JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. D4, PAGES 3893–3898, APRIL 20, 1988

Enhanced Biogenic Emissions of Nitric Oxide and Nitrous Oxide Following Surface Biomass Burning

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Recent measurements indicate significantly enhanced biogenic soil emissions of both nitric oxide (NO) and nitrous oxide (N_2O) following surface burning. These enhanced fluxes persisted for at least 6 months following the burn. Simultaneous measurements indicate enhanced levels of exchangeable ammonium in the soil following the burn. Biomass burning is known to be an instantaneous source of NO and N_2O resulting from high-temperature combustion. Now we find that biomass burning also results in significantly enhanced biogenic emissions of these gases, which persist for months following the burn.

INTRODUCTION

Nitric oxide (NO) and nitrous oxide (N_2O) are key species affecting the photochemistry and chemistry of the troposphere [*Logan et al.*, 1981; *Graedel*, 1985] and stratosphere [*Turco*, 1985], respectively. In addition, N_2O, like carbon dioxide, absorbs infrared radiation and thus impacts the climate of our planet via the greenhouse effect [*Kuhn*, 1985; *Ramanathan et al.*, 1985]. We have obtained measurements that indicate for the first time that fires in a natural ecosystem can result in significantly enhanced biogenic emissions of both N_2O and NO from soils. These enhanced emissions from a semiarid Mediterranean ecosystem persisted for at least 6 months following a prescribed burn and exceeded emissions measured from recently fertilized agricultural soils. Thus burning could have a twofold impact on the emissions of NO and N_2O to the atmosphere: the instantaneous production of NO and N_2O during the high-temperature burning process itself and the enhancement of biogenic emissions of NO and N_2O from burned land for extended periods following the fire.

We measured NO and N_2O fluxes at burned and unburned sites in the San Dimas Experimental Forest, located in the Angeles National Forest (San Gabriel Mountains), approximately 60 km northeast of Los Angeles, California. The vegetation is typical of a Mediterranean chaparral ecosystem [*Hanes*, 1971]. The study was initiated during the dry season in July 1986, 2 weeks after the area had undergone a prescribed burn conducted by the U.S. Department of Agriculture (USDA) Forest Service. Additional measurements were made at the end of the dry season in December (6 months later) at the same sites.

MEASUREMENT SITES

Three measurement sites were established in an unburned area, consisting of established plantings of chaparral species, including *Ceanothus crassifolius*, *Quercus dumosa* (scrub oak), and *Adenostoma fasciculatum* (chamise). At such vegetated sites, flux measurements were made over bare soil between the plants in order to avoid uptake of gases by or onto the plants.

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Paper number 8D0093.

Six additional sites were set in a burned canyon: one at a high site close to the ridge, two midlevel sites, and three low sites located at about 65-m intervals down into the canyon. Measurements at these replicate sites allowed us to determine the amount of spatial variability within our data sets. In order to simulate rain events that occur sporadically during the dry season and with arrival of the wet season, 1.3–2.5 cm of distilled water were applied evenly over the surface of the measurement sites.

MEASUREMENT TECHNIQUES

Nitric oxide and nitrous oxide fluxes were determined using a closed box flux technique [*Anderson and Levine*, 1987]. In the present study, NO was measured using a recently developed Scintrex LMA3 nitrogen dioxide (NO_2) detector (Scintrex-Unisearch, Toronto, Canada). This instrument detects the chemiluminescence produced when luminol and oxygen react with NO_2. Since this reaction is temperature sensitive, the instrument was equipped for temperature compensation. In the temperature compensation mode, two extra operational amplifiers are switched into the circuit. The input resistor for each of these amplifiers is a thermistor. As temperature increases, the thermistor resistances drop, increasing the gain of the amplifiers. The increase in gain versus temperature is matched to the decrease in raw signal versus temperature. The net result is a constant signal for a given NO_2 mixing ratio over the temperature range 10°–40°C. Sample air passed through a fiberglass filter was pumped at approximately 2.2 L min^{-1} through a 1-m length of Nafion tubing (Type 815, Dupont perfluorinated polymer, 1.0 mm ID × 0.875 mm OD, Perma Pure, Incorporated), packed in silica gel. The dried air was then passed to the detector, either through a stainless steel converter tube (7.6 cm) containing approximately 10% chromium trioxide on firebrick (30/60 mesh, Chromosorb P, Johns Manville Corporation), prepared as described by *Levaggi et al.* [1974], or through a blank tube. Nitric oxide is converted to NO_2 at 100% efficiency provided that the relative humidity of the sample air is less than 25%. Nitric oxide was calculated as the difference between the converted and unconverted signals. The instrument was calibrated for NO_2, using a National Bureau of Standards approved NO_2 permeation tube system, and for NO, using a field calibration

