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Article

Effect of Intermittent Drainage on Nitrous Oxide Emission and Global Warming Potential in Rice Paddy Soil

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Water control is mainly one of the key factors that can affect nitrous oxide (N_2O) emissions from soils. This study was undertaken to determine the effect of intermittent drainage compared to continuous flooding (conventional water regime) on N_2O emission to global warming potential (GWP) with NPK (standard cultivation practice), NPK+Straw, and PK fertilizations. Nitrous oxide emission rates were collected twice a week using a closed chamber method. With continuous flooding, nitrogen (N) application increased N_2O emission by 106.6% (0.64 kg ha^{-1} in NPK) with respect to the PK treatment (0.31 kg ha^{-1}), and straw addition to NPK enhanced 148.3% of seasonal N_2O flux (0.77 kg ha^{-1} in NPK+Straw). Although seasonal N_2O emission slightly increased by 16.1-42.9% with intermittent irrigation, its seasonal CH_4 emission drastically reduced at 43.5-52.8% resulting in a lower GWP at 48.9-58.5% with respect to that of continuously flooded treatments (4.51 Mg CO_2 ha^{-1}, PK; 7.60 Mg CO_2 ha^{-1}, NPK; 14.55 Mg CO_2 ha^{-1}, NPK+Straw). Rice yield, at similar fertilization with the continuously-flooded rice field, was not affected by intermittent irrigation. Conclusively, intermittent irrigation can be very effective and a rational soil management strategy to mitigate GWP with considering rice productivity in a temperate paddy rice field like Korea.

Key words: Nitrous oxide emission, Global warming potential, Intermittent irrigation, Fertilization

Introduction

Nitrous oxide (N_2O) has been recognized as an important greenhouse gas, with a global warming potential about 310 times than carbon dioxide (CO_2) in a 100-year time frame (Amon, 2000). Its concentration in the atmosphere has progressively increased at an annual rate of 0.2-0.3% due to human activities, which contributes to the massive destruction of the stratospheric ozone layer (Weiss, 1981; Rasmussen and Khalil, 1986; Huang, 2007). Agricultural soils contribute approximately 60% to total anthropogenic emission of N_2O (Kroeze et al., 1999).

So far the study on N_2O emission from soil has been stressed on upland soil rather than the paddy soil, and it has been generally thought that rice paddy soil emits only small amount of N_2O (Smith et al., 1982; Buresh and Austin, 1988), and mainly focused the determination of CH_4 emission characteristics. In recent years, however, the research on N_2O emission from paddy rice fields has received public attention (Minami, 1987). In particular, N_2O is associated with rice cultivation being emitted to the atmosphere via denitrification and/or nitrification after chemical or organic fertilization (Huang et al., 2007). But irrigated rice, due to rapid natural drainage, the upper layers of soil remain aerobic for a rice growing season, and dissolved oxygen through irrigation water may add oxygen to the surface soil. Thus considerable amount of N_2O can be produced via nitrification as well as denitrification are emitted from the soil subsequently (Ghosh et al., 2003; Mitsch et al., 2005). In our previous study, intermittent irrigation control reduced significantly CH_4 emission during rice cultivation, but N_2O emission also could be expected to be significantly increased. However, there is little information on the effect of intermittent irrigation to the global warming potential (GWP) as affected by N_2O emission in paddy rice fields.

Since rice is the principal food crop for more than half of the world's population, rice production must increase from a 1990 value of 473 million tons to at least 781 million tons by 2020 (IRRI, 1989) to fulfill the demand of the expanding world population. Attain-

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ment of rice production requirement would be achieved by means of increasing cultivation and productivity. This increased production can be achieved through increased use of inputs, particularly irrigation and fertilizer (Bhatia et al., 2010). However, increased use of nitrogenous fertilizer and irrigation would increase the emission of greenhouse gases such as CO_2, CH_4 and N_2O causing global warming and climate change (IPCC, 2007; Pathak and Wassmann, 2007). Thus it is important to quantify the trade-offs between rice production and GWP, which is defined as the ratio of the warming of atmosphere caused by one substance to that caused by a similar mass of CO_2 (Bhatia et al., 2005). This study was undertaken to evaluate the effect of intermittent irrigation with different fertilization background on N_2O emission and total GWP during rice cultivation in Korea.

