How does inorganic N fertilizer affect soil nitrogen mineralization?

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Abstract
The effect of N fertilizer on soil organic matter mineralization is uncertain. This uncertainty has led to suggestions that inorganic N fertilizer may enhance soil N mineralization, thereby decreasing soil organic matter. This uncertainty has also led to confusion about how to measure crop system fertilizer N use efficiency (FNUE). Two options exist to measure FNUE: The indirect ‘N difference’ method compares N uptake in a zero N control plot compared to N uptake in a fertilized plot (FNUE = (N uptake in fertilized – N uptake in control)/N fertilizer input). The direct ‘^{15}N tracer’ method uses isotopically labeled N fertilizer to directly measure the uptake of individual N atoms. The ‘N difference’ method always measures higher FNUE and this result has been hypothesized to be due to a ‘priming effect’ or enhancement of added-N on soil N mineralization. The objective of this study was to quantify the effects of inorganic N fertilizer application on soil organic matter mineralization via measurement of gross ammonification. We measured gross ammonification rates in long-term N fertilizer rate experiments at two sites located in central and southern Iowa. In 2015, plots with continuous corn that had received one of three historic N fertilizer rates for the past 15 years: 0, 202 (long-term AONR) and 269 kg N/ha (highest rate) at the central Iowa site and 0, 224 (rate increment just below the AONR) and 269 (long-term AONR, at the highest rate) at southern Iowa site, were split into two subplots that received either the agronomic optimum N rate (AONR) or zero N fertilizer. Gross ammonification was measured at the V5 and V12 maize growth stages. Across all historical N fertilizer rates at the V5 maize growth stage, N fertilizer input at the AONR significantly reduced gross ammonification rates by 15 and 12% as compared to zero N at the central and southern Iowa sites, respectively; whereas there was no effect at the V12 stage. At both sites, the effect of N fertilizer on gross N ammonification rate decreased with an increase in historic N application rate from zero to highest. Because C and N mineralization occur in tandem, our results are inconsistent with the hypothesis that N fertilizer application reduces soil organic matter. Moreover, our results suggest that the ‘N difference’ method is more accurate than the ‘^{15}N tracer’ method for measurement of FNUE, because gross N mineralization is positively associated with soil C mineralization.

Keywords
Fertilizer nitrogen use efficiency, N mineralization, priming effect, agronomic optimum N rate, inorganic N fertilizer, continuous maize system.

Introduction
The fertilizer N use efficiency (FNUE) is important information for improving maize cropping systems N use efficiency (NUE). Although two methods are commonly used to determine FNUE, they consistently produce different results. The indirect ‘N difference’ method calculates FNUE based on the difference in N uptake between a fertilized and an unfertilized crop, using the equation: $\frac{(NF - NC)}{R} * 100$, where NF = total plant N uptake from fertilized plots, NC = total N uptake from unfertilized plots and R = rate of N fertilizer applied (Varvel and Peterson, 1990). The direct ‘tracer’ method calculates FNUE based on plant uptake of a ^{15}N labelled fertilizer relative to the amount of fertilizer ^{15}N applied (Hauck and Bremner, 1976). The indirect ‘N difference’ method always results in greater FNUE than the direct ‘tracer’ method (Jansson and Persson, 1982). The ‘N difference’ method may provide an artificially high FNUE due to a ‘priming’ – or enhancement – effect of added-N on soil N mineralization rate, as it has been hypothesized that the addition of N fertilizer increases soil organic matter decomposition and N mineralization, and thus the use of N uptake in an unfertilized crop may artificially inflate FNUE results (Khan et al., 2007; Mulvaney et al., 2009). In contrast, the ‘tracer’ method may provide an artificially low FNUE because the ^{15}N isotope mixes with the native soil N pool resulting in a diluted ^{15}N signal (Cassman et al. 2002).

Measurements of gross ammonification can determine if N fertilizer addition increases or 'primes' soil N mineralization. Gross ammonification is the microbially-mediated total flux of N from an organic form to the ammonium form (Hart et al., 1994) and, in general, is positively associated with soil organic matter level (Booth et al. 2005). Long-term N fertilization can increase SOM by increasing crop residue input and therefore is assumed to contribute to maintenance of soil fertility for sustained agricultural productivity (Brown et al., 2014). However, Mulvaney et al. (2009) proposed that inorganic N fertilizer could increase microbial activity and deplete soil organic matter stocks by promoting microbial C utilization and N mineralization. The reported impacts of N fertilization on soil organic matter decomposition and N mineralization in Mulvaney et al. (2009) are inconsistent in regard to other research on response to N fertilizer where there was a decrease in SOM mineralization with N application (Al-Kaisi et al., 2008). The objective of this study was to quantify the effects of inorganic fertilizer addition on gross ammonification (soil organic matter mineralization) across gradients of SOM in continuous maize.