TABLE 1. Soil Parameters: San Dimas (July)

Sites	Exchangeable Ammonium,[a] μg N/g dry soil	Nitrate,[a] μg N/g dry soil	pH
Unburned sites[b]			
Ceanothus	13.3	6.6	5.8
Scrub oak	13.5	1.2	6.5
Chamise	15.6	1.2	5.6
Burned sites[c]			
High site	24.9	2.4	5.9
Midlevel site 1	24.5	1.6	7.0
Midlevel site 2	22.8	2.1	6.8
Low site 1	22.1	5.2	6.2
Low site 2	71.8	2.3	8.0
Low site 3	56.8	4.5	6.6

[a]Fourteen standards were run for each group of determinations. The coefficient of determination (r^2), when optical density was plotted versus concentration for each of the measurement sets, was at least 0.99. Each sample represented a composite of multiple subsamples taken within each of the plots.

[b]Unburned sites were located in established plantings of typical chaparral species.

[c]Sites were prescribe-burned 2 weeks prior to the start of the study. The high site was located closest to the ridge of the burned canyon. Midlevel and low sites were located at about 65-M intervals down into the canyon.

standard containing approximately 9 parts per million by volume (ppmv) of NO. The field calibration source was checked frequently against a National Bureau of Standards Standard Reference Material (SRM). The instrument has a detection limit of at least 20 parts per trillion by volume (pptv) at a signal-to-noise ratio of 2. It weighs 6.8 kg and is battery operated. The minimum flux of NO that could be measured with this detection system over a 12-min period at 298 K was 13 pg (10^{-12} g) N m^{-2} s^{-1} of NO.

Nitrous oxide measurements were performed as described by *Anderson and Levine* [1987]. A Hewlett Packard model 5790 gas chromatograph, lacking a sample loop, fitted with an electron capture detector and stainless steel Poropack Q column (3.5 m × 0.3 cm), was used for N_2O measurements performed in July. The detector temperature was 330°C; oven temperature was 60°C. Nitrogen was supplied as carrier gas at a flow rate of 38 mL min^{-1}. The precision of this instrument was 6% (standard deviation/mean). The minimum flux of N_2O that could be detected with this system over a 30-min period at 298 K was 4.8 ng (10^{-9} g) N m^{-2} s^{-1} of N_2O. For our December measurements we used a Hewlett Packard model 5880 gas chromatograph operated as described previously; however, it was fitted with a sample loop. Its precision was 2% and the minimum flux detectable with this system was 1.6 ng N m^{-2} s^{-1} over a 30-min period at 298 K.

The following soil parameters were measured in samples taken to a soil depth of 2.0 cm at each site: nitrate (NO_3^-), exchangeable ammonium (NH_4^+), percent moisture, pH, and temperature. The measurements of the soil parameters are described by *Anderson and Levine* [1987].

Results: Soil Exchangeable Ammonium and Nitrate

Burning of the dry chaparral in the San Dimas Experimental Forest during July resulted in increased exchangeable soil ammonium concentrations. Soil nitrate concentrations remained approximately the same (Table 1). Exchangeable NH_4^+ was lowest at the unburned sites and was highest where the fire was most intense, as judged by the appearance of the ash at the site. For example, low site 2 was covered by white ash, whereas low site 3 was covered by black ash. Low site 1, immediately adjacent to the burned area, was scorched, but lacked an ash covering. The exchangeable soil NH_4^+ concentrations as well as pH were highest at low site 2, intermediate at low site 3, and lowest at low site 1. Soil exchangeable NH_4^+ concentrations at the burned sites were comparable to those at newly fertilized agricultural fields in eastern Virginia, where NO and N_2O fluxes were measured [*Anderson and Levine*, 1987]. *DeBano et al.* [1979] similarly observed increased exchangeable NH_4^+ and decreased NO_3^- concentrations in soil chaparral following a burn. In dry soils, NH_4^+ was produced directly during the burn as a result of physicochemical breakdown of the proteinlike components of soil clay-organic complexes as well as organic matter [*DeBano et al.*, 1979; *Kovacic et al.*, 1986]. On the other hand, in moist soils, little NH_4^+ was produced during the burn; however, following the burn, NH_4^+ concentrations increased steadily over a 140-day period as a result of microbial ammonification of residual organic matter [*Dunn et al.*, 1979]. The NH_4^+ thus produced, either directly during the burn or by ammonification following the burn, can serve as a substrate for bacterial nitrification, a process which has been shown to result in emissions of both NO and N_2O [*Anderson and Levine*, 1986]. Since the soil bacterial populations recover more rapidly than plants decimated by the burn, the decreased competition for nitrogenous substrates and therefore greater availability of ammonium for nitrification can contribute to increased emissions of NO and N_2O in the months following the burn.

