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Effects of Nitrogen and Phosphorous Fertilisation on Nitrous Oxide Emission and Nitrogen Loss in an Irrigated Rice Field

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ABSTRACT

Nitrous oxide is an important greenhouse gas which contributes to stratospheric ozone destruction, but still little is known about emission of this trace gas from paddy rice fields treated with N and P fertilisation and how it is affected by irrigation. Therefore, a field experiment was conducted to measure nitrous oxide (N_2O) emissions and nitrogen loss through the emission from irrigated rice fields treated with different nitrogen and phosphorous fertilisers. Emissions of nitrous oxide (N_2O) were measured by the closed chamber method during the vegetative period (6 July to 8 August) of the paddy plant in ShuangQiao farm in the northern part of *Zhejiang* Province in the Southeast coastal area of China. Jia-9312 rice variety was used for rice cultivation. Treatments of five nitrogen rates (0, 90, 180, 270, 360 kg N ha^{-1}) and three phosphorous rates (0, 40 and 60 kg P ha^{-1}) were laid out in a randomised block design with 3 replications in 45 plots. Submerging the rice field by continuous flooding irrigation at 7 cm depth up to maturity caused a remarkable reduction in N_2O emission. First and second peaks of emission were observed immediately after basal and top dressing of fertiliser addition due to nitrification and denitrification process. The study indicates that 180 kg N ha^{-1} incorporation with 40 kg P ha^{-1} may be practised in mitigation of N_2O emissions from irrigated paddy rice fields. The amount of total N_2O emission from different N and P treatments ranged from 431.89 to 1181.21 g N ha^{-1} which was a N loss of 0.10 to 1.18% through emission of applied nitrogen.

Keywords: Denitrification, nitrification, submerged soil, vegetative period

INTRODUCTION

Nitrous oxide is an important greenhouse gas and contributes to the destruction of the ozone layer (Bowden 1986; Graedel and Crutzen 1994). Considerable amouns of this trace gas are emitted from natural and cultivated soils through microbial process, the most important being nitrification and denitrification (Bowden 1986; Tidje 1988). Fertiliser application in rice soil leads to increased N_2O emissions (Eicher 1990). China is the most densely populated country in the world. It contains 26% of the world’s total crop harvested area and is responsible for

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more than half of the total global chemical N fertiliser consumption, as of 1999 (FAOSTAT 2002). Production and harvest area of rice in these regions account for almost 50% of the total world rice production and harvest (FAOSTAT, 2002). Urea and ammonium bicarbonate account for 85% of the total chemical N fertilisers, which is unlike the situation in the rest of the world (Xings 1998). Therefore, great efforts should be taken to understand the processes and key regulating factors of N_2O emissions from rice paddy fields (Zheng *et al*. 1999). Nitrous oxide emission from fertilised rice has been reported by several other authors (Smith *et al.* 1982; Buresh and DeDatta, 1990: Lindau *et al*. 1990; Cai *et al*. 1997;1999). Nitrous oxide emissions from lowland rice fields, although small compared with those from upland systems, represent a substantial source of atmospheric N_2O (Hasegawa *et al.* 1998; Xing 1998). According to IPCC (1995) and Houghton *et al.* (1995), anthropogenic emissions of N_2O needs to be reduced by 50%. Nitrous oxide emission is stimulated by nitrogen fertiliser application. Nitrous oxide emission from nitrogen fertiliser application in rice fields of Taiwan ranged from 0.05 to 0.28% (Chao 1997). The quantification of N_2O and N_2 losses is uncertain because of the large spatial and temporal variability. By reviewing data for N_2O emissions from agricultural soils, emission of N_2O was found to range from 0.20 to 41.8 kg N ha^{-1} per year (Eichner 1990). Calculated as a percentage of the N fertiliser applied, N losses vary from about 0.07 to 5.3% for N_2O (Granli and Bockman 1994) and about 0-25% for N2 (Ryden 1983; Svensson *et al.* 1991; Barraclough *et al.* 1992; Khalil *et al.* 2002).

There have been few studies on N_2O emission and N losses through emission from rice fields to which both nitrogen and phosphorous fertilisers have been applied under irrigated conditions.

The aim of this study was to investigate various treatments of nitrogen and phosphorous fertiliser rates that could accelerate or amplify the N_2O emissions and N loss during vegetation period from rice fields and determine possible mitigation of N_2O emission with P fertiliser and water management.

