AP42 Section:	9.2.1
Background Ch	4
Reference:	23
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acid as it may have done in pre-industrial times. Figure 2*a* implies an increase in nitrate ion deposition over eastern North America of ~0.06 equiv m^{-2} yr^{-1} since 1880. In regions receiving a 100-cm annual precipitation this would imply a precipitation weighted mean p_H shift from 5.6 to about 4.2 in carbon dioxide equilibrated water. Note that the present day deposition of sulphate ions (0.09 equiv m^{-2} yr^{-1}; 1.2 g (S) m^{-2} yr^{-1} wet deposition and 0.25 g (S) m^{-2} yr^{-1} dry deposition[6]) is not very much larger than the current deposit of nitrate (0.065 equiv m^{-2} yr^{-1}), reaffirming that the nitrate component of rain makes an important contribution to its acidity. Agricultural records do hint at an increase in sulphur deposition, but problems experienced in early analysis make these changes less clear than those for the nitrate and ammonium ion. The relative contribution of the nitrate and sulphate components of western European precipitation are different. In the English east Midlands, for example[15], the deposits are: NO_3^-, <0.03; SO_4^{2-}, 0.055 equiv m^{-2} yr^{-1}, showing a slightly smaller contribution from the nitrogen component than in the North American observations. This difference might be expected from the differing patterns of fuel usage, as the number of equivalents provided by the NO_x component of the UK fuel emission is less than one-quarter of that derived from sulphur, while in the US it is about one-half.[16]

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Emissions of nitrous oxide from soils

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Potential changes in the concentration of nitrous oxide (N_2O) in the atmosphere have sparked considerable interest because of the proposed role of N_2O in regulating stratospheric ozone levels, and in contributing to the atmospheric greenhouse effect. A substantial portion of the atmospheric N_2O is thought to result from microbial transformations of inorganic forms of nitrogen in soils; N_2O is an intermediate in denitrification (reduction of NO_3^- to N_2) and is formed during nitrification (oxidation of NH_4^+ to NO_3^-) in soils, although the mechanism is unclear. Several models have predicted that input of nitrogen into cropland, either from commercial fertilizers or N-fixing leguminous crops, could sufficiently increase emissions of N_2O from soils to deplete stratospheric ozone levels[1–3] and raise average world temperatures[4]. We report here N_2O emissions from mineral and organic soil sites in New York and from organic soil sites in the Florida Everglades Agricultural Area.

Only a few studies of emissions of N_2O from soils have been carried out over extended time periods in commerical aricultural conditions. In the US Hutchinson and Mosier[5] measured a loss of 2.6 kg N_2O–N ha^{-1} during corn growth in typical Colorado conditions and emissions of N_2O ranging from 6 to 40 kg N ha^{-1} yr^{-1} have been reported for heavily fertilized, irrigated, vegetable fields in California[6,7]. Ryden found that 3.3 kg N_2O–N ha^{-1} yr^{-1} were evolved from fertilized perennial ryegrass in the UK[8]. These data exceed the Council for Agricultural Science and Technology's (CAST) estimated average value for cropland of 1 kg N_2O–N ha^{-1} yr^{-1} (ref. 9) and indicate the need for further assessment of emissions of N_2O from agricultural fields.

Measurement of N_2O flux from sites in New York and Florida was by a chamber method[10]. Sampling locations within a site were defined for extended periods of time by a metal rim (60 or 76 cm diameter) sunk 5 or 10 cm into the soil. When a flux measurement was to be made, a chamber was completed by sealing an insulated top to the rim with a wide rubber band cut from tire innertubes. Chamber volume was 28, 56, or 80 l and tops were removed immediately after each flux measurement. Gas samples (5 or 10 ml) were withdrawn from the chamber at zero time and 10-min intervals up to 30 min or at 30-min intervals up to 1 h, and their N_2O contents were determined by gas chromatographic analysis using a ^{63}Ni electron capture detector[10]. Analytical precision was routinely 1% at the 1 p.p.m. level. Changes in concentration of N_2O greater than 10 p.p.b. in 1 h (3% of ambient level, corresponding to a flux of about 0.5 g N ha^{-1} day^{-1}) were considered significant. Frequency of flux measurement was based on the magnitude of observed fluxes and on environmental and management variables. Measurements were usually made daily during high flux periods.

Daily flux values were the mean of four or five simultaneous flux measurements from chambers spaced randomly (5–10 m apart) over the site. The coefficient of variation (CV) for daily flux measurements ranged from 0 to 224%, with means in the range 60–94% for New York and 43–56% in Florida. No relationship between flux magnitude and CV was found. Fluxes from individual chambers showed similar trends with time but were sometimes out of phase during high flux periods. Variability amongst chambers was consistently reduced when fluxes were summed over important flux periods, allowing significant effects of treatment and/or crop on N_2O emissions to be demonstrated.

