Nitrification of Ammonium Applied to Soils in Fall, Winter and Early Spring

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Introduction

One of the major problems associated with fall, winter, and early spring applications of ammoniacal fertilizers is the loss of nitrate that occurs following nitrification of added N. Any nitrate present in the profile during the period from March through June has the potential to be lost by leaching (coarse-textured soils) or denitrification (fine-textured soils). Producers are interested in fall and early spring fertilizer applications to avoid excessive work loads at planting time and to take advantage of lower fertilizer prices in the fall. Thus, management procedures that minimize loss of fall or early spring applied N are needed. Two techniques that have been proposed to reduce N losses are: (i) to delay fertilizer application until low soil temperatures prevent nitrification, or (ii) to employ chemicals (nitrification inhibitors) that kill the soil bacteria (*Nitrosomonas* spp.) responsible for ammonium oxidation.

The effect of soil temperature on nitrification is not well defined. Sabey et al. (1956) found that only minimal nitrification occurred when soils were fertilized after soil temperatures had fallen below 10 °C. However, other workers have reported that appreciable nitrification occurred at 7 °C (Frederick, 1956) and some nitrification occurred at 2 °C (Frederick, 1956; Siefert, 1961). Most soil science extension personnel in the Cornbelt recommend that fall application of ammoniacal fertilizers be delayed until soil temperatures decline below 10 °C. However, there is little scientific evidence to support this position. Nitrapyrin [2-chloro-6-(trichloromethyl)pyridine] is a specific and highly effective nitrification inhibitor (Goring, 1962; Huber et al., 1977), however, little is known about the activity of the chemical at low soil temperatures. Therefore, a laboratory study was conducted to define the relationships between cool season temperatures and nitrification in soils in the presence and absence of nitrapyrin.

Materials and Methods

Samples (0-15 cm depth) of two cultivated soils were collected near W. Lafayette, Indiana, air-dried, and crushed to < 2-mm. Chalmers silty clay loam (Typic Argiaquoll) contained 30% clay, 51% silt, 0.20% total N, and 2.60% organic C and had a water pH of 6.8. Fox silt loam (Typic Hapludalf) contained 18% clay, 75% silt, 0.14% total N, and 1.71% organic C and had a water pH of 6.9.

Ten g (oven-dry equivalent) samples of soils were mixed with 30 g of washed quartz sand and added to 225 cm^3 glass bottles containing 4 cm^3 of deionized water. The bottles were covered with 1 mil polyethylene film and incubated without light in a constant temperature cabinet. The temperature was varied throughout the incubation to simulate average long term fall, winter, and spring soil temperatures (10 cm depth) at the Purdue University Agronomy Farm, W. Lafayette, Indiana. Initial starting temperature was 13 °C (simulating conditions on October 15) and the incubation was conducted for 186 days. Termination of the incubation occurred at a spring temperature of 13 °C which simulated conditions on April 20. Different sets of samples were periodically (10 times during the study) removed, treated with 2 cm^3 of ammonium sulfate solution containing 2 mg of N, and returned to the constant temperature cabinet. Other sets of samples were treated with 2 cm^3 of a solution that contained 2 mg of ammonium sulfate N and 30μg of nitrapyrin. After varying periods of incubation, duplicate samples of treated soils were removed from the incubator and analyzed for ammonium and nitrate by an extraction-distillation procedure (Keeney and Nelson, 1982).

The percent nitrification occurring at varying times after N addition was calculated by the procedure of Bundy and Bremner (1973). The degree-days (DD) that accumulated during an incubation period after N addition were calculated from the equation:

$$DD = \sum_{i=1}^{N} (t \bullet n)$$

where t = temperature during the period
n = number of days in the incubation period
N = number of incubation periods for which DD are accumulated

Nitrification rates were calculated by dividing the amount of nitrate N formed per g of soil by the number of days in the incubation period. All data reported are means of at least duplicate determinations and all values are reported on a moisture-free basis. Values for duplicate samples agreed within ±5%.

Results and Discussion

Table 1 gives data on nitrification in Chalmers soil as affected by N application time and soil temperatures after fertilization. Ammonium added on October 15 (13 °C initial temperature) was almost completely nitrified by Dec. 21. Nitrification of ammonium was 92 and 84% complete by Apr. 20, for ammonium added on Oct. 30 and Nov. 10, respectively. For ammonium additions made between Jan. 1 and Mar. 21, < 17% had nitrified by Apr. 20.