MATERIALS AND METHODS

Site, Climate and Soil

The field experiment was carried out in ShuangQiao farm of Zhejiang University in the northern part of Zhejiang Province (120°40'E, 30° 50'N), in the Southeast coastal area of China. The annual precipitation of the area was 1205.5mm, of which 1006.7mm occurred from April to August. According to USDA, the soil is silt and blue soil that comprises 29.5% sand, 50.5% silt and 20.2% clay. The soil in the plot trail contained 0.06-0.08% total N, 0.05-0.06% total P, 1.2-1.4% organic matter, pH 7.6-7.8. The mean air temperature during the experimental period was 28.1^{o}C and the average maximum temperature was 34^{o}C.

Crop

Rice (*Oryza sativa* L.) was grown in July – October of 2007, which was the summer season in Southern China where rice is s cultivated in almost all rice growing regions of that season. The rice cultivar JIA-9312 with a growing period of 120-125 days under such conditions was used because it is the most widespread cropping system in Zhejiang province, with an approximate rice cultivated area of 1.88 x 10^6 hectares. The summer season is characterised by overcast sky, rainfall, high humidity and temperature. Thirty-day-old paddy rice seedlings were transplanted in different main plots after ploughing and puddling.

Treatments

The experimental field consisted of 45 plots each having dimensions of 4m × 5m. A strip of 0.3 m land was left between the plots. The experiment was laid down in a completely randomised block design with three replicates. Factors were N and P fertilisers. Table 1 shows the nitrogen and phosphorous fertiliser application rates in each experimental plot in different forms. Urea was applied as N fertiliser and P_2O_5 was added in the form of single super phosphate as a P fertiliser. Cai *et al*. (1997) reported that the form of N fertiliser did not cause significant differences in the N_2O flux. Application of N fertiliser up to 100 kg N ha^{-1} also did not significantly affect N_2O flux, compared with the unfertilised plot, until it was increased to 300 kg N ha^{-1}. This study consisted of higher N fertiliser treatment. Granule urea is applied by farmers in China on their fields. This type of urea causes quick release of ammonia and emission of N_2O and formation of nitrate throughout the paddy growing season. For this reason, rates of N higher than the typical N application rate were considered to investigate the magnitude of nitrogen loss by N_2O emission. The 180 kg N ha^{-1} as urea was the typical N application rate (TNAR) in the region. There were five treatments:(1) N0, no N application (control); (2) N1, 90 kg N ha^{-1} as urea (i.e. 50 % t of the TNAR); (3) N2, 180 kg N ha^{-1} (i.e. 100%t of the TNAR); (4) N3, 270 kg N ha^{-1} (i.e. 150% of the TNAR) and (5) N4, 360 kg N ha^{-1} (i.e 200 % of the TNAR). Sixty percent of the N fertiliser was applied as basal fertiliser and 40% as top dressing. Also, there were three treatments for phosphorous fertiliser: (1) P0, no P application (control); (2) P1, 286 kg ha^{-1} as super phosphate or 40 kg P ha^{-1} P_2O_5 (3) P2, 429 kg ha^{-1} as super phosphate or 60 kg ha^{-1} P_2O_5. All P applications were made as basal dressings incorporated into the surface soils. Each plot received the same fertiliser treatment throughout the experiment, that is, incorporated in the plough layer before flooding. The rice seedlings were transplanted the same day when basal fertiliser was applied. All fields were ploughed with a tractor and harrowed three times in a dry condition to about 15 cm depth.

TABLE 1
Nitrogen and phosphorus fertiliser sources, amounts and treatments for the experiment

Nitrogen treatment	Urea (kg ha^{-1})	Nitrogen (kg ha^{-1})	Phosphorus treatment	Super phosphate (kg ha^{-1})	Phosphorous (kg ha^{-1})
N0	0	0	P0	0	0
N1	196	90	P1	286	40
N2	392	180	P2	429	60
N3	588	270			
N4	784	360			

Irrigation in the Field

There were three rainfalls during the growing season of rice but as total amount of rainfall was too low, the field was irrigated. Irrigation water was applied as flood irrigation from an overhead tank via flexible plastic pipes to the rice field that maintained a certain water depth. Irrigation was provided from time to time to maintain a 7-cm depth of water above ground level. The same water depth was maintained in a flooded condition continuously throughout the vegetative period of the npaddy plant in each of the 15 plots. Also, irrigation was given at different intervals up to physical maturity (20 days before harvesting) of the crop.

