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# Impact of maize growth on $N_2O$ emission from farmland soil

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**Abstact**: Crop growth is a key factor that effects nitrous oxide ($N_2O$) emission in farmland soil. Clarification and quantification of the impact of maize growth on $N_2O$ emission are important to guide maize planting and patterns, which is also useful for building model to simulate $N_2O$ emission in an agroecosystem. In this study, we carried out a three-year (2013–2015) field experiment to evaluate the contribution of maize growth on $N_2O$ emission using a split-plot design. The factors included planting versus not planting maize, and four rates of nitrogen (N) application (0, 150, 300, 450 kg N/ha). Our results showed the impacts of maize growth on $N_2O$ emission decreased linearly with the growth of maize from the 43rd day after sowing ($y = -1.07x + 26.85$, $R^2 = 0.95$). Nitrogen fertilizer application can reduce the impacts of maize growth on $N_2O$ emission. The impact of maize growth on soil $NH_4^+$-N and $NO_3^-$-N are similar to $N_2O$ emission, and they have a strong correlation. We concluded that maize growth reduces soil $N_2O$ emission but N application can exert an antagonistic effect, and the impact of maize growth on soil $NH_4^+$-N and $NO_3^-$-N largely determines the impacts of maize growth on $N_2O$ emission.

**Keywords**: global warming; *Zea mays* L.; nitrification; fertilization; greenhouse gas; nitrogen uptake; growth dynamic

Approximately 6% of global warming caused by increases in nitrous oxide ($N_2O$) since the industrialized era and approximately 88% of these emissions occur from soil (Van Groenigen et al. 2010). Factors that affect agricultural soil $N_2O$ emission are complex (Snyder et al. 2009, Akiyama et al. 2010), but crops are one of the key factors. Therefore, it is valuable to study the impact of crops growth on $N_2O$ emission.

The effect of crop growth on $N_2O$ emission is complex. One important factor affecting $N_2O$ emissions is the amount of $NH_4^+$-N available for nitrification and the amount $NO_3^-$-N available for denitrification (Kool et al. 2011). Competition between crop growth and the microbes for effective nitrogen (N) causes the reduction in farmland soil $N_2O$ emissions. The crop uptakes a large amount of N from the soil for growth (Ciampitti and Vyn 2012), reducing the effective N content in the soil, and thus reducing soil $N_2O$ emissions. Plaza-Bonilla et al. (2014a) found that the decrease in soil $NH_4^+$-N and $NO_3^-$-N content directly affects the biological processes determining $N_2O$ production. $N_2O$ emission is also impacted by soil temperature, water content, range of oxygen ($O_2$) concentrations, and microbial activity. All of these processes more or less affected by the growth of the crop. Jarecki et al. (2009) found that crops reduced rhizospheric $O_2$ pressure through root respiration created an anaerobic environment. There are several previous studies focused on $N_2O$ emissions from different crop farms and impacts of crop management practices such as tillage, irrigation, and fertilizer (Zhang et al. 2015). However, few studies have reported the effects of crop growth on $N_2O$ emissions.

Maize is one of the most important food and feeds crops, with an area of 183 million hectares planted around the world (FAO 2015). The humid and hot climate in the growing season of corn is more conducive to $N_2O$ emission than other crops like winter wheat (Zou et al. 2010). Many studies reported that the use of nitrogen fertilizer promoted the soil $N_2O$ emission (Hoben et al. 2010, Abalos et al. 2014). Meanwhile, N fertilizer is an important factor affect-

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ing maize growth and development processes (Liu and Wiatrak 2012). Linear or exponential relationship between fertilizer N rates and direct $N_2O$ emissions have been established (Kim et al. 2013). However, these relationships mostly don't isolate the effects of crops growth, so more researches are needed to quantify the impact of crop growth on $N_2O$ emission.

