Journal of the Korean Society of Grassland and Forage Science 41(4): 280~286, 2021
https://doi.org/10.5333/KGFS.2021.41.4.280

ISSN 2287-5824 (Print)
ISSN 2287-5832 (Online)

Research Article

Effects of Charcoal Application 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 prove the effect of pig slurry application with charcoal on nitrogen use efficiency (NUE), feed value and ammonia (NH_3) emission from maize forage. The four treatments were applied: 1) non-pig slurry (only water as a control), 2) only pig slurry application (PS), 3) pig slurry application with large particle charcoal (LC), 4) pig slurry application with small particle charcoal (SC). The pig slurry was applied at a rate of 150 kg N ha^{-1}, and the charcoal was applied at a rate of 300 kg ha-1 regardless of the size. To determine the feed value of maize, crude protein, dry matter intake, digestible dry matter, total digestible nutrient, and relative feed value were investigated. All feed value was increased by charcoal treatment compared to water and PS treatment. Also, the NUE for plant N was significantly higher in charcoal treatments (LC and SC) compared to PS treatment. On the other hand, there is no significant difference for feed value and NUE between LC and SC. The NH_3 emission was significantly reduced 15.2% and 27.9% by LC and SC, respectively, compared to PS. Especially, SC significantly decreased NH_3 emission by 15% compared to LC. The present study clearly showed that charcoal application exhibited positive potential in nitrogen use efficiency, feed value and reducing N losses through NH_3 emission.

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

Ⅰ. INTRODUCTION

The scale of livestock breeding in South Korea continues to increase as meat consumption increases. The amount of pig slurry (PS) was increased from 4,370 million tons to 4,724 million tons in 5 years (Jang et al., 2018). PS emission accounts for 38.2% of the total quantity of manure generated from livestock production (MAFRA, 2010). PS has been utilized for a long time as a fertilizer for crops and is the most important organic resource (Ndayegamiye and Côté, 1989). PS contains nitrogen (N), phosphorus (P), potassium (K) and other nutrients like unknown growth factor, and these essential nutrients can be used to grow and develop plants. However, the application of PS as fertilizer accompanies environmental problems. The application of PS has the risk of atmospheric ammonia (NH_3) loss as the key important air pollutant contributing to an offensive odor, eutrophication of ecosystems, and the formation of secondary particulate matter. Also, volatilization of NH_3 results in N loss during pig slurry fertilizer application on field. When NH_3 is released into the atmosphere, it can react with acidic compounds to form particulate matter which can turn into a health-threatening substance (Bittman and Mikkelsen, 2009).

Many strategies have been suggested and evaluated for mitigating NH_3 emission. The NH_3 in manure volatilizes when ammonium-N (NH_4^+-N) is converted to gas under high pH level condition. The positive effects of manure acidification have been widely studied and recently reviewed (Birkmose and Vestergaard, 2013; Park et al., 2015; Neerackal et al., 2017; Cao et al., 2020). The PS spread is a general method of application in Korea. However, the spread application of PS occurs high volatilization of NH_3 from the surface of field. The injection of PS into soil efficiently prevents NH_3 volatilization. Park et al. (2018) reported that injection application of PS decreased total NH_3 emission by 40% compared to broadcasting application of PS. In addition, application of urease inhibitor (*N*-(-*n*-butyl) thiophosphoric triamide; NBPT) that can reduce ammonia emission from urea-based fertilizer with PS has decreased from 5.0 to 12.3% of total NH_3(Lasisi et al., 2020). Also, the application of zeolite with PS can reduce the NH_3 emission 20%, compared to PS only (Choi et al., 2020). The

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zeolite is the micro-porous crystalline mineral having a regular structure of pores and extra-framework cations that are commonly exchangeable (Inglezakis and Zorpas, 2012).

In this experiment, charcoal was used to mitigate the NH_3 emission. Charcoal also has a porous structure that can accommodate a variety of cations (Subedi et al., 2015). Due to its physio-chemical characteristics, charcoal shows potential as a treatment for composting and application. Charcoal application can absorb the NH_4^+ resulting in reduction of N loss also charcoal itself can be used as a carbon source. Also, if the size of the charcoal is small, the surface of the capturing site is wider that can collect more NH_3. Miles et al. (2020) reported that NH_3 emission was reduced small size of lignite coal and biochar from broiler litter. Therefore, this study aimed to investigate the effect of charcoal application and particle size of charcoal on maize productivity and mitigating of ammonia emission from pig slurry applied maize.