Mineral soil sites in New York were on silt loam soils. Alfalfa and field corn were grown following established practices for the northeastern US and an unmanaged timothy grass-mixed weed stand was included for comparative purposes. Only corn received fertilizer N; 20 kg N ha^{-1} was applied to the seed bed at planting, but the major nitrogen supply came either from manure applied and ploughed down before planting (C_M) or from a sidedressing of commercial liquid fertilizer applied 40 days after planting (C_F). Annual emissions of N_2O from

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Table 1 Emissions of nitrous oxide from cultivated soils

Crop	N fertilizer treatment*	Maximum observed daily N_2O flux	Annual N_2O emissions May 1979 –May 1980	May 1980 –May 1981
		(kg N ha^{-1})		
Mineral soils				
Alfalfa	0	0.63	4.2	2.3
Field corn A	130 (M)	0.22	2.4	2.9
	130 (F)	0.28	—	2.2
Field corn B	130 (M)	0.19	—	3.8
	130 (F)	0.36	1.6	2.9
Timothy-weeds	0	0.23	1.7	0.9
Organic soils				
Onions (NY)	170	4.5	85	72
Sweet corn	170	2.9	76	152
Sugarcane (FL)	0	3.1	48	7
St Augustine-grass (FL)	0	4.6	97	16
None (fallow) (FL)	0	4.5	165	59

* Field corn sites received 20 kg N ha^{-1} added as NH_4NO_3 in the seedbed and 112 kg N ha^{-1} supplied by either $(NH_2)_2CO$–NH_4NO_3 (1:1) fertilizer sidedressed 40 days after planting (F), or manure (45 tonnes ha^{-1}) applied before planting (M). A single fertilizer treatment (M or F) was applied to each site in 1979–80. In 1980–81 each site was subdivided into 10-m wide strips which received either the M or F treatment on an alternating strip basis. Fertilizer containing NH_4NO_3 was broadcast on the organic soil sites in New York before planting.

these sites over the 2 yr period from 1 May 1979 to 30 April 1981 ranged from 1.5 to 4.2 kg N ha^{-1} (Table 1). Nitrous oxide evolution from the N-fixing alfalfa site was greater than from the corn sites in the first year of the study, but in the second year, emissions increased in the order alfalfa $\leq C_F < C_M$. In both years, more N_2O was evolved from the C_M than from the C_F treatment and the least N_2O was lost from the timothy-mixed weed pasture. The pattern of N_2O emissions from the four sites varied considerably. High fluxes of N_2O were always associated with wet soil conditions, which promote denitrification, but the converse was not always true. Nitrous oxide evolution from the alfalfa and timothy-mixed weed sites was greatest during early spring thaws; for example, 66 and 57% of the 1979–80 annual total from the alfalfa and timothy plots, respectively, was evolved between 20 March and 7 April 1980. The highest observed daily flux was 0.63 kg N ha^{-1} from the alfalfa plot on 20 March 1980 and 27% of the 1979–80 annual total was evolved in the two days 19–20 March.

Peak emissions of N_2O from the corn plots occurred following fertilization. Over the two study years, 62–78% of the annual loss of N_2O from the manured sites occurred in the 9 weeks following manure application (end of April). Evolution of N_2O from site B (Table 1) following sidedressing of liquid fertilizer nitrogen on 25 June in 1979 and 1980 is shown in Fig. 1. Nitrogen was applied to alternate rows and the impact of fertilization was compared using four pairs of chambers. The chambers in each pair were placed opposite each other in adjacent fertilized and unfertilized rows. In 1979, fluxes of N_2O from fertilized rows were elevated compared with unfertilized rows for 9 weeks following fertilization. During this time, N_2O emissions were 0.80 and 0.18 kg N ha^{-1} for fertilized and unfertilized rows, respectively. A similar pattern was observed in 1980 but wetter soil conditions resulted in evolution of 3.40 and 0.35, kg N_2O–N ha^{-1} from fertilized and unfertilized rows, respectively, during the 7-week period that fluxes were elevated by fertilizer. These differences were significant at the 5% confidence level.

Significant effects of crop and/or treatment on N_2O emissions could be demonstrated for selected time intervals within a year because, with the exception of the alfalfa and timothy plots, peak flux periods did not coincide. When cumulative fluxes from individual chambers were compared, N_2O emissions from the alfalfa site were significantly greater (5% confidence level) than from all other sites for the period 24 March to 10 April. Similar results were obtained for the corn (M) and corn (F) sites for the periods 1 May to 24 June and 25 June to 10 August, respectively. Statistical comparison of annual N_2O emission totals could not be made because chambers were moved between peak flux periods.