Methods

A field study was conducted at two sites located in central and southern Iowa, USA. The sites were established in 1999 and maintained in a continuous maize system. Individual plots within each site received one of 5 (central) or 7 (southern) N fertilizer rates ranging from 0-269 kg N /ha/y, with 4 replicates. Each plot received the same N fertilizer rate from 1999-2014. The long-term AONR, i.e., the fertilizer rate at which additional N fertilizer will not increase grain yield, was 202 kg N/ha (central) and 269 kg N/ha (southern, response to highest N rate). In 2015, three of the historic N rates at each site were selected for this study: zero N, the rate closest to AONR (202 and 224 kg N/ha at central and southern sites, respectively), and the highest N rate (269 kg N/ha). The long-term AONR for each site (202 and 269 kg N/ha at central and southern, respectively) was applied to one-half of each plot and zero N was applied to the other half after maize planting. Soil samples from 5-15 cm depth were collected at V5 (5 collared leaves) and V12 (12 collared leaves) maize growth stages. Gross ammonification rate was determined using the ^{15}N isotope dilution approach in laboratory incubations (Hart et al. 1994). Data was analyzed with a split-plot design with repeated measures using PROC MIXED in SAS/STAT software, version 9.3 (SAS Institute Inc., Cary, NC).

Results

Across all historic N fertilizer rates at the V5 maize growth stage, N fertilizer input at the AONR in 2015 reduced gross ammonification rates by 15% as compared to zero fertilizer addition at the central Iowa site, and reduced gross ammonification by 12% at the southern Iowa site. In contrast, there was no effect of N fertilizer on gross ammonification at the V12 stage at either site. The impact of AONR application in 2015 decreased with an increase in the historic N rate at both sites. At the V5 growth stage at the central Iowa site, N fertilization with the AONR reduced gross ammonification rate by 20 and 18% in the historic zero and AONR (202 kg N/ha/y), respectively. Similarly, at the V5 growth stage at the southern Iowa site, AONR application in 2015 reduced gross ammonification rates by 17 and 13% in the historic zero and 224 kg N/ha/y rate, respectively. In contrast, at the highest long-term historic N rate (269 kg N/ha/y), the AONR rate had no effect on gross ammonification compared to no N fertilizer input at either site (Figure 1). These results indicate that the reduced mineralization due to fertilizer addition could be attributed to the suppressive effects of N addition on the phenol oxidase activity in soil. The long-term N additions have impacted the microbial community size, composition (fungal:bacterial biomass ratio) and function; as previous study by Brown et al. (2014) reported N fertilizer addition decreased microbial biomass and arbuscular mycorrhizal fungi biomass while bacterial biomass increased; therefore suppressive effects could have decreased with the increase in rate of historic N addition.

Conclusion

The recent fertilizer-N addition reduced gross N mineralization where there had been low long-term historic N fertilizer rate. In contrast, at high historical N fertilizer rates, the recent fertilizer N addition had no effect on gross N mineralization. Nitrogen fertilizer application had a negative to no effect on gross N mineralization rate. Thus the 'N difference' method may actually underestimate FNUE, especially in systems with N application at or below agronomic optimum rates, as opposed to the common view that this method overestimates FNUE. However, the degree of underestimation should be smaller than that of the 'tracer' method. Therefore, our results suggest that the indirect 'N difference' method is a more accurate method for the determination of FNUE as compared to the direct 'tracer' method. In addition, as gross N mineralization occurs in tandem with soil C mineralization, results indicate that N fertilizer application does not enhance soil organic matter decomposition. Thus, our results do not support the hypothesis that N fertilizer application contributes to depletion of carbon stocks in agricultural soils.

