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Research Article

Changes in Nitrogen Mineralization as Affected by Soil Temperature and Moisture

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ABSTRACT

Soil is the main nitrogen (N) provider for plants but N in soil is not all available to advanced plants. Mineralization is a critical biological process for transferring organic N to inorganic N that can be used by plants directly. To investigate the effect of different levels of soil temperature and water content to soil mineralization, a field experiment was established on three different sites (A, B and C). We measured soil temperature, moisture and electrical conductivity once daily after swine slurry application. Average soil moisture and temperature in site A is the highest among three sites (40.9% and 9.7°C, respectively). Following is in site C (37.3% and 9.6°C) and the lowest is in site B (28.0% and 9.0°C). Ammonium N (NH4+-N) and nitrate N (NO3--N) were determined on the first and fifth day after treatment. Compared with site B and C, site A always had the highest soil total N content (1.54 g N kg-1 on day one; 1.22 g N kg-1 on day five) and highest NO3-- N content (93.18 mg N kg-1 on day one; 16.22 mg N kg-1 on day five) and a significant decrease on day five. Content of NH4+-N in site B and C reduced while in site A, it increased by 6.7%. Results revealed that net N mineralization positively correlated with soil temperature (P<0.5, r=0.675*) and moisture (P<0.01, r=0.770**), suggesting that to some extent, higher soil moisture and temperature contribute more to inorganic N that can be used by plants.

(Key words : Microorganism, Mineralization, Soil moisture, Soil temperature, Swine slurry

Ⅰ. INTRODUCTION

Livestock manure, such as swine slurry, has been used for centuries as a fertilizer for farming. It is an important eco-friendly fertilizer containing nitrogen (N), phosphorus (P), potassium (K) and other nutrients. Swine slurry can be utilized as a viable resource of alternative organic fertilizer and accounted for more than 83% of recycled animal manure in Korea (Oh et al., 2009). The application of manure to soil improves soil physical and chemical quality as well as N nutrient for plant growth (Möller and Stinner, 2009). When manure is applied to land, a portion of the organic N is converted by soil microbes to ammonium (NH_4^+) and nitrate (NO_3^-) which are plant-available forms of N, while organic N cannot be utilized immediately by plant (Park et al., 2017). Several other forms of inorganic N have been proposed as intermediates during N mineralization in soil, but these compounds are thermodynamically unstable and have not been detected in soil (Mulvaney, 1996). Therefore, a better understanding on how the organic form N change to plants available N and its relevant factors are quite important to improve availability of N.

The process of soil N mineralization is a microbial transformation of organic N from manure, organic matter or crop residues to produce ammonium and nitrate which are plant-available form of N (Sullivan et al., 2003). The higher mineralization rate usually means more plant-available form of N. There are several factors which have been proved that could influence mineralization rate. Fangueiro et al. (2012) indicated that swine slurry resulted in a higher availability of mineral N in soil than dairy slurry. Some studies also pointed out that the rate of mineralization in soil depends upon its carbon:nitrogen (C:N) ratio (Azeez and Averbeke, 2010). However, some inorganic N may be lost through ammonia

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volatilization and immobilized by microorganisms during mineralization (Cabrera and Gordillo, 1995).

To our knowledge, because mineralization occurs by microbial activities, net mineralization rate has always been of great concern in past studies and also vary according to soil temperature and moisture. Some studies have shown that the net N mineralization rate was positively related to soil moisture (Zhang et al., 2008; Chen et al., 2012). Laboratory incubation experiment has been done by Li and Li (2014) who focus on the sensitivity of N mineralization to temperature and moisture by using disturbed soil samples. However, mineralization is more affected by various external factors in the field condition. Therefore, this study was focused on effect of soil temperature and moisture on soil net N mineralization after application of swine slurry under field condition.

Ⅱ. MATERIAL AND METHODS

1. Experimental design

This study was carried out on permanent grass sward, consisting mainly of perennial ryegrass (*Lolium perenne*) on a sandy loamy soil, which is located in the east-northern upland South of Korea (E127°14’, S35°12’). Three different sites A, B and C were chosen by various soil environmental condition which are covered by ryegrass (Table 1). For each experiment site, we chose 1 m^2 as experiment area and give 200 kg N ha^{-1} of swine slurry which was shown in Table 2. In this study the total nitrogen concentration of swine slurry was 0.07%. It was much lower compared with common swine slurry because it had been a long time after fermentation. After application of swine slurry, soil temperature, moisture and electrical conductivity (EC) were determined by WT1000B (RF sensor, Korea) every day.

2. Soil sampling

Three randomly positions were chosen to collect surface soil samples (50-150 mm) within 1.0 m^2 in the morning 09:00 at day 1 and 5 after application of swine slurry. After mixing and sieving to remove roots and stones, the soil samples were dried at 60 °C for ≥ 24 h and ground to 0.2 mm to measure total-N, ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N).