Materials and Methods

Experimental field preparation and rice cultivation The effect of intermittent irrigation on N_2O emission from paddy rice fields was examined in the rice farm (N 37°15'42.76", E 126°59'13.06"), National Academy of Agricultural Science, Rural Development Administration, Suwon, South Korea, in 2001. The soil was classified as clay loam, mixed, mesic, Aquic Hapludalfs belonging to the Hwadong series and had the following properties before the experiment: clay content 32%, pH (1:5, H_2O) 5.8, organic matter 17 g kg^{-1}, total N 1.2 g kg^{-1}, available P_2O_5 30 mg kg^{-1}, exchangeable Ca^{2+}, Mg^{2+}, and K^+ 6.6, 2.2, and 0.6 $cmol^+$ kg^{-1}, respectively.

The experimental field consisted of 18 plots, each 80 m^2 and laid down in a randomized block design (RBD). The field was divided into two, which was the continuously-flooded (control main treatment) and the intermittently-irrigated fields and these fields were then further divided into 3 plots in accordance with different fertilizer applications : NPK (conventional cultivation practice), NPK+Straw, and PK. The chemical fertilizers were applied at rates N-P_2O_5-K_2O =160-70-30 kg ha^{-1} in NPK, and NPK+Straw using urea, superphosphate and potassium chloride, respectively. The shredded rice straw (5-10 cm size) was added 2 weeks prior to flooding, which was mixed mechanically within 10-15 cm depth of the surface soil at the rate of 5 Mg ha^{-1} in the NPK+Straw treatment. The basal chemical fertilizers were applied 1 day before transplanting: 80 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 21 kg K_2O ha^{-1}. Tillering fertilizer (32 kg N ha^{-1}) was applied about 2 weeks after rice transplanting and panicle fertilizer (48 kg N ha^{-1}, 9 kg K_2O ha^{-1}) on 6 weeks of rice transplanting.

Twenty-one days old seedlings (3 plants per hill) of rice (cultivar, Dongjinbyeo, *Oryza sativa*, Japonica) were seeded on 20th April 2001, transplanted into field plots at a spacing 15 cm x 30 cm on the 25th May, and harvested by early October 2001. Floodwater depth was maintained at 5-7 cm in the continuously-flooded rice field until the mid-maturity stage of rice growth. Meanwhile, the field was flooded until 33 days after transplanting (DAT) and was drained for the period of 26 days (34–60 DAT) in the intermittently-irrigated rice field.

N_2O gas sampling, GWP analysis and calculation Nitrous oxide was measured by transparent acryl chamber (length 62 cm, width 62 cm and height 112 cm) and air gas samples were collected by air-tight syringes at 0 to 30 minutes intervals after closing the top of the chamber over the rice planted plots (Hou et al., 2000). The gas sampling time was done at 11:00-13:00, assuming that the daily emission pattern remained the same the whole season. Eight rice hills were covered by each chamber. The chamber contained 4 holes at the bottom through which water movement was controlled. Nitrous oxide analyses were carried out on a Shimadzu 14A gas chromatograph with an ECD detector (Shimadzu Scientific Instruments Inc., Columbia, MD).

Nitrous oxide emission from the paddy field was calculated from the increase in N_2O concentrations per unit surface area of the chamber for a specific time intervals. A closed-chamber equation was used to estimate N_2O fluxes from each treatment.

$$F = \rho \times (V/A) \times H \times (\triangle c/\triangle t) \times (273/T)$$

where F= N_2O flux (mg N_2O m^{-2} hr^{-1}), ρ = gas density (1.96 mg cm^{-3}), V = volume of chamber (m^3), A = surface area of chamber (m^2), H = height of the chamber (m), $\triangle c/\triangle t$ = rate of increase of N_2O gas concentration in the chamber (mg m^{-3} hr^{-1}), T (absolute temperature) = 273+mean temperature in chamber (℃).

