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EFFECTS OF DIFFERENT NITROGEN FERTILIZERS ON EMISSION OF NITROUS OXIDE FROM SOIL

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Abstract. Field studies of emissions of nitrous oxide (N_2O) from a fallow soil treated with different forms and amounts of fertilizer N showed that N_2O emissions from plots treated with N in the form of ammonium sulfate or urea markedly exceeded those from plots treated with the same amount of N in the form of calcium nitrate. This supports evidence from laboratory research that most of the N_2O evolved from soils treated with ammonium and ammonium-producing fertilizers is generated by nitrifying microorganisms during oxidation of ammonium to nitrate and not, as previously assumed, through reduction of fertilizer-derived nitrate by denitrifying microorganisms. Emissions of N_2O from plots treated with fertilizer N as ammonium sulfate or urea increased with the amount of N applied. Emissions of N_2O in 25 days were increased 329-524% by application of 125 kg N ha⁻¹ as ammonium sulfate or urea and increased 1024-1319% by the application of 250 kg N ha⁻¹ in these forms, but these applications did not markedly increase N_2O emissions after 25 days, and the fertilizer-induced emissions of N_2O -N observed in 96 days from plots treated with ammonium sulfate or urea represented only 0.11-0.18% of the fertilizer N applied. Emissions of N_2O from plots treated with different amounts of N as calcium nitrate did not increase with the amount of N applied and were not appreciably greater than the emissions observed when no fertilizer N was added.

Introduction

There is concern that increased nitrogen (N) fertilization of soils to aid world food production may substantially increase emissions of nitrous oxide (N_2O) from soils and thereby pose a threat to the stratospheric ozone layer protecting the biosphere from biologically harmful ultraviolet radiation from the sun (see Council for Agricultural Science and Technology, 1976; Crutzen and Ehhalt, 1977; Liu et al., 1977; McElroy et al., 1977). Although it has been generally assumed that this threat is from N_2O produced by denitrification of fertilizer-derived nitrate in soils under anaerobic conditions, recent laboratory studies (Blackmer and Bremner, 1977; Bremner and Blackmer, 1978, 1979a,b) have provided evidence that N_2O is released to the atmosphere during nitrification of ammonium and ammonium-producing fertilizers in soils and that nitrifying microorganisms contribute significantly to emissions of N_2O from soils. Because most of the fertilizer N applied to soils is in the form of ammonium or ammonium-producing fertilizers, there is an urgent need for reliable information concerning the effects of these nitrifiable forms of fertilizer N on emissions of N_2O from soils.

We report here the results of highly replicated field experiments showing that fertilizer-induced emissions of N_2O from plots treated with nitrifiable forms of fertilizer N (ammonium sulfate and urea) markedly exceed those from plots receiving an equivalent treatment of fertilizer N as calcium nitrate.

Experimental

The experiments reported were performed on a field at the Iowa State University Agronomy Research Center 10 km southwest of Ames. The soil in this field was representative of Harps soil used extensively for corn and soybean production in north-central Iowa. A composite sample of surface (0-15 cm) soil collected at 12 sites within the field had a pH of 8.2 and contained 32% sand, 32% clay, 4.9% organic carbon, 7.7% calcium carbonate, 15 μ g ammonium N g⁻¹ and 30 μ g nitrate N g⁻¹.

To study the effects of different nitrogen fertilizers on emissions of N_2O , three forms of fertilizer N (ammonium sulfate, urea and calcium nitrate) were applied at two rates (125 to 250 kg N ha⁻¹) to 72 plots, and N_2O emissions from these plots were compared with those from 12 unfertilized plots. An area approximately 30 m by 30 m was rototilled to a depth of 20 cm and divided into 84 plots. After appropriate treatment, each plot was again rototilled to a depth of 20 cm. Treatments were applied by sprinkling the plots evenly with 1.5 liters of water or with 1.5 liters of water containing the appropriate form and amount of fertilizer N. Each of the seven treatments were replicated twice in each of six randomized complete blocks [each treatment was replicated 12 times to minimize error due to spatial variability in emission of N_2O from soils (Robbins et al., 1979)].

Rates of N_2O emission from the experimental plots were measured by a chamber technique (Matthias et al., 1979) involving placement of an insulated cylindrical metal chamber over the soil surface for 10 minutes and removal of air samples from the chamber at intervals for N_2O analysis by a gas chromatographic technique that permits use of the xenon in air as an internal standard (Blackmer and Bremner, 1978).

Soil temperature was measured at a depth of 7.5 cm below the soil surface by a mercury thermometer. Soil moisture content was determined by gravimetric determination of weight loss when soil samples collected 7.5 to 12.5 cm below the soil surface were dried at 105°C for 24 hours. It is expressed as a percentage of oven-dry soil. The field capacity of the soil in the experimental area was determined as described by Peters (1965). Exchangeable ammonium and nitrate in soil samples (0-15 cm) taken at various times after application of fertilizer N were determined as described by Bremner and Keeney (1966).

