Nitrogen fertilization management can decrease methane emission from wetland rice fields of Central Vietnam

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Abstract
Wetland rice is the largest source of CH_4 emission from cropping and also offers the most options to modify crop management for reducing these emissions. The experiment was conducted in two rice cropping systems in 2014 and 2015 to assess the influence of rates and types of nitrogen fertilizer on CH_4 emission in rice fields of Central Vietnam. Results show that high fertilizer N rates (120 kg N ha^{-1}) increased seasonal cumulative CH_4 emissions from 11.6 – 26.7 g m^{-2} for urea and 6.7 – 19.5 g m^{-2} for ammonium chloride in winter spring and summer cropping seasons relative to when no N fertilizer was applied. Replacing urea with ammonium chloride at the same N rate significantly reduced CH_4 emissions by 35% (winter spring cropping season) and 32% (summer cropping season) at the rate of 120 kg N ha^{-1}. Average CH_4 emission was about 2.1 – 2.2 times higher in summer season as compared in winter spring season. To develop effective GHG mitigation strategies future work is needed to (i) quantify the effects on both CH_4 and N_2O emissions), (ii) investigate options for combining mitigation practices.

Key Words
Ammonium chloride, cropping seasons, rate, type, urea

Introduction
Agricultural activities influence atmospheric concentrations of the greenhouse gasses (GHG), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide, (N_2O), and contribute about 20% of the world's global radiative forcing (Lal et al 1999). Globally, agricultural CH_4 and N_2O emissions have increased by nearly 17% from 1990 to 2005, an average annual emission increase of about 60 Mt CO_2-eq/yr (IPCC 2007). CH_4 is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, from stored manures, and from rice grown under flooded conditions (Mosier et al. 1998). Nitrogen is generally the most limiting nutrient in intensive crop production systems (Robertson and Vitousek 2009), and N fertilizer is commonly applied to rice, corn, wheat and other non-leguminous crops. There is an increasing pressure on the rice-growing resources, especially in Asia where more than 90% of rice is grown and consumed (Becker 1993). Knowledge of the trade-offs between CH_4 emission and N fertilizer management practice is therefore an essential requirement for informing management strategies that aim to reduce the agricultural CH_4 burden without compromising productivity and economic returns. A number of management technologies have been proposed to reduce agricultural CH_4 emission (Mosier et al 2001; CAST 2004; Follett et al 2005). Agricultural management can mitigate global radiative forcing by increasing storage of soil organic carbon (SOC), increasing oxidation of CH_4 in soil (Mosier et al 2006). Improving nitrogen use efficiency (NUE) through nitrogen fertilization management has been identified to reduce farm costs and CH_4, N_2O emission. It has been found some researches in different countries on the effect of nitrogen fertilizer types and rates on methane emissions from rice field (Bruce et al 2012; Ibrahim et al 1999), but there is still lack of this information in Central Vietnam. Therefore, this study was conducted to assess the influence of rates and types of nitrogen application on CH_4 emission in the two rice cropping seasons in Central Vietnam.

Methods
Experimental site
The site of field experiment was located in Huong An village (16°28′2″N and 107°31′2″E), Huong Tra town, Thua Thien Hue province, Central Vietnam. The typical paddy soil was classified as Dystric Fluvisols (Gleyi-Dystric Fluvisols) (Le Thai Bat and Pham Quang Khanh 2015). A tropical monsoon climate prevailed in the area with mean annual temperature and precipitation of 26.7◦C and 2300 mm, respectively. The basic properties of topsoil (0–20 cm) before the experiment are given with pH_{KCl} (4.10); OC (1.14%); total N (0.085%), total P (0.034%); total K (0.48%) and clay content (60%).
Nitrogen and fertilization treatment
The field experiment was conducted with four rates of nitrogen (0, 40, 80 and 120 kg N/ha) and two types of

nitrogen namely urea and ammonium chloride (NH_4Cl) for rice cropping. The experiment was arranged in a split plot design with N rates in subplots and N types in main plots. Each treatment subplot was 3 x 5 m and each treatment main plot was 60 m^2. Each treatment was carried out in triplicate. The individual plots were separated by protection rows that were 0.6 m in width, each with an irrigation and drainage outlet. Lime was applied 15 days before sowing and incorporated into soil. Farmyard manure (C 25%; N 0.89%; P 0.30% and K 0.5%) at 5 t ha^{-1} was spread on the surface, thoroughly mixed with soil by a wooden rake, and incorporated to a depth of over 10 cm. The N fertilizers were applied with 30% as a basal fertilizer before sowing, another 10% at 10 days after sowing, 45% at the tillering stage and the remaining 25% at the panicle initiation stage. Superphosphate was also applied as basal fertilizer before sowing at the rate of 60 kg P_2O_5/ha. KCl was applied at 60 kg K_2O/ha (50% at 10 days after sowing and 50% at panicle stage) in 2014 and 2015.