Ⅱ. Materials and Methods

1. Experiment design

The field experiment was conducted in at Chonnam National University, located in Gwangju, South Korea from 8th June 2021 to 23rd August 2021. The forage crops that used in this experiment was Gwang-Myeong maize for feed. The experiment was allocated with four treatments; control (non-pig slurry fertilizer, only water), PS, LC and SC. Pig slurry used in this experiment was collected from manure treatment facility (Namwon, Korea). Pig slurry was separated into solid and liquid, only liquid pig slurry was used in this study. The characteristics of pig slurry were shown in Table 1. Charcoal used in this experiment was oak charcoal collected from Yerang charcoal Co. (Yangsan, Korea). Charcoal divided into two size as large particle (3 - 6 mm) and small particle (< 3 mm).

2. Plant growth and harvest

Forage maize (Gwang-Myeong) was planted at 8th June in randomized complete block design with three replications; each treatment field size was 2 m × 10 m. The maize seeding was performed in lines keeping maize to maize distance 20 cm of seed spacing and 75 cm of row spacing. The pig slurry (without or with charcoal) was applied before 1 week of seedling. Pig slurry was applied in 150 kg N ha^{-1} and charcoal was applied in 300 kg ha^{-1}. Harvesting of maize was conducted 76 days after seedling (23rd August). Seedling rate of maize was 25 kg ha^{-1}. Cutting height of maize was 3 cm from the soil. 0, 14, 28 and 56 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 30ml tube containing 50mM sulfuric acid for trapping the ammonia. Vacuum pump was connected to the chamber to pull air through the chambers. The ammonia traps flow a rate of 0.5 L per minute for 24 h. The ammonia sampling was done at 5: 00 P.M. The sampling was continued for 51 days until the ammonia emission ends.

4. Chemical analysis

All harvested samples were collected and dried at 80°C for 48 hours in a dry oven for calculation of dry matter (DM) content. The dried samples were ground into powder undersize of 1.0 mm and stored at 4°C dark-dried storage room prior to analysis. The samples were analyzed for crude protein (CP) according to the methods of (Nancy et al., 2002). CP was calculated by N content according to the assumption that protein contained 16% of N (CP = 6.25 × total N). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by the method of Van Soest et al. (1991). 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 was determined by digestion using the Kjeldahl method. 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). Nitrogen use efficiency was calculated following equation:

Table 1. Chemical characteristics of the pig slurry

N fraction	Total N (g N kg^{-1})	NH_4^+-N (mg N kg^{-1})	NO_3^--N (mg N kg^{-1})
Pig slurry	1.48±0.06	175.0±14.0	0.47±0.23

The values are mean ± SE of five replicates
Total N: total nitrogen; NH_4^+-N: ammonium nitrogen; NO_3^--N: nitrate nitrogen.

(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

Analysis of variation was conducted to assess the effects of application on NH_3 emission and feed value. To compare the means of replications between 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 amount of total N, NH_4^+-N and NO_3^--N in soil of each treatment for 56 days are shown in Table 2. The total N in soil was gradually decreased in non-pig slurry treatment for the experiment period. However, PS with/without charcoal treatment increased the total N in soil for the first 14 days. After 14 days later, total N was decreased also in the PS treatment.

Table 2. 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), only pig slurry (PS), PS with large charcoal (LC) and PS with small charcoal (SC) applied plot for 56 days

Nitrogen	Treatment	Days after treatment			
		Day 0	Day 14	Day 28	Day 56
Total N (g N kg^{-1})	Water	1.9±0.1^b	1.1±0.1^b	1.0±0.0^b	0.7±0.1^b
	PS	1.0±0.1^a	1.6±0.1^a	1.2±0.1^a	0.9±0.1^a
	LC	1.0±0.1^a	1.8±0.1^a	0.9±0.1^b	0.6±0.1^b
	SC	1.1±0.0^a	1.8±0.1^a	1.0±0.1^b	0.7±0.1^b
NH_4^+-N (mg N kg^{-1})	Water	3.3±0.5^a	3.0±0.6^b	1.9±0.2^b	0.5±0.2^b
	PS	31.0±0.8^a	45.5±0.4^a	39.4±0.6^a	32.9±0.4^a
	LC	32.0±0.2^a	47.4±0.2^a	31.5±0.4^a	24.7±0.9^a
	SC	32.0±0.2^a	46.0±0.2^a	38.0±1.0^a	34.5±0.2^a
NO_3^--N (mg N kg^{-1})	Water	0.2±0.2^a	1.4±0.0^b	0.9±0.2^c	0.2±0.2^a
	PS	0.9±0.2^a	1.6±0.2^b	2.3±0.2^{ab}	1.2±0.2^a
	LC	0.5±0.5^a	4.0±0.2^a	2.6±0.2^a	0.7±0.4^a
	SC	0.2±0.2^a	4.4±0.2^a	1.6±0.2^{bc}	0.5±0.2^a
Inorganic N (mg N kg^{-1})	Water	3.5±0.4^a	4.4±0.6^c	2.8±0.4^b	0.7±0.4^c
	PS	32.0±0.9^a	47.1±0.6^b	41.8±0.6^a	34.1±0.5^a
	LC	32.4±0.6^a	51.3±0.2^a	34.1±0.5^a	25.4±1.3^{ab}
	SC	32.2±0.4^a	50.4±0.0^a	39.4±1.0^a	35.0±0.4^b

