ISSN 0367-6315 (Print) / ISSN 2288-2162 (Online)
Korean J. Soil Sci. Fert. 46(6), 463-468 (2013)
http://dx.doi.org/10.7745/KJSSF.2013.46.6.463

Article

Nitrous Oxide Emissions from Red Pepper, Chinese Cabbage, and Potato Fields in Gangwon-do, Korea

Youngho Seo, Gunyeob Kim[1]*, Kijin Park, Kyunghi Kim, and Yeong-Sang Jung[2]

Gangwon Agricultural Research & Extension Services, Chuncheon 200-150, Korea
[1]National Academy of Agricultural Science, RDA, Suwon 441-707, Korea
[2]Kangwon National University. Chuncheon 200-701, Korea

(Received: August 12 2013, Accepted: November 18 2013)

The level of nitrous oxide (N_2O), a long-lived greenhouse gas, in atmosphere has increased mainly due to anthropogenic source, especially application of nitrogen fertilizers. Quantifying N_2O emission from agricultural field is essential to develop national inventories of greenhouse gases (GHGs) emission. The objective of the study was to develop emission factor to estimate direct N_2O emission from agricultural field in Gangwon-do, Korea by measuring N_2O emissions from potato (*Solanum tuberosum*), red pepper (*Capsicum annum* L.), and Chinese cabbage (*Brassica campestris* L.) cultivation lands from 2009 to 2012. Accumulated N_2O emission was 1.48±0.25 kg N_2O-N ha^{-1} for red pepper, 1.27±0.27 kg N_2O-N ha^{-1} for potato, 1.49±0.06 kg N_2O-N ha^{-1} for Chinese cabbage cultivated in spring, and 1.14±0.22 kg N_2O-N ha^{-1} for fall Chinese cabbage. Emission factor of N_2O calculated from accumulated N_2O emission, nitrogen fertilization rate, and background N_2O emission was 0.0051±0.0016 kg N_2O-N kg^{-1} N for cropland in Gangwon province. More extensive study is deserved to be conducted to develop N_2O emission factor for upland crops in Korea through examining the emission factors from various regions and crops because N_2O emission is influenced by many factors including climate characteristics, soil properties, and agricultural practices.

Key words: Chinese cabbage, Greenhouse gas, Nitrous oxide, Potato, Red pepper

N_2O emission factors, kg N_2O-N kg N^{-1}, for Chinese cabbage, red pepper, and potato from 2009 to 2012.

Crop	2009	2010	2011	2012	Mean±SD
Red pepper	0.00676	0.00548	0.00640	0.00545	0.00602±0.00066
Potato	0.00800	0.00616	0.00702	0.00541	0.00665±0.00112
CC, S	0.00405	0.00422	0.00483	0.00447	0.00439±0.00034
CC, F	0.00308	0.00226	0.00387	0.00355	0.00319±0.00070

---

*Corresponding author : Phone: +82312900240, Fax: +82332486905, E-mail: gykim1024@korea.kr

§Acknowledgement: This study was carried out with the support of “Cooperative Research Program for Agricultural Science & Technology Development (Project No. PJ009315052013)”, Rural Develop- ment Administration, Republic of Korea.

Introduction

Atmospheric nitrous oxide (N_2O) level has increased at a rate of 0.2~0.3% per year (Saggar *et al.*, 2009). The concentration of N_2O in atmosphere was 314 ppbv in 1998 (IPCC, 2001), while 285 ppbv before 1700 (Stauffer and Neftel, 1988). Park *et al.* (2012) concluded that rise in N_2O concentration in atmosphere was mainly due to an increased application of nitrogen fertilizers by investigating trends and seasonal cycles in the isotopic composition of nitrous oxide from 1940 to 2005. Nitrous oxide has approximately 300 times the global warming potential of carbon dioxide (CO_2) based on a 100 yr time horizon (IPCC, 2007).

Nitrous oxide is produced in agricultural soils after amending nitrogen fertilizers and manure compost through both nitrification and denitrification by the microbial activity (Freney, 1997; Singh and Tyagi, 2009). Nitrification is an oxidation process of ammonia produced from nitrogen fertilizer or compost to nitrate under aerobic condition, and denitrification is a reduction process of nitrate to N_2O and N_2 under anaerobic condition. Nitrous oxide emission from agricultural soils is significantly determined by N application rate, soil organic carbon content, soil pH, texture, crop type, and the type of fertilization source (Stehfest, 2008).