About 54% of ammonium added to Fox soil on Oct. 15 had been nitrified by Apr. 20 (Table2). Nitrification was only 33 and 30% complete by Apr. 20 for am-

TABLE 1. *Effect of soil temperature on nitrification of ammonium added to Chalmers soil*

Date of sampling[+]	Time and soil temperature (°C) when N applied									
	15 Oct 13	30 Oct 10	10 Nov 7.2	28 Nov 4.4	21 Dec 1.7	14 Jan -0.8	4 Feb 1.7	22 Feb 4.4	9 Mar 7.2	21 Mar 10
	% of added NH_4^+ − N nitrified									
30 Oct (10)	34									
10 Nov (7.2)	61	1								
28 Nov (4.4)	88	15	0							
21 Dec (1.7)	98	33	15	1						
14 Jan (-0.8)	—	—	24	16	0					
4 Feb (1.7)	—	—	—	16	0	0				
22 Feb (4.4)	100	77	73	—	0	0	0			
9 Mar (7.2)	—	—	—	30	—	3	—	0		
21 Mar (10.0)	100	85	83	36	7	—	2	1	2	
5 Apr (13.0)	—	—	—	—	—	11	9	4	4	6
20 Apr (15.0)	100	92	84	48	21	16	17	14	16	17

[+] Values in parentheses are soil temperatures (°C) at the end of incubation period.

TABLE 2. *Effect of soil temperature on nitrification of ammonium added to Fox soil.*

	Time and soil temperature (°C) when N applied									
Date of sampling[+]	15 Oct 13	30 Oct 10	10 Nov 7.2	28 Nov 4.4	21 Dec 1.7	14 Jan -0.8	4 Feb 1.7	22 Feb 4.4	9 Mar 7.2	21 Mar 10
	% of added NH_4^+ – N nitrified									
30 Oct (10)	13									
10 Nov (7.2)	31	1								
28 Nov (4.4	41	18	0							
21 Dec (1.7)	42	13	4	0						
14 Jan (-0.8)	—	—	11	6	0					
4 Feb (1.7)	—	—	—	7	0	0				
22 Feb (4.4)	73	17	21	—	4	1	0			
9 Mar (7.2)	—	—	—	16	—	2	1			
21 Mar (10.0)	47	28	29	21	—	—	2	2	0	
5 Apr (13.0)	—	—	—	—	—	6	4	5	4	4
20 Apr (15.0)	54	33	30	23	20	11	8	11	12	6

[+] Values in parentheses are soil temperatures (°C) at the end of incubation period.

monium additions made on Oct. 30 and Nov. 10. Ammonium added to Fox soil between Nov. 28 and Mar. 21 was < 23% nitrified by Apr. 20. There was no nitrification in samples of Chalmers and Fox soils treated with ammonium and nitrapyrin regardless of time N was applied or length of incubation following fertilization.

These findings suggest that nitrification occurred in some soils at temperatures near freezing and that a significant potential for loss of fall applied N existed with such soils. However, other soils have low nitrification potentials and only modest amounts of nitrate were formed by mid spring when ammonium was applied at times soil temperatures were < 10°C. The addition of nitrapyrin at 3 $\mu g\ g^{-1}$ of soil completely eliminated nitrification in two soils incubated at temperatures of < 13°C. Therefore, ammoniacal fertilizers can be safely applied in the fall if soil temperatures are < 13°C and nitrapyrin is added. However, significant nitrification may occur in some soils not treated with a nitrification inhibitor even though N applications are delayed until soil temperatures are < 10°C.

Soil temperatures have a marked effect on nitrification rates (Table 3). Nitrification rates of soils incubated at a simulated fall temperature of 10°C averaged 8 and 4 times higher than those of soils incubated at simulated spring temperatures of 10

TABLE 3. *Effect of soil temperature on nitrification rates in two soils.*

		Soil type		
Season	Soil temperature	Chalmers	Fox	Average
	°C	mg NO_3^- – N formed/g/day		
Fall	10.0	3.45	2.09	2.77
Fall	7.2	1.56	0.62	1.09
Fall	4.4	0.90	0.32	0.61
Winter	1.7	0.71	0.30	0.51
Winter	-0.8	0	0	0
Winter	1.7	0.09	0.06	0.08
Spring	4.4	0.27	0.18	0.23
Spring	7.2	0.33	0.31	0.32
Spring	10.0	0.38	0.32	0.35
Spring	13.0	0.87	0.47	0.67

and 13 °C, respectively. Nitrification rates decreased markedly as simulated fall temperatures decreased from 10° to 1.7 °C and no nitrification was measured at temperatures < 0 °C. Increasing soil temperatures from 1.7 to 13 °C during a simulated spring season resulted in increased nitrification rates. However, the nitrification rate at a simulated spring temperature of 13 °C was only slightly higher than the rate at a simulated fall temperature of 4.4 °C.