At unburned sites in July, exchangeable NH_4^+ concentrations were high relative to NO_3^- concentrations, most likely as a result of the decreased rate of conversion of NH_4^+ to NO_3^- by autotrophic, nitrifying bacteria [*Focht and Verstraete*, 1977] during the dry season and also to reduced uptake of NH_4^+ by plants due to water stress. Thus even at the unburned sites, NH_4^+ concentrations were high, although not as high as at burned sites.

In addition to the NH_4^+ produced during the burn itself and that released by ammonification after the burn, other sources of NH_4^+ to our experimental sites may include nitrogen fixation and dry deposition. Since the San Dimas Experimental Forest lies within the Los Angeles basin and since it receives large amounts of dry deposition, we estimated the percentage of the exchangeable NH_4^+ and NO_3^- measured at our experimental sites in July (Table 1) that might have resulted from deposition. On the basis of deposition measurements made by *Bytnerowicz et al.* [1987] from May–October in the San Dimas Experimental Forest, we have calculated that dry deposition might account for as much as 21% of the exchangeable NH_4^+ in unburned soil and from 4 to 13% of that in burned soil measured 2 weeks after the burn. On the other hand, the NO_3^- deposition observed by *Bytnerowicz et al.* [1987] would more than account for the soil NO_3^- observed at our measurement sites in July. Thus burning appears to be a far more important source of NH_4^+ to our soil sites than is dry deposition. Similarly, nitrogen fixation in the absence of plants appears to be a negligible source of nitrogen to the soil (M. A. Poth, unpublished data, 1987).

Results: Nitric Oxide and Nitrous Oxide Emissions

Nitric oxide and nitrous oxide flux measurements were performed at unburned and burned sites, both prior to and fol-

TABLE 2. NO and N_2O Fluxes From Burned Versus Unburned San Dimas Sites

Soil Conditions	Mean Flux NO, ng N m^{-2} s^{-1}		Mean Flux N_2O, ng N m^{-2} s^{-1}	
	Unburned	Burned	Unburned	Burned
Dry	9.7 (4.5, 5)[a]	13.3 (1.1, 9)	NA	not detectable[b]
Wetted[c] (1 day)	21.4 (3.5, 5)	60.7 (4.5, 14)	NA	53.9 (10.0, 7)
Wetted[c] (7–11 days)	NA	23.7 (2.6, 7)	NA	69.3 (12.0, 8)
Wetted[c] (180 days)	1.1 (1.1, 2)	22.3 (2.3, 8)	NA	not detectable[d]

NA indicates measurement was not attempted.

[a]The first number in parentheses represents the standard error; the second number represents the number of measurements. The standard error = $s/\sqrt{n}$, where s is the standard deviation and n is the number of measurements.

[b]Flux was not detectable with our measurement system. The minimum detectable flux was 4.8 ng N m^{-2} s^{-1} over a 30-min period at 298 K.

[c]Most sites were irrigated with 1.3–2.5 cm of distilled water 30 min prior to making NO flux measurements. Under these conditions, N_2O was not detectable. For detection of N_2O, sites were flooded or continuously drip-irrigated.

[d]Flux was not detectable with our measurement system. The minimum detectable flux was 1.6 ng N m^{-2} s^{-1} over a 30-min period at 298 K.