Total N_2O flux for the entire crop period were computed by the formula (Singh et al., 1999); Total N_2O flux = $\sum_i^n$ (Ri × Di), where Ri is the rate of N_2O flux (g m^{-2} d^{-1}) in the i^{th} sampling interval, Di is the number of days in the i^{th} sampling interval, and n the number of sampling intervals.

The GWP was calculated using the equation: GWP = CO_2 + CH_4 × 23 + N_2O × 310 (Bhatia et al., 2010)

Measurements of in situ soil properties Soil redox potential and pH was measured twice a week by Eh meter (PRN-41, DKK-TOA Corporation), where electrodes were permanently installed at 8 cm soil depth, and a pH meter, respectively throughout the entire rice cultivation period. Soil temperature was recorded during N_2O sampling, while air temperature and rainfall data were obtained from Suwon Meteorological Station, Korea.

Soil samples were collected from the surface layer (0-15 cm depth) after rice harvesting. The soil samples were air-dried, sieved (<2 mm) and analyzed for pH (1:5 with H_2O), organic matter content (Walkey and Black method; Allison, 1965), and exchangeable Ca^{2+}, Mg^{2+}, and K^+ (1 M NH_4-acetate pH 7.0, AA, Shimazu 660). The available phosphate content was determined using Lancaster method (RDA, 1988).

Statistical analysis Statistical analyses were conducted using SAS software (SAS, 1990). Rice growth, yield, soil properties and N_2O emission data were subjected to the analysis of variance and regression. Fisher's protected least significant difference (LSD) was calculated at the 0.05 probability level for making treatment mean comparisons.

Results and Discussions

The temperature and rainfall pattern during the study period were typical and showed did not vary from the temperature and rainfall records for the past 30 years (Fig. 1). Changes in soil temperature showed a similar tendency with the changes in air temperature, however, soil temperature was slightly higher than atmospheric temperature since it was determined at noontime with

