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Research Article

Acidification and Biochar Effect on Ammonia Emission and Nitrogen Use Efficiency of Pig Slurry in the Vegetative Growth of Maize (*Zea mays* L.)

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ABSTRACT

The objective of this study was to verify the effect of pig slurry application with acidification and biochar on feed value, nitrogen use efficiency (NUE) of maize forage, and ammonia (NH_3) emission. The four treatments were applied: 1) non-pig slurry (only water as a control, C), 2) only pig slurry application (P), 3) acidified pig slurry application (AP), 4) acidified pig slurry application with biochar (APB). The pig slurry and biochar were applied at a rate of 150 kg N ha^{-1} and 300 kg ha^{-1}, respectively. The AP and APB treatments enhanced all feed values compared to C and P treatments. The NUE for plant N was significantly increased 92.1% by AP and APB treatment, respectively, compared to the P treatment. On the other hand, feed values were not significantly different between AP and APB treatments. The acidification treatment with/without biochar significantly mitigated NH_3 emission compared to the P treatment. The cumulative NH_3 emission throughout the period of measurement decreased by 71.4% and 74.8% in the AP and APB treatments. Also, APB treatment reduced ammonia emission by 11.9% compared to AP treatment. The present study clearly showed that acidification and biochar can reduce ammonia emission from pig slurry application, and pig slurry application with acidification and biochar exhibited potential effects in feed value, NUE, and reducing N losses from pig slurry application through reduction of NH_3 emission.

(Key words: Ammonia emission, Biochar, Feed value, Maize, Nitrogen use efficiency, Pig slurry)

Ⅰ. INTRODUCTION

As demand for pork increases constantly, Korean pork production has increased on an intensive scale over the past few decades. The manure generated in pig production accounts for 38.2% of total livestock manure emissions (MAFRA, 2013). Pig slurry (PS) has less organic matter compared to other manures (Ndayegamiye and Côté, 1989). On the other hand, it has a positive effect on improving the soil quality, regarding inorganic fertilizer (Bernal et al., 1992). However, the pig slurry application can cause environmental problems that provoke negative environmental impacts. These environmental impacts are largely due to aerial emission of hazardous gases from PS including odor compounds, ammonia (NH_3), greenhouse gases like methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), and particulate matter (PM) (Bittman and Mikkelsen, 2009). Among these environmental problem gases, NH_3 has become the main problem for the environmental and residential welfare of livestock animals and humans who live in the marginal area of livestock farms. NH_3 in the atmosphere will be transported with the wind and may redeposited in previously clean areas hundred miles from the original source of NH_3 (Bittman and Mikkelsen, 2009). NH_3 in the soil can be converted to nitrate (NO_3^-), with an accompanying release of acidity (H^+) during nitrification that can lead to eutrophication and acidification of water and soil (Koerkamp et al., 1998). Also, NH_3 is a typical reason for offensive odors, thereby creating an odor nuisance in the surrounding communities.

Many strategies have been applied to reduce the NH_3 emission in livestock production. The control of feeding reduces the nitrogen (N) excretion that causes NH_3 and N_2O emission and NO_3^- leaching. The dietary crude proteins supplemented with synthetic amino acids can reduce N excretion in pigs and poultry (Jongbloed et al., 1975; Nahm, 2002). When manure is applied by spreading, almost NH_3 can be volatilized within a few days of application. Direct injection

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of manure slurry into the soil is an effective way to reduce N loss via NH_3 and N_2O emissions. When PS is injected, the total NH_3 emission was 40% lower than broadcasting application (Park et al., 2018a). Rotz (2004) reported that NH_3 loss is less than 5% when slurry was injected and covered by soil. Slurry acidification is one of the approaches to reduce the NH_3. The NH_3 volatilization occurs when ammonium (NH_4^+) is converted to gas under high pH level conditions. The positive effects of manure acidification in reducing NH_3 emission have been widely reported (Petersen et al., 2013; Fangueiro et al., 2015; Park et al., 2018b, Silva et al., 2022). In addition, porous materials such as charcoal, biochar, and zeolite can accommodate a wide variety of cations and high cation exchange capacity. The application of porous materials can absorb the NH_4^+ resulting in the reduction of N loss. The NH_3 emission from PS was reduced by 20% with zeolite (Choi et al., 2020) and 22% with charcoal (Lee et al., 2021).

