Simultaneous Records of Methane and Nitrous Oxide Emissions in Rice-Based Cropping Systems under Rainfed Conditions

Article *in* Nutrient Cycling in Agroecosystems · November 2000

DOI: 10.1023/A:1009842502608

Kevin Bronson

172 PUBLICATIONS **8,150** CITATIONS

Upendra Singh

International Fertilizer Development Center (IFDC)

187 PUBLICATIONS **12,982** CITATIONS

Nutrient Cycling in Agroecosystems **58:** 131–139, 2000.

Simultaneous records of methane and nitrous oxide emissions in rice-based cropping systems under rainfed conditions

E.B. Abao Jr.[1], K.F. Bronson[1,2], R. Wassmann[1,3] & U. Singh[1,4]

[1] International Rice Research Institute, P. O. Box 3127, Makati City 1271, Philippines; [2] Texas A&M University, Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX 87401, USA; [3] Fraunhofer Institute for Atmospheric Environmental Research (IFU), Garmisch-Partenkirchen, Germany; [4] International Fertilizer Development Center, Muscle Shoals, AL 35662 USA

Key words: automated closed chamber method, wheat, cowpea, slow-release nitrogen fertilizer, residue management, denitrification, methane sink, rainfall

Abstract

Rainfed rice (*Oryza sativa* L.)-based cropping systems are characterized by alternate wetting and drying cycles as monsoonal rains come and go. The potential for accumulation and denitrification of NO_3^- is high in these systems as is the production and emission of CH_4 during the monsoon rice season. Simultaneous measurements of CH_4 and N_2O emissions using automated closed chamber methods have been reported in irrigated rice fields but not in rainfed rice systems. In this field study at the International Rice Research Institute, Philippines, simultaneous and continuous measurements of CH_4 and N_2O were made from the 1994 wet season to the 1996 dry season. During the rice-growing seasons, CH_4 fluxes were observed, with the highest emissions being in organic residue-amended plots. Nitrous oxide fluxes, on the other hand, were generally nonexistent, except after fertilization events where low N_2O fluxes were observed. Slow-release N fertilizer further reduced the already low N_2O emissions compared with prilled urea in the first rice season. During the dry seasons, when the field was planted to the upland crops cowpea [*Vigna unguiculata* (L.) Walp] and wheat (*Triticum aestivum* L.), positive CH_4 fluxes were low and insignificant except after the imposition of a permanent flood where high CH_4 fluxes appeared. Evidences of CH_4 uptake were apparent in the first dry season, especially in cowpea plots, indicating that rainfed lowland rice soils can act as sink for CH_4 during the upland crop cycle. Large N_2O fluxes were observed shortly after rainfall events due to denitrification of accumulated NO_3^-. Cumulative CH_4 and N_2O fluxes observed during this study in rainfed conditions were lower compared with previous studies on irrigated rice fields.

Introduction

Rainfed rice-based production systems make up 25% of the world's area of harvested rice (IRRI, 1998). These systems are characterized by a monsoon season in which rice is grown in the wet season and various upland crops are grown in the dry season without irrigation (Tripathi et al., 1997). At any time of the year, rains can flood the soil, resulting in denitrification and leaching of accumulated NO_3^- (Buresh et al., 1989; George et al., 1993).

Production and emission of CH_4, a "greenhouse gas" about 30 times more radiatively active than CO_2, is an important feature in the cycle of C in flooded rice soils. Methane and CO_2 are the final products of organic matter decomposition under anaerobic conditions. Emission of CH_4 from rice fields makes up about one-fifth of all sources of CH_4 emitted to the atmosphere globally (IPCC, 1992). Nitrous oxide (N_2O) is about 300 more radiatively active than CO_2 (mass basis, considering residence time in the atmosphere (Rodhe, 1990). Agriculture is the main source of most N_2O emissions. Nitrous oxide is produced from soil processes as an intermediate product of microbial nitrification and denitrification (Granli & Bockman, 1994). The potential of N_2O emission increases when the amount of N available for microbial transformation is enhanced through fertilizer application (Eichner, 1990), cropping of legumes, return to soil of manures and crop residue (Aulakh et al., 1991), and mineralization of soil biomass and other forms of soil organic matter. In previous work, we found that residue incorporation had no effect on N_2O emissions in fallow rice fields (Bronson et al., 1997b) but could reduce N_2O fluxes during a rice growing season with midseason drainage (Bronson et al., 1997a).