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.

Table 3. Nitrogen content and nitrogen use efficiency (NUE) for plant N in maize as affected by the non-pig slurry (water), only pig slurry (PS), PS with large charcoal (LC) and PS with small charcoal (SC)

Maize	Water	PS	LC	SC
Nitrogen contents (%)	1.26±0.06[c]	1.91±0.04[b]	2.24±0.16[a]	2.234±0.10[a]
NUE_N	0	34.41±4.0[b]	66.52±7.1[a]	59.13±6.0[a]

The analysis of N content and NUEN was conducted after harvest (76 d)
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.

Especially, PS application with charcoal significantly decreased the total N in soil compared to only PS application. Chen et al. (2010) reported that bamboo charcoal decreased Total Kjeldahl N loss from NH_3 volatilization by adsorbing NH_3 gas during pig manure composting. The inorganic N (NH_4^+-N + NO_3^--N) showed a similar pattern with total N. In addition, charcoal application significantly increased the plant N after harvest compared to water and PS treatment. However, there was no significant difference between charcoal size (Table 3). The NUE for plant N was increased in pig slurry with charcoal application compared to only PS. Nottfige et al. (2005) reported that the wood ash with compound fertilizer increased the maize leaf N, P and K contents. These results indicated that charcoal 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 higher in pig slurry

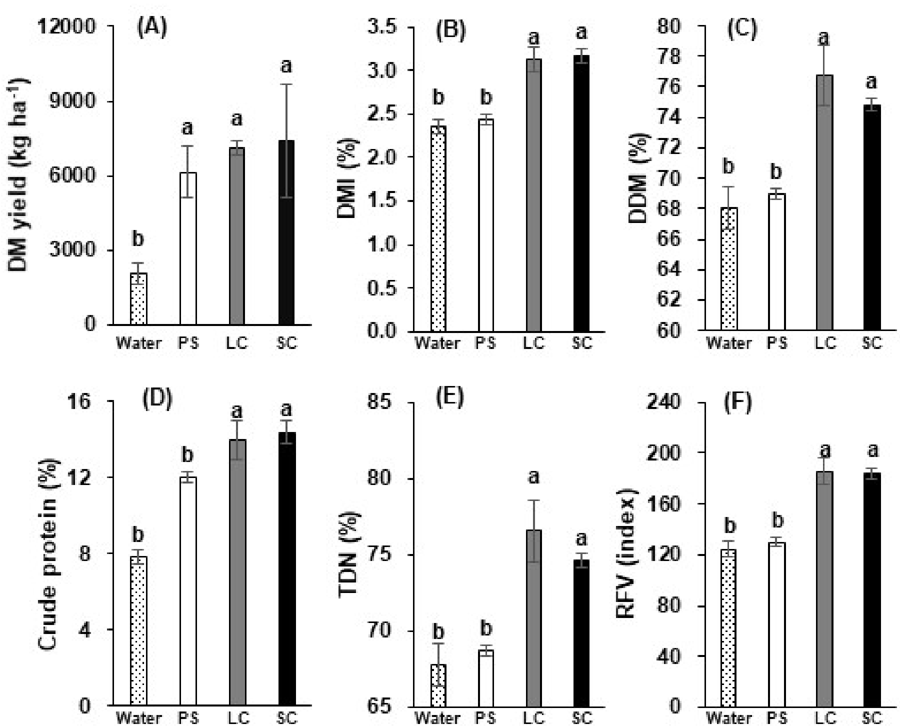

Fig. 1. The yield of dry matter (DM, A), dry matter intake (DMI, B), digestible dry matter (DDM, C), crude protein (CP, D), total digestible nutrient (TDN, E) and relative feed value (RFV, F) in maize as affected by the non-pig slurry (water), only pig slurry (PS), PS with large charcoal (LC) and PS with small charcoal (SC). 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.