Cultivated organic soil sites were included in the present study because most of the estimated 600–1,200 kg ha^{-1} of nitrogen mineralized each year[11,12] appears to be denitrified. The study sites were located in a fallow field (bare) and fields cropped to St Augustine-grass (*Stenataphrum secundatum* (Walt) Kintz) and sugarcane (*Saccharum* spp.) in the Florida Everglades, and in fields cropped to onions (*Allium*) and sweet-corn (*Zea mays* L. Rugosa) in NewYork.

Both daily fluxes and annual emissions of N_2O from the organic soil sites were considerably higher than from the mineral soil sites. Maximum daily fluxes of N_2O ranged from 2 to 5 kg N ha^{-1} and annual totals from 7 to 165 kg N ha^{-1} (Table 1). High N_2O fluxes were sustained for substantial periods of time (Fig. 2); for example, the daily flux of N_2O from the fallow field in Florida was above 1 kg N ha^{-1} for 27 days in July 1979. Peak emissions of N_2O occurred during the wet summer months in Florida and the wet spring and fall periods in New York. A striking feature of the emission pattern in New York was daily fluxes commonly in the range of 0.2–0.4 kg N ha^{-1} during January and February, despite the fact that the surface soil was generally frozen. Soil atmosphere measurements indicated that N_2O was generated in the section of the soil profile that was unfrozen and above the water table.

Annual N_2O emissions from the Florida sites differed substantially in the two study years (Table 1). The dramatic reduction in the second year was attributed to an unusually low amount of precipitation (92 cm compared with 157 cm in the first year and a 54 yr average of 145 cm). Annual emissions varied considerably with crop and showed the same relative pattern in both years increasing in the order sugarcane < grass <

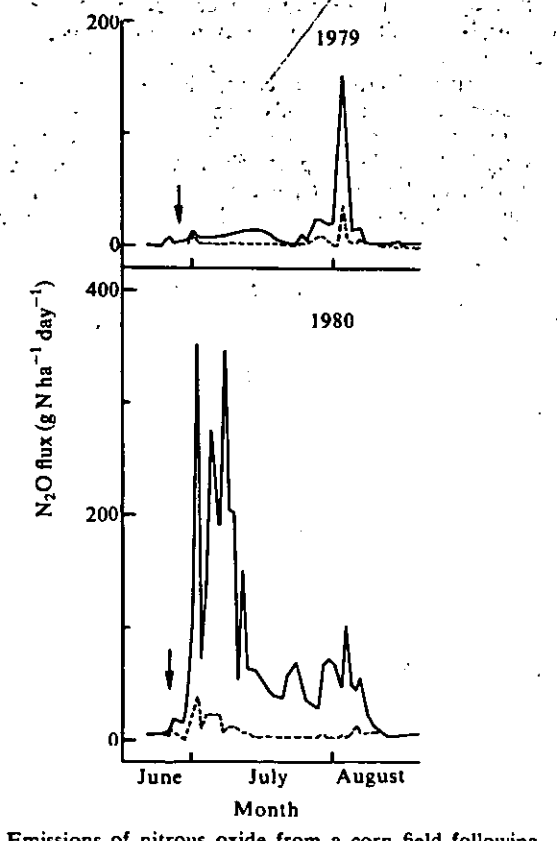

Fig. 1 Emissions of nitrous oxide from a corn field following sidedressing with $(NH_2)_2CO$–NH_4NO_3 (1:1) at the rate of 112 kg N ha^{-1}. Fertilizer was applied to alternate rows at the time indicted by the arrow. Solid and dashed lines are the N_2O flux from the fertilized and unfertilized rows, respectively.

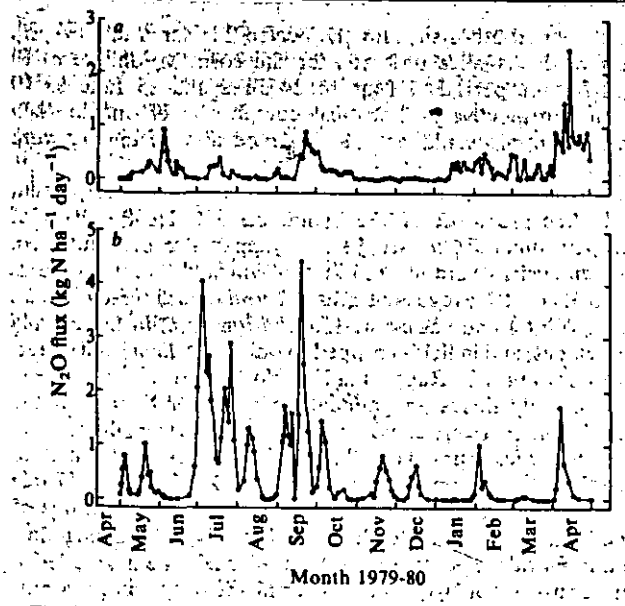

Fig. 2 Emissions of nitrous oxide from cultivated organic soils. *a*, Sweet corn field (New York); *b*, fallow field (Florida).

fallow. At the 5% confidence level, the differences between the sites were all significant in the first study year. In the second year, N_2O loss from the fallow field was significantly higher than from the other sites, which were not different. The large loss from the fallow field compared with the cropped fields was probably the combined result of wetter soil and higher soil nitrate levels in the absence of plants.