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Table 1. Amounts of N₂O Evolved from Plots Treated with Different Forms and Amounts of Fertilizer Nitrogen

Nitrogen fertilizer added		Amount of N ₂ O-N evolved (g ha ⁻¹)				Fertilizer-induced emission of N ₂ O-N calculated as % of N added ^d			
Form ^a	Amount (kg N ha ⁻¹)	13 days ^b	25 days ^b	43 days ^b	96 days ^{b,c}	13 days	25 days	43 days	96 days
None	-	16	21	55	330	-	-	-	-
CN	125	23(144)	35(167)	77(140)	382(116)	0.01	0.01	0.02	0.04
CN	250	24(150)	34(162)	73(131)	358(109)	<0.01	0.01	0.01	0.01
U	125	83(519)	90(429)	136(247)	503(153)	0.05	0.06	0.07	0.14
U	250	215(1344)	236(1124)	288(524)	617(196)	0.08	0.09	0.09	0.12
AS	125	114(713)	131(624)	184(335)	557(169)	0.08	0.09	0.10	0.18
AS	250	267(1669)	298(1419)	355(645)	613(186)	0.10	0.11	0.12	0.11

^aCN, calcium nitrate; U, urea; AS, ammonium sulfate.

^bFigures in parentheses indicate amount of N₂O-N evolved calculated as percentage of amount evolved from unfertilized soil.

^cAnalysis of variance showed that emissions of N₂O from the plots treated with ammonium sulfate or urea were significantly higher (P = 0.01) than those from the plots treated with calcium nitrate and that emissions of N₂O from the plots treated with 250 kg N ha⁻¹ as urea or ammonium sulfate were significantly higher (P = 0.01) than those from the plots treated with 125 kg N ha⁻¹ as urea or ammonium sulfate.

^d[(Amount of N₂O-N evolved from fertilized plot - amount evolved from unfertilized plot) ÷ amount of fertilizer N added] × 100.

Results and Discussion

Figure 1 and Table 1 show that treatment of plots with fertilizer N as ammonium sulfate or urea led to marked increases in emissions of N₂O, but that treatment of plots with fertilizer N as calcium nitrate did not lead to comparable increases in N₂O emissions. Table 1 also shows that, whereas an increase in the rate of application of ammonium sulfate or urea from 125 to 250 kg N ha⁻¹ led to a marked increase in emission of N₂O, a corresponding increase in the amount of fertilizer N applied as calcium nitrate did not increase the amount of N₂O evolved.

Laboratory research (Bremner and Blackmer, 1978, 1979a) has shown that most of the N₂O evolved from soils fertilized with ammonium sulfate or urea is generated within 2 weeks and that N₂O emissions from such soils after about 3 weeks are not significantly greater than N₂O emissions from unfertilized soils. Figure 1 shows that a similar pattern of N₂O production was observed in our field study of emissions of N₂O from plots treated with ammonium sulfate or urea. Soil analyses indicated that most of the N added to these plots was nitrified (i.e. oxidized to nitrate) within 3 weeks (less than 5% of this N could be recovered as ammonium N after 21 days). These observations support our conclusion from laboratory research (Bremner

and Blackmer, 1978, 1979a) that most of the N₂O evolved from soils fertilized with ammonium sulfate or urea is generated by nitrifying microorganisms during oxidation of ammonium to nitrate because Figure 1 shows that most of the N₂O evolved in 6 weeks from plots treated with ammonium sulfate or urea was produced within the first 3 weeks.

In view of the general assumption that most of the N₂O evolved from soils treated with N fertilizers is produced through reduction of fertilizer-derived nitrate by denitrifying microorganisms under anaerobic conditions, attention should be drawn to our finding that application of fertilizer N as calcium nitrate did not lead to a marked increase in N₂O emissions from the plots studied (Figure 1 and Table 1) even though rainfall during the study period was considerably above average and the moisture content of the soil in the study area (see Figure 1) was frequently near, and at times above, field capacity (32%). This finding cannot be attributed to loss of nitrate by leaching because soil analyses showed that the nitrate-treated plots contained substantial amounts of nitrate throughout the study period. The fact that the nitrate-treated plots did not evolve substantial amounts of N₂O during this unusually wet period merits emphasis because it has been assumed that high soil moisture content promotes emission of N₂O through reduction of