Sampling and Measurements of N_2O Emission

Gas sampling for nitrous oxide emission was initiated by the closed chamber method. The chamber was made using Plexiglas with dimensions of 90 cm × 60 cm × 100 cm. Before sampling, boxes were kept on the rice plants for 2 hours continuously during the daytime (10:00-12:00 hours) on the days of sampling. Gas samples were collected through sampling ports fitted at the top of the chamber using gas-tight syringes. The headspace gas was sampled during the vegetative period (6 July to 8 August) of the paddy plant. A gas-tight syringe was used to transfer air samples into evacuated headspace vials which were sealed with stopcock and stored in room temperature (23-30^{0}C) until analysis. Before sampling, the headspace gas was mixed by withdrawing and injecting headspace gas three times using a 25-ml gas-tight syringe with a stopcock. Then a 12-ml vial sample of headspace gas was collected from the closed box for N_2O analysis. After sampling, the same volume of air was injected into the jars to maintain constant pressure inside the jars. The concentration of N_2O in each of the 12-ml vial was determined by automated IMRS (Stevens *et al.* 1993). Automation of the valve switching and source setting enabled the analysis of the N_2O emission. A Europa Scientific 20-20 Stable Isotope Analyzer was interfaced to a Europa Scientific Trace Gas Preparation System with Gilson auto-sampler and was used for N_2O analysis. Also, the ion currents at *m/z* 44 (^{44}I), 45 (^{45}I) and 46 (^{46}I) enabled concentrations, ^{45}R (^{45}I/^{44}I) and ^{46}R (^{46}I/^{44}I) to be calculated for N_2O emissions. Emissions were reported as N_2-N g d^{-1} ha^{-1}. Total emissions of N_2O-N during the entire period were estimated by multiplying the average emissions of two consecutive sampling dates by the number of days in between.

Data Analysis

Differences between treatments were determined through analysis of variance (ANOVA) using the General Linear Model (GLM) procedures of the Statistical Analysis System software 8.1 (SAS Institute, Inc., Cray, NC, USA). Statistical comparisons were considered significant at $P<0.05$. In order to evaluate the effects of the treatments and combination of treatments on N_2O emission, the variance of daily data was analysed (ANOVA) followed by the Least Significant Difference (LSD) and Least Squares Means (LSM).

RESULTS AND DISCUSSION

Irrigation and its Effect on N_2O Emissions

Fig.1 describes the daily decrease of surface water from the paddy field. Daily measurements of the depth of standing water in the plots were taken to know the daily decrease in surface water after the first fertiliser application. Water was applied as flood irrigation from an overhead tank and maintained at a depth of 7 cm in the field. Water was applied a number of time during the dry spells. Application of irrigation water was made just a day after the standing water had almost vanished from the field. Maximum decreasing value of surface water was 17.5 mm after 47 days of planting and minimum was 2.5 mm after 40 days of planting. From planting to harvest, three rainfalls occurred in the paddy field. Generally, this routine work of water management practices was to control weeds as is currently done in Chinese rice farming practices and depress N_2O emissions from the field. During the rice-growing period, soil moisture is usually over-saturated so that almost no change of soil moisture or O_2 availability happens when rain events occur. To maintain water levels in the rice fields, they were frequently irrigated. When fields were irrigated with fresh water, it brought substantial amount of dissolved oxygen and the soil remained partially aerobic for sometime even after submergence. Similar observations were found in other reported experiments. Chen et al. (1996) found that rice fields in China emitted little N_2O while the fields were flooded, but when fields were drained, substantial N_2O was emitted. On an annual basis only 0.04 kg N_2O ha^{-1} was emitted while the fields were flooded compared to 1.7 kg N_2O ha^{-1} during non-flooded periods. Cheng *et al*. (1998) found that little N_2O was emitted from the soil to the atmosphere when the soil was saturated. Soil moisture is of great importance for mitigation of N_2O emission from irrigated rice fields because it is the most sensitive factor to regulate N_2O emission and is easy to to be artificially controlled (Zheng *et al.* 1996). As soil is generally flooded, the condition becomes unfavorable to nitrification which leads to low N_2O production through the denitrification process. Early studies reported that N_2O emission from paddy field was negligible. Under submergence, N_2O emission is low even though its formation in soil may be high, as the pressure of standing water prevents N_2O from being released into atmosphere, and also because it gets denitrified to N_2 within the soil (Granli and Bockman 1994).