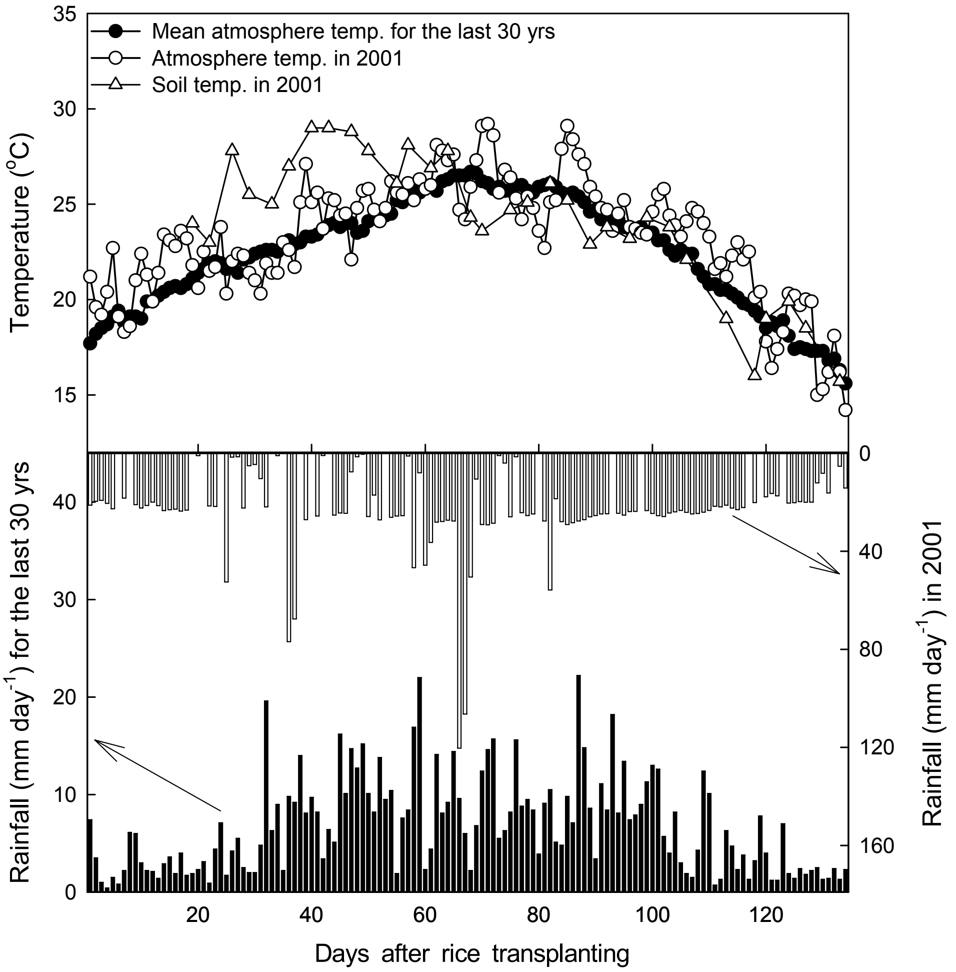

Fig. 1. Changes of atmosphere and soil temperatures, and rainfall during rice cultivation.

N_2O sampling, when daily emission was highest (11:00 AM-1:00 PM).

In the continuously flooded fields, soil redox (Eh) continually decreased and reached a value lower than -300 mV until the maturity stage of rice growth in the NPK and PK treatments (Fig. 2). Meanwhile, soil Eh was instantly decreased at less than -200 mV at the start of rice growing season in the NPK+Straw treatment which might be due to the higher demand for oxygen for the oxidative degradation of straw (Bossio and Scow, 1997; Sass and Fisher, 1997). As soil Eh decreased, less N_2O could be emitted since N_2O can be reduced to N_2 under low redox potential conditions (Hou et al., 2000). On the other hand, as soil Eh increased, soil conditions become more favorable for N_2O production primarily through denitrification, and then by nitrification which followed after O_2 had entered into the soil (Hou et al., 2000). Soil pH ranged 5.6 - 6.5 before rice harvesting, favorable to the microbial activities that can enhance the production of greenhouse gases such as CO_2, CH_4 and N_2O.

Highest N_2O peaks in the treatments were observed at the initial stages of rice growth, which gradually decreased with the development of soil's reductive condition until rice plant reached maturity stage of growth under the continuously flooded fields (Fig. 3). On the other hand, three obvious N_2O emission peaks appeared in the treatments 20 days after basal fertilizer, 1 day, and 1 month after top-dressing, respectively with intermittent irrigation. After the third flux peak, N_2O flux continually decreased until rice harvesting. In general, draining the rice fields may create suitable O_2 availability in the soil for N_2O production as the intermediate product of either nitrification or denitrification, while increasing use of N fertilizers in rice fields makes them important sources of N_2O as well (Xiong et al., 2007; Zheng et al., 2000).

In our previous report, CH_4 emission rate extensively reduced by 43.5% in the NPK treatment (181.7 kg ha^{-1}) with intermittent irrigation, as compared to con-