3. Chemical analysis

Total N of soil or swine slurry samples was determined by Kjeldahl digestion (Bremner, 1996). For NH_4^+-N and NO_3^--N determination, the samples were extracted with 250 mL of 2 M KCl. The extracts were put in a distillation flask and steam-distilled with magnesium oxide (MgO) for NH_4^+, the samples in flask then were distilled again after addition of Devarda’s alloy for NO_3^- determination. The liberated NH_3 was collected into boric acid ($H_3BO_3^-$) indicator solution (Keeney and Nelson, 1982). The concentration of NH_4^+-N and NO_3^--N was determined by titration with standard sulfuric acid (H_2SO_4), converted to kg N ha^{-1} using soil bulk density concurrently determined using soil core.

Table 1. Vegetation and physical properties of three sites.

Property	Site A	Site B	Site C
Plant height (cm)	3-4	5-9	10-30
Slope of site (º)	0	0	10
Illumination (h d^{-1})	8	4	7

Table 2. Nitrogen compounds of swine slurry

Sample	Total N (mg N kg^{-1})	NH_4^+ (mg N kg^{-1})	NO_3^- (mg N kg^{-1})	Organic N (mg N kg^{-1})
Swine slurry	730.24 ± 9.2	4.75 ± 0.3	77.51 ± 3.5	647.98 ± 11.1

Values are mean ± SE (n=3) of three replicates.

Net N mineralization was calculated as the difference between post- and pre- incubation inorganic N (NH_4^+-N + NO_3^--N) and net N mineralization rate (mg N kg^{-1} soil day^{-1}) was calculated by following equation where t is incubation time (Hood, 2003; Li et al., 2014).

Net N mineralization rate
$= [(NH_4^+ + NO_3^-)_{Dt} - (NH_4^+ + NO_3^-)_{D0}] / t$

4. Statistical analysis

Duncan's multiple range tests were used to compare the means of three replications between treatments. Unless otherwise stated, conclusions are based on differences between the means, with the significant level at $p \leq 0.05$ by using SAS 9.1.3 software.

Ⅲ. RESULTS AND DISCUSSION

The average soil moisture in site A, B and C were 40.9 %, 28.0% and 37.3%, while average temperature were 9.7 °C, 9.0 °C and 9.6 °C, respectively (Table 3). Even it showed some fluctuations within 6 days, the general trends of temperature and moisture in these three sites were A>C>B. In site A, the higher temperature and moisture of soil were due to the long time exposure to the sun. In addition, low-growing plants in site A could contribute to high temperature (Morecroft et al., 1998). Soil electrical conductivity (EC) which is the strong potential to estimate variations in soil particle size and texture (Grisso et al., 2005) presented highest in site A and not a significant difference in site B and C (Table 3).

After swine slurry application, compared with other two sites, site A tend to have the highest soil total N and nitrate N (NO_3^-- N) content (Fig. 1). At 5 days after the application of swine slurry, total N decreased 20.8%, 34.0% and 44.3% in site A, B and C, respectively. During N mineralization, nitrogen denitrification as N_2 and nitrous oxide (N_2O), volatilization as ammonia (NH_3), immobilization, or leaching by NO_3^- result in permanent or temporary N losses from the soil (Courtney et al., 2005). During 5 days, slight N mineralization is appeared as decrease of organic N (Fig.1B). These results were due to easily decomposable organic N which can be used by microorganism at the beginning time, as suggested by Khalil et al. (2005).

Inorganic nitrogen including ammonium (NH_4^+) and NO_3^- is plant-available N forms, while organic nitrogen can not immediately be used by plant. NO_3^--N largely decreased after the application of swine slurry, while NH_4^+-N had a slight decrease for 5 days in both site B and C (Fig. 1C and 1D). Myrold (1988) reported that NO_3^--N loss in winter is caused mainly by leaching. Compared with reduced NH_4^+-N in site B and C, the content of NH_4^+-N in site A obviously increased by 6.7% (Fig. 1). It potentially indicated that in site A, more soil organic N transferred to inorganic N, resulting in higher soil N mineralization rate. This was not consistent with Calderon et al. (2004) pointed out that cattle manure found the rapid decline of soil NH_4^+-N content in a short period after incubation. These contradictory results were because variable N of manure is highly depending on manure composition, appropriate timing and

Table 3. Changes of soil moisture, temperature and electrical conductivity (EC) in soils receiving swine slurry at the three different sites.