In Korea, N_2O estimates have been based on Intergovernmental Panel on Climate Change (IPCC) emission factor methodology due to absence of country-specific emission factor for N_2O. The default value for N_2O emission factor has been changed from 0.0125 to 0.01 of N applied to the cropped soils (IPCC, 2006), which means that 1% of unvolatilized N inputs are produced in the soil as direct N_2O emission. Country-specific emission factor can be more representative of soil, climate, and agricultural practices in Korea, resulting in more accurate and lesser uncertainty than the default factor. Many developed countries have used their own N_2O emission factor; 0.0062 kg N_2O-N kg^{-1} N for all fertilized upland fields in Japan (Akiyama *et al.*, 2006), 0.01~0.015 kg N_2O-N kg^{-1} N for Sweden (Swedish Environmental Protection Agency, 2006), 0.01 kg N_2O-N kg^{-1} N for chemical fertilizers and 0.02 kg N_2O-N kg^{-1} N for animal manure in the Netherlands (Netherlands Environmental Assessment Agency, 2006), and 0.003 kg N_2O-N kg^{-1} N for rain fed upland in dry region and 0.021 kg N_2O-N kg^{-1} N for horticultural crops in Australia (Australian Greenhouse Office, 2006).

This study was conducted in order to assess N_2O emissions from potato (*Solanum tuberosum*), red pepper (*Capsicum annum* L.), and Chinese cabbage (*Brassica campestris* L.) cultivation land in Gangwon-do, Korea and to provide information for developing Korea-specific N_2O emission factor.

Materials and Methods

Crop cultivation Three crops including potato (*Solanum tuberosum*), red pepper (*Capsicum annum* L.), and Chinese cabbage (*Brassica campestris* L.) were cultivated at the Gangwon-do Agricultural Research & Extension Services field in Chuncheon (N 37° 57’ 15.9” E 127° 46’ 26.6”), Korea from 2009 to 2012. The crops were transplanted on Apr. 29, 2009, May 5, 2010, May 3, 2011, and May 11, 2012. Chinese cabbage was cultivated twice a year, spring and fall, and the other crops were grown once a year. Chinese cabbage in fall was transplanted on Aug. 26, 2009, Sep. 5, 2010, Aug. 23, 2011, and Sep. 5, 2012. The soil in the field is classified to Yonggye series (fine loamy, mixed, mesic Typic Dystrudepts) and the selected physic-chemical properties of the soil are provided in Table 1. Fertilizers were applied based on standard fertilization rate of the three crops; N-P_2O_5-K_2O = 320-78-198 kg ha^{-1} for Chinese cabbage, 190-112-149 kg ha^{-1} for red pepper, and 137-33-114 kg ha^{-1} for potato. All the fertilizers were applied before planting potato. For Chinese cabbage, 52% of nitrogen was applied before transplanting and 48% was split twice during cultivation. For red pepper, 54% of the fertilizers were applied before transplanting and the rest 46% was split three times during cultivation. Potato was harvested on July 10, 2009, July 27, 2010, July 18, 2011, and July 24, 2012. For Chinese cabbage, the harvesting dates were June 30, 2009, Nov. 16, 2009, July 1, 2010, Nov. 25, 2010, July 28, 2011, Nov. 23, 2011, July 10, 2012, and Nov. 20, 2012. The treatments were arranged in a randomized block design with three replicates. The plot size of each replicate was 18 m^2.

Collection and analysis of nitrous oxide Gas samples were collected using static chambers, the most commonly used tools worldwide for the greenhouse gas research (Kim et al., 2006; Kim et al., 2008; Saggar et al., 2009; Kim et al., 2010; Seo et al., 2012; Yang et al., 2012a; Yang et al., 2012b; Yang et al., 2012c), twice a week from just

Table 1. Selected physico-chemical characteristics of the field used in the study.

pH (1:5)	EC	OM	Avail. P_2O_5	T-N	NO_3-N	Exch. Cation			Particle size distribution		
						Ca	K	Mg	Sand	Silt	Clay
	dS m^{-1}	g kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	------- cmol$_c$ kg^{-1} -------			------------ % ------------		
6.0	0.33	22	470	1.1	14	3.5	0.63	0.87	54	18	28

after transplanting the crops to next growing season in the following year. Parkin (2008) reported that gas sampling at 1-4 days intervals resulted in cumulative N_2O emissions with a precision of ±10% compared with ±14% for 3-7 days intervals. The level of nitrous oxide in the gas samples was determined by a gas chromatography (Varian GC 450) equipped with an electron capture detector (ECD). Flux of N_2O was calculated using the following equation (Shin et al., 2003; Kim et al., 2008; Kim et al., 2010; Seo et al., 2012):

$$F = \rho \cdot V \cdot A^{-1} \cdot \Delta c \cdot \Delta t^{-1} \cdot 273 \cdot T^{-1}$$

where F is N_2O flux (mg m^{-2} h^{-1}), ρ is the gas density of N_2O (1.96 mg m^{-3}), V is the volume of the chamber (m^3), A is the area of the chamber (m^2), $\Delta c \cdot \Delta t^{-1}$ is the average increase of gas concentration in the chamber, and T is mean temperature in the chamber (℃) plus 273. For the greenhouse gas flux measurements using chamber, linear regression is less sensitive to chamber deployment time and analytical precision than other methods and has small detection limit thresholds (Parkin et al., 2012). Emission factor is calculated by dividing accumulated N_2O emission from cultivated plots by unvolatilized portion of the applied nitrogen.