Rice cultivation and water regime management

Rice (*Oryza sativa* L., cv. Khang Dan 18) from China was cultivated for the field experiment in 2014 (summer season from June to August) and in 2015 (spring season from January to May), respectively. Rice seeds were directly sowed in plots on 1st June, 2014 and 17th January, 2015, respectively. Rice was harvested on 1st September 2014 and on 10th May 2015, respectively. For rice production, field water regime was maintained by flooding at 3 – 7 cm depth at nursery, tillering, panicle initiation and spiking stages followed by a subsequent drainage from ripening till harvesting stages.

CH_4 emissions

Gas flux measurements started at two weeks after direct seedling to ripening stage. Methane flux was measured in three replicates of the experiment using the static chamber method as described by Parkin and Venterea (2010) every seven days for the period 8 to 10 am. Closed polyethylene bucket with diameters of 40 cm (top) and 50 cm (bottom) x 70 cm height were used to quantify the CH_4 flux from all plots during the rice growing seasons. A round polyethylene base, with dimensions of 50 cm length × 30 cm height, served as the anchor for each chamber. The anchor was inserted about 10 cm into the soil with two rice hills on the inside and installed in the plots at least one day before the first sample collection to allow stabilization, and they were left in the field throughout the growing period of the crop. The base height and water depth inside the round polyethylene frames were measured at each gas sampling time. At the time of sampling, the gas collection chambers were placed on the trough of the polyethylene bases with a water seal. Gas samples inside the chambers were collected using a 60-mL syringe fitted with a stopcock at 0, 10, 20, and 30 min after chamber closure. Then the gases in the chamber were drawn off with a syringe and immediately transferred into a 20 ml vacuum glass container. When gas samples were collected, air temperature and soil temperature in chamber were measure simultaneously. Temperature was recorded using digital thermometer when the reading was stable within 5 seconds after insertion of the probe at depth of 5 cm. CH_4 concentrations were measured with gas chromatograph (GC- SRI 8610) by a flame ionization detector.

Statistical Analysis of Data

The SPSS 16.0 software package was used for all statistical analyses. All data (mean±SE, $n = 3$) were checked for normal distribution. Statistical analysis was performed by two–way ANOVA to analyze the effects of N fertilizer (rate and type) on the CH_4 flux, using the SPSS general linear model procedure.

Results

Increasing rates of N application for rice resulted in increasing CH_4 emission (Figure 1). The highest CH_4 flux was found at 120 kg N/ha for both types of N fertilizer. According to Schimel (2000), N fertilizers stimulate CH_4 production by increasing rice plant growth, thus, increasing the carbon supply for methanogenic bacteria. Under flooded conditions, the growth of rice crop plants increases CH_4 emission by providing C sources and by favoring CH_4 transport to the atmosphere (Dannenberg and Conrad 1999). A stimulatory effect of rice plant growth on CH_4 production potential by providing CH_4 substrates has been demonstrated in pot experiments (Jia et al 2006) and in field experiments (Xu et al 2004). Zheng et al (2006) found that high rates of N application stimulated CH_4 emission more than low N application under a FACE environment because high N application improved the C/N ratio in crop straw and roots, and rice yield. Singh et al (1999) studied the effect of urea application at 100 kg N/ha on CH_4 emissions from rice fields planted with three rice varieties and found that CH_4 emissions from fertilized fields were all greater than those from unfertilized fields. A stimulatory effect of chemical N fertilizers on CH_4 emissions was also observed by Rath et al (1999) in an irrigated rice field. CH_4 emission from application of urea fertilizer was higher than from NH_4Cl fertilizer. The commonly applied chemical N fertilizer is urea, which is rapidly hydrolyzed into ammonium soon after its application to rice fields. Generally speaking, less CH_4 is emitted from rice fields supplied with NH_4Cl compared with fields supplied with urea (Cai et al 1997).