In this study, we conducted a three-year field trial and greenhouse experiment to investigate soil $N_2O$ emission from a field planting maize and a field without maize at different maize growth stages with four N application treatments. The aims were (1) to clarify the influence of maize growth on soil $N_2O$ emission and analyze the difference of the influence at different growth stages; (2) to quantify the difference of the influence under different N application levels; (3) to understand the absorption of N by maize is one of the main reasons affecting $N_2O$ emission.

## MATERIAL AND METHODS

**Study site**. The field experiment was carried out at Dawenkou experiment stations (35°58'N, 117°3'E) of Shandong Agricultural University in Huang-Huai-Hai region from 2014–2016. The soil type is brown soil, and its physical and chemical properties (0–20 cm depth) were as follows: total N, 0.82 g/kg; available P, 27.48 mg/kg; available K, 129.70 mg/kg; available S, 43.35 mg/kg; organic carbon, 22.93 g/kg; bulk density, and 1.04 g/cm$^3$. The climatic conditions from 2014–2016 are shown in Figure 1. The farming system in this area is wheat-maize double cropping system, the growing season of wheat is from mid-October to early June, and of maize from mid-June to early October. The traditional fertilizer application and irrigation amount in the wheat season were 225 kg N/ha and 110 mm, respectively.

**Experimental design**. The experiments conducted in eight districts from 2014, in 50 × 46 m$^2$ plots. Each processing area was 10 × 20 m$^2$ and surrounded by 2 m-wide borders. The experiment consisted of four N levels, N0 (0 kg N/ha), N150 (150 kg N/ha), N300 (300 kg N/ha), and N450 (450 kg N/ha), with each N level being employed in both maize planting and no maize planting treatments. The N treatment without planting maize is used to compare the effect of maize growth on $N_2O$ emission under different fertilizer rates. Under the same experimental conditions, maize growth, as the only variable, is the main reason for the difference in $N_2O$ emission between fields planted with and without maize.

Maize (cv. Zhengdan 958) planted on June 18 in 2014, 2015 and 2016 with a row spacing of 60 × 22.2 cm. N fertilizer (urea) was applied in each plot and was divided into two parts: 40% of the urea was applied before sowing, and 60% of urea was applied to 5-cm-deep trenches between the rows of maize plants at the twelve-leaf stage. The application rates of phosphate and potash fertilizers were 65.49 kg P/ha and 124.47 kg K/ha before sowing. After fertilization, we irrigated the maize to avoid ammonia volatile. The amount of water for each irrigation is 40 mm on June 8 and July 30, respectively. Pesticide management and plowing management (50 mm) during the maize-production season was by the conventional practices. All the management procedures were identical for each treatment.

**Sample collection and measurement**. $N_2O$ emissions measured using the closed static chamber method (Huang et al. 2017). Measurements carried out about 7 days for maize after sowing and continued until harvest. The $N_2O$ concentration in each sample analyzed using a gas chromatograph (GC-2010 plus, Shimadzu, Kyoto, Japan). The hourly