Climatic condition Mean air temperature and precipitation during the study period are shown in Fig. 1 and Fig. 2, respectively. The mean air temperature in 2009, 2010, and 2011 was 10.3℃, 10.3℃, and 10.8℃, respectively, which is 0.4~0.9℃ below the normal data (1981~2010), 11.2℃. The annual precipitation in 2009, 2010, and 2011 was 1,789 mm, 1,634 mm, and 1,851 mm, respectively, which is about 300-500 mm higher than the normal data, 1,325 mm.

Results and Discussion

Emission rates of N_2O for red pepper were less than 35.5 g N_2O-N ha^{-1} d^{-1} in 2009, 19.8 g N_2O-N ha^{-1} d^{-1} in 2010, 26.9 g N_2O-N ha^{-1} d^{-1} in 2011, and 26.3 g N_2O-N ha^{-1} d^{-1} in 2012 (Fig. 3). For potato, the highest N_2O emissions rate was 29.5 g N_2O-N ha^{-1} d^{-1} in 2009, 16.3 g N_2O-N ha^{-1} d^{-1} in 2010, 28.5 g N_2O-N ha^{-1} d^{-1} in 2011, and 30.7 g N_2O-N ha^{-1} d^{-1} in 2012. Most of N_2O emission occurred during first three months for the two crops. Chinese cabbage cultivated in fall showed different N_2O emission pattern from the emission pattern for spring cultivation. Nitrous oxide emission rates markedly increased immediately after transplanting the crop in fall, up to 98.3 g N_2O-N ha^{-1} d^{-1} in 2009, 79.2 g N_2O-N ha^{-1} d^{-1} in 2010, 60.3 g N_2O-N ha^{-1} d^{-1} in 2011, and 64.8 g N_2O-N ha^{-1} d^{-1} in 2012 compared with 53.3 g N_2O-N ha^{-1} d^{-1}, 37.4 g N_2O-N ha^{-1} d^{-1}, 37.5 g N_2O-N ha^{-1} d^{-1}, and 40.8 g N_2O-N ha^{-1} d^{-1}, respectively for each spring cultivation probably because of greater activity of microorganisms by relatively high temperature and precipitation at transplanting (Fig. 1 and 2). The N_2O emission rates, however, sharply decreased after the peak emission and even reach almost zero in late fall and winter possibly because of decreasing temperature and soil inorganic-nitrogen level. Kim et al. (2008) reported that relative contribution of inorganic-nitrogen and soil temperature to N_2O emission was 24~51% and 26~36%, respectively for red pepper cultivation.

Accumulated N_2O emission for red pepper was 1.83 kg N_2O-N ha^{-1} in 2009, 1.31 kg N_2O-N ha^{-1} in 2010, 1.46 kg N_2O-N ha^{-1} in 2011, and 1.31 kg N_2O-N ha^{-1} in 2012 (Fig. 4), 1.66 kg N_2O-N ha^{-1} in 2009, 1.13 kg N_2O-N ha^{-1} in 2010, 1.23 kg N_2O-N ha^{-1} in 2011, and 1.04 kg N_2O-N ha^{-1} in 2012 for potato, 1.51 kg N_2O-N ha^{-1} in 2009, 1.41 kg N_2O-N ha^{-1} in 2010, 1.53 kg N_2O-N ha^{-1} in 2011, and 1.52 kg N_2O-N ha^{-1} in 2012 for spring cultivated Chinese cabbage, and 1.22 kg N_2O-N ha^{-1} in 2009, 0.82 kg N_2O-N ha^{-1} in 2010, 1.34 kg N_2O-N ha^{-1} in 2011, and 1.17 kg N_2O-N ha^{-1} in 2012 for fall Chinese cabbage. In 2012, the gas samples were collected until Nov. 22, resulting in shorter analysis duration, 196 days than the other three years, 317~370 days. It needs to be noted very low N_2O emission in winter due to low temperature and residual nitrogen from 2009 to 2011 (Fig. 3). Cantarel et al. (2011) reported significant increase in N_2O emissions with increase