lowing irrigation. Soil moisture at these sites prior to irrigation was less than 1% dry weight. Results of these flux measurements are presented in Table 2, which summarizes measurements made at sites under a particular set of environmental conditions, and Table 3, which follows fluxes of NO from particular sites over a time course of treatment following the initial irrigation. In Table 3, data for replicate measurements are pooled for the unburned and the midlevel site areas. However, at the low level, data are given for individual measurement sites, since the sites had been exposed to burning of different intensities, as judged by the presence and appearance of the ash. Fluxes of NO from dry, burned sites were similar to those measured at dry, unburned sites (Table 2) and were surprisingly high, relative to those measured at a fertilized wheat field site in Colorado during the dry season and at both fertilized and unfertilized agricultural sites in Virginia, as well as a forest site in Sweden and a pasture in Australia (Table 4). This suggests that microorganisms adapted to semiarid environments can continue to oxidize NH_4^+, which has accumulated during the dry season, even though exposed to severe water stress. Upon irrigation of our sites (1.3–2.5 cm water), as might occur during sporadic showers during the dry season or with onset of the rainy season, there was a dramatic increase in NO flux (Tables 2, 3). The increased flux was much greater at the burned sites (approximately a 4.5-fold increase) than at the unburned sites (approximately a twofold increase) (Table 2). A similar dramatic increase in flux occurred when a fertilized wheat field site in Colorado was irrigated during the dry season (Table 4). The mechanism for this immediate increase in NO flux is not clear, although *Birch* [1958, 1960] has shown that wetting of soil markedly accelerates carbon and nitrogen mineralization (ammonification) rates, and *Winn* [1977] has shown sharp increases in microbial respiration. During approximately a 2-day period following irrigation and with continued intermittent irrigation, NO fluxes declined, finally leveling off at approximately one third of their maximum values (Tables 2 and 3). This pattern of declining gas emissions following repeated irrigation is similar to changes in microbial respiration that occur after repeated wetting. *Winn* [1977] noted that microbial respiration in San Dimas soil peaks 1 hour after wetting and declines to 25% of the maximum value after continued irrigation.

We returned to our measurement sites 180 days after the initial flux measurements were performed. Measurements were made at an unburned site (Chamise) and at three of the previously burned sites (one high site and two midlevel sites). Between July and December the study sites had received 14.8 cm of rainfall on five occasions. The latest storm delivered 1.35 cm of rainfall 10 days prior to our making measurements. Soil moisture ranged from 3.1 to 17.8% dry weight. Fluxes of NO (Tables 2 and 3) from the unburned site had declined to very low or undetectable values, similar to those measured

TABLE 3. Nitric Oxide Fluxes: San Dimas

Site	Day	Condition	Mean Flux, ng N m^{-2} s^{-1}
Unburned site	0[a]	dry[b]	9.7 (4.5, 5)[c]
	0	wet[d]	21.4 (3.5, 5)
	180	wet	1.1 (1.1, 2)
High site	0	wet	60.0 (11.6, 5)
	1	wet	19.0 (4.5, 4)
	3	wet	12.9 (2.9, 5)
	11	wet	20.5 (1.8, 3)
	180	wet	17.0 (1.7, 3)
Midlevel site	0	wet	67.1 (3.1, 6)
	1	wet	40.2 (10.7, 2)
	7	wet	25.4 (4.0, 4)
	180	wet	27.7 (1.9, 4)
Low level (site 1)	0	wet	49.2 (8.2, 2)
	1	wet	35.2 (1.1, 2)
	2	wet	19.3 (2.8, 2)
	7	wet	23.5 (6.7, 2)
Low level (site 2)	0	wet	40.9 (8.0, 2)
	1	wet	9.0 (3.3, 2)
	2	wet	9.2 (0, 1)
	7	wet	13.5 (3.5, 2)
Low level (site 3)	0	dry	14.0 (2.9, 2)
	1	dry	15.3 (2.6, 2)
	2	wet	54.6 (6.4, 2)
	7	wet	25.2 (8.5, 2)

[a]Measurements were started on July 10, 1986, 2 weeks postburn.

[b]Sites prior to irrigation. Soil moisture was less than 1% dry weight.

[c]The first number in parentheses represents the standard error; the second number represents the number of measurements.

[d]Sites irrigated with 1–2 cm water 30 min prior to the flux measurement.