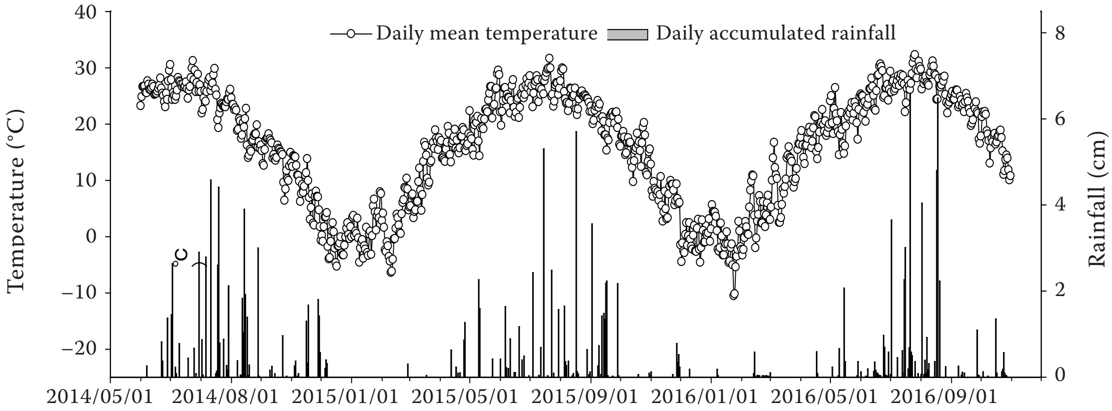

Figure 1. Daily means air temperature and precipitation during the test of 2014–2016

$N_2O$ fluxes (μg/m$^2$/h $N_2O$-N) calculated from the slope of the linear increase in $N_2O$ concentration in the sealed collection box (Rafique et al. 2011). The daily $N_2O$ emissions estimated as the hourly $N_2O$ emission multiplied by 24 h (Hu et al. 2013). Seasonal and annual cumulative $N_2O$ emission was a total of measurement and no-measurements days. $N_2O$ emission of no-measurements days estimated by linear interpolation (Mosier et al. 2006).

We collected soil samples on V3 (trilobites period); V6 (six leaf stage); V12 (twelve leaf stage); VT (tasseling stage); R3 (ratooning buds), and R6 (full ripeness period). We sampled soil from 0–20 cm. Soil $NH_4^+$-N and $NO_3^-$-N content analyzed with a continuous flow analyzer (Seal Auto Analyzer III, Hamburg, Germany).

**Statistical analysis**. The effect of maize growth on $N_2O$ emission estimated by comparing the difference of $N_2O$ emissions between planting maize field and no planting maize field calculated by the following equation:

$$NEI = (M_i - NM_i)/NM_i \quad (1),$$

Where: NEI – effect of maize growth on $N_2O$ emission; $M_i$ – $N_2O$ emission from planting maize field, measured on an $i^{th}$ day from plots planting maize; $NM_i$ – $N_2O$ emission on an $i^{th}$ day from plots no planting maize. NEI > 0 indicates that the maize growth increased farmland $N_2O$ emissions; NEI < 0 indicates that the maize growth reduced the farmland $N_2O$ emissions, and greater values of |NEI| indicate a greater effect. The effect of maize growth on soil N (SNI) calculated in the same way.

To test the differences among the treatments, the data analyzed using an analysis of ANOVA. The means were compared with at least significant difference (*LSD*) test at the 5% level using Microsoft Excel 2010 software (Microsoft, Redmond, USA) for windows and PASW Statistics 18.0 (SPSS, Chicago, USA).