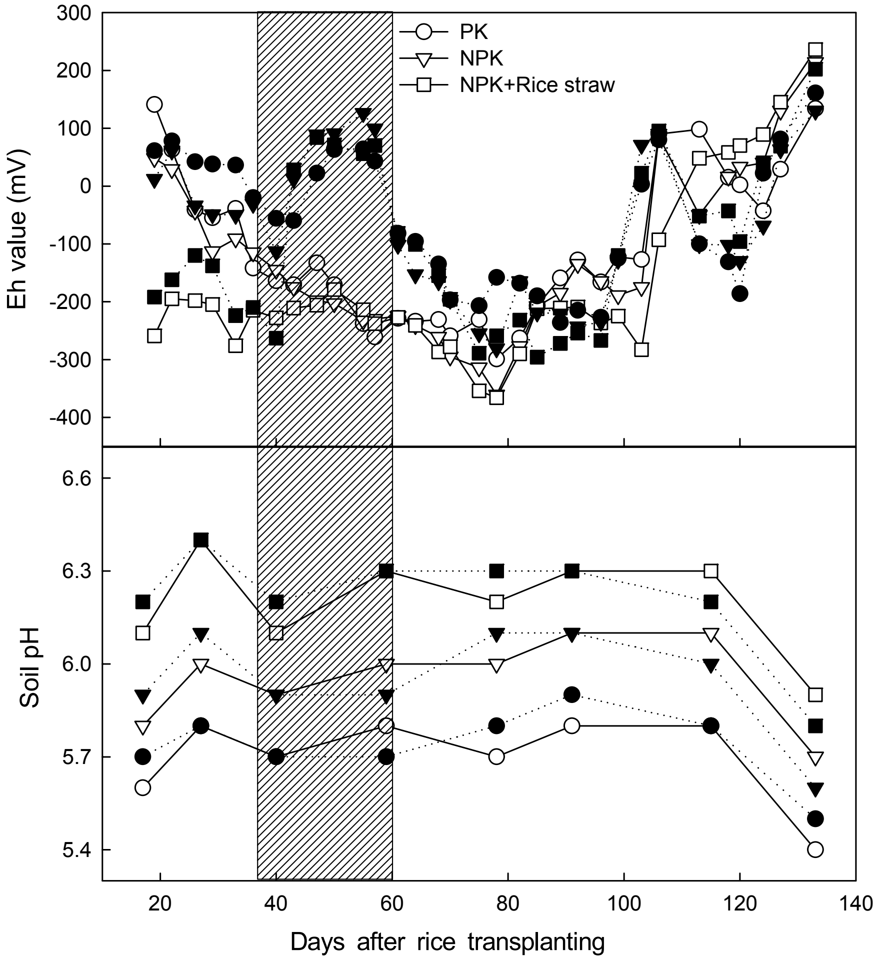

Fig. 2. Changes of soil Eh values and pHs during rice cultivation.
† PK (P_2O_5, K_2O only), NPK (N-P_2O_5-K_2O).