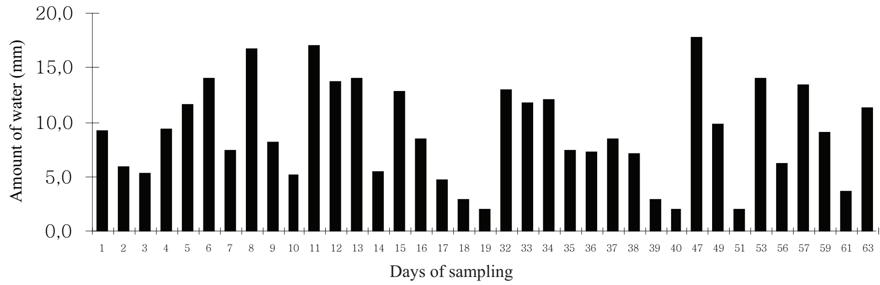

Fig. 1. Amount of water applied in the field

Fertilisation and its Effects on N_2O Emission:

Fig. 2(a) shows nitrous oxide emission for control P and different nitrogen fertiliser treatments during the vegetative period (6 July to 8 August) of the paddy plant. A basal dose of fertiliser was applied on 6 July. After that, N_2O emissions were higher in all nitrogen treatments. Up to two weeks (6 to 19 July), a fluctuation in emissions was observed because at that time more nitrogen existed in submerged soil. As water was available in the field, less emission occurred from 19 to 30 July. Again N_2O increased in all treatments due to second dose of N fertiliser applied on 1 August in field plots. N_2O emission was higher in N4 treatment, but later showed less emission from all the treatments. However, for N3 treatment, initially there was less emission and then higher emission later.

Fig. 2(b) reveals the N_2O emission from interaction of 40 kg P ha^{-1} with different N fertiliser treatments under irrigation and natural rainfall conditions. The highest emission was 113.27 g $d^{-1}ha^{-1}$ on 10 July and the lowest emission was 2.45 g $d^{-1}ha^{-1}$ on 5 August for N_0P_1 treatment. From 19 to 30 July, the fluctuation trend of N_2O flux was almost similar in all treatments. Prior to that, a wide variation was observed from day to day and treatment to treatment. Also, less emission was observed in N2P1 treatment, that is, 180 kg N ha^{-1} and 40 kg P ha^{-1}.

Fig. 2 (c) shows nitrous oxide emission during the vegetative period (6 July to 8 August) of the paddy plants for different nitrogen treatments with 60 kg P ha^{-1}. From 11 to 14 July, emissions were higher in all treatments. The highest peak emission value was observed for N_4P_2 treatment on July and the second highest peak emission was observed for N_2P_2 treatment on 12 July. N_2O fluxes (i.e. rate of emission per hectare and day) in N_0P_2 treatment was low throughout the study period, never exceeding 50 g d^{-1} ha^{-1}.