Previous research by our team involved measurements of CH_4 and N_2O emissions in irrigated rice fields using automated chambers from double-cropped irrigated rice fields (Bronson et al., 1997a) and the short rainfed fallow periods (Bronson et al., 1997b). This study represents a continuation of those studies in which we hypothesized that CH_4 and N_2O emissions will be of different magnitude and pattern in rainfed rice-upland cropping systems compared with double-cropped irrigated rice.

Materials and methods

Experimental site and field design

The field studies were conducted at the International Rice Research Institute, Los Baños, Philippines on Maahas clay soil (pH 7.0, 1.2 g N kg^{-1}, CEC of 17.2 cmol(+) kg^{-1}). The experiments covered two cropping cycles with wet and dry seasons and the fallow periods in between. Rice was grown under rainfed lowland conditions in the wet seasons while wheat and cowpea was grown in the dry seasons.

The treatments during the 1994 wet/rice season were

1. Prilled urea (90 kg N ha^{-1} applied in three equal splits at final harrowing, midtillering, and flowering)
2. Polyon 12, a slow-release N fertilizer urea (90 kg N ha^{-1} applied at final harrowing)

In the 1995 dry season, the treatments/crops were

1. Weed-free fallow
2. Cowpea (30 kg urea N ha^{-1} applied pre-plant) planted in previous prilled urea plots
3. Cowpea (30 kg urea N ha^{-1} applied pre-plant) planted in previous slow-release N plots
4. Wheat (60 kg urea N ha^{-1} applied pre-plant)

In the 1995 wet/rice season, the treatments were

1. Urea (90 kg N ha^{-1} applied in three equal splits at final harrowing, midtillering, and flowering) in weed-free fallow plots
2. Urea (90 kg N ha^{-1} applied in three equal splits at final harrowing, midtillering, and flowering) with cowpea residue removed
3. Urea (30 kg N ha^{-1} applied in three equal splits at final harrowing, midtillering, and flowering) and 3 t ha^{-1} dry cowpea residue incorporated at final harrowing
4. Urea (90 kg N ha^{-1} applied in three equal split applications at final harrowing, midtillering, and flowering) with 3 t ha^{-1} dry wheat residue incorporated at final harrowing

During the 1996 dry season, the treatments/crops were

1. Weed-free fallow
2. Cowpea (30 kg N ha^{-1} applied pre-plant in plots with previous cowpea residue removed)
3. Cowpea (30 kg N ha^{-1} applied pre-plant in plots with previous cowpea residue incorporated)
4. Wheat (90 kg N ha^{-1} applied pre-plant in plots with previous wheat residue incorporated)

Measurement of CH_4 and N_2O fluxes

An automated chamber system which operated for 24 h a day was used to measure CH_4 and N_2O fluxes. The details of the system were described in Bronson et al. (1997a). Fluxes were measured from all plots every 2 h. Two-hour flux rates were averaged over 12-h daytime and 12-h night time periods for each treatment. Cumulative fluxes for each season were also calculated. This measurement system was used continuously from the 1994 wet season to the 1996 dry season.

Grain yield determination

Harvesting was done on a 2- × 2-m area in the middle of each experimental plot. The crops were cut at ground level and put in cloth bags and dried. After drying, the grains were threshed and weighed. Grain yields were adjusted to 14% moisture. For cowpea, the pods were collected and the seeds separated, dried, and weighed.

Statistical analysis

Analysis of variance was done using SAS (SAS, 1987) on 12-hourly and seasonal CH_4 and N_2O fluxes. Duncan's multiple range test was used at $P= 0.05$ level of probability to distinguish treatment differences.