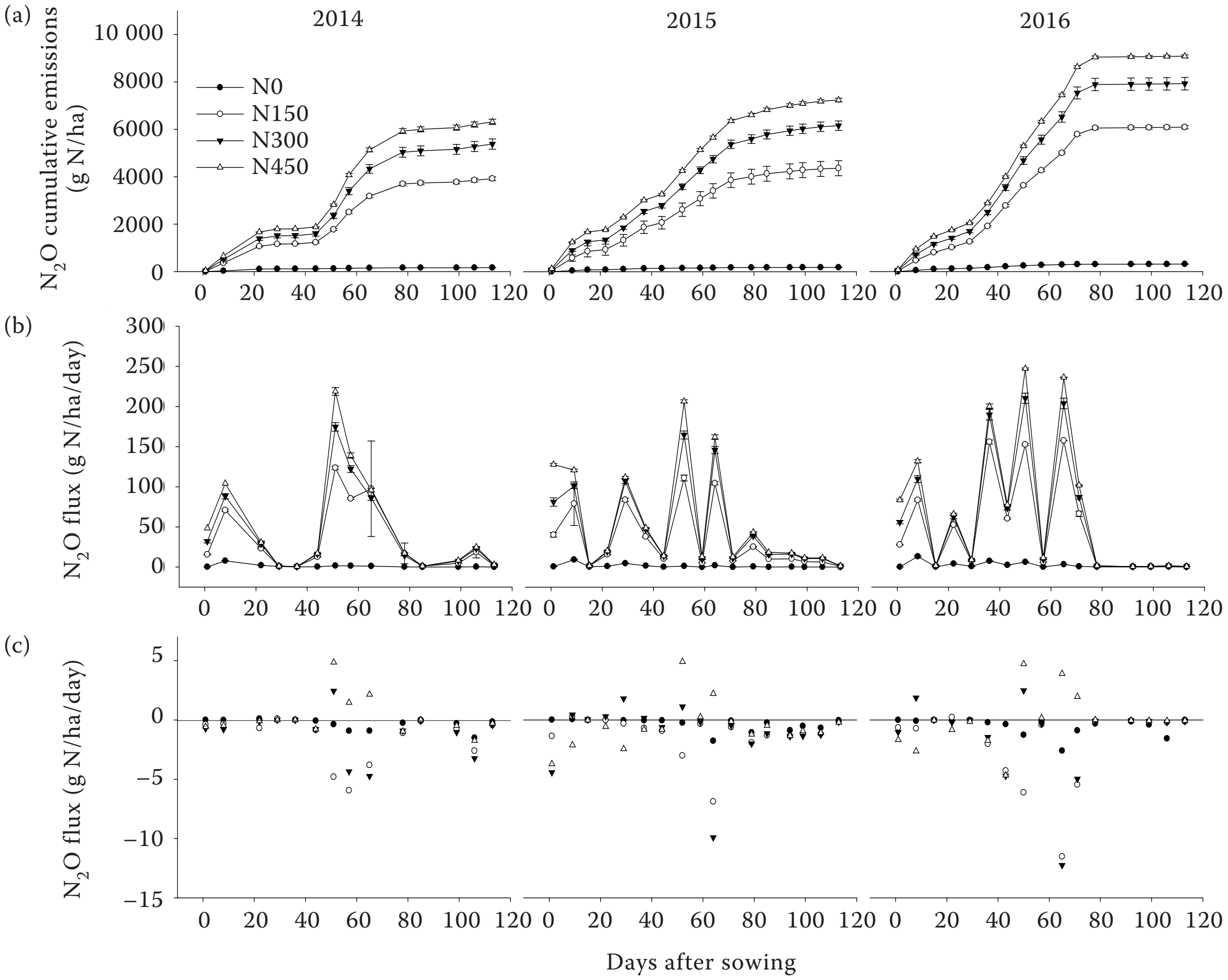

Figure 2. The planting maize field $N_2O$ cumulative emissions (a); daily $N_2O$ flux (b) and the daily $N_2O$ flux difference between planting maize field and no planting maize fields (c) under different fertilizer rates during the maize growing season (2014–2016). N0 – 0, N150 – 150, N300 – 300, N450 – 450 kg N/ha

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## RESULTS AND DISCUSSION

**$N_2O$ emission dynamics of planting and no planting maize field**. Cumulative $N_2O$ emission in maize growing season of N0, N150, N300, and N450 ranged from 166.43 to 317.11 g/ha, from 3920.0 to 6090.49 g/ha, from 5380.24 to 7926.54 g/ha and from 6314.96 to 9084.19 g/ha, respectively, which significantly increased with nitrogen application (Figure 2a and Table 1). The trends of daily soil $N_2O$ emissions from planting maize field under different treatments were mostly identical, with emission peaking after fertilizing, irrigation, and rainfall (Figure 2b). However, $N_2O$ emissions were different from planting maize field and no planting maize field under the same N application levels, and the degree of difference changed with the growth periods (Figure 2c).