There were close relationships between the degree-days that accumulated and the amount of nitrate N that formed within a time period when ammomium-treated Chalmers soil was incubated at varying temperatures (Figure 1). However, approximately 7 times more nitrate N accumulated per degree-day with fall applied N as compared to spring applied N. Similar results were obtained with Fox soil. The regression equations for Chalmers soil were:

$y = -48 + 0.36X$ $r^2 = 0.86$ (Fall applied N)

$y = -4 + 0.05X$ $r^2 = 0.82$ (Spring applied N)

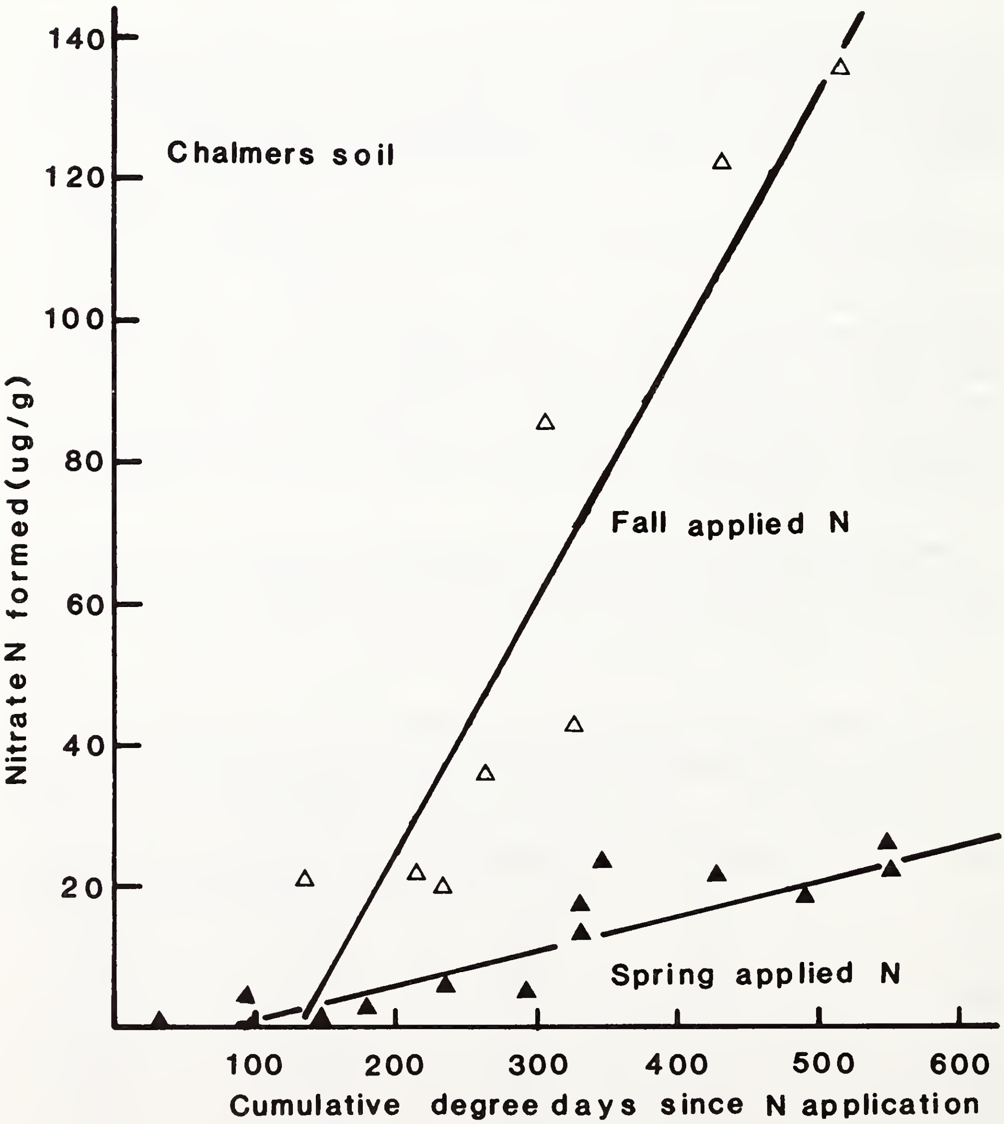

FIGURE 1. *Relationship between nitrate N formed in Chalmers soil and degree-days accumulated during an incubation period.*

The regression equations for Fox soil were:

$y = -19 + 0.14X$ $r^2 = 0.81$ (Fall applied N)

$y = -1 + 0.03X$ $r^2 = 0.88$ (Spring applied N)

where y = nitrate N formed in $\mu g\ g^{-1}$ of soil

x = cumulative degree-days in incubation period.

These data indicate that freezing had a profound impact on nitrification in soils. Nitrification rates at a specified temperature were much lower after freezing as compared to those in unfrozen soil. The number of degree-days accumulated per unit of nitrate N formed was much greater for spring applied N than for fall applied N. A possible explanation for these findings is that freezing kills a major proportion of the *Nitrosomonas* spp. in soil and the population expands slowly in the spring because of cool soil temperatures. Campbell et al. (1971) have previously shown that microorganisms present in soils during the fall condition themselves to low temperatures, but soil microorganisms are very sensitive to low temperatures in the spring. These findings suggest that freezing may be a major mechanism for N conservation in soils and that there is little potential for rapid nitrification following ammonium addition to soils in winter or early spring.

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