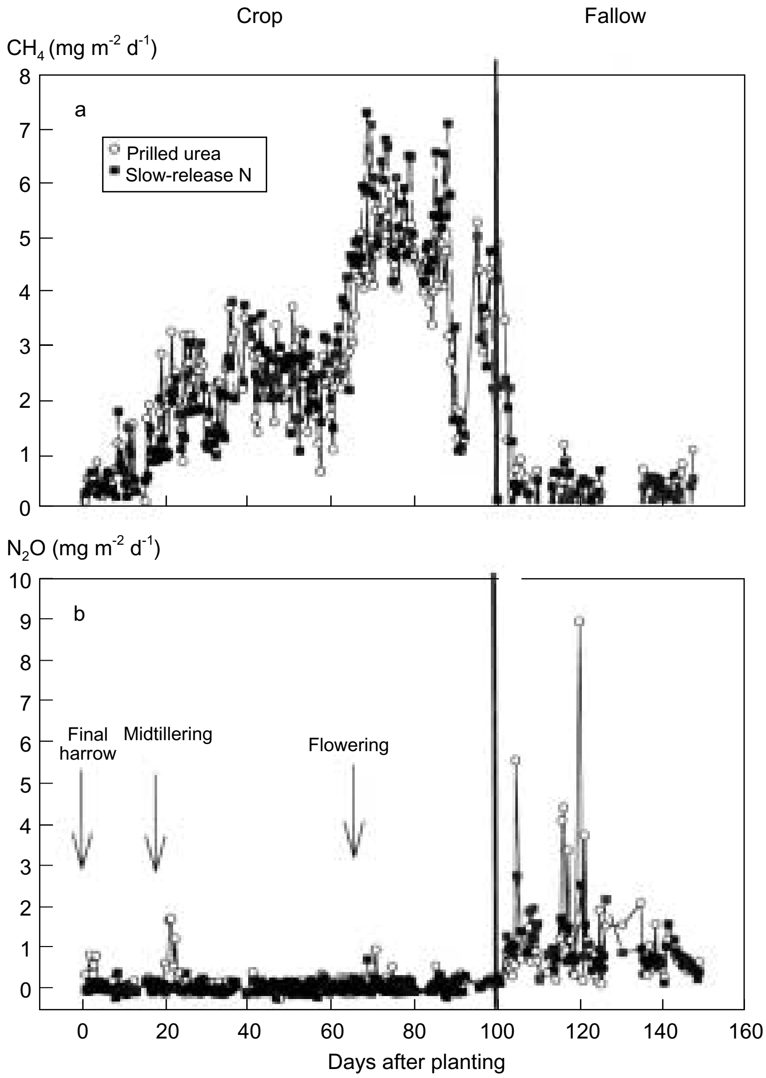

Figure 1. Methane (a) and N_2O (b) fluxes during the 1994 wet season (rice crop and fallow period)

Results and discussion

1994 wet season

Methane fluxes for both prilled urea and slow-release N showed the same pattern during the entire season wherein two peaks were observed (Figure 1a). The first major peak of CH_4 activity was at 40 d after transplanting (DAT) or maximum tillering when CH_4 fluxes rose to about 4 mg CH_4-C m^{-2} d^{-1}. The second peak was observed at 70 DAT where CH_4 fluxes increased to 7 mg CH_4-C m^{-2} d^{-1}. The two distinct peaks of CH_4 flux observed may be attributed to increase in tillers which serve as CH_4 channels and decomposing roots which provide C source for CH_4-producing bacteria (Neue et al., 1994). There was no significant difference in cumulative CH_4 fluxes between the two N fertilizer sources, slow-release and prilled urea (Table 1). Seasonal fluxes of CH_4 were lower than those reported by Bronson et al. (1997a) for a nearby irrigated site of higher soil organic matter content.

During the fallow period after the 1994 wet season, CH_4 fluxes drastically decreased shortly after harvest to less than 1 mg CH_4-C m^{-2} d^{-1} for both treatments (Figure 1a) until the end of the fallow period.

Nitrous oxide fluxes were generally less than 1 mg N_2O-N m^{-2} d^{-1} during the entire rice-growing season. In the prilled urea treatment, low but distinct N_2O

Table 1. Grain yields of rice, cowpea, and wheat, and cumulative CH_4 and N_2O fluxes as affected by crop and residue management under rainfed conditions during 1994-96 dry and wet seasons.[a]

Year/ season	Treatment	Cropping period			Fallow	
		CH_4 emission (mg C m^{-2})	N_2O emission (mg N m^{-2})	Yield (t ha^{-1})	CH_4 emission (mg C m^{-2})	N_2O emission (mg N m^{-2})
1994/WS	Rice, prilled urea	230 a	9.7 a	6.0	11.1 a	48.6 a
	Rice, polyon 12	220 a	0.3 b	5.9	1.5 a	41.2 a
1995/DS	Cowpea, urea (after urea)	–67.8 b	31.9 b	0.99	12.6 a	34.7 a
	Cowpea, urea (after polyon)	–37.8 b	38.3 b	1.11	19.8 a	67.1 a
	Fallow, (weed-free)	2.8 a	36.8 b	–	14.5 a	42.2 a
	Wheat, urea	4.4 a	64.5 a	1.41	24.7 a	59.2 a
1995/WS	Rice, urea, no residue	530 b	24.9 a	5.2	10.2 a	40.0 a
	Rice, urea, cowpea residue	1560 a	23.2 a	5.3	3.9 a	56.0 a
	Rice, urea	560 b	24.5 a	5.4	29.8 a	59.1 a
	Rice, urea, wheat residue	2580 a	11.5 a	5.1	40.7 a	40.6 a
1996/DS	*Cowpea*, urea (after no residue)	–15.3 a	10.6 b	0.9		
	Cowpea, urea (after cowpea residue)	–15.1 a	27.7 b	1.0		
	Fallow (weed-free)	2.4 a	28.5 b	–		
	Wheat, urea	1.8 a	61.2 a	1.1		