Nitrogen content is the main factor determining soil nitrification and denitrification, which is, in turn, the main factors to affect soil $N_2O$ emission (Allen et al. 2010, Nan et al. 2016). As maize absorbs large amounts of soil N for growth, maize growth is also the main factor affecting soil nitrification and

Table 1. Cumulative $N_2O$ emissions from planting maize field and no planting maize fields under different fertilizer rates and the differential during the maize growing season (2014–2016)

| Treatment | | Planting maize field | No planting maize field | Differential |
|---|---|---|---|---|
| | | (kg N/ha) | | |
| 2014 | N0 | 0.17 ± 0.01 | 0.21 ± 0.01 | –0.04 |
| | N150 | 3.92 ± 0.08 | 4.11 ± 0.11 | –0.19 |
| | N300 | 5.38 ± 0.22 | 5.52 ± 0.19 | –0.14 |
| | N450 | 6.29 ± 0.11 | 6.31 ± 0.17 | –0.02 |
| 2015 | N0 | 0.18 ± 0.01 | 0.22 ± 0.01 | –0.04 |
| | N150 | 4.36 ± 0.32 | 4.52 ± 0.30 | –0.16 |
| | N300 | 6.16 ± 0.20 | 6.29 ± 0.10 | –0.13 |
| | N450 | 7.24 ± 0.08 | 7.30 ± 0.11 | –0.06 |
| 2016 | N0 | 0.32 ± 0.02 | 0.38 ± 0.01 | –0.07 |
| | N150 | 6.09 ± 0.07 | 6.34 ± 0.19 | –0.25 |
| | N300 | 7.93 ± 0.26 | 8.09 ± 0.27 | –0.16 |
| | N450 | 9.08 ± 0.05 | 9.10 ± 0.36 | –0.01 |