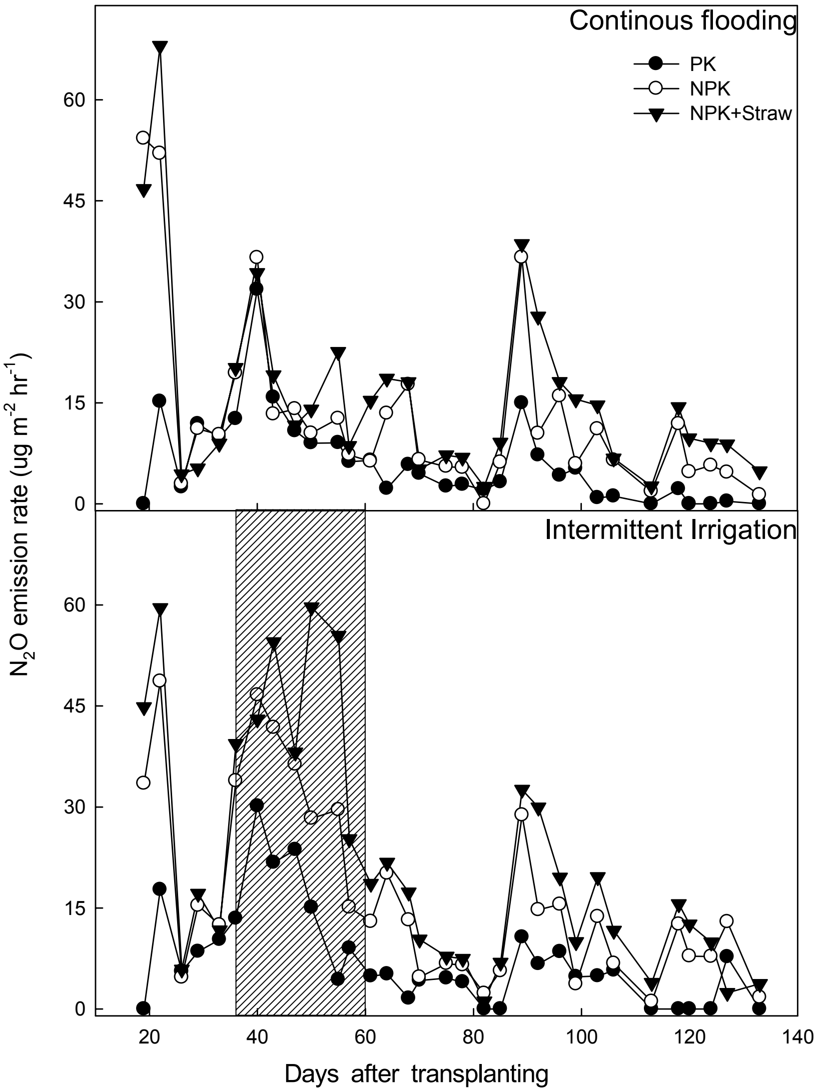

Fig. 3. Changes of nitrous oxide (N_2O) emission rates during rice cultivation.

ventional flooding (321.7 kg ha^{-1} in continuous flooding). Methane released in NPK+Straw and PK treatments were also effectively reduced by 51.6 and 52.8%, respectively, by intermittent irrigation. Meanwhile, N_2O emission was lowest in no-N fertilization (0.31 kg ha^{-1} in PK), which increased by 106.6% with N application (0.64 kg ha^{-1} in NPK), and straw incorporation to NPK increased by 148.3% (0.77 kg ha^{-1} in NPK+Straw) with continuous flooding (Table 1). Straw incorporation, which supplied more decomposable carbon, hastened the drop in redox potential, sharply increased CH_4 production and resulted in higher GWP. In addition, application of N influenced CH_4 and N_2O emissions and enhanced GWP; however, CH_4 could also be more impacted by temperature and organic matter content of soil, crop growth stages and water regime (Halvorson et al., 2005; Pathak et al., 2005). Nitrogen plus straw application gave the highest seasonal N_2O flux at 1.10 kg ha^{-1} in the intermittently-irrigated treatments, but had a lower total GWP at 7.26 Mg CO_2 ha^{-1}, with respect to that of continuous flooding (4.55 Mg CO_2 ha^{-1}; NPK+Straw). As maximum response to increased N level was observed in the combined application of N fertilizer and rice straw, which could also result in a greater increase in GWP, a countermeasure to lower the global warming effect in rice cultivation with considering rice productivity should be seriously considered in paddy rice systems.

With intermittent irrigation, lower total GWP of 2.20, 4.43 and 7.26 kg CO_2 ha^{-1} in PK, NPK and NPK+Straw, respectively, were observed than that of continuous irrigation treatments (4.51 kg CO_2 ha^{-1}, PK; 7.60 kg CO_2 ha^{-1}, NPK; 14.55 kg CO_2 ha^{-1}, NPK+ Straw) (Table 1). Intermittent irrigation increased sea-

Table 1. Grain yield and total emission of green house gases in different flooding and fertilization conditions during rice cultivation.