Date	Moisture (%)			Temperature (°C)			EC (dS m^{-1})		
	Site A	Site B	Site C	Site A	Site B	Site C	Site A	Site B	Site C
0	41.3±1.6[a]	25.8±1.7[c]	30.8±1.5[b]	7.0±0.5[a]	5.7±0.8[b]	8.0±0.8[a]	0.74±0.07[a]	0.27±0.05[c]	0.49±0.06[b]
1	44.1±3.6[a]	26.3±1.0[c]	36.5±2.1[b]	9.7±0.2[a]	9.5±0.5[a]	9.7±0.4[a]	0.89±0.05[a]	0.46±0.07[b]	0.59±0.07[b]
2	40.9±3.8[a]	30.3±4.0[b]	42.7±2.1[a]	10.4±1.2[a]	9.4±0.2[a]	10.0±0.4[a]	0.83±0.05[a]	0.44±0.08[b]	0.57±0.09[b]
3	41.8±3.2[a]	32.6±2.6[b]	41.8±1.2[a]	10.4±0.2[a]	9.7±0.2[a]	10.2±0.1[a]	0.85±0.06[a]	0.51±0.08[b]	0.52±0.08[b]
4	37.2±2.1[a]	27.5±1.4[b]	38.6±2.4[a]	9.6±0.4[a]	9.0±0.2[a]	9.7±0.1[a]	0.79±0.06[a]	0.49±0.12[b]	0.59±0.06[b]
5	39.9±5.9[a]	25.4±2.1[b]	33.6±3.2[ab]	11.1±0.5[a]	10.8±0.5[a]	10.8±0.2[a]	0.84±0.14[a]	0.49±0.09[b]	0.58±0.06[b]

Values are mean±SD (n=10). Different letters in column indicate significant difference at $p<0.05$ according to the Duncan's multiple range test.

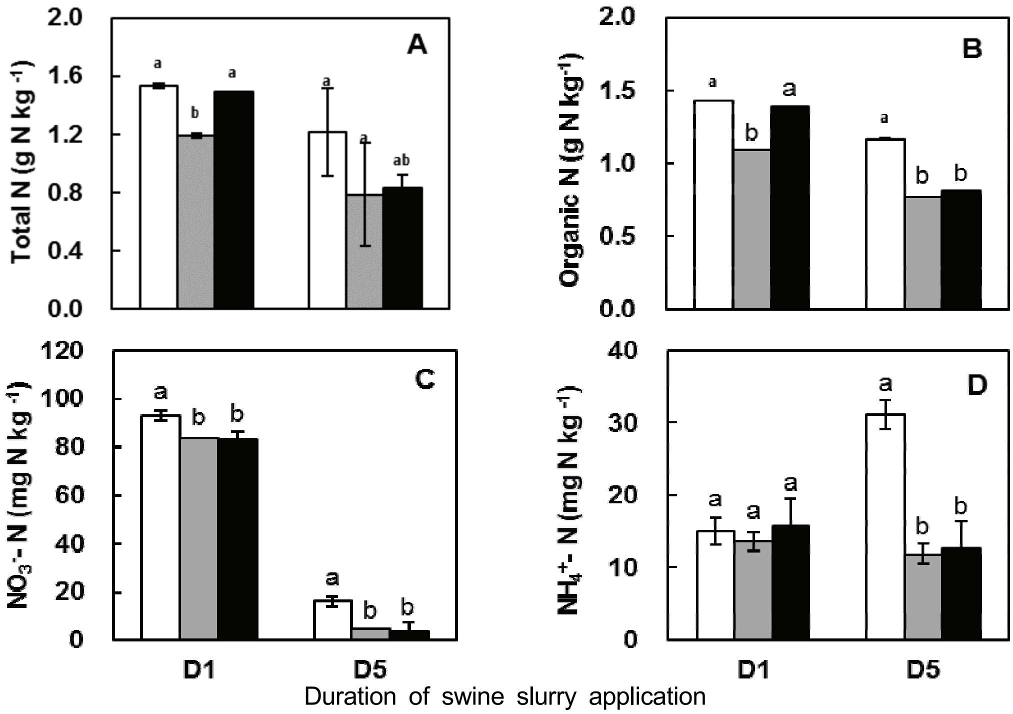

Fig. 1. Total nitrogen (A), organic nitrogen (B), nitrate nitrogen (C) and ammonium nitrogen (D) in soil after swine slurry application in site A (white), B (grey), and C (black) at day 1 (D1) and day 5 (D5). Data are mean ± SE (n=3). Bars marked with different letter were significantly different at $P < 0.05$ according to the Duncan's multiple range test.

method of application to plants (Mohanty et al., 2011). Previous studies have shown that the overuse of nitrogen fertilizer can result in reduced microbial biodiversity (Hallin et al., 2009; Seneviratne, 2009). Microorganisms prefer NH_4^+-N for their growth and utilize NO_3^--N when NH_4^+-N content is lower than 1 μg N g^{-1} soil (Gioacchini et al., 2007). In addition, the amount of plant-available N lost by denitrification is generally small relative to other process that effect available N (Eghball, 2000).