[a] Values in the same season of the same year followed by the same letter in a column are not significantly different by Duncan's multiple range test at P = 0.05.

fluxes appeared shortly after fertilizer applications at final harrow, midtillering, and flowering. Low N_2O emissions with small peaks after N fertilization events and high CH_4 emissions in rice have been observed by other workers (Bronson et al., 1997a; Cai et al., 1997). A maximum flux of 1.7 mg N_2O-N m^{-2} d^{-1} was observed at midtillering. Slow-release N resulted in very low N_2O flux rates throughout the season and showed no distinct peaking pattern (Figure 1b). Cumulative seasonal N_2O fluxes were significantly higher in prilled urea than in slow-release N (Table 1). In the fallow period, N_2O fluxes were also generally higher in prilled urea than in slow-release N fertilizer (Figure 1b). This is one of the first reports of N_2O emissions from slow-release N fertilizer in rice. Minami (1994) first reported that slow-release N fertilizer in carrots can reduce N_2O emissions compared with ammonium sulfate. Delgado and Mosier (1996) reported N_2O flux measurements using polyolefin-coated urea in an upland crop—spring barley. They reported initial mitigation of N_2O fluxes with coated urea compared with prilled urea, but the opposite result was observed in the latter part of the growing season. The amounts of N_2O seasonal emission in our study were much smaller than those reported by Bronson et al. (1997a) on the same soil with higher soil organic matter under irrigated condition.

1995 dry season

Starting in the 1995 dry season, the field experiments encompassed four treatments per season. Cumulative flux results of all treatments are shown in Table 1 while the respective figures on seasonal patterns show only two out of four treatments to allow a visual distinction among the graphs (Figure 2a,b).

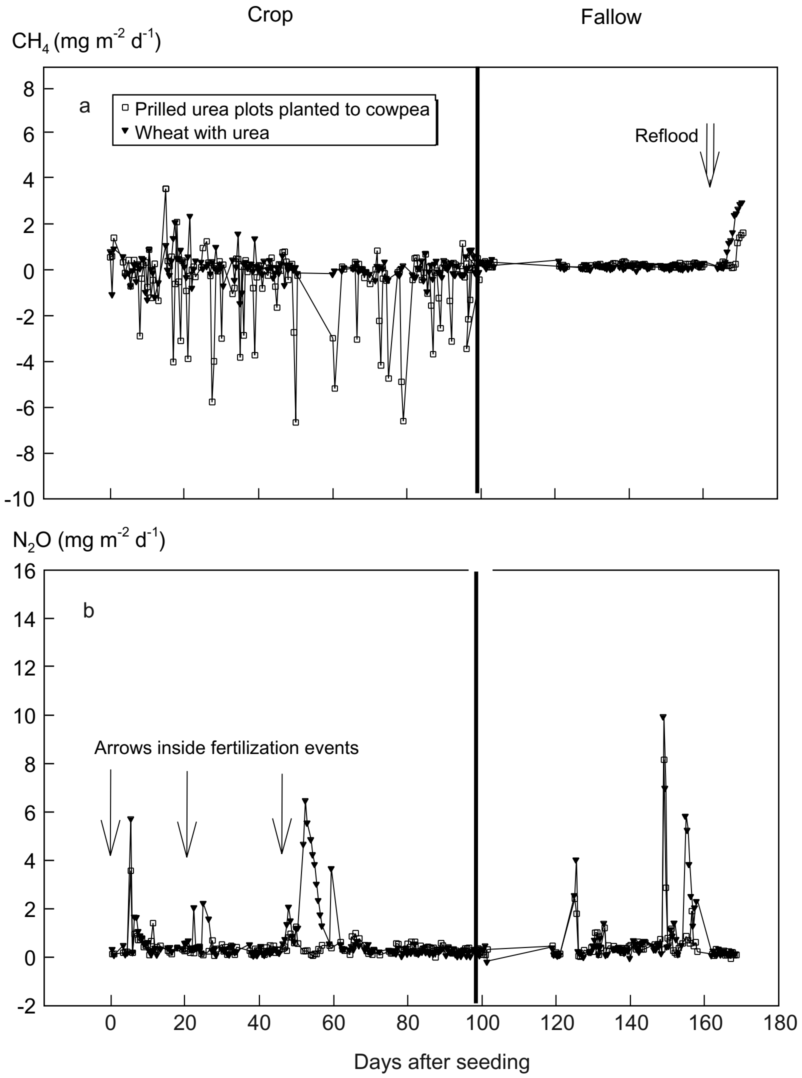

Figure 2. Methane (a) and N_2O (b) fluxes during the 1995 dry season (upland crop and fallow period)