TABLE 4. NO Emissions From a Variety of Global Ecosystems

Habitat	Flux, ng N m^{-2} s^{-1} Mean	Range	Reference
Burned semiarid chaparral (California)	31[a]	6–101[a]	this study
Unburned semiarid chaparral (California)	13[a]	0–35[a]	this study
Fertilized corn (5–30 day average)[b] (Virginia)	25	6–67	*Anderson and Levine* [1987]
Soy (fertilized 3 months prior to study, summer average) (Virginia)	4	0.7–9.4	*Anderson and Levine* [1987]
Unfertilized grass (Virginia)	3	0.003–9.0	*Anderson and Levine* [1987]
Wheat, dry season July (Colorado)	2	0.001–6.1	*Anderson and Levine* [1987]
Wheat, dry season, July, irrigated (Colorado)	10	2.4–16.0	*Anderson and Levine* [1987]
Wheat, wet season, May (Colorado)	2.8	0.8–5.0	*Anderson and Levine* [1987]
Ungrazed pasture (Australia)	1.6	0.6–2.6	*Galbally and Roy* [1978]
Grazed pasture (Australia)	3.5	1.5–7.3	*Galbally and Roy* [1978]
Fertilized cropland (Sweden)		0.1–62	*Johansson and Granat* [1984]
Unfertilized cropland (Sweden)		0.1–17	*Johansson and Granat* [1984]
Unfertilized forest (Sweden)	0.3	0.1–0.8	*Johansson* [1984]
Unfertilized soil (Finthen) (Germany)	2.2	−5.8–14.2	*Slemr and Seller* [1984]
Unfertilized semiarid soil (Utera) (Spain)		−2.2 –107	*Slemr and Seller* [1984]
Recently fertilized corn (Pennsylvania)		1.1–231	*Williams et al.* [1986]
Unfertilized grassland (Colorado)	3.0	0.03–59	*Williams et al.* [1987]

[a]Measurements of NO fluxes, made during July and December, 1986 at times ranging from 1000 to 1700 LT, at both dry and irrigated sites.

[b]Measurements were made starting 5 days after fertilization and continued for 25 days.

during the wet season (May) at a wheat field site in Colorado (Table 4). On the other hand, fluxes from burned sites in San Dimas were comparable to those observed in July, even though the soil temperature range in December (13°–21°C) was much lower than that in July (28°–42°C). The persistently high fluxes observed at the burned sites are most likely related to the high concentrations of soil NH_4^+ made available for nitrification initially during the burn as well as by continued ammonification of organic matter, primarily dead microbial biomass, which can occur for many months following the burn. Addition of water to these already moist sites did not further enhance the flux of NO.

For a given set of conditions, spatial variability of NO fluxes measured under field conditions was remarkably low. For example, the 95% confidence interval for the NO flux from irrigated, burned areas was 60.7 ± 9.7 ng N m^{-2} s^{-1} and from irrigated, unburned areas was 21.4 ± 9.7 ng N m^{-2} s^{-1}.

Unlike NO fluxes, N_2O fluxes showed a great deal of spatial and temporal variability. Earlier laboratory studies of NO and N_2O emissions from pure cultures of nitrifying and denitrifying bacteria had suggested that NO production by nitrifying bacteria is relatively insensitive to available oxygen, as long as conditions are not completely anaerobic, whereas N_2O production by both nitrifying and denitrifying bacteria is very sensitive to oxygen availability [*Anderson and Levine*, 1986]. Thus we would expect that N_2O fluxes would be more variable, since its production is more sensitive to environmental conditions than is NO production. As predicted by our laboratory studies, N_2O emissions from the San Dimas sites were highest when the soil was flooded or continuously drip-irrigated (Table 2). Under such conditions the maximum N_2O fluxes measured during the first week following initial irrigation approximated the maximum NO fluxes (observed only when the soil was not flooded). When soil moisture was low, N_2O could not be detected with our system. Those conditions which optimized N_2O emissions minimized NO emissions and vice versa.

Our previous studies have suggested that NO fluxes from soil result primarily from nitrification, performed by autotrophic nitrifiers under aerobic conditions [*Anderson and Levine*, 1986, 1987]. On the other hand, N_2O fluxes appear to result from denitrification, performed either by nitrifying or denitrifying bacteria under near anaerobic or anaerobic conditions [*Bremner and Blackmer*, 1980; *Poth and Focht*, 1985; *Anderson and Levine*, 1986, 1987]. In order to determine whether or not autotrophic nitrifiers were responsible for the NO fluxes observed at the San Dimas sites, 1 L of acetylene (an inhibitor of nitrification [*Hynes and Knowles*, 1978; *Hyman and Wood*, 1985] was added to the headspace of the flux box while making a flux measurement. Addition of acetylene arrested NO emissions immediately (Table 5).