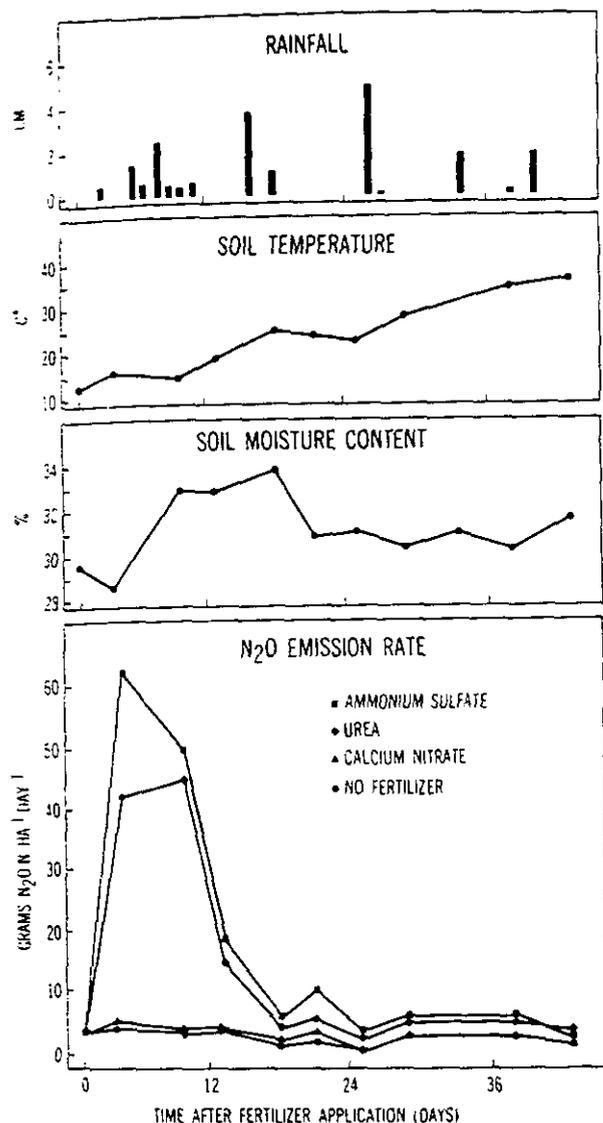


Fig. 1. Results of measurements of N_2O emission rates, soil temperature, soil moisture content, and rainfall during the period June 1 - July 14, 1979. Fertilizer N was applied on June 2 (250 kg/ha). Each N_2O emission rate reported represents the mean rate for 12 replicated plots.

nitrate to N_2O by denitrifying microorganisms.

Our finding that N_2O emissions from plots fertilized with calcium nitrate were much smaller than those from plots fertilized with ammonium sulfate or urea is in harmony with the results of laboratory studies of the effects of ammonium sulfate, urea, and potassium nitrate on N_2O emissions from soils at different moisture contents (Bremner and Blackmer, 1978, 1979a), and it clearly supports our conclusion that most of the N_2O evolved from soils treated with fertilizer N as ammonium sulfate or urea is produced by nitrifying microorganisms during oxidation of this N to nitrate and not, as previously assumed, by anaerobic denitrification of the nitrate produced by these microorganisms.

The work reported shows that, to obtain reliable data in studies of the effects of N fertilizers on N_2O emissions from soils, it is necessary to perform long-term studies because

short-term studies can greatly overestimate these effects. This is illustrated by Table 1, which shows that, whereas the fertilizer-induced emissions of N_2O in 13 days from the plots treated with 250 kg N ha^{-1} as ammonium sulfate were 15.7 times greater than the emissions of N_2O from the unfertilized plots, the corresponding fertilizer-induced emissions in 96 days were only 0.86 times greater than the emissions from the unfertilized plots.

Hahn and Junge (1977) calculated that, when soils are treated with N fertilizers, the amount of fertilizer N converted to N_2O by soil microorganisms during the first one or two weeks after fertilization probably represents between 3 and 12% of the fertilizer N added. This seems a gross overestimate of the percentage of fertilizer N converted to N_2O in soils treated with ammonium sulfate, urea or calcium nitrate because Table 1 shows that the fertilizer-induced emissions of N_2O -N we observed in 13 weeks after application of these fertilizers represented only 0.01-0.18% of the fertilizer N added. It should be noted, however, that work in progress has shown that N_2O emissions from soils fertilized with anhydrous ammonia markedly exceed those from soils treated with ammonium sulfate, urea or calcium nitrate (Bremner and Blackmer, 1979b). The fertilizer-induced emissions of N_2O -N observed in the work reported in Table 1 are similar to those observed in recent laboratory studies (Bremner and Blackmer, 1978, 1979a) of the effects of ammonium sulfate, urea and potassium nitrate on N_2O emissions from Iowa soils and in a recent field study (McKenney et al., 1978) of the effects of different amounts of ammonium nitrate on N_2O emissions from two Canadian soils.

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