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RESEARCH ARTICLE

Effects of long-term fertilization on soil gross N transformation rates and their implications

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Abstract

Application of fertilizer has been found to significantly affect soil N cycling. However, a comprehensive understanding of the effects of long-term fertilization on soil gross N transformation rates is still lacking. We compiled data of observations from 10 long-term fertilization experiments and conducted a meta-analysis of the effects of long-term fertilization on soil gross N transformation rates. The results showed that if chemical fertilizers of N, P and K were applied in balance, soil pH decreased very slightly. There was a significantly positive effect of long-term fertilization, either chemical or organic fertilizers or their combinations, on gross N mineralization rate compared to the control treatment (the mean effect size ranged from 1.21 to 1.25 at 95% confidence intervals (CI) with a mean of 1.23), mainly due to the increasing soil total N content. The long-term application of organic fertilizer alone and combining organic and chemical fertilizer could increase the mineralization-immobilization turnover, thus enhance available N for plant while reduce N losses potential compared to the control treatment. However, long-term chemical fertilizer application did not significantly affect the gross NH_4^+ immobilization rate, but accelerated gross nitrification rate (1.19; 95% CI: 1.08 to 1.31). Thus, long-term chemical fertilizer alone would probably induce higher N losses potential through NO_3^- leaching and runoff than organic fertilizer application compared to the control treatment. Therefore, in the view of the effects of long-term fertilization on gross N transformation rates, it also supports that organic fertilizer alone or combination of organic and chemical fertilizer could not only improve crop yield, but also increase soil fertility and reduce the N losses potential.

Keywords: chemical fertilizer, organic fertilizer, gross N transformation rate, long-term fertilization experiment, meta-analysis

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1. Introduction

The large majority of the anthropogenic reactive N (Nr) is applied to agricultural ecosystems, which has greatly changed soil N cycling, and stimulated NH_3 volatilization, NO and N_2O emissions, N leaching, and runoff, inducing some serious negative impacts on the environment (Meng *et al.* 2005; Galloway *et al.* 2008; Ding *et al.* 2010). However, N fertilizer also plays a very important role in crop production that supported the burgeoning human population in the world. Therefore, appropriate fertilizer managements are required to enhance crop yield, improve soil fertility, while minimize negative environmental impacts. Soil N transformations play a key role in regulating plant N availability and N loss potential (Houlton *et al.* 2007; Galloway *et al.* 2008; Zhang *et al.* 2016a, b). Compared to net mineralization and net nitrification rates, gross N transformation rates, determined by using ^{15}N pool dilution technique or ^{15}N tracing model method, can present actual rates of specific N form transformation processes that governed the N cycling in soils and can help to elucidate the relationships between N cycling, N fate and N losses (Kirkham and Bartholomew 1954; Paterson 2003; Huygens *et al.* 2007, 2008; Rütting *et al.* 2008). Gibbs and Barraclough (1998) reported that the application of organic matters (C/N 12) could not only affect gross rate of N mineralization, but also significantly increase the immobilization of mineral N in the short-term incubation conditions (29 days). Thus, organic matter applications may reduce mineral N pools and associated N losses (e.g., leaching, gaseous N). While, several investigations have demonstrated that long-term fertilizer applications, whether chemical or organic fertilizer, can significantly increase gross rates of N mineralization and nitrification, which is closely related to increasing crop yield and N losses, respectively (Müller *et al.* 2011; Zhang *et al.* 2012b; Wang *et al.* 2015). In fact, many of changes in soil N transformations may become apparent only in the long-term fertilizer application experiments. Thus it is important to take into account the effects of long-term organic or chemical fertilizer applications on gross rates of soil N transformations, which can provide an understanding of N dynamics in the different N fertilizer managements and help to optimize N fertilizer management.

In this paper, we performed a comprehensive analysis of the effects of long-term fertilizer applications on gross rates of soil N transformations by a meta-analysis to explore if there is a general pattern of fertilizer application effects on gross rates of soil N transformations, to identify the mechanisms of fertilizer applications affecting soil N transformations, and to propose the appropriate fertilizer management for agricultural production.

2. Materials and methods

2.1. Data compilation

A total of 31 observations from 10 papers that were derived from the Web of Science were selected (Table 1) following three criteria: (1) field experiments were conducted for more than 10 years. Thus, those field experiments conducted less than 10 years and laboratory incubation studies were excluded; (2) chemical fertilizer treatment was N, P, K balanced application. Thus the treatments of N or P or K application alone were not included in the data compilation; (3) gross rates of soil N transformations were measured using ^{15}N pool dilution technique and ^{15}N tracing model. No fertilizer application treatment was used as the control. Data were extracted using Getdata software if the data were presented in figures in the original publication. In order to better identify the effects of long-term fertilization on gross rates of N transformations, fertilizer types were grouped as chemical fertilizer, combination of organic and chemical fertilizers, and organic fertilizer only.

2.2. Statistical analyses

The effect size, presented by the natural log of the response ratio (R), was used to measure the response of variables such as gross rates of N transformations, soil properties, and crop yield to long-term fertilization (Hedges *et al.* 1999; Liu *et al.* 2016). R was the ratio of data in the fertilization treatments (X_t) to that in the control (X_c):

$$\ln(R)=\ln(\frac{X_t}{X_c}) \tag{1}$$

The variance (v) of ln$R$ was calculated using the eq. (2):

$$v=\frac{S_t^2}{n_t X_t^2}+\frac{S_c^2}{n_c X_c^2} \tag{2}$$

Where, n_c and n_t were the sample sizes for the control and fertilization treatment, respectively. S_c and S_t were the standard deviations for the control and fertilization treatments, respectively.

A fixed-effect model was used in our meta-analysis to determine whether long-term fertilization had a significant effect on the studied variable using Metawin 2.1 software. 95% confidence intervals (CI) of the weighted effect size were generated using bootstrap resampling procedure with 9 999 iterations. Fertilizer application was considered to have a significant effect on a variable if the 95% CI values did not overlap with 0.

3. Results

The results of meta-analysis showed that most studied variables were significantly changed by long-term fertilization, except for C/N ratio. The mean effect size of long-term fertilization on C/N ratio was 0.01 (95% CI: –0.0003 to 0.02). Long-term fertilization decreased soil pH, but very slightly with the mean effect size of –0.01 and the range of –0.015 to –0.009 at 95% CI, which was very close to zero. There was a variation of the effect size on soil pH between fertilizer types, with a positive value in combination of organic and