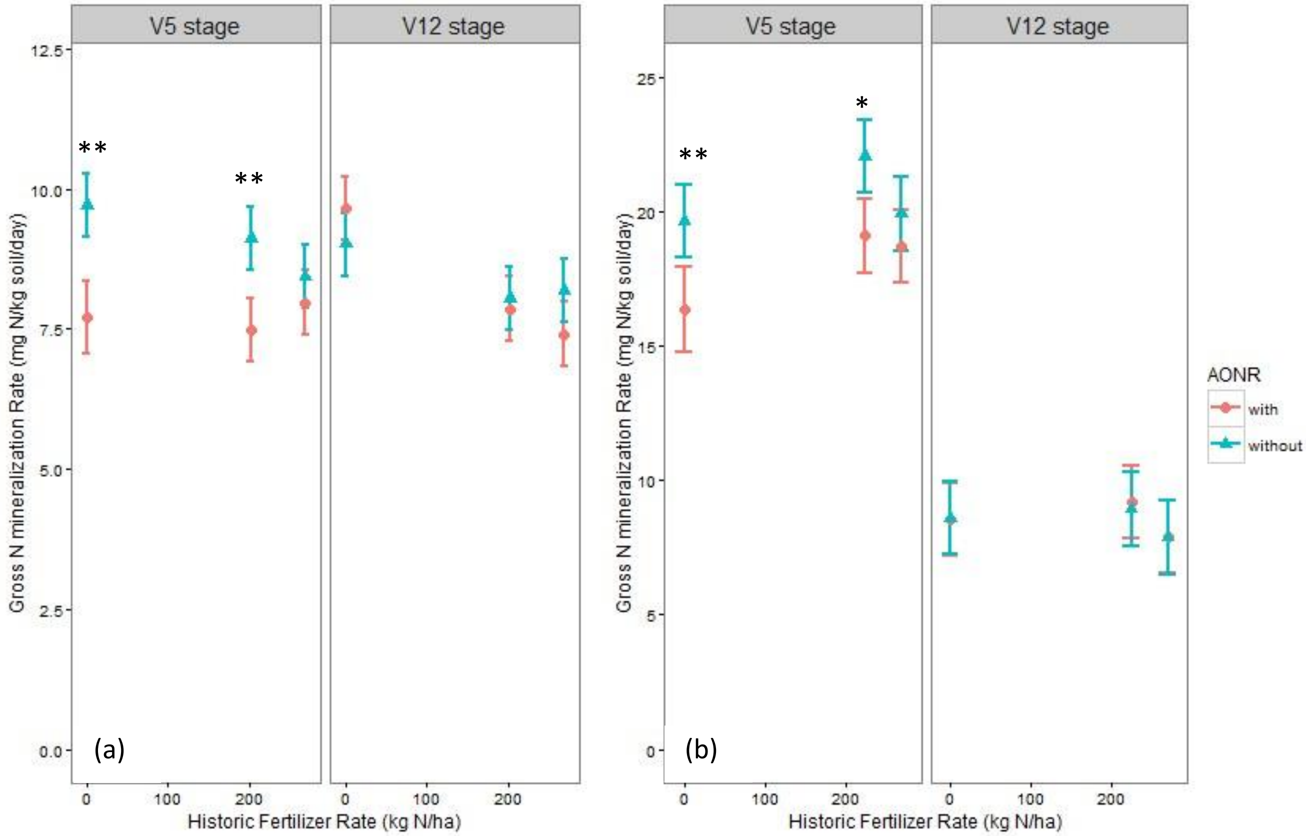

Figure 1. Mean gross N mineralization rate and standard error (vertical bars) in continuous maize for three historic N rates of 0, 202 (long-term AONR) and 269 kg N/ha (highest rate) at the central Iowa site (a) and 0, 224 (rate increment just below the AONR) and 269 (long-term AONR, at the highest rate) at southern Iowa site (b) where either no N or the long-term AONR fertilizer rate was applied; determined at the V5 (5 collared leaves) and V12 (12 collared leaves) maize growth stage. ** indicates the difference between zero and AONR fertilizer application is significant at P = 0.05 and * indicates the differences are significant at P = 0.10.

References

Al-Kaisi, M. M., Kruse, M. L., & Sawyer, J. E., 2008. Effect of nitrogen fertilizer application on growing season soil carbon dioxide emission in a corn–soybean rotation. Journal of Environmental Quality, 37(2), 325-332.

Booth, M. S., Stark, J. M., & Rastetter, E., 2005. Controls on nitrogen cycling in terrestrial ecosystems: a synthetic analysis of literature data. Ecological Monographs, 75(2), 139-157.

Brown, K. H., Bach, E. M., Drijber, R. A., Hofmockel, K. S., Jeske, E. S., Sawyer, J. E., & Castellano, M. J., 2014. A long-term nitrogen fertilizer gradient has little effect on soil organic matter in a high-intensity maize production system. Global Change Biology, 20(4), 1339-1350.

Cassman, K. G., Dobermann, A., & Walters, D. T., 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO, 31(2), 132-140.

Hart, S. C., Stark, J. M., Davidson, E. A., & Firestone, M. K., 1994. Nitrogen mineralization, immobilization, and nitrification. Methods of Soil Analysis: Part 2—Microbiological and Biochemical Properties, 985-1018.

Hauck, R. D., & Bremner, J. M., 1976. Use of tracers for soil and fertilizer nitrogen research. Advances in Agronomy, 28, 219-266.

Jansson, S. L., & Persson, J., 1982. Mineralization and immobilization of soil nitrogen. Nitrogen in agricultural soils, 229-252.

Khan, S. A., Mulvaney, R. L., Ellsworth, T. R., & Boast, C. W., 2007. The myth of nitrogen fertilization for soil carbon sequestration. Journal of Environmental Quality, 36(6), 1821-1832.
Mulvaney, R. L., Khan, S. A., & Ellsworth, T. R., 2009. Synthetic nitrogen fertilizers deplete soil nitrogen: a global dilemma for sustainable cereal production. Journal of Environmental Quality, 38(6), 2295-2314.
Varvel, G. E., & Peterson, T. A., 1990. Nitrogen fertilizer recovery by corn in monoculture and rotation systems. Agronomy Journal, 82(5), 935-938.