In contrast to the report of Ryden[8], none of the soils we studied were ever found to be sinks for atmospheric N_2O. Over the 2-yr period of the study ~13,000 N_2O flux measurements were made. A likely explanation for this difference is that in our study soil nitrate levels never reached the very low level (≤ 1 μg N g^{-1} soil) that Ryden found to be associated with sink activity.

The crucial factor in assessing the impact of agriculture on emissions of N_2O from soils is the extent of perturbation from the undisturbed environment. True baseline data for present day agricultural lands probably cannot be obtained because man has, in the recent past, modified almost all of the land surface in the major agricultural regions of the world, and has increased precipitation inputs of nitrogen. Nevertheless, a survey of soils in Iowa that have no history of fertilizer N treatment showed that annual emissions of N_2O generally did not exceed 0.5 kg N ha^{-1} (A. M. Blackmer and J. M. Bremner, personal communication). Our measurements at a forested mineral soil site in New York and at an organic soil site in a Florida Everglades Conservation Area gave emissions of about 0.9 and 1 kg N_2O–N ha^{-1}, respectively, for the calendar year 1980. Compared with these values, it can be concluded that agriculture caused N_2O emissions from soils to increase up to fourfold for mineral soil sites in New York and by as much as two orders of magnitude from the organic soil sites studied.

It is difficult to place the observations on N_2O emission from agricultural lands in a global perspective because the data base is limited to a few agricultural systems and temperate climates[5-8,13-19]. Nevertheless, from an evaluation of the present data base, we conclude that forests and grasslands, which lose the least N_2O on a unit area basis, may well be the major contributors to the global total because of their large areas. Conversely, the contribution of vegetable cropland and drained organic soils, which lose high amounts of N_2O, is probably small because of their small areas. It is clear, however, that there is a need for further research on N_2O emissions from soils to focus on unmanaged lands and the least intensively managed agricultural lands, which has not been the trend to date.

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A predatory slime mould

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I report here the discovery of a single isolate of a new species of cellular slime mould, *Dictyostellum caveatum*, in bat guano from Blanchard Springs Cavern, Arkansas. Amoebae of this species form common aggregates with all species that have been tested and interfere with their morphogenesis in a dramatic way. The *D. caveatum* amoebae induce a delay of morphogenesis while they consume all of the amoebae of the other species by phagocytosis. Morphogenesis is reinitiated and fruiting bodies containing only *D. caveatum* spores are erected.

The bat guano deposit from which *D. caveatum* was isolated is situated in darkness where the temperature is a constant 15 °C and the relative humidity is always 100%. Seven other species were isolated from the same deposit. A single isolate of *D. caveatum* was obtained which represented less than 1% of the total clones recovered. Stages in the life cycle are shown in Fig. 1.

The amoebae of this species respond in chemotactic tests to *Polysphondylium violaceum* acrasin but do not respond to cyclic AMP, suggesting a close relationship to *Polysphondylium*. The presence of polar spore granules[2] and the high G+C content (30.6%) of the main band DNA[3] also suggest a close affinity to the *Polysphondylium*-related group defined by Traub and Hohl[2]. This group includes several *Dictyostelium* species that are classified in this genus because they lack whorls on their fruiting bodies. *D. caveatum* amoebae migrate as single cells without forming chains and streams (Fig. 1*a*, *b*). However, towards the end of aggregation, short radial streams can sometimes be observed.

D. caveatum amoebae follow the normal cellular slime mould life cycle[4] when growing on bacteria. However, when *D. caveatum* amoebae are washed free of bacteria and mixed with amoebae of other species, only *D. caveatum* spores can be recovered at the end of morphogenesis. This occurs in mixtures of *D. caveatum* with *Dictyostelium discoideum*, *Dictyostelium purpureum*, *Dictyostelium mucoroides*, *Dictyostelium polycephalum*, *Dictyostelium rosarium*, *Dictyostelium minutum*, *Polysphondylium pallidum*, *Polysphondylium violaceum*, *Acytostelium leptosomum* and an unidentified isolate in this laboratory designated LOl-1.

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