N0 – 0, N150 – 150, N300 – 300, N450 – 450 kg N/ha

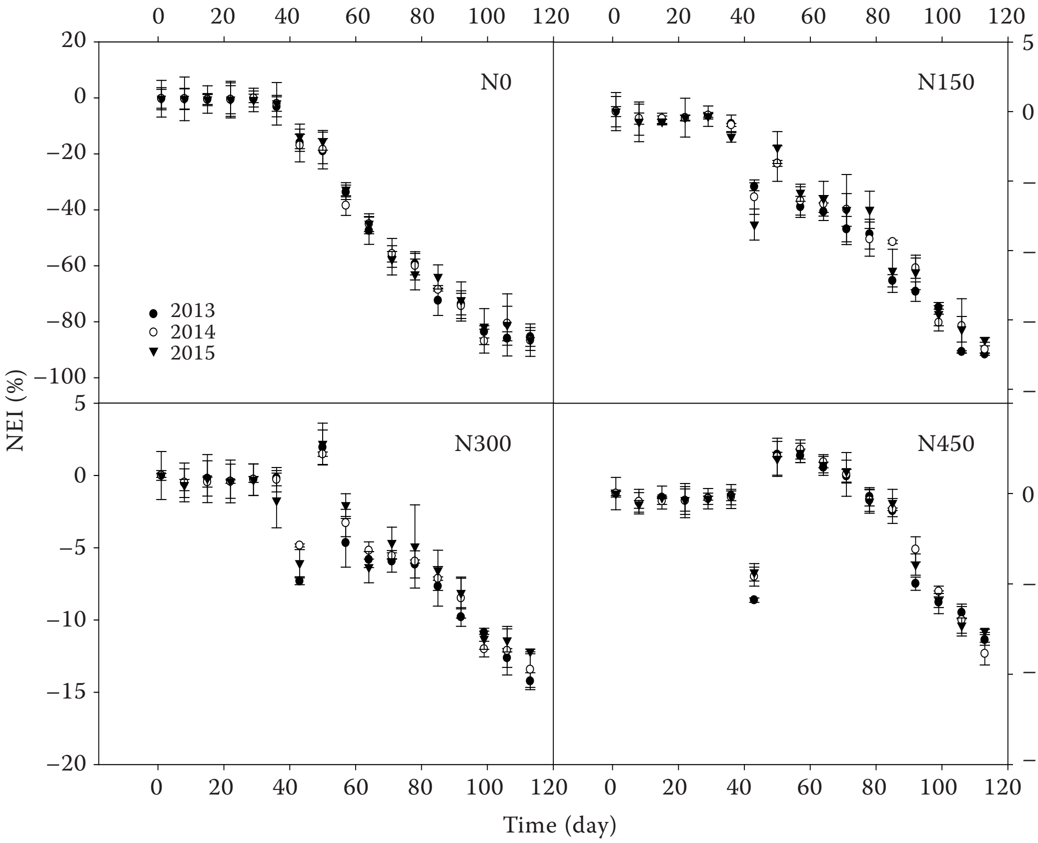

Figure 3. The impact of maize growth on $N_2O$ emission (NEI) in maize growth stages under different nitrogen (N) application rates. N0 – 0, N150 – 150, N300 – 300, N450 – 450 kg N/ha

denitrification, and a potential driver of soil $N_2O$ emission levels (Snyder et al. 2009). As a result, under the same N fertilizer conditions, $N_2O$ emissions from planting maize field was less than that of no planting maize field.

**NEI during the maize growth period**. The altering trend and degree about NEI of various years are similar, the average of 2014, 2015 and 2016 are −37.56, −37.39, and −35.74%, respectively (Figure 3, N0). The NEI values showed a decreasing trend with the growth of maize in all years, but there were no significant changes (average: 0.730 ± 0.115%) during the growth period from 0 to 36 days after sowing (sowing to V6). The average NEI was −56.923 ± 1.010% from 37 to 113 days (V12 to R6) and decreased linearly ($y = -1.07x + 26.85$, $R^2 = 0.95$) with the growth of maize.

The NEI was negative in planting maize field because maize growth reduced farmland $N_2O$ emissions by absorbs large amounts of soil N. The N-absorption capacity varied among different stages of maize development (Grzebisz 2013). The absorption capacity of maize at different growth stages directly affects the concentration of soil $NH_4^+$-N and $NO_3^-$-N (Manzur et al. 2014, Plaza-Bonilla et al. 2014b), which in turn affects the soil $N_2O$ emissions (Bonelli et al. 2016). The rate of reduction of soil $NH_4^+$-N and $NO_3^-$-N increases gradually through the growth period of maize, while the reduction rate in the field with no planting maize field was steady (Cassman et al. 2002). Hence, the difference in $N_2O$ emission between maize planting field and no planting maize field increased through the maize growth period.

**Changes in the NEI with N application rate**. NEI was consistent across years under the same N application rate but significantly increased with the increase of N application rate (Figure 3). NEI for N150, N300, and N450 were −6.74, −4.75, and −1.57, respectively. With the increasing of N application from N0 to N450, NEI decreased linearly