Thus, this study aimed to evaluate the effects of PS acidification and biochar on nitrogen use efficiency (NUE), forage yield, feed value of maize, and NH_3 emission.

Ⅱ. Materials and Methods

1. Experiment design

The field experiment was conducted at Chonnam National University, located in Gwangju, South Korea from 3rd May 2021 to 8th June 2021. Gwang-Myeong maize for feed was used in this experiment for the forage crops. Forage maize (Gwang-Myeong) was planted on 3rd May in randomized complete block design with three replications; each treatment field size was 2 m × 10 m. The experiment was allocated with four treatments; control (non-PS application, only water, C), only PS application (P), acidified PS (AP), acidified PS with biochar (APB). The PS used in this experiment was collected from the manure treatment facility (Namwon, Korea). The PS was separated into liquid and solid, and only liquid PS was used in this study. The characteristics of PS were the same of the previous study (Lee et al., 2021). The PS was acidified by slowly (to avoid foaming) adding 1.5 M sulfuric acid until pH 5.5 was reached. Biochar used in this study was rice hull biochar collected from Flower Gardening Co. (Changwon, Korea).

2. Plant growth and harvest

The maize seeding was performed in lines keeping maize to maize distance 20 cm of seed spacing and 75 cm of row spacing. The PS (without or with biochar or acidification) was applied before 1 week of seedling. The PS was applied in 150 kg N ha^{-1} and biochar was applied in 300 kg ha^{-1}. Harvesting of maize was conducted 38 days after seedling (23rd August). Seedling rate of maize was 25 kg ha^{-1}. Cutting height of maize was 3 cm from the soil. 7, 14, 21 and 28 days after seedling soil samples were collected for soil nitrogen analysis.

3. Ammonia emission sampling

To collect ammonia emission, acid trap method was used (Ndegwa et al., 2009). Chamber size was 6 L and each chamber was connected to the 30 mL tube containing 50 mM sulfuric acid for trapping the ammonia. Vacuum pump was connected to the chamber to pull air through the chambers. The ammonia traps flow at a rate of 0.5 L per minute for 24 h. The ammonia sampling was done at 17:00. The sampling was continued for 24 days until the ammonia emission ended.

4. Chemical analysis

After harvest, the samples were collected and dried at 60℃ for 48 hours in a dry oven for calculation of dry matter (DM) content. The dried samples were ground under the 1.0 mm and stored at 4 °C dark-dried storage room before analysis. The methods of Thiex et al. (2002) were used to analyze the crude protein (CP) of the samples. The CP was calculated by N content according to the assumption that protein contained 16% of N (CP = 6.25 × total N). Also, the method of Van Soest et al. (1991) was used to determine the neutral detergent fiber (NDF) and acid detergent fiber (ADF). The NDF was expressed free of residual ash and using heat stable α-amylase. Dry matter intake (DMI) and digestible dry matter (DDM) were calculated following equation: DMI (%) = 120 / NDF%, DDM (%) = 88.9 − (0.779 × ADF%), respectively. Also, total digestible nutrient (TDN) and relative feed value (RFV) were calculated by the equation described by Holland et al. (1990): TDN = 88.9 − 0.79 × ADF%, RFV = DDM% × DMI% / 1.29.

Total nitrogen of soil and sample was determined by digestion using the Kjeldahl method (Thiex et al., 2002).

Inorganic N, such as ammonium nitrogen and nitrate nitrogen, was extracted with 2 M KCl and the NH_4^+-N was determined by distillation in an alkaline medium (MgO), NO_3^--N was reduced by Devarda's alloy (Lee et al., 2017). NUE was calculated following equation: (plant nitrogen in pig slurry or pig slurry with charcoal applied pot – plant nitrogen in unfertilized control)/plant nitrogen in unfertilized control × 100. The concentration of NH_3 in the acid trap solution was determined by colorimetrical method by using Nessler's reagent (Krug et al., 1979) after microdiffusion in a Conway dish (Kim and Kim, 1996).

5. Statistical analysis

Variation analysis was conducted to assess the effects of acidification and biochar application with PS on NUE, feed value and NH_3 emission. To compare the means of replications among the treatments Duncan's multiple range tests were used. Unless otherwise stated, conclusions are based on mean differences, with the significant level set at $p<0.05$ by using SAS 9.1.3 software (SAS Institute, Cary, NC, USA).