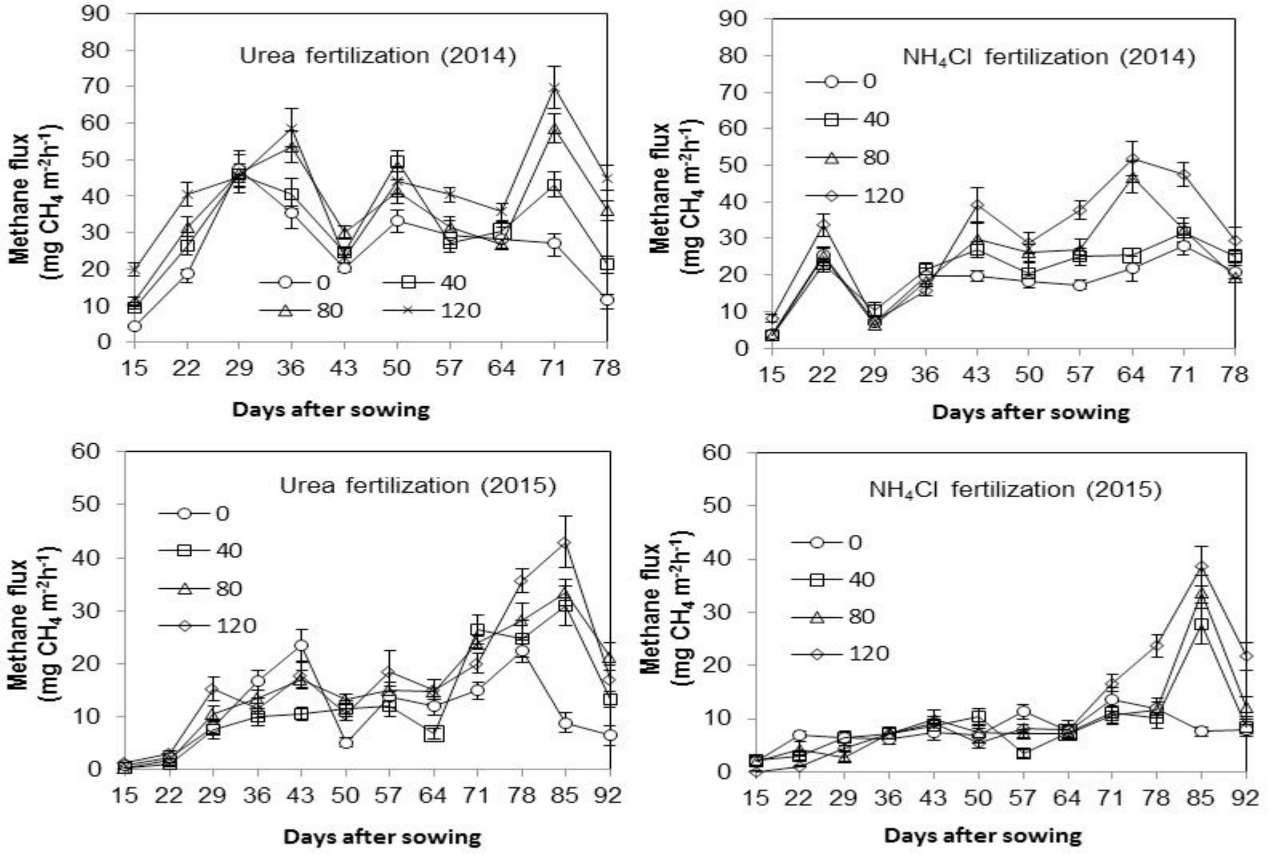

Figure 1: Effect of N rates and types on CH_4 emission flux in two rice cropping systems

A number of comparisons of CH_4 emissions from treatments supplied with different types of N fertilizers are available in the literature. However, there have also been many reports demonstrating that the application of fertilizers containing ammonium (e.g. ammonium chloride) decreased CH_4 emission from rice paddies as compared to urea application due to along with the quick decomposition of NH_4Cl in flooded conditions during a long rice growing period (Kimura et al 1992; Ibrahim et al 1999). The CH_4 emission was higher in summer rice crop season as compared with winter spring rice crop season at the same rate and type of N fertilizer application. Jain et al (2004) indicated that CH_4 oxidation by methanotrophs in rice paddies shows pronounced seasonal variation. According to Van Hulzen et al (1999), temperature influences CH_4 production by regulating anaerobic carbon mineralization, availability of alternative electron acceptors and methanogen activity. At higher temperature, mineralization increases and more carbon substrate become available, resulting in faster depletion of the alternative electron acceptor pool. Neue and Scharpenseel (1984) reported that most of the methanogenic bacteria display optimum rates of CH_4 production at around 30^{o}C. Daily variations of CH_4 emission in rice fields are related with temperature variations.

Conclusion

The effect of inorganic fertilizer N on CH_4 emission depends on rate of N application: high N rates of either urea or ammonium chloride increase CH_4 emissions relative to when no N is applied. Of the two types of N fertilizer tested, ammonium chloride reduced CH_4 emissions relative to urea. CH_4 emission from rice growing in winter spring season was much lower than in summer season. Our analysis has focused on the effect of N fertilizer management practices on CH_4 emissions, but further research should aim at quantifying the effects of it on N_2O emission and combining mitigation options.