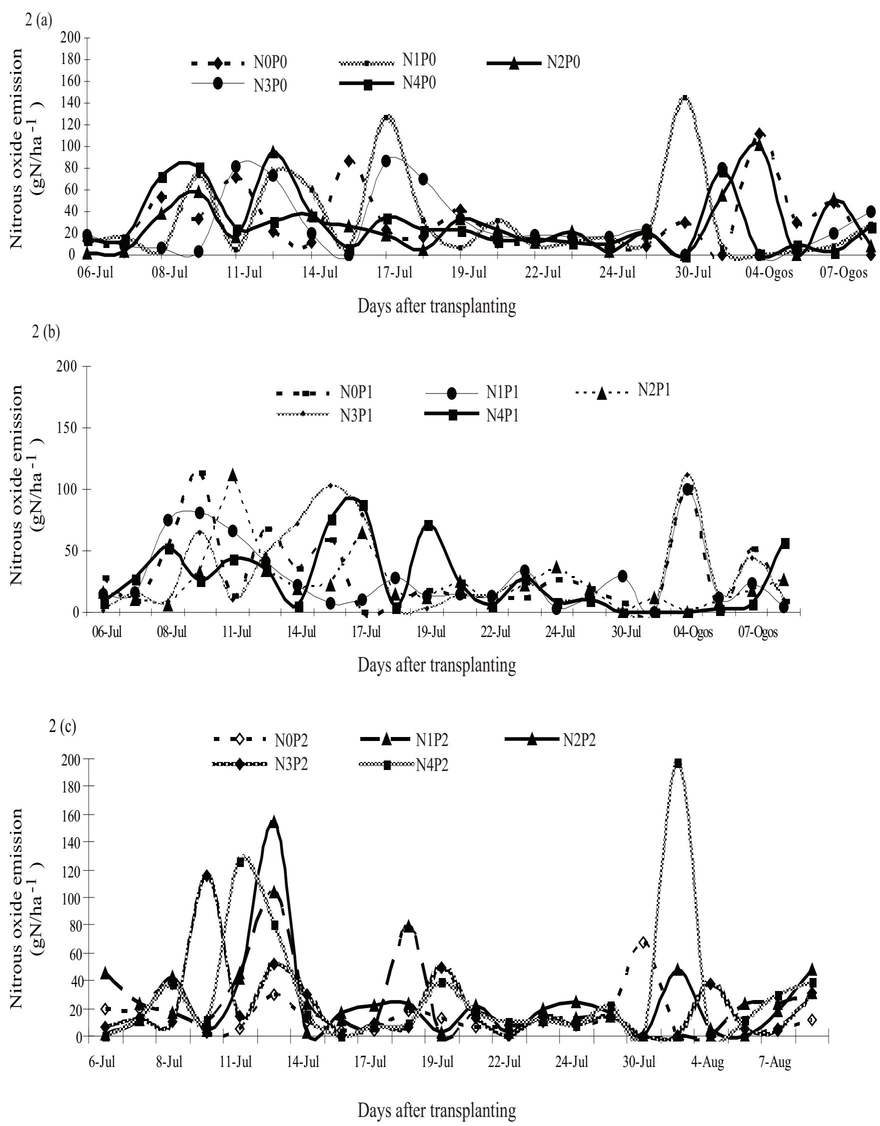

Fig. 2: Nitrous oxide emission during the vegetative period for the different N fertilising treatments with a P addition of 0 (a), 40 (b) and 60 (c) kg P ha^{-1}.

As Fig. 2(a) - (c) obviously demonstrate, variation patterns of N_2O emissions from N and P fertiliser treatments were quite similar. Applied nitrogen was an immediate source of N_2O formation through nitrification and denitrification under strongly anaerobic conditions and that was why the peak appeared earlier when nitrogen was applied as basal fertiliser and time of top dressing. This observation was consistent with the results of other experiments. Nitrification and denitrification are not a separate process. NO_3^- produced during nitrification can be utilised by nitrifiers. Nitrification and denitrification can take place in soils where favourable conditions for both nitrification and denitrification are present in neighbouring microhabitats (Arah 1997). In a study of these microhabitats, Khdyer and Cho (1983) investigated the degree of nitrification and denitrification which occurred after the addition of urea in soil. Nitrification take place in the aerobic surface layer, wheareas the anaerobic zone was dominated by denitrification. N_2O was mainly produced at the aerobic-anaerobic interface from where it could diffuse into the soil surface. This suggests that the production of N_2O is highest when conditions are suboptimal for both nitrifiers and denitrifiers. Comparable mechanisms are active in natural soils. Here, nitrification can take place in aerobic surface layers or cracks. Denitrification is mostly confined to anaerobic deeper layers, waterlogged areas or the interior of soil aggregates (Tiedje *et al.* 1984; Leffelaar, 1986). In rice paddy fields treated with nitrogen fertilisers, including urea, emission of N_2O was suppressed when the plots were flooded and again reached its peak when fertiliser was applied due to nitrification and denitrification process (Cai *et al*. 1997; Xu *et al.* 1997).

ANOVA results showed significant difference in emission over the days of gas sampling ($P<0.05$) (Table 3). Also, N and N*P was significant ($P \leq 0.001$ 0.001) on N_2O emission as well as phosphorous (P) treatment was significant ($P \leq 0.05$) for N_2O emission (Table 2). The results showed that emission significantly increased over the first week of fertilisation and decreased in the second week and increased again in the third week at which fertiliser was applied in the field (Fig.2 (a)-(c)).

