ure 4 shows the temperature pattern for 2 days during the 1963 and 1977 SSW in which the nightly minimum temperature remained above freezing over only a small part of the United States.

Another effect, not discussed here, results from large modifications in the atmospheric energy cycle. During SSW a large portion of the energy available for storm development is lost to the stratosphere and to space (up to 60 percent of the annual variation of this energy) (*7*). With such a dearth of energy for storm development, a reduction or at least a modification in storm activity is anticipated. However, the magnitude of this reduction as well as the change in the average storm track position, are difficult to substantiate statistically on the basis of the relatively few strong SSW presently available for study.

At any rate, weather over the United States is remarkably similar during strong SSW, as shown by the weather summaries prepared by the National Weather Service for 1958 and 1963 (*10*). These descriptions of snow in the upper Midwest and Florida, warm weather in Alaska, dryness in the West, and persistent cold east of the Rockies were repeated in the January 1977 weather. Therefore, the extreme conditions of January 1977 seem to be typical of strong SSW and thus they should not be considered all that rare.

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Nitrous Oxide: Emission from Soils During Nitrification of Fertilizer Nitrogen

Abstract. *Nitrous oxide is released from soils to the atmosphere during nitrification of ammonium and ammonium-producing fertilizers under aerobic conditions as well as by denitrification of nitrate under anaerobic conditions. Emissions of nitrous oxide during nitrification of fertilizer nitrogen may be significant in regard to the potential threat of fertilizer-derived nitrous oxide to the stratospheric ozone layer. Such emissions can be greatly reduced through the use of nitrapyrin, which inhibits nitrification of ammonium by soil microorganisms.*

Recent literature reflects international concern that increased use of fertilizer N to aid world food production may pose a threat to the stratospheric O_3 layer (*1–3*). This concern stems from the hypothesis that N_2O released to the atmosphere through denitrification of fertilizer-derived nitrate in soils may trigger reactions in the stratosphere leading to partial destruction of the O_3 layer (*2, 4*).

Most of the fertilizer N now added to soils is in the form of ammonium or of urea, which is rapidly hydrolyzed by soil urease with the formation of $(NH_4)_2CO_3$. This N is not susceptible to denitrification until it is nitrified, that is, oxidized to nitrite or nitrate by soil microorganisms. Although there is evidence that heterotrophic microorganisms may contribute to the nitrification of ammonium in soils (*5*), it is generally believed that autotrophic bacteria (species of *Nitrosomonas* and *Nitrobacter*) are largely responsible for nitrification in soils and other natural ecosystems (*6*). *Nitrosomonas* sp. oxidize ammonium to nitrite, and *Nitrobacter* sp. oxidize nitrite to nitrate.

There is abundant evidence that N_2O is released from soils through denitrification of nitrate under anaerobic conditions. We report here evidence that this gas also is released from soils during nitrification of ammonium under aerobic conditions.

The possibility that N_2O may be released to the atmosphere during nitrification of fertilizer N was studied because several workers have detected formation of small amounts of N_2O during the oxidation of ammonium by intact cells or cell-free extracts of *Nitrosomonas europaea* under certain conditions (*7*). To investigate this possibility, we studied the release of N_2O from soils incubated under aerobic conditions after treatment with different forms of fertilizer N. The soils were surface (0 to 30 cm) samples of Iowa soils used for corn and soybean production. They were sieved (2-mm screen) in the field-moist condition, and samples of the screened soils containing 30 g of oven-dry material were incubated at 30°C for various times after treatment with different forms of N and sufficient water to bring their water content to about 60 percent of the water-holding capacity. Incubations were carried out in 1.2-liter bottles sealed with glass stoppers fitted with a ground-glass joint and a glass stopcock. The atmospheres in the bottles were sampled at 2-day intervals for determination of N_2O and O_2 by gas chromatography (*8*), and the bottles were aerated for a few minutes immediately after these determinations. The O_2 determinations showed that the atmospheres analyzed always contained at least 20 percent O_2 (by volume).

Table 1 shows that the amounts of N_2O released from well-aerated soils treated with $(NH_4)_2SO_4$ or urea were much greater than the amounts released from soils treated with KNO_3 (*9*). Whereas the amounts of N_2O released from soils treated with $(NH_4)_2SO_4$ or urea increased with the amount of ammonium N or urea N added, the amounts of N_2O released from soils treated with KNO_3 did not increase significantly with the amount of nitrate N added and were not appreciably different from the amounts released from unamended soils. This result indicates that very little, if any, of the N_2O released from the soils treated with $(NH_4)_2SO_4$ or urea was produced through denitrification of nitrate. Evidence that the observed emissions of N_2O resulted from microbial activity was obtained from experiments showing that no release of N_2O could be detected when soils sterilized by autoclaving at 120°C for 2 hours were incubated under aerobic conditions at 30°C after treatment with N as $(NH_4)_2SO_4$ or urea (100 μg of N per gram of soil).