Methane fluxes during the entire dry season crop were generally very low and ranged from -7 to 5 mg CH_4-C m^{-2} d^{-1} (Figure 2a). For all treatments, CH_4 uptake by the aerobic soil was evident throughout the season particularly in the cowpea plots. Only plots planted to cowpea showed net cumulative CH_4 uptake for the season (Table 1). Methane uptake or consumption in soil is a result of CH_4 oxidation by methanotrophic bacteria (Lidstrom & Stirling, 1990). Methane uptake has been reported in temperate native grasslands and in fertilized cropped fields (Bronson & Mosier, 1993) and in tropical forests and agricultural soils (Keller et al., 1990). Only recently have reports been made of CH_4 consumption in rice soils (Singh et al., 1998; 1999). It is not clear why the cowpea plots exhibited the highest CH_4 uptake rates. Nitrogen fertilizer addition in the wheat plots may have inhibited CH_4 uptake (Bronson & Mosier 1994; Singh et al., 1999), but this would not explain the similar result for the unfertilized fallow treatment.

In the fallow period after the 1995 dry season, CH_4 fluxes were generally below detection limit for all treatments. Methane fluxes as high as 3 mg CH_4-C m^{-2} d^{-1} appeared about a week after the imposition of a permanent flood prior to rice cultivation (Figure 2a).

Nitrous oxide fluxes appeared shortly after seeding and 25 and 55 d after seeding of cowpea and wheat, events which coincided with the time of fertilizer application. Fluxes of N_2O fluxes were generally low (mean <2 mg N_2O-N m^{-2} d^{-1}) during the entire season. Plots planted to wheat showed the highest cumulative fluxes (Table 1) since these plots received the highest amount of N (90 kg N ha^{-1}). Nitrous oxide fluxes were generally low during the ensuing fallow period except at 52 d after harvest where N_2O fluxes as high as 9 (Figure 2b) mg N_2O-N m^{-2} d^{-1} appeared after a large rainfall event. Smaller N_2O fluxes also appeared after the imposition of a permanent flood prior to rice transplanting (Figure 2b). These trends of N_2O fluxes were similar to the report of Bronson et al. (1997b) for a rainfed fallow, although the magnitude of the fluxes was lower.

1995 wet season

Methane fluxes appeared shortly after transplanting in all treatments, but the residue-amended plots had higher CH_4 emissions than the unamended plots (Figure 3a). Initially, CH_4 fluxes were higher in cowpea residue-added plots than wheat-residue plots (data not shown). Thereafter, wheat residue-amended plots showed higher CH_4 fluxes. Cowpea had more easily decomposable C than wheat, but more C on a dry-weight basis was added as wheat straw. Wheat straw-amended plots showed the highest cumulative CH_4 fluxes followed by cowpea residue-added plots (Table 1). The maximum cumulative CH_4 flux of 2.6 g CH_4-C m^{-2} with wheat residue was lower than those reported by Bronson et al. (1997a) with similar amounts of straw addition on an irrigated soil. Plots that were weed-free in the previous fallow and those that did not receive any residue had the same magnitude of CH_4 fluxes (Table 1). Stimulation of CH_4 fluxes in rice following organic amendments have been reported extensively (Yagi & Minami, 1990; Sass et al., 1990; Neue et al., 1994).

In the fallow period after the 1995 wet season, there was a rapid decline of CH_4 fluxes after harvest especially with residue-amended plots as CH_4 entrapped in the soil was completely released. Thereafter, CH_4 fluxes remained at a lower level of <10 mg CH_4-C m^{-2} d^{-1} (Figure 3a).

Nitrous oxide fluxes were again low during the rice-growing season except shortly after transplanting and at 65 d after transplanting which corresponded to fertilization applications where N_2O fluxes rose to as much as 2.5 mg N_2O-N m^{-2} d^{-1} (Figure 3b). Fluxes of N_2O continued at a low level (<2 mg N_2O-N m^{-2} d^{-1}) after harvest (Figure 3b). Rainfall events during this fallow period resulted in increased N_2O emission to as high as 8 mg N_2O-N m^{-2} d^{-1} (Figure 3b).