Ⅲ. Results and Discussion

1. Soil nitrogen and plant nitrogen use efficiency

The content of total nitrogen, NH_4^+-N and NO_3^--N in soil for 28 days are shown in Table 1. The total nitrogen in soil was gradually decreased in all treatments during the experiment as the maize grew. After 7 days, the total nitrogen content was higher in PS treatment with or without acidification and biochar compared to C treatment. However, there is no significant difference between AP and APB treatments in total nitrogen content. The NH_4^+-N showed a similar pattern with total N in C treatment, However, in P, AP and APB treatment, the NH_4^+-N content increased until 21 days and then decreased gradually. At 28 days, the NH_4^+-N content of AP and APB treatment was higher than P treatment. It indicates that acidification treatment can contain nitrogen from PS to soil. Park et al. (2018b) reported that the acidification of pig slurry increased NH_4^+-N and N derived from PS urea-NH_4^+-N in the soil with progressing regrowth as nitrification occurred. Similar results were reported from laboratory incubation studies (Fangueiro et al., 2013; Fangueiro et al., 2015) and field experiments (Sørensen and Eriksen, 2009) that conducted the effect of acidification of pig and cattle slurry applied to various

Table 1. Changes in amount of total N, ammonium-N (NH_4^+-N), nitrate-N (NO_3^--N) and total inorganic N in the soils in non-pig slurry (water, C), only pig slurry (P), acidified pig slurry (AP) and acidified pig slurry with biochar (APB) applied plot for 38 days

Nitrogen	Treatment	Sampling period			
		Day 7	Day 14	Day 21	Day 28
Total N (g N kg^{-1})	C	0.47±0.02^{b}	0.37±0.02^{b}	0.26±0.05^{c}	0.14±0.04^{c}
	P	1.40±0.04^{a}	1.28±0.09^{a}	0.89±0.02^{a}	0.61±0.02^{a}
	AP	1.45±0.02^{a}	1.31±0.02^{a}	0.68±0.02^{b}	0.44±0.02^{b}
	APB	1.42±0.05^{a}	1.26±0.04^{a}	0.68±0.05^{b}	0.51±0.04^{ab}
NH4^{+}-N (mg N kg^{-1})	C	2.57±0.47^{c}	1.87±0.23^{d}	1.17±0.23^{c}	0.93±0.23^{c}
	P	31.97±0.62^{b}	38.97±0.47^{c}	44.57±0.47^{b}	40.83±0.47^{b}
	AP	33.60±0.70^{ab}	67.20±0.40^{b}	65.80±0.40^{a}	63.47±0.47^{a}
	APB	35.00±0.40^{a}	74.67±3.76^{a}	66.27±0.62^{a}	64.17±0.93^{a}
NO3^{-}N (mg N kg^{-1})	C	0.23±0.23^{c}	0.47±0.23^{c}	0.23±0.23^{d}	0.00±0.00^{d}
	P	0.93±0.23^{b}	1.63±0.23^{b}	3.27±0.23^{c}	6.07±0.62^{b}
	AP	0.47±0.23^{a}	3.03±0.47^{a}	4.20±0.40^{b}	4.43±0.47^{c}
	APB	0.93±0.23^{a}	3.27±0.23^{a}	5.13±0.23^{a}	7.47±0.23^{a}

The values are mean ± SE of three replicates.
Different letters in vertical row indicate significantly different at $p<0.05$ according to the Duncan's multiple range test.

soil types. The NO_3^--N content showed a nitrification effect of acidification and biochar. On day 28, the NO_3^--N content of APB was higher than the NO_3^--N content of AP for 41.1%. This also indicates that the biochar can increase nitrification ratio. In addition, biochar application significantly increased the plant N after harvest compared to C and P treatment (Table 2). The NUE for plant N was increased in AP and APB treatment compared to only PS treatment for 92.1%. Nottfige et al. (2005) reported that the wood ash with compound fertilizer increased the N, P and K contents of the maize leaf. These results indicated that biochar treatment enhanced plant N uptake.