TABLE 2

Significance levels for the main and interactive effects of N and P on N_2O emission

Source of variance	N_2O emission
Nitrogen (N)	***
Phosphorous (P)	*
N×P	***

Where * and *** represent probability of ≤ 0.05 and ≤ 0.001, respectively.

The variance in daily emission was analysed up to day 22, because after that the plant height was high and no nitrogen fertiliser was added; also comparison on emission was no longer valid (Table 3). It was found that N_2O emission depends on amount and time of nitrogen fertiliser application. Similar results have been reported from other studies. The amount of N_2O emission would then depend on the amount of fertiliser or nitrate transferred to the denitrifying layer and irrigation water level. The more urea applied, the more nitrate available from the nitrification of ammonia. Likewise, with more frequent flooding, more nitrogen gas (N_2) and not N_2O would be produced (Buresh and Austin 1988).

Nitrogen Loss through N_2O Emission

Nitrogen loss through N_2O emission for nitrogen and phosphorous fertiliser treatment is shown in Table 4. Losses were calculated from each plot during total vegetative period of paddy rice plant. Nitrogen loss for 0 and 40 kg P ha^{-1} treatments decreased linearly with respect to different nitrogen treatments. But for 60 kg P ha^{-1}, no relationship was observed with different nitrogen treatments. Total N2O emission for N0P0, N2P0, N2P2, N3P2, N4P2 were the same, that is, 998.54 g ha^{-1}. The highest amount of N_2O emission was 1181.28 in N0P1 treatment and lowest amount of N_2O emission was 431.89 g ha^{-1} in N0P2 treatment. Nitrogen loss through N_2O emission for N1P0, N2P0, N3P0, N4P0 was 1.18%, 0.55%, 0.37%, 0.27%, respectively, and for N1P1, N2P1, N3P1, N4P1, was 1.15%, 0.43%, 0.40% and 0.25% and for N1P2, N2P2, N3P2, N4P2, it was 0.10%, 0.55%, 0.37%, 0.28%, respectively. From this value, it was evaluated that N_2O emission loss through nitrogen appears to be lower for phosphorous treatments, with the exception of N3P1, and, N2P2 and N4P2. This was consistent with other studies which indicated that 3.1% of the total N applied is lost as N_2O (Hansen *et al.*1993). The losses of N_2O-N emissions were reported to vary between 0.01 - 0.55% of the total nitrogen applied in rice (Smith *et al.* 1983; Minami, 1987; Cai *et al*. 1997).

TABLE 3

Least Significant Difference (LSD) of mean N_2O emission

Source of variance	Mean/N_2O^-emission (g N ha ^{1})						
Days	3	4	5	6	9	18	19
N_2O emission	34.29^{bcde}	47.28^{ab}	45.21^{abc}	63.06^{a}	32.28^{bcdef}	31.83 ^{bcdef}	38.10^{bcd}

Values within a row followed by different letters are significantly different from other values ($P<0.05$).

TABLE 4
Nitrogen loss by N fertilizer through N_2O emission during sampling period.

Treatment	P treatment	Emmission amount (g ha^{-1})	Loss percentage (%)
0	0	998.54	-
1	0	1059.82	1.18
2	0	998.54	0.55
3	0	998.54	0.37
4	0	933.31	0.26
0	1	1181.28	-
1	1	1031.12	1.15
2	1	777.06	0.43
3	1	1078.4	0.40
4	1	888.08	0.25
0	2	431.89	-
1	2	897.19	0.10
2	2	998.54	0.55
3	2	998.54	0.37
4	2	998.54	0.28

Data were mean values of different treatment with three replications. Mean sharing different letter(s) differ significantly at 5% level of probability.

CONCLUSIONS

In the experimental design of this study, the highest amount of nitrogen and phosphorous fertiliser doses were considered to detect N_2O emission from the interaction of N and P fertilisers under an irrigated system. An optimum rate of 180 kg N ha^{-1} and 40 kg P ha^{-1} was effective in reducing N losses through N_2O emission and maintain crop yields compared to the traditionally high N rates (240 and 360 kg N ha^{-1}). The main effect on emission is significant ($P<0.05$) for days as well as N ($P\leq 0.001$, P ($P\leq 0.05$) and interaction between them was significant ($P\leq 0.001$). This emission was significant ($P<0.05$) at 3,4,5,6,9,18 and 19 days during the emission measurement. Applied nitrogen was an immediate source of N_2O emission through denitrification under strongly anaerobic conditions and that was why the peak appeared earlier when nitrogen was applied as basal fertilizer and time of top dressing. Total N_2O emissions varied from 431.89 to 1181.28 g ha^{-1} and nitrogen loss through N_2O emission varied from 0.10 to 1.18%.