1996 dry season

During the 1996 dry season, CH_4 fluxes were generally insignificant with values ranging from –4 to 4 mg CH_4-C m^{-2} d^{-1} (Figure 4a). Unlike in the previous 1995 dry season, negative CH_4 fluxes were few and small (Table 1). Again, as in the 1995 dry season, cowpea plots without residue added had the highest cumulative CH_4 uptake (–12.6 mg CH_4-C m^{-2} d^{-1}) during the entire fallow period. The reasons for the much lower CH_4 uptake levels in this dry season than in the previous one are not clear, but this was probably related to the less frequent rains. Soil moisture is one of the main controlling factors in CH_4 uptake in rice soils (Singh et al., 1999).

Nitrous oxide fluxes appeared right after seeding for all treatments with residue-amended plots showing the highest N_2O fluxes. Nitrous oxide emissions, however, remained low (<2 mg N_2O-N m^{-2} d^{-1}) during the entire season except during fertilizer application where small (<4 mg N_2O-N m^{-2} d^{-1}) but significant N_2O fluxes appeared. Particularly, after a big rainfall event of >3 cm, a dramatic increase in N_2O fluxes was observed from plots with wheat straw amended in the previous season. Nitrous oxide flux rose to as high as 16 mg N_2O-N m^{-2} d^{-1} in these plots. Similar to the 1995 dry season, plots planted to wheat had the highest seasonal flux of N_2O (Table 1).

Crop yields

Rice grain yields were similar between treatments of a given season (Table 1). Rice yields were very low in dry seasons due to water stress under rainfed conditions (Table 1). Cowpea seed yields were stable at about 1 t ha^{-1} regardless of season or treatment (Table 1). Wheat yields were low as expected in a tropical environment.

Conclusions

The results from this study revealed that positive CH_4 fluxes were evident during the rice-growing season but not during the fallow periods or dry seasons except when the field was subjected to submergence prior to rice transplanting. Addition of residues such as cowpea,

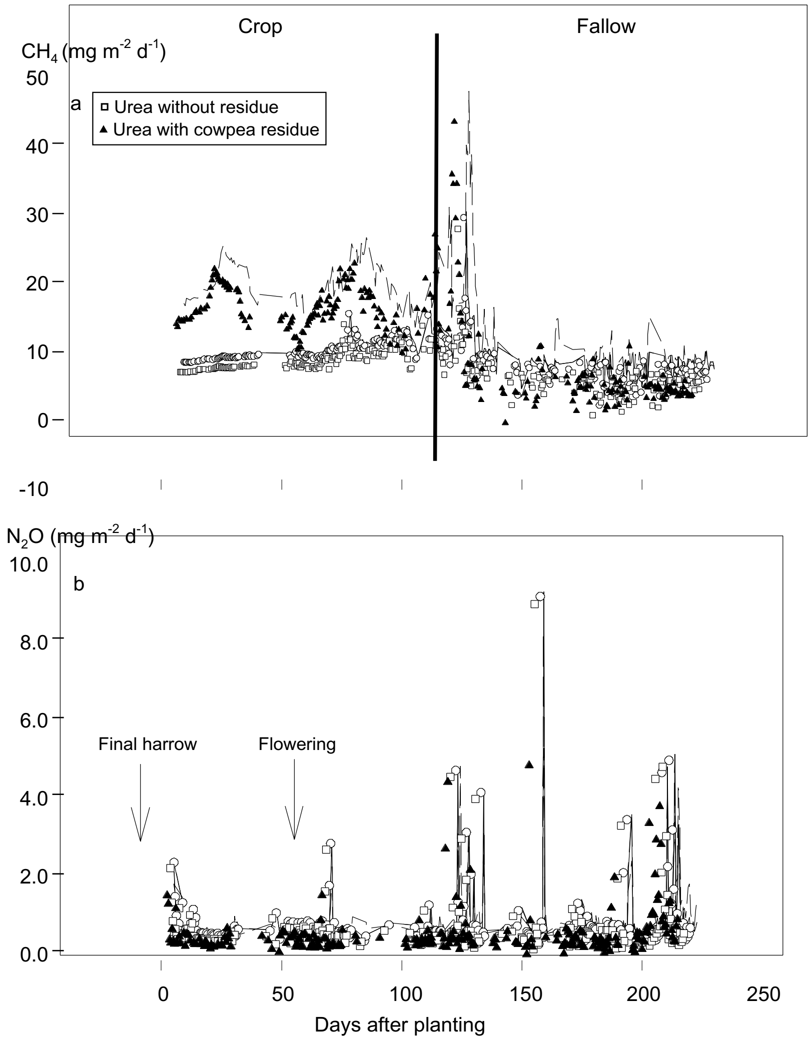

Figure 3. Methane (a) and N_2O (b) fluxes during the 1995 wet season (rice crop and fallow period)