Flooding (A)	Fertilization (B)	Grain yield (kg ha^{-1})	CH_4 emission		N_2O emission		Total GWP (Mg CO_2 ha^{-1})	Grain yield/ GWP
			Seasonal flux (kg CH_4 ha^{-1})	GWP† (Mg CO_2 ha^{-1})	Seasonal flux (kg N_2O ha^{-1})	GWP (Mg CO_2 ha^{-1})		
Continuous	PK	4605	192.0	4.05	0.31	0.096	4.15	1.11
	NPK	5525	321.7	6.76	0.64	0.198	6.96	0.79
	NPK+Straw	6276	622.2	13.07	0.78	0.239	13.31	0.47
Intermittent	PK	4646	90.7	1.90	0.36	0.112	2.01	2.31
	NPK	5694	181.7	3.82	0.82	0.254	4.07	1.40
	NPK+Straw	6312	300.9	6.32	1.10	0.341	6.66	0.95
ANOVA	A	ns§	***‡	***	**	**	***	***
	B	***	***	***	***	***	***	***
	A × B	ns	***	***	ns	ns	***	***

† GWP (global warming potential) of CH_4 and N_2O were calculated by multiplying 23 and 310 times on seasonal CH_4 and N_2O fluxes, respectively, ‡**,*** = significant at the 0.01 and 0.001 probability level, respectively. § ns = not significant at the 0.05 probability level.

sonal N_2O flux by only 16.13-42.86%, but significantly reduced the seasonal CH_4 flux by 43.5-52.8% compared with continuous flooding. Under continuous flooding, the grain yield without N fertilization (PK) was 4,605 kg ha^{-1}, which increased by 20% with N addition (5,525 kg ha^{-1} in NPK), while straw incorporation to NPK increased by 14% (6,276 kg ha^{-1} in NPK+Straw). The application of inorganic fertilizers with/without organic amendments with conventional flooding management had been long established to effectively increase crop yield and productivity. Rice productions in all treatments were 0.6-3.0% higher (5,694 kg ha^{-1} in NPK, 6,312 kg ha^{-1} in NPK+Straw, 4,646 kg ha^{-1} in PK) with intermittent irrigation than those of continuous flooding, and considered as typical averages of rice production in Korea. More importantly, trade-offs between grain yield and GWP was 76.6-107.0% higher in all treatments under continuous flooding than by intermittent irrigation (1.28, NPK; 2.11, NPK+Straw; 0.87, PK). With considering a number of mitigation options of greenhouse gases, intermittent irrigation seems to be the most practical and effective compromise, which reduced the total GWP by 48.85-58.51% without decreasing rice production rate.

Conclusion

Intermittent irrigation significantly increased N_2O emissions by 16.13-42.86% in PK, NPK, NPK+Straw treatments during rice cultivation; however, the increase in N_2O seasonal flux emission was lower comparable to the decrease in CH_4 emissions by 43.5-52.8%. Grain yield was not affected and the total GWP decreased by 48.86-58.51% for intermittent irrigation, compared to those under continuous flooding. Water management strategies like intermittent irrigation, which significantly decreased the GWP of greenhouse gases like CH_4 during rice cultivation, can be one of the most rational management practices to reduce the global warming contribution coming from the agricultural sector. There is a greater need to also further establish the long-term effect of intermittent irrigation on reducing greenhouse emissions and rice yield.

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References

Allison, L.E. 1965. Organic carbon. p. 1367-1376. In C.A. Black et al. (ed.) Methods of Soil Analysis, Part 2. American Society of Agronomy, Madison, WI, USA.

Amon, B., T. Amon, C. Alt, G. Moitzi, and J. Boxberger. 2000. Nitrous oxide emissions from agriculture and mitigation options N_2O emission aus der Landwirtschaft und Minderungsmoglichkeiten. p. 29-31. Paper Presented at Nussdorfel Laende A-1190, Vienna, Austria.

Bhatia, A., H. Pathak, N. Jain, P.K. Singh, A.K. Singh. 2005. Global warming potential of manure amended soils under rice-wheat system in the Indo-Gangetic Plains. Atmos. Environ. 39:6976-6984.