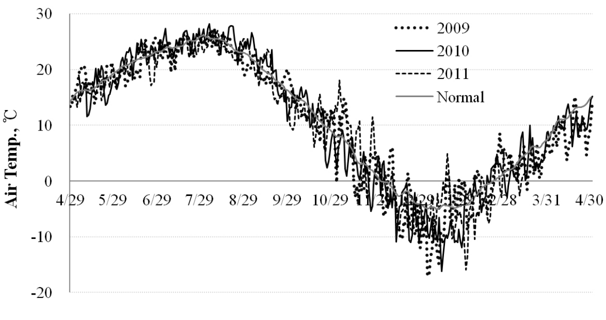

Fig. 1. Mean air temperature during the study period compared with normal data (1981~2010).

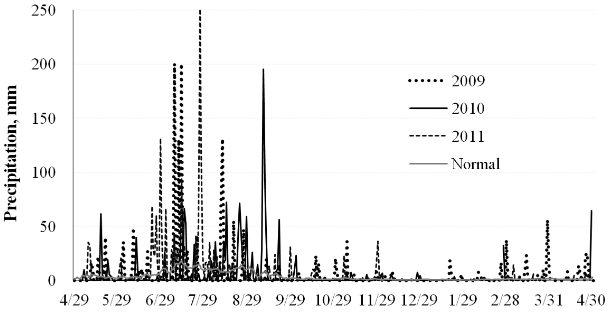

Fig. 2. Mean air temperature during the study period compared with normal data (1981~2010).

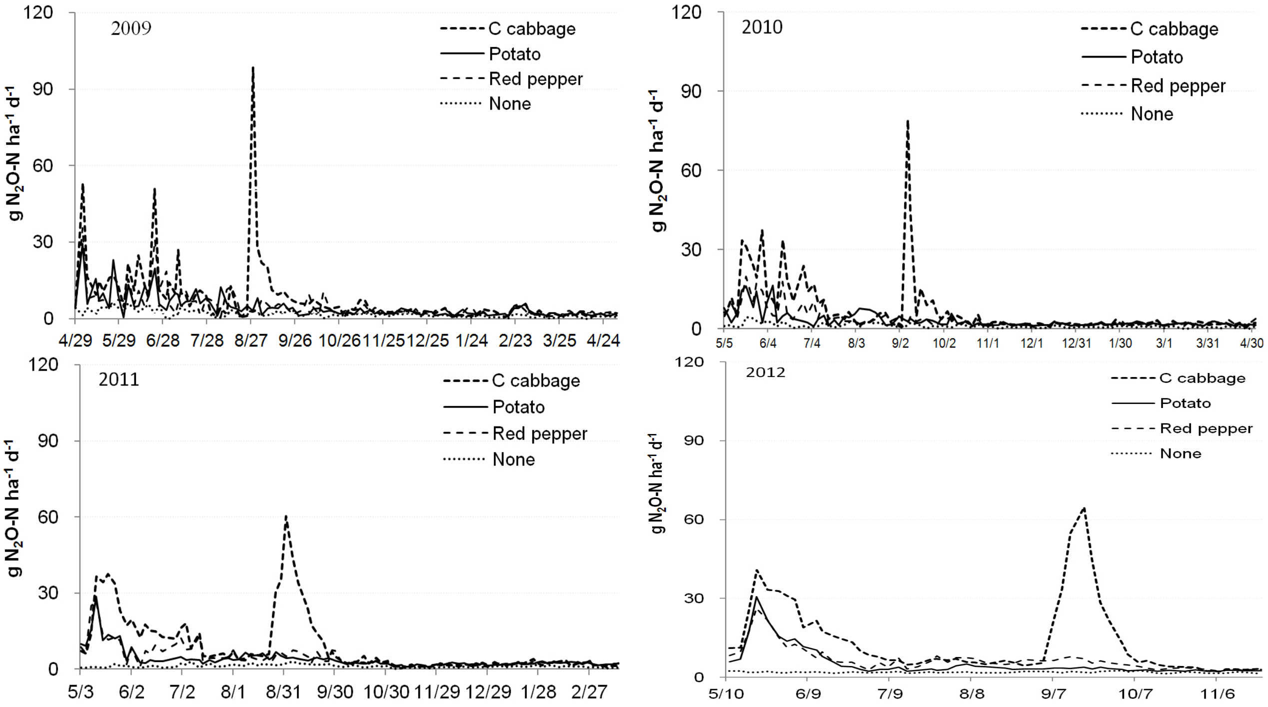

Fig. 3. N_2O emission patterns of Chinese cabbage, red pepper, and potato from 2009 to 2012. Chinese cabbage was cultivated twice a year, spring and fall, while once a year for red pepper and potato.