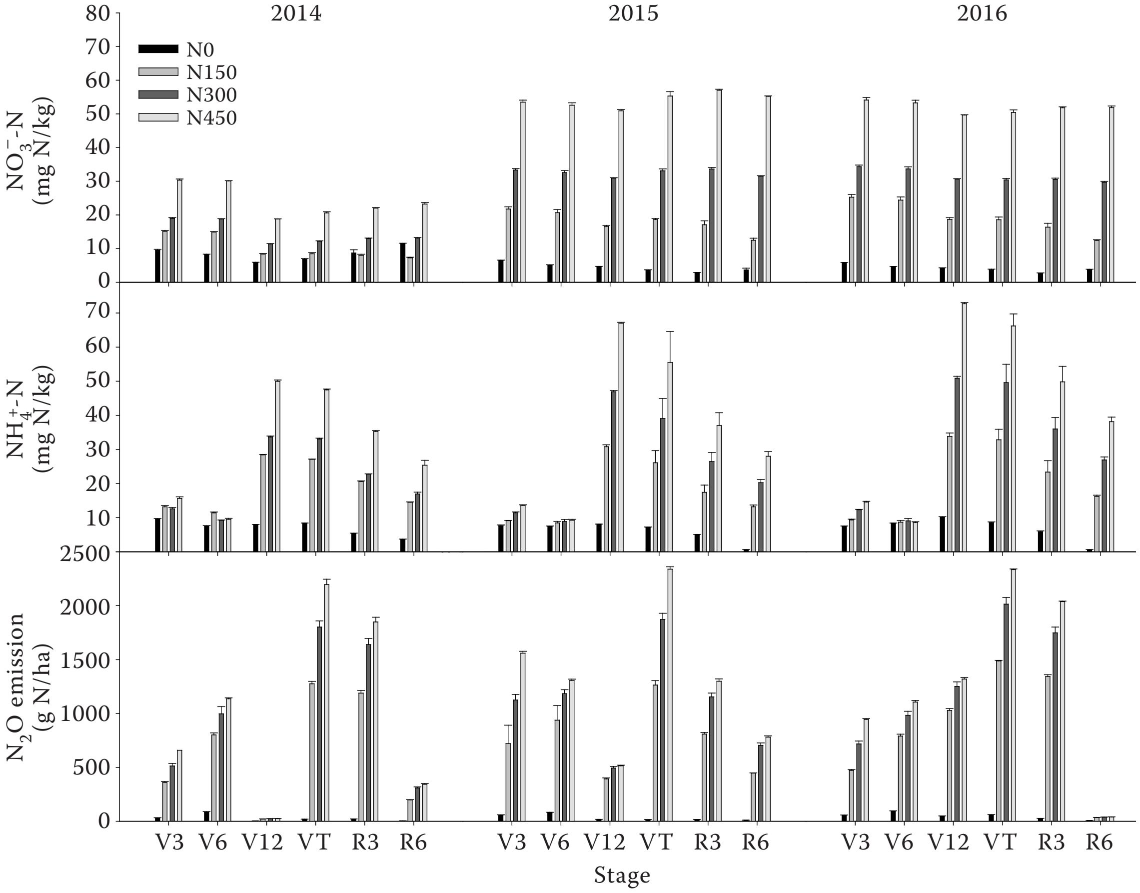

Figure 4. Nitrate nitrogen ($NO_3^-$-N) and ammonium nitrogen ($NH_4^+$-N) at 0–20 cm depth, and accumulative $N_2O$ emissions from critical maize stages in the N0, N150, N300, and N450 treatments. Vertical bars denote the standard error of the means ($n = 3$). N0 – 0, N150 – 150, N300 – 300, N450 – 450 kg N/ha; V3 – trilobites period; V6 – six leaf stage; V12 – twelve leaf stage; VT – tasseling stage; R3 – ratooning buds; R6 – full ripeness period