Our study showed that N_2O emissions may not be a serious concern from the economic point of view considering the low percentage of applied N lost through N_2O emissions. However, its high global warming potential and total annual emission load to the atmosphere by widespread rice cultivation in China, may add significantly to enhance the green house effect. This illustrates that high doses of N and P fertiliser application to soils in China is a waste of resources that could lead eventually to water pollution and loss of income to farmers. So, efforts are needed to mitigate N_2O emission, as agriculture needs increasingly higher fertiliser N to meet production demands.

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REFERENCES

Arah, J.R.M. 1997. Apportioning nitrous oxide fluxes between nitrification and denitrification using gas-phase mass spectrometry. *Soil Biology and Biochemistry* **29**: 1295-1299.

Bandivas, J., A.Vermoesen, C.J. De Groot and O. van Cleemput. 1994. The effect of different moisture regimes and soil characteristics on nitrous oxide emission and consumption by different soils. *Soil Science.* **158**:106-114.

Barraclough, D., S.C. Jarvis, G.P. Davies and J. Williams. 1992. The relation between fertilizer nitrogen application and nitrate leaching from grassland. *Soil Use Manage*. **8**: 51-56.

Bouwman, A.F.1990. Soils and the greenhouse effect. John Wiley and Sons, Chichester, 61-127.

Bowden, W.D., 1986. Gaseous nitrogen emission from undisturbed terrestrial ecosystem: An assessment of their impact on local and global nitrogen budgets. *Biochemistry*. **2**: 249-279.

Buresh, R.J. and E.R. Austin. 1988. Direct measurement of dinitrogen and nitrous oxide flux in flooded rice fields. *Soil Science Society of Australia Journal.* **52**: 681-687.

Buresh, R.J. and S.K. Dedatta. 1990. Denitrification losses from puddle rice soils in the tropics. *Biology and Fertility in Soils*. **9**:1-13.

Cai, Z., G. Xing, X. Yan, H. Xu, H. Tsuruta, K. Yagi, and K. Minami. 1997. Methane and nitrous oxide emissions from rice paddy fields as affected by nitrogen fertilizers and water management. *Plant and Soil*. **196**:7-14.

Chao, C.C. 1997. Nitrous oxide emission from paddy field, upland, wetland, forest and slopeland in central and southern Taiwan and their effect factors. In: Lu, S.C., Liu, C.M., Yang, S.S. (Eds.), Research on Atmospheric Environments of Taiwan Area. Global Change Research Center and Department of Agricultural Chemistry, National Taiwan University, Taipei, Taiwan, pp.173-194.

Chang, C., H.H. Janzen, C.M. Cho and E.M. Nakonechny, E.M. 1998. Nitrous oxide emission through plants. *Soil Science Society of America Journal*. **62**:35-38.

Eichner, M.J. 1990. Nitrous oxide emissions from fertilized soils: summary of available data. *Journal of Environment Quartarley*. **19**: 272-280.

Freney J.R, O.T Den mead and Watanable .1981. Ammonia and nitrous oxide losses following applications of ammonia sulphate to flooded rice. *Australian Journal of Agricultural Research*. **32**: 37-45.

Graedel, T.E. and P.J. Crutzen. 1994. Chemic der Atmosphäre. Spektrum Akademischer Verlag, Heidelberg.511pp.

Granli, T. and O.C. Bockman. 1994. Nitrous oxide from agriculture. *Norwaign Journal of Agricultural Science*. **12**: 48-53.

Hansen, S., J.E. Maehlum and R.M. Harrison. 1995. Studies on NO and N_2O fluxes from a wheat field. *Atmospheric Environment.* **29**:1627-1635.

Hasegawa, K., K. Hanaki, T. Matsuo and S. Kidaka. 1998. Production and degradation of nitrous oxide in the paddy field and a small river contaminated with high-nitrate nitrogen. Journal of Japan Society on Water Environment. 21(10): 676-682 (In Japanese).