wheat, or rice straw enhanced CH_4 emissions. Methane uptake was observed during the first dry season particularly in cowpea plots, apparently due to the activities of CH_4-oxidizing bacteria. Nitrous oxide fluxes were insignificant during the rice-growing period except after fertilization events where low but significant N_2O peaks were observed. During the fallow periods, larger N_2O fluxes were seen shortly after large rainfalls (>2 cm), apparently due to denitrification of accumulated NO_3. The use of slow-release N fertilizer reduced N_2O emissions, although the emissions from prilled urea were already low. These findings in rainfed rice-upland crop systems are similar to our previous studies in irrigated double-cropped rice fields, with the important exception that these rainfed studies showed lower CH_4 and N_2O emissions and some CH_4 uptake.

Acknowledgements

The research described in this paper was funded by the UNDP-Global Environment Facility (GLO/91/G31 under agreement with the International Rice Research Institute and the International Fertilizer Development Center (IFDC).

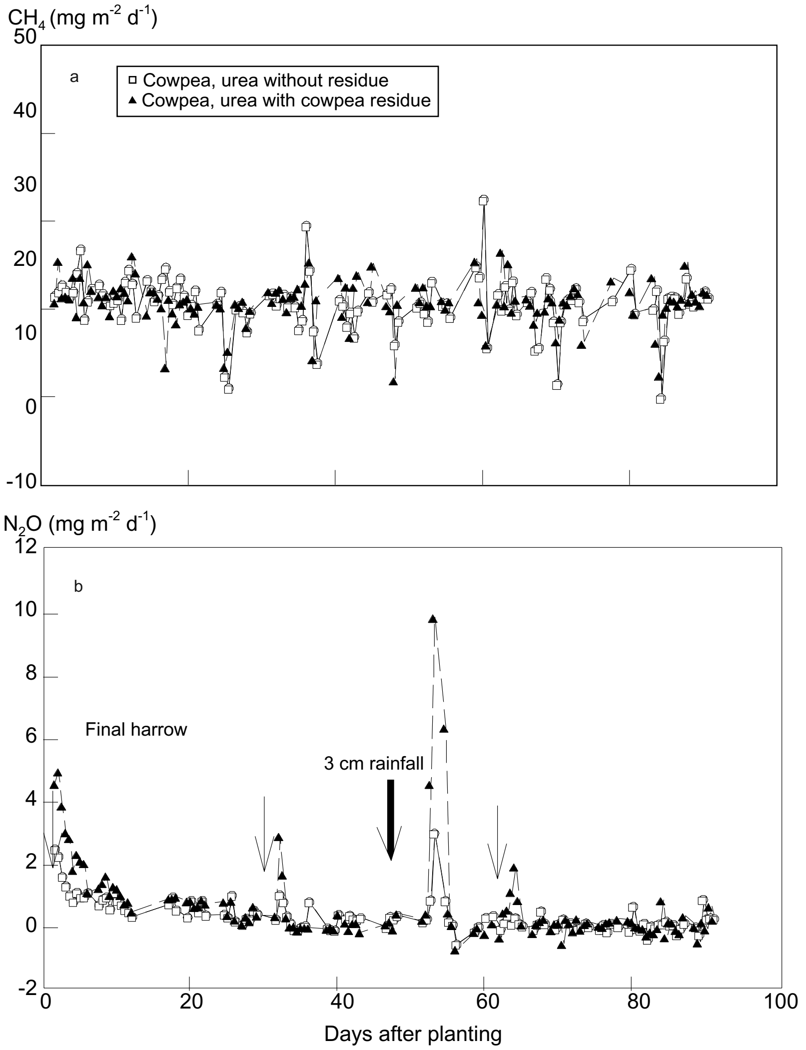

Figure 4. Methane (a) and N_2O (b) fluxes during the 1996 dry season (cowpea crop and fallow period)

References

Aulakh MS, Doran JW, Walters DT, Mosier AR & Francis DD (1991) Crop residue type and placement effects on denitrification and mineralization. Soil Sci Soc Am J 55:1010-1025