The deduction from Table 1 that N_2O is produced during nitrification of ammonium N or urea N in soils under aerobic conditions is supported by our finding (Table 2) that nitrapyrin [2-chloro-6-(trichloromethyl)pyridine] greatly reduces the emission of N_2O from well-aerated soils treated with $(NH_4)_2SO_4$ or urea. We studied the effect of nitrapyrin because this compound inhibits the oxidation of ammonium to nitrite by *N. europaea* (*10*) and greatly retards nitrification of ammonium N and urea N in soils (*11*).

It seems very unlikely that formation of N_2O during nitrification of fertilizer N is of any practical significance in regard to loss of fertilizer N. Table 1 shows that the amounts of N released as N_2O in 30 days from soils treated with $(NH_4)_2SO_4$ or urea represented only 0.04 to 0.45 percent of the N added. However, the work reported here indicates that emission of N_2O from soils during nitrification of fertilizer N may be significant in relation to the potential threat of fertilizer-derived N_2O to the stratospheric O_3 layer. This is evident from Table 1, which shows that, when expressed as kilograms of N per hectare of soil, the amounts of N released as N_2O in 30 days from soil samples treated with 300 or 400 μg of ammonium or urea N per gram of soil were comparable to estimates in a recent report of the Council for Agricultural Science and Technology (CAST) (*1*) of the amounts of N_2O-N released annually from soils to the atmosphere. Calculations in the CAST report suggest that the average fluxes of N_2O-N from cropped and uncropped land are about 1.0 and 0.2 kg ha^{-1} $year^{-1}$, respectively. These fluxes are similar to those calculated by Focht *et al.* (*12*) from studies to assess the release of N_2O-N from soils in California (0.5 to 1.0 kg ha^{-1} $year^{-1}$).

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Table 1. Amounts of N_2O released from well-aerated soils treated with different forms of nitrogen. Ammonium N was added as $(NH_4)_2SO_4$; nitrate N was added as KNO_3.

N added		N_2O-N released (ng per gram of soil)				PC*	KH†
Form	Amount (μg per gram of soil)	4 days	8 days	16 days	30 days		
Harps soil (pH 7.8), 4.4 percent organic C and 33 μg of nitrate N per gram of soil							
None	0	1	2	4	5		0.003
Ammonium	25	18	20	23	26	0.10	0.015
Urea	25	25	28	30	32	0.13	0.018
Nitrate	25	2	3	4	5	0.02	0.003
Ammonium	50	50	52	55	58	0.12	0.032
Urea	50	54	58	61	64	0.13	0.036
Nitrate	50	3	4	5	5	0.01	0.003
Ammonium	100	135	146	150	153	0.15	0.086
Urea	100	113	118	121	124	0.12	0.069
Nitrate	100	3	4	5	7	0.01	0.004
Ammonium	200	223	239	244	246	0.12	0.138
Urea	200	266	280	284	286	0.14	0.160
Nitrate	200	3	4	6	7	<0.01	0.004
Ammonium	300	336	406	412	416	0.14	0.233
Urea	300	387	499	507	511	0.17	0.286
Nitrate	300	3	4	7	8	<0.01	0.004
Ammonium	400	421	1230	1740	1800	0.45	1.01
Urea	400	556	1390	1670	1700	0.43	0.95
Nitrate	400	5	6	14	15	<0.01	0.008
Webster soil (pH 6.8), 3.9 percent organic C and 7 μg of nitrate N per gram of soil							
None	0	3	6	9	11		0.006
Ammonium	100	12	21	35	43	0.04	0.024
Urea	100	25	42	49	55	0.06	0.031
Nitrate	100	3	6	11	16	0.02	0.009
Sparta soil (pH 5.4), 0.7 percent organic C and 7 μg of nitrate N per gram of soil							
None	0	2	4	7	14		0.008
Ammonium	100	4	16	25	36	0.04	0.020
Urea	100	10	19	33	50	0.05	0.028
Nitrate	100	3	5	7	14	0.01	0.008

*Amount of N evolved as N_2O in 30 days calculated as a percentage of N added. †Amount of N evolved as N_2O in 30 days expressed as kilograms of N per hectare of soil.

Table 2. Effect of nitrapyrin on the release of N_2O from samples of Harps soil incubated under aerobic conditions after treatment with different forms of N; N was added at the rate of 100 μg per gram of soil [ammonium N as $(NH_4)_2SO_4$, nitrate N as KNO_3].

Form of N added	Nitrapyrin*	Amount of N_2O-N released (ng per gram of soil)			
		2 days	6 days	10 days	20 days
None	−	1	2	3	4
None	+	1	2	3	4
Ammonium	−	62	144	147	148
Ammonium	+	4	7	8	10
Urea	−	73	117	119	122
Urea	+	1	2	3	4
Nitrate	−	3	4	5	6
Nitrate	+	1	2	3	4

*Added at a rate of 8 μg per gram of soil.

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