2. Forage yield and feed value

Forage yield and feed value of each treatment are shown in Fig. 1. Forage DM yield was significantly increased by 3.6, 3.8, and 3.9 times in P, AP, and APB treatments compared to C, respectively (Fig. 1A). However, the DM content was not significantly different among P, AP, and APB treatments. These results were consistent with the results of Ginebra et al. (2022) which reported a potential effect of biochar as a fertilizer amendment. The CP content was higher in AP and APB treatments than non-acid. This result is related with the increased N content in soil and plant by acidification and/or biochar treatment (Tables 1 and 2). The DMI, DDM, TDN, and RFV showed a similar tendency with CP. All feed values of AP and APB were significantly high than other treatment. Husk and Major (2011) reported that ADF and NDF were decreased by 5.2% and 5.9% from biochar application, respectively. The NDF and ADF represent the compounds constituting cell membrane and low value are desired for feed value. Low ADF and NDF values result in high feed value like DMI, DDM, TDN, and RFV (Kaplan et al., 2016).

3. Ammonia emission

To use PS as a resource, the application of pig slurry as a fertilizer is good method. However, PS emits NH_3 gas into atmosphere and it provokes nitrogen loss from soil application. To solve this problem, rice hull biochar and acidification method were used for reducing NH_3 emission from PS application. The daily and cumulative NH_3 emission of each treatment were shown in Fig. 2. The NH_3 emission has not emitted in non-PS application treatment (Only water for control, C). However, the NH_3 emission was highest in the P treatment that emits 55.6 mg kg^{-1} during the experiment. Except for the water treatment as control, all treatments emitted NH_3 until 22 days. In AP treatment, the NH_3 emission was 15.9 mg kg^{-1} that decreased 71.4%, respectively, compared to P treatment. Also, in APB treatment, the NH_3 emission was 14.0 mg kg^{-1} that reduced 14.8% compared to P treatment. Biochar was also effected. Compared to AP treatment, APB treatment decreased 11.9%, respectively. These results indicate that acidification is great method for reducing NH_3 emission from PS application. Also, it indicates that biochar effects on NH_3 emission as well. There is a lot of studies that improve the effect of biochar at decreasing NH_3 during livestock manure fertilizer application or livestock manure composting. In addition, biochar is the good method for decreasing NH_3 mitigation during application (Chen et al., 2017). Also, Malińska et al. (2014) reported that the addition of biochar during sludge as an amendment composting can reduce NH_3 emission from 9.2 to 24.4%. Agyarko-Mintah et al. (2016) reported that biochar addition could improve nitrogen retention with decreasing NH_3 emission for 60% compared to non-poultry litter application. This involves that biochar can reduce NH_3 emission by using its physical or chemical characteristics.

Table 2. Nitrogen content and nitrogen use efficiency (NUE) for plant N in maize as affected by the non-pig slurry (water, C), only pig slurry (P), acidified pig slurry (AP) and acidified pig slurry with biochar (APB)

Maize	C	P	AP	APB
Nitrogen contents (%)	1.2±0.0^c	1.9±0.0^b	2.6±0.1^a	2.5±0.1^a
Nitrogen use efficiency$_N$*	0	63.17±7.1^b	121.92±11.0^a	121.34±10.4^a

The analysis of N content and NUE$_N$ was conducted after harvest (76 days).
The values are mean ± SE of three replicates.
Different letters in horizontal row indicate significantly different at $p<0.05$ according to the Duncan's multiple range test.