Houghton, J.T., L.G. MeiraFilho, J. Bruce, L. Hoesung, B.A. Callander, E. Haites, N. Harris and K. Maskell.(Eds.), 1995. Climate change 1994. An evaluation of the IPCC IS92 Emission Scenarios. Cambridge University Press, Cambridge, pp.25-28.

IPCC. 1995. Climate Change 1995. Summary for policy makers: the science of climate change. In: IPCC Second Assessment Report. pp.25-28.

Khalil, M.I., A.B. Rosenani, O. Van Cleemput, C.I. Fauziah and J. Shamshuddin. 2002. Nitrous Oxide Emissions from an Ultisol of the Humid Tropics under Maize–Groundnut Rotation. *Journal of Environmental Quality*. **31**:1071-1078.

Khdyer, I.I., and C.M Cho. 1983. Nitrification and denitrification of nitrogen fertilizers in a soil column. *Soil Science Society of America Journal.* **47**: 1134-1139.

Lai, C.M. 2000. Mitigation strategies of nitrous oxide emission from agricultural soils (II). In: Yang, S.S. (Ed.), Flux and Mitigation of Green house gases (II). Department of Agricultural Chemistry and Agricultural Exhibition Hall, National Taiwan University, Taipei, Taiwan, pp.110-126.

Liffelaar, P.A. 1986. Dynamics of partial anaerobiosis, denitrification and water in a soil aggregate: experimental. *Soil Science*. **142**:352-366.

Lindau, C.W., W.H. Patrick Jr., R.D. Delaune and K.R. Reddy. 1990. Rate of accumulation and emission of N_2, N_2O and CH_4 from flooded soil. *Plant and Soil.* **129**:296-276.

Lin Erda, H. Dong and Y. Li. 1994. Methane emissions of China: Agricultural Sources and Mitigation Options, in J. van Ham et al (eds), Non. CO_2 Greenhouse Gases, Kluwer Academic Publishers, pp 405-410.

Ryden, J.C.1981. Nitrous oxide exchange between a grassland soil and the atmosphere. *Nature.* **292**: 235-237.

Sevensson, B.H., L. Klemedtsson, S. Simkins, K. Paustian and T. Rosswall. 1991. Soil denitrification in three cropping systems characterized by difference in nitrogen and carbon supply. *Plant and Soil*. **138**: 257-271.

Smith, C.J., M. Brandon, and W.H. Patrick Jr. 1982. Nitrous oxide emissions following urea-N fertilization of wetland rice. *Soil Sci. Plant Nutr.* **28**:161-171.

Smith, C.J. and W.H. Patrick Jr. 1983. Nitrous oxide emissions as affected by alternate anaerobic and aerobic conditions from soil suspicious enriched with $(NH_4)^2SO_4$. *Soil Biology and Biochemistry.* **15**:693-696.

Stevens, R.J., R.J. Laughlin, G.J. Atkins and S.J. Prosser. 1993. Automated determination of nitrogen-15-labeled dinitrogen and nitrous oxide by mass spectrometry. *Soil Science Society of America Journal.* **57**: 981-988.

Tiedje, J.M., A.J. Sexstone, T.B. Parkin, and N.P. Revsbech. 1984. Anaerobic processes in soil. *Plant and Soil.* **76:** 197-212.

Minami, K., 1987. Emission of nitrous oxide (N2O) from agro-ecosystem. *Japanese Agricultural Research Quartely*. **21**:21-27.

Xing, G.X., 1998. N_2O emission from cropland in China. *Nitrogen cycling in Agroecosystems*. **52**: 249-252.

Xu, H., G. Xing, Z. Cai and H.Tsuruta. 1997. Nitrous oxide emission from rice paddy field in China. *Nutrient Cycling in Agro ecosystems.* **49**:23-28.

Zheng, X., M. Wang, Y. Wang, R. Shen, Y. Gong, D. Luo, W. Zhang, J. Jin and L. Li. 1996. Impact of soil humidity on N_2O production and emission from a rice-wheat rotation ecosystem. *Chinese Journal of Applied Ecology.* **7**(3): 213-219 (in Chinese).

Zheng X., M. Wang, Y. Wang, R. Shen, J. Li, J. Heyer, M. Kogge, H. Papen, J. Jin and L. Li. 1999. Characters of green house gas (CH_4, N_2O, NO) emission from croplands of southeast China. *World Resource Review* **11(2)**: 229-246.