treatments. The decreased pH values observed in all the treatment at day 49 does not negate the report of previous studies on increase in pH after urea addition into the soil [29]. It should be noted that a temporary increase in pH usually occurs immediately after urea addition and decreases with time. In a study performed by Kim et al. [23], NH_3 emission increased immediately after fertilizer application, peaked on day 7, and later decrease gradually over time. The rapid increase in soil pH following urea addition is described as a universal phenomenon that occurs in all urea-treated soil after which the pH decreases with time either via infiltration or nitrification process. Generally, soil pH plays an important role in nutrient availability and nutrient adsorption that usually enhances the photosynthesis process thus increasing plant growth and yield [13]. However, many reactions influence soil pH following urea addition to the soil. Immediately after the addition of urea into the soil, the pH around urea granules tends to increase above 8 which thus increases the formation of carbonate [2]. Additionally, changes in soil pH during urea hydrolysis could also trigger the conversion of NH_4^+ to NH_3 thus leading to an increase in NH_3 emission [25]. The reduction in pH level in T4 is an indication that the application of urea at a high rate could lead to soil acidification and metal toxicity thus reducing the soil fertility which in turn affects the productivity of the soil. As soil pH level is an important factor controlling nutrient availability and microbial activities in the soil, however, this effect varies with soil types. At the end of the incubation experiment, T2 and T3 brought the pH of the soil near the optimal pH for nutrient availability, crop tolerance, and soil microbial activity. The nitrification process results in the oxidation of ammonium to nitrate instigating the release of proton thus reducing the pH value of the soil [5]. The reduction in the NH_4^+ concentrations of the soil on day 49 coincides with the increase in the soil available NO_3^-. Our study showed that most of the organic N from T1, T2, and T3 respectively, were in NH_4^+ form which will continue to be mineralized and available for plant use. However, if not taken up by the plant and not properly held by the soil exchange site it can be leached as NO_3^- or denitrified [31]. Moreover, an increase in SOM is known

to reduce NH_3 volatilization, however, our observation of OM content among treatments in this study is negligible. Although the effect of SOM on NH_3 volatilization is negligible, the soil pH across all the treatments decreased near the optimal level for nutrient availability and microbial activities except in T4 where pH was found acidic. This effect may be attributed to the formation of various organic acids and humus during the decomposition of OM. In addition, OM, soil texture, $CaCO_3$, and total salt content can be considered complementary while pH and CEC as essential soil properties that affect NH_3 volatilization following the addition of N-based fertilizer [52]. In a study performed by Zhenghu and Honglang [52] soil CEC, OM, and clay content were found to be negatively correlated with NH_3 volatilization which implies their ability to inhibit NH_3 volatilization. Similarly, in our study SOM recorded in T2 and T3 was higher compared to T4 where the highest NH_3 volatilization was observed. This effect could be attributed to the improvement in soil texture following the addition of manure compost and urea. The soil clay content enhances the absorption of NH_4^+ and NH_3, simultaneously reducing the concentration of NH_4^+ in the soil solution and N loss via NH_3 volatilization [52]. The acidic nature of T4 on day 49 confirms the fact that a higher rate of urea addition to the soil is detrimental to the soil and its organisms. Therefore, adequate application of organic manure combined with urea could mitigate NH_3 volatilization and improve soil fertility and productivity.

Abbreviations

N: Nitrogen; TOC: Total organic carbon; OM: Organic matter; EC: Electrical conductivity; C: N: Carbon to nitrogen ratio; SOM: Soil organic matter; CEC: Cation exchange capacity; ICP–OES: Inductively coupled plasma–optical emission spectrometry; UV–VIS: Ultraviolet–visible spectrophotometer.

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Author contributions

ATO: conceptualization, performance of the experiment, data formal analysis and curation, and writing of the manuscript, MT-I: data collection, KH-W: funding acquisition, conceptualization, investigation, data formal analysis and curation, and writing-reviewing. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used during this study and any other important information are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare no competing interests.

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