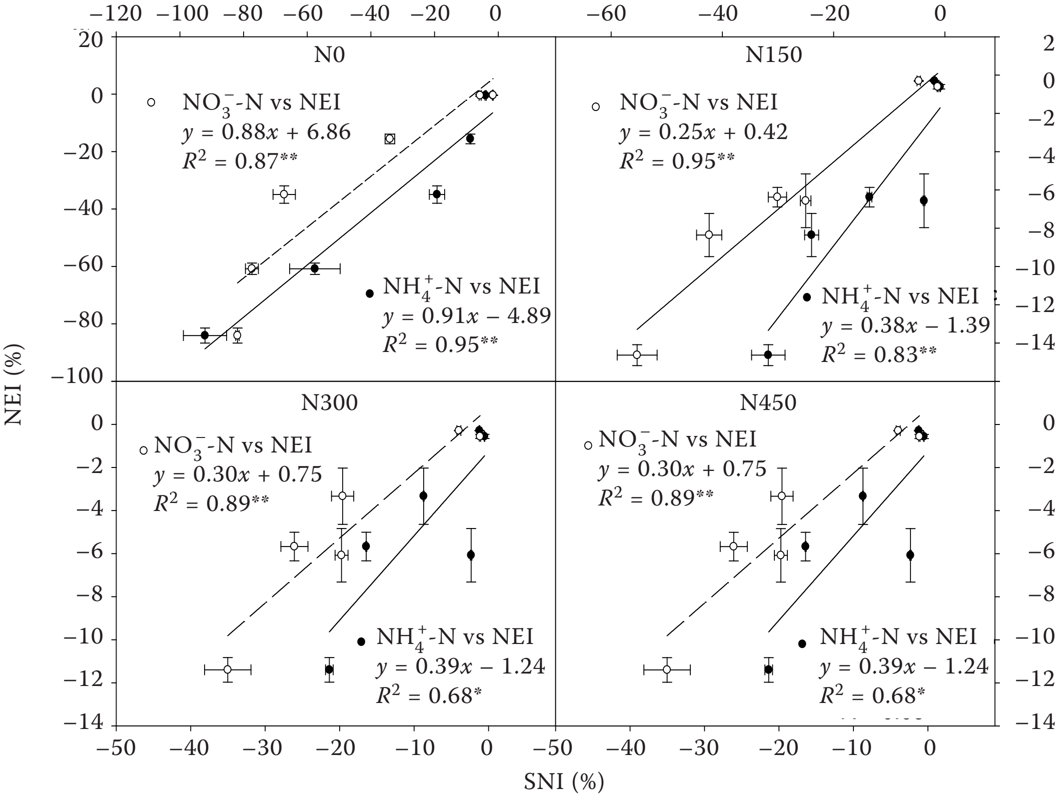

Figure 5. The correlation between the effect of nitrogen (N) on $N_2O$ emission and soli N ($NH_4^+$-N and $NO_3^-$-N). N0 – 0, N150 – 150, N300 – 300, N450 – 450 kg N/ha; $^*P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$; NEI – effect of maize growth on $N_2O$ emission

($y = -0.016x + 0.245$, $R^2 = 0.99$). The N application has a significant impact on NEI after topdressing. From topdressing to harvest, the NEI for N150, N300, and N450 reduced by 15.796, 12.545, and 8.026%, respectively, than that before topdressing.

Nitrogen fertilizer application promotes crop growth and absorption of soil N (Boomsma et al. 2010, Manzur et al. 2014). With the increase of N application, N gradually satisfied the need of crop growth, microbial processes of $N_2O$ obtained more $NH_4^+$-N and $NO_3^-$-N at the same time (Linquist et al. 2012). The effect of maize growth on $N_2O$ emission gradually decreases with the increase of N application. Thus, the NEI increased significantly with N fertilizer application. However, NEI being greater than zero after topdressing (Figure 3, N300 and N450). The possible reason is topdressing can prompt crop roots and soil microbes to secrete more enzymes related to the decomposition of organic molecules and N compounds (Berg and Smalla 2009). Many other factors linked with maize growth are likely to be involved in increasing soil $N_2O$ emissions, but the specific factors and the mechanisms involved remain unclear.

**Soil N is the key factor for the NEI**. The $NH_4^+$-N and $NO_3^-$-N from 2014 to 2016 with the N application levels at the six growth stages shown in Figure 4. The trend of $N_2O$ accumulated emissions with the maize growth period from planting maize field was not completely consistent with this concentration of soil $NH_4^+$-N and $NO_3^-$-N. However, the NEI was closely correlated with SNI of $NH_4^+$-N and $NO_3^-$-N (Figure 5).

In addition to soil N, field management can influence crop growth and affect the NEI directly or indirectly (Yao et al. 2009). Further study is needed on the interaction between farmland management and the effect on $N_2O$ emission to determine the mechanisms of crops affect soil $N_2O$ emission.

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