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References

Becker T (1993). Asia's food challenge: to produce more with less. Dev Coop 6:15-16.
Bruce AL, Maria AAB, Cameron MP, Chris VK, Kees, JVG (2012). Fertilizer management practices and

greenhouse gas emissions from rice systems: A quantitative review and analysis. Field Crops Research 135 (2012) 10 -21.
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.
CAST, Council for Agricultural Science and Technology (2004). Climate change and greenhouse gas mitigation: challenges and opportunities for agriculture. Task Force Report No. 141. Ames, Iowa. pp. 133.
Dannenberg S, Conrad R (1999). Effect of rice plants on methane production and rhizospheric metabolism in paddy soil. Biogeochemistry, 45, 53–71.
Follett RF, Shafer SR, Jawson MD, Franzluebbers AJ (2005). Research and implementation needs to mitigate greenhouse gas emissions from agriculture in the USA. Soil Till Res 83(1):159–166.
Ibrahim T, Shen DS, Min H, Chen M, Feng XS (1999). Effect of different fertilizers on methane emissions from a paddy field of Zhejiang, China. Environmental Sciences. Vol. 11. No. 4: 457-461.
IPCC Intergovernmental Panel on Climate Change (2007). Climate Change. 2007: The Physical Science Basis. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 996 pp.
Jain MC, Kumar S, Wassman R, Mitra S, Singh SD, Singh JP, Singh R, Yadav AK, Gupta S (2000). Methane emissions from irrigated rice fields in northern India (New Delhi). Nutr. Cycl. Agroecosys. 58, 75–83.
Jia ZJ, Cai ZC, Tsuruta H (2006). Effect of rice cultivar on CH_4 production potential of rice soil and CH_4 emission in a pot experiment. Soil Sci, Plant Nutr., 52, 341–348.
Kimura M, Asai K, Watanabe A, Murase J, Kuwatsuka S (1992). Suppression of methane fluxes from flooded paddy soil with rice plants by foliar spray of nitrogen fertilisers.
Soil Sci. Plant Nutr. 38(4), 735–740.
Lal R, Follett RF, Kimble J, Cole CV (1999). Managing U.S. cropland to sequester carbon in soil. Soil and Water Cons. 54, 374-381.
Le Thai Bat, Pham Quang Khanh (2015). Soil resources of Vietnam, major soil types and their use in agriculture. In Proceedings of National Workshop on Vietnam soils: present use and opportunities. Hanoi Agricultural Publishing House. p 16 – 46.
Mosier AR, Duxbury JM, Freney JR, Heinemeyer O, Minami K (1998). Mitigating agricultural emissions of methane. Climatic Change. 40:39-80.
Mosier AR, Bleken MA, Pornipol C, Ellis EC, Freney JR, Howarth RB, Matson PA, Minami K, Naylor R, Weeks KN, Zhu Z (2001). Policy implications of human-accelerated nitrogen cycling. Biogeochemistry 52:281–320.
Mosier AR, Halvorson AD, Reule CA, Liu XJ (2006). Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. J. Environ. Qual. 35:1584-1598.
Neue HU, Scharpenseel HW (1984). Gaseous products of the decomposition of organic matter in submerged soils. p. 311-328. In Organic matter and rice. International Rice Research Institute. Los Banos, Philippines.
Parkin TB, Venterea RT (2010). Sampling Protocols. Chapter 3. Chamber-Based Trace Gas Flux Measurements. IN Sampling Protocols. R.F. Follett, editor. p. 3-1 to 3-39. Available at: www.ars.usda.gov/research/GRACEnet.
Rath AK, Swain B, Ramakrishnan B et al (1999). Influence of fertilizer management and water regime on methane emission from rice fields, Agric. Ecosyst. Environ., 76(2–3), 99–107.
Robertson GP, Vitousek PM (2009). Nitrogen in agriculture: balancing an essential resource. Annu Rev Energy Environ 34:97–125. doi:10.1146/annurev.environ.032108.105046.
Schimel J (2000). Rice, microbes and methane. Nature 403, 375–377.
Singh S, Singh JS, Kashyap AK (1999). Methane flux from irrigated rice fields in relation to crop growth and N fertilization. Soil Biol. Biochem. 31, 1219–1228.
Xu ZJ, Zheng XH, Wang YS, Han SH, Huang Y, Zhu JG (2004). Effects of elevated CO_2 and N fertilization on CH_4 emissions from paddy rice fields. Global Biogeochemical Cycles, 18 (3), GB3009.
Van Hulzen JB, Segers R, Van Bodegom PM, Leffelaar PA (1999). Temperature effects on soil methane production: an explanation for observed variability. Soil Biology and Chemistry 31:1919-1929.
Zheng XH, Zhou ZX, Wang YS (2006). Nitrogen-regulated effects of free-air CO_2 enrichment on methane emissions from paddy rice fields. Global Change Biology, 12(9), 1717–1732.