and both charcoal treatment than control. Compared to non-fertilized control, DM content of PS, LC and SC treatment increased 200%, 248% and 261% (Fig. 1A). However, the DM content was not significantly different between PS and charcoal, also LC and SC. 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 both charcoal treatments than non-charcoal application treatments. This result related with the increased N content in soil and plant by charcoal treatment (Table 2, 3). The DMI, DDM, TDN, and RFV showed a similar tendency with CP. Husk and Major (2011) reported that NDF and ADF were decreased by 5.9% and 5.2% 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 DMI, DDM, TDN, and RFV (Kaplan et al., 2016).

3. Ammonia emission

The application of PS is a great method to recycle resources, however, it emits NH_3 gas and nitrogen loss. In this experiment, charcoal was effective at reducing NH_3 emission. The daily NH_3 emission of PS was shown in Fig. 2A. The NH3 emission has not occurred in non-PS treatment. However, the NH_3 emission was highest in the PS treatment and decreased significantly in the LC and SC treatments relative to the PS. In all treatments, the NH_3 emission occurred until 41 days then it was not emitted. Cumulative NH_3 emission throughout the period of the experiment decreased by 15.2% and 27.9% in the LC and SC treatments, respectively, compared to the PS treatment (Fig. 2B). In addition, the cumulative NH_3 emission was affected by charcoal size. The SC treatment significantly decreased cumulative NH_3 emission by 15% compared to LC. Similarly, several studies have reported that the absorption of biochar or charcoal can decrease the NH_3 emission. Pereira et al. (2020) reported that the addition of biochar and clinoptilolite can reduce ammonia emissions from 77 to 12%. Also, Ro et al. (2015) reported that the gas emissions by using the biochar are comparable to that of other commercial activated absorbent carbon and nature zeolite. Taken together, charcoal can reduce NH_3 emission by using its physio-chemical characteristics. Also, the smaller size of charcoal more efficiently decreases the NH_3 emission. The application of charcoal does not affect the quantity or feed value of maize but can be considered positively in terms of the environment.

Ⅳ. Acknowledgments

This study was financially supported by the National Research Foundation of South Korea (NRF-2019R1A6A3A01092319).

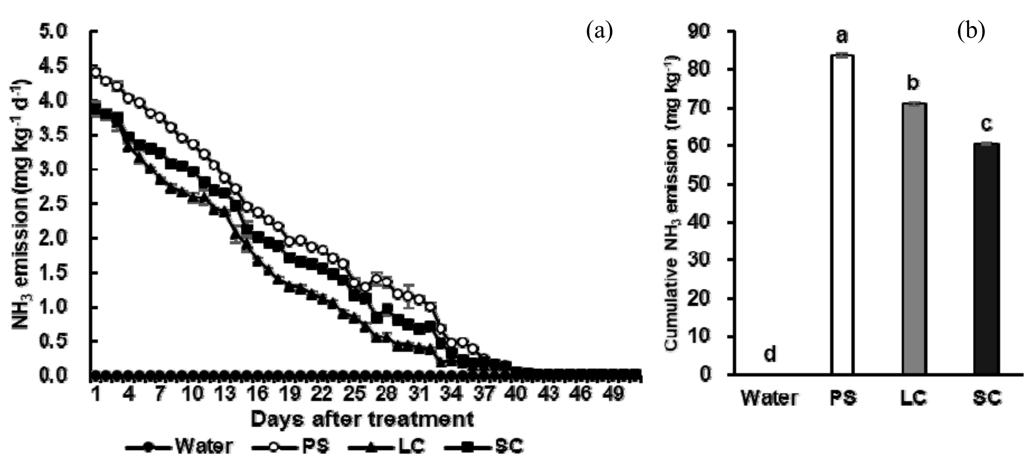

Fig. 2. The absolute ammonia emission and cumulative ammonia emission in the soils in non-pig slurry (water), only pig slurry (PS), PS with large charcoal (LC) and PS with small charcoal (SC) applied plot for 56 days. Data are presented as means ± SE (n=3). Different letters indicate significantly different at p 〈 0.05 according to the Duncan's multiple range test.

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(Received : November 29, 2021 | Revised : December 13, 2021 | Accepted : December 15, 2021)