Bronson KF & Mosier AR (1993) Nitrous oxide emissions and methane consumption in wheat and corn-cropped systems in northeastern Colorado. p 133-144. In: L. Harper (ed) Agroecosystem Effects on Trace Gases and Global Climate Change. American Society of Agronomy, Madison, Wisconsin

Bronson KF & Mosier AR (1994) Suppression of methane oxidation in aerobic soil by nitrogen fertilizers, nitrification inhibitors, and urease inhibitors. Biol Fertil Soils 17:263-268

Bronson KF, Neue H, Singh U & Abao Jr, E (1997a) Automated chamber measurements of methane and nitrous oxide flux in a flooded rice soil: I. Residue, nitrogen, and water management. Soil Soc Am J 61:981-987

Bronson KF, Neue H, Singh U & Abao Jr, E (1997b) Automated chamber measurements of methane and nitrous oxide flux in a flooded rice soil: II. Fallow period emissions. J Soil Sci Soc Am 61:988-993

Buresh RJ, Woodhead T, Shepherd KD, Flordelis E & Cabangon R (1989) Nitrate accumulation and loss in mungbean lowland rice cropping system. Soil Sci Soc Am J 53:477-482

Cai ZC, Xing GX, Yan XY, Xu H, Tsuruta H, Yagi K & Minami K (1997) Methane and nitrous oxide emissions from rice paddy fields as affected by nitrogen fertilizers and water management. Plant Soil 196:7-14

Delgado JA & Mosier AR (1996) Mitigation alternatives to decrease nitrous oxide emissions and urea-nitrogen loss and their effect on methane flux. J Environ Qual 25:1105-1111

Eichner MJ (1990) Nitrous oxide emissions from fertilized soils: Summary of available data. J Environ Qual 19:272-280

George T, Ladha JK, Buresh RJ & Garrity DP (1993) Nitrate dynamics during the aerobic phase in lowland rice-based cropping systems. Soil Sci Soc Am J 57:1526-1532

Granli T & Bockman OC (1994) Nitrous oxide from agriculture. Norwegian J Agric Sci ( ):7-16

IPCC—Intergovernmental Panel on Climate Change (1992) Climate change. The supplementary report to the IPCC scientific assessment. Cambridge University Press, New York.

IRRI—International Rice Research Institute (1998) IRRI Rice Almanac, (2nd ed) Manila, Philippines, 181 p

Keller M, Mitre ME & Stallard RF (1990) Consumption of atmospheric methane in soils of Central Panama: effects of agricultural development. Global Biogeochem Cycles 4:21-27

Lidstrom ME & Stirling DI (1990) Methanotrophs: genetics and commercial applications. Annu Rev Microbiol 44:27-58

Minami K (1994) Effect of nitrification inhibitors and slow-release fertilizer on emissions of nitrous oxide from fertilized soils. pp 187-196. In: CH_4 and N_2O: Global Emissions and Controls from Rice Fields and Other Agricultural and Industrial Sources, National Institute of Agro-Environmental Sciences, Tsukuba, Japan

Neue, H, Lantin RS, Wassmann R, Aduna JB, Alberto CR & Andales MJF (1994) Methane emission from rice soils off the Philippines. pp 55-63. In: K. Minami, A. Mosier, & R. Sass (eds) CH_4 and N_2O - Global Emissions and Controls from Rice Fields and Other Agricultural and Industrial Sources. National Institute of Agro-Environmental Sciences, Tsukuba, Japan

Rodhe H (1990) A comparison of the contribution of various gases to the greenhouse effect. Science 248:1217-1219

SAS Institute Inc (1987) SAS user's guide: Statistics. Cary, NC

Sass R, Fischer FM, Wang YB, Turner FT & Jund MF (1990) Methane emission from rice fields as influenced by solar radiation, temperature, and straw incorporation. Global Biogeochem Cycles 5:335-350

Singh JS, Raghubanshi AS, Reddy VS, Singh S & Kashyap AK (1998). Methane flux from irrigated paddy and dryland rice fields, and from seasonally dry tropical forest and savanna soils of India. Soil Biol Biochem 30:135-139

Singh S, Singh JS & Kashyap AK (1999) Methane consumption by soils of dryland rice agriculture: Influence of varieties and N-fertilization. Chemosphere 38:175-189

Tripathi BP, Ladha JK, Timsina J & Pascua SR (1997) Nitrogen dynamics and balance in intensified rainfed lowland rice-based cropping systems. Soil Sci Soc Am J 61:812-821

Yagi K & Minami K (1990) Effect of organic matter application on methane emission from some Japanese rice fields. Soil Sci Plant Nutr 36:599-610