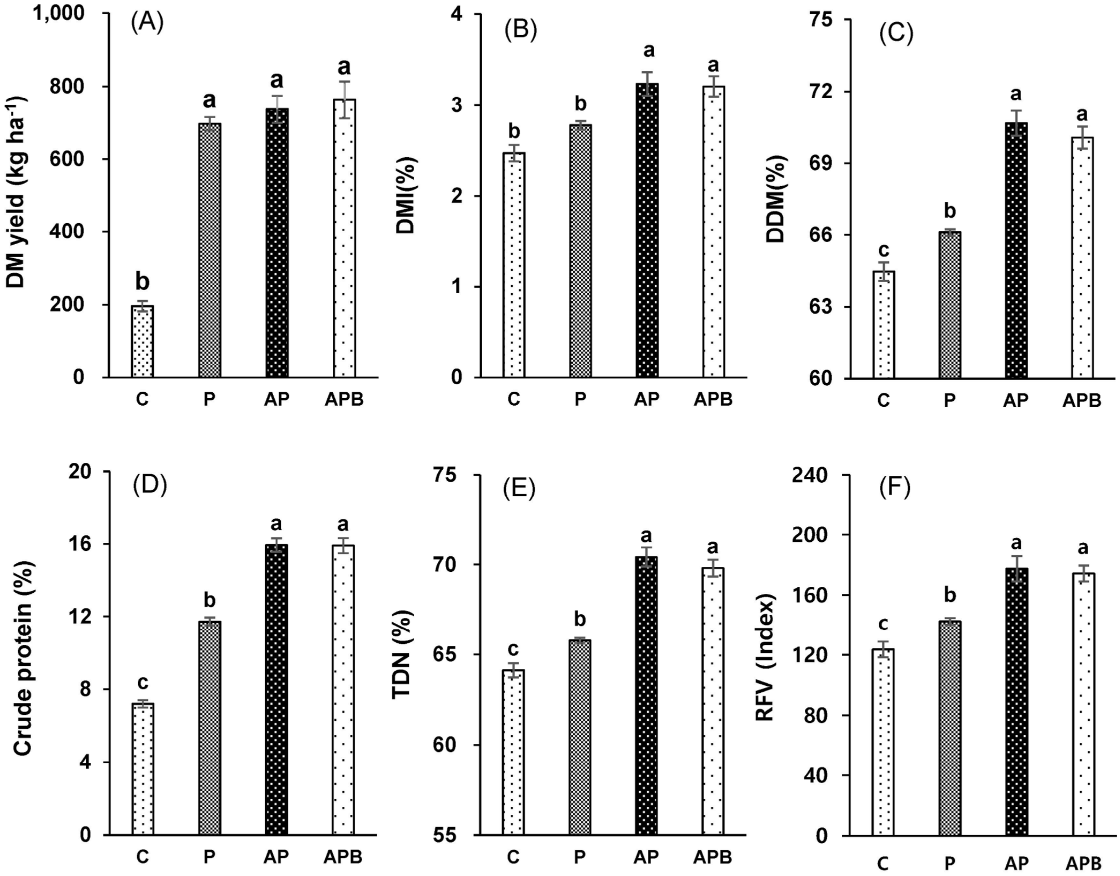

Fig. 1. The yield of dry matter (DM, A), dry matter intake (DMI, B), digestible dry matter (DDM, C), crude protein (CP, D), total digestible nutrient (TDN, E) and relative feed value (RFV, F) in maize as affected by the non-pig slurry (water, C), only pig slurry (P), acidified pig slurry (AP) and acidified pig slurry with biochar (APB). Data are presented as means ± SE (n = 3). Different letters indicate significantly different at $p<0.05$ according to the Duncan's multiple range test.

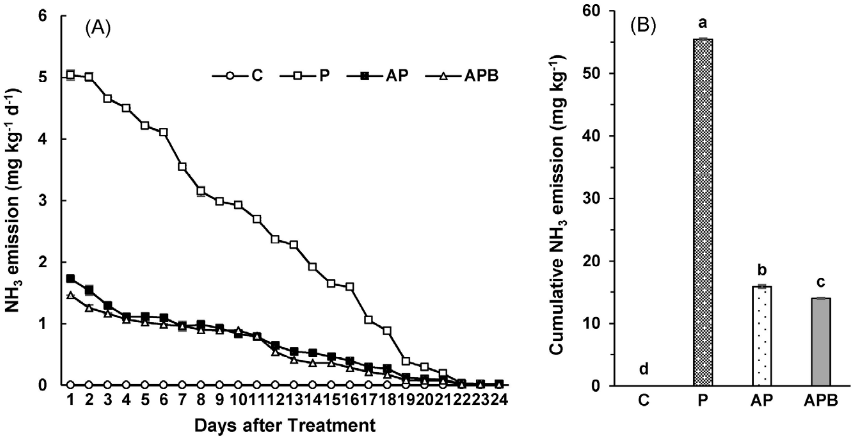

Fig. 2. The absolute ammonia emission and cumulative ammonia emission in the soils in non-pig slurry (water, C), only pig slurry (P), acidified pig slurry (AP) and acidified pig slurry with biochar (APB) applied plot for 24 days. Data are presented as means ± SE (n = 3). Different letters indicate significantly different at $p<0.05$ according to the

Duncan's multiple range test.

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