When acetylene was added to wet soils, NO fluxes often became negative, suggesting that heterotrophic denitrification in the soil can serve as a sink for the NO in the box. In addition, N_2O fluxes from the wet soils did not increase upon addition of acetylene, evidence that the bulk of the N_2O emitted was produced by nitrifying bacteria (Table 5). If denitrifying bacteria were responsible, we would have expected increased fluxes of N_2O, since acetylene blocks nitrous oxide reductase [*Yoshinari et al.*, 1977]. Our results are similar to those reported by *Poth and Anderson* [1987] describing an experiment performed at the same San Dimas site. Using the technique described by *Ryden et al.* [1978], they trapped N_2O collected under 8.5-L flux boxes on molecular sieve for 3-hour periods in the presence and absence of acetylene. The soil in the boxes was irrigated. The minimum detectable flux for N_2O with their system was less than 0.3 ng N m^{-2} s^{-1}. They observed lower N_2O fluxes in the boxes containing acetylene than in those without acetylene. They concluded that N_2O had been produced by nitrifying bacteria. We believe that this is one of the first studies to demonstrate that nitrifying bacteria are responsible for production of N_2O in a natural ecosystem.

We have compared the preburn and postburn NO fluxes measured in the San Dimas study with fluxes measured at agricultural sites in eastern Virginia and Colorado [*Anderson and Levine*, 1987] and with fluxes observed by others from a variety of fertilized and unfertilized sites (Table 4) [*Galbally and Roy*, 1978; *Johansson*, 1984; *Johansson and Granat*, 1984;

TABLE 5. NO Fluxes Before and After Acetylene Blockage

Day	Site	Conditions	NO Flux, ng N m^{-2} s^{-1}		N_2O Flux, ng N m^{-2} s^{-1}	
			Before	After	Before	After
1	high	dry[a]	10.5	0	NA	NA
1	low	dry[a]	10.6	0	NA	NA
1	midlevel 1	very wet[b]	66.0	−11.0	NA	NA
2	midlevel 2	wet[c]	50.8	−18.5	NA	NA
7	midlevel 1	very wet[b]	1.9	−1.6	125	128
7	midlevel 2	very wet[d]	32	−0.6	108	49

NA indicates measurements not attempted.
[a]Sites prior to irrigation. Soil moisture was less than 1% dry weight.
[b]Site irrigated with 2.5 cm water 2 hours prior to measurement and with another 2.5 cm water 30 min prior to measurement.
[c]Site irrigated with 1 cm water 22 hours prior to measurement.
[d]Site irrigated with 2.5 cm water 30 min prior to making initial NO and N_2O measurements and then irrigated with 2.5 cm water 30 min prior to making second set of NO and N_2O measurements. Immediately before starting the second flux measurements, 1.3 cm water containing 1 L of dissolved acetylene was added.

Slemr and Seiler, 1984; *Williams et al.*, 1987]. The mean fluxes emitted from the soil of burned chaparral were higher than those observed from a recently fertilized cornfield in eastern Virginia during the month following fertilization. No correction was made for time of day in either measurement set; however, flux measurements were made at times when the soil temperature ranges in Virginia and in California were similar. The San Dimas postburn mean flux and its range were higher than that reported by most others, although *Williams et al.* [1987] observed higher NO fluxes from a recently fertilized cornfield in Pennsylvania. *Slemr and Seiler* [1984] reported results from semiarid, unvegetated, agricultural sites in Spain that were somewhat similar to those observed postburn in San Dimas. They observed dramatic increases in flux from both fertilized and unfertilized sites after irrigation, which followed a long period of hot, dry weather. Fluxes from the fertilized Spanish sites, after one or two irrigations, exceeded those from the irrigated, burned San Dimas sites by as much as tenfold. However, by the fourth irrigation (16 days later), fluxes from these Spanish sites had returned to preirrigation levels, whereas fluxes from the burned San Dimas sites remained relatively high for at least 6 months after the burn.

CONCLUSIONS

The measurements reported here indicate that NO and N_2O emissions from burned areas equal or exceed those from fertilized agricultural areas and persist for much longer periods of time. Hence burned land, which each year may equal 2–5% of the total land area of our planet [*National Academy of Sciences*, 1984], may be a very important source of gaseous nitrogen oxides to the Earth's atmosphere and should be included in NO and N_2O budget studies. Of the total biogenic nitrogen oxide flux, the percentage emitted as NO or N_2O will vary depending primarily on available oxygen in the soil, a parameter which is controlled to a large extent by the soil moisture level. NO emissions will be the primary nitrogen component when the soil is aerobic; N_2O emissions will become the more important component as soil oxygen availability decreases.

Acknowledgments. We thank Edward L. Winstead of the Bionetics Corporation, Hampton, Virginia, and Anna Schaffroth and Joy Jackson of the USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Riverside, California, for their excellent technical assistance. I.C.A. was a NASA-National Research Council Postdoctoral Research Fellow at the time of this research.

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(Received August 13, 1987;
revised January 19, 1988;
accepted January 25, 1988.)