Bhatia, A., H. Pathak, P.K. Aggarwal, and N. Jain. 2010. Trade-off between productivity enhancement and global warming potential of rice and wheat in India. Nutr. Cycl. Agroecosyst. 86: 413-424.

Bossio, D.A., and K.M. Scow. 1997. Management changes in rice production alter microbial community. California Agriculture 51: 33-40.

Buresh, R.J., and R.A. Austin. 1988. Direct measurement of dinitrogen and nitrous oxide flux in flooded rice fields. Soil Sci. Soc. Am. J. 52: 681-687.

Ghosh, S., D. Majumdar, and M.C. Jain. 2003. Methane and nitrous oxide emissions from an irrigated rice of North India. Chemosphere 51: 181-195.

Halvorson, A.D., B.J. Wienhold, and A.L. Black. 2005. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. Soil Sci. Soc. Am. J. 66: 906-912.

Huang, S., H. Pant, and J. Hu. 2007. Effects of water regimes on nitrous oxide emission from soils. Ecol. Eng. 31: 9-15.

Hou, A.X., G.X. Chen, Z.P. Wang, O. Van. Cleemput, and W.H. Jr. Patrick. 2000. Methane and nitrous oxide emissions from a rice field in relation to soil redox and microbiological processes. Soil Sci. Soc. Am. J. 64: 2180-2186.

International Rice Research and Institute. 1989. IRRI Toward 2000 and Beyond. IRRI, Manila, Philippines.

IPCC. 2007. The physical science basis. In S. Solomon et al., (ed.) Climate change 2007: contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge.

Kroeze, C., A. Mosier, and L. Bouwman. 1999. Closing the global N_2O budget: a restrospective analysis 1500-1994. Global Biogeochem. Cycl. 13:1-8.

Minami, K. 1987. Emission of nitrous oxide from agro-ecosystem. Japan Agri. Res. Quarterly 21: 21-27.

Mitsch, W.J., L. Zhang, C.J. Anderson, A.E. Altor, and M.E. Hernandez. 2005. Creating riverine wetlands: ecological succession, nutrient retention, and pulsing effects. Ecol. Eng. 25: 510-527.

Pathak, H., C. Li, and R. Wassmann. 2005. Greenhouse gas emissions from Indian rice fields: calibration and upscaling using the DNDC model. Biogeosci. 2:113-123.

Pathak, H., and R. Wassmann. 2007. Introducing greenhouse gas mitigation as a development objective in rice-based agriculture: I. Generation of technical coefficients. Agricultural Systems. 94: 808-825.

Rasmussen, R.A., and M.A.K. Khalil. 1986. Atmospheric trace gases: Trends and distributions over the last decade. Science 232: 1623-1624.

Rural Development Administration (RDA) 1988. Method of Soil Chemical Analysis. National Institute of Agricultural Science and Technology, Suwon, Korea.

SAS. 1990. SAS/STS User's Guide, vol. 1, ACECLUS-FREQ version 6, 4th ed. SAS Institute, Inc., Cary, NC.

Sass, R.L. and Jr. F.M. Fisher. 1997. Methane emissions from rice paddies: a process study. Nutr. Cycl. Agroecosys. 49: 119-127.

Singh, S., Singh, J.S., Kashyap, A.K., 1999. Methane consumption by soils of dryland rice agriculture: Influence of varieties and N-fertilization, Chemosphere 38, 175-189.

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

Weiss, R.F. 1981. The temporal and spatial distribution of tropospheric nitrous oxide. J. Geophys. Res. 86: 7185-7195.

Xiong, Z.Q., G.X. Xing, and Z.L. Zhu. 2007. Nitrous oxide and methane emissions as affected by water, soil and nitrogen. Pedosphere 17(2):146-155.

Zheng, X., M. Wang, Y. Wang, R. Shen, J. Gou, J. Li, J. Jin, and L. Li. 2000. Impacts of soil moisture on nitrous oxide emission from croplands: a case study on rice-based agroecosystem in Southeast China. Chemosphere 2:207-214.