It is difficult to estimate the availability of soil nitrogen to plants due to the processes of immobilization and mineralization, as well as N losses. Microorganisms have a major impact on nitrogen cycle; participate in mineralization, nitrogen fixation, oxidation, nitrification and other processes which lead to decomposition of soil organic matter and transformation of nutrients (Amato and Ladd, 1994). Thus, soil temperature and moisture which highly cooperated with microbial activities are going to effect on soil mineralization as well.

In this study, moisture and temperature presented a significant correlation with soil N net mineralization (Fig. 3). The highest soil N net mineralization could be seen in site A due to the higher moisture and temperature (Fig. 2). Soil temperature and moisture were closely related with N net mineralization (Fig. 3). Similar result was reported that soil net N mineralization positively correlated with temperature (Tian et al., 2010).

These results clearly indicate that in field condition soil N net mineralization followed soil moisture and temperature levels, higher moisture and temperature have the capacity to contribute to higher soil N net mineralization and may lead to higher plant-available N content in soil which can be utilized in a short time by plant directly. For future works, the application of isotope ^{15}N will absolutely advance our understanding of N cycling in practical agricultural field.

Ⅳ. ACKNOWLEDGEMENTS

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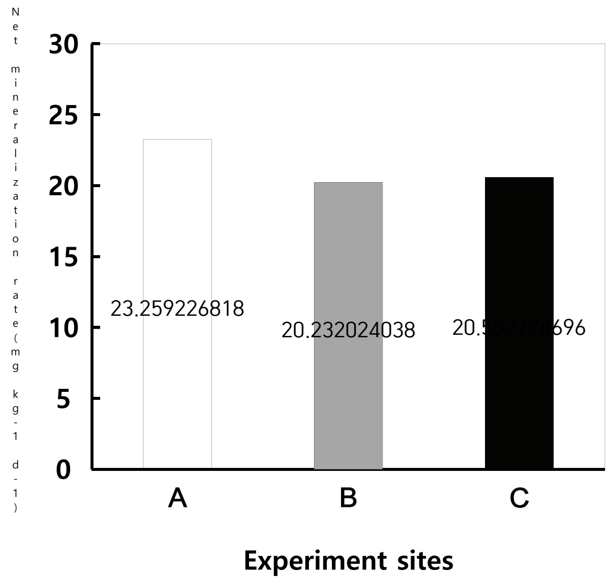

Fig. 2. Soil mineralization in site A (white), B (grey) and C (Black). Data are mean ± SE (n=3). Different letters indicate significantly different at $p < 0.05$ according to the Duncan's multiple range test.

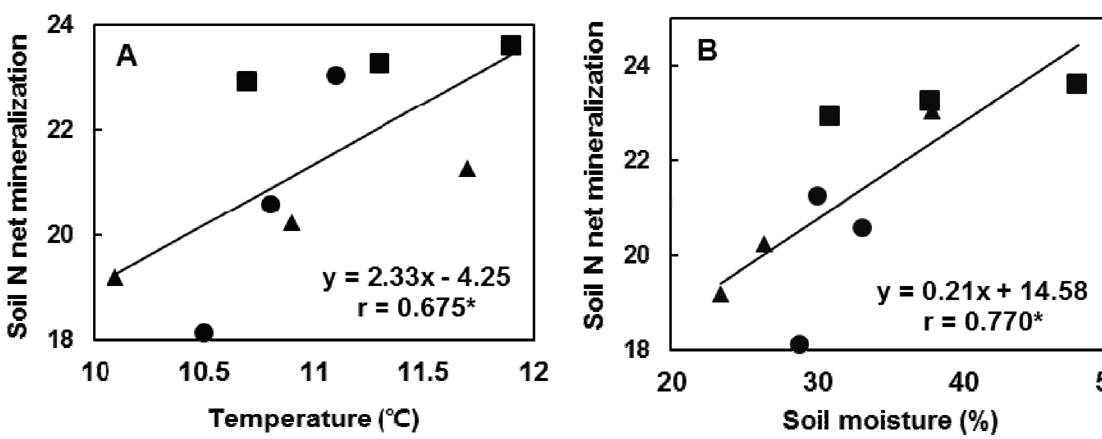

Fig. 3. Correlations between soil temperature (A), moisture (B) and soil N mineralization in site A (n), site B (▲) and site C (l). Significant levels of the linear correlation coefficient were denoted by* and**for $P < 0.05$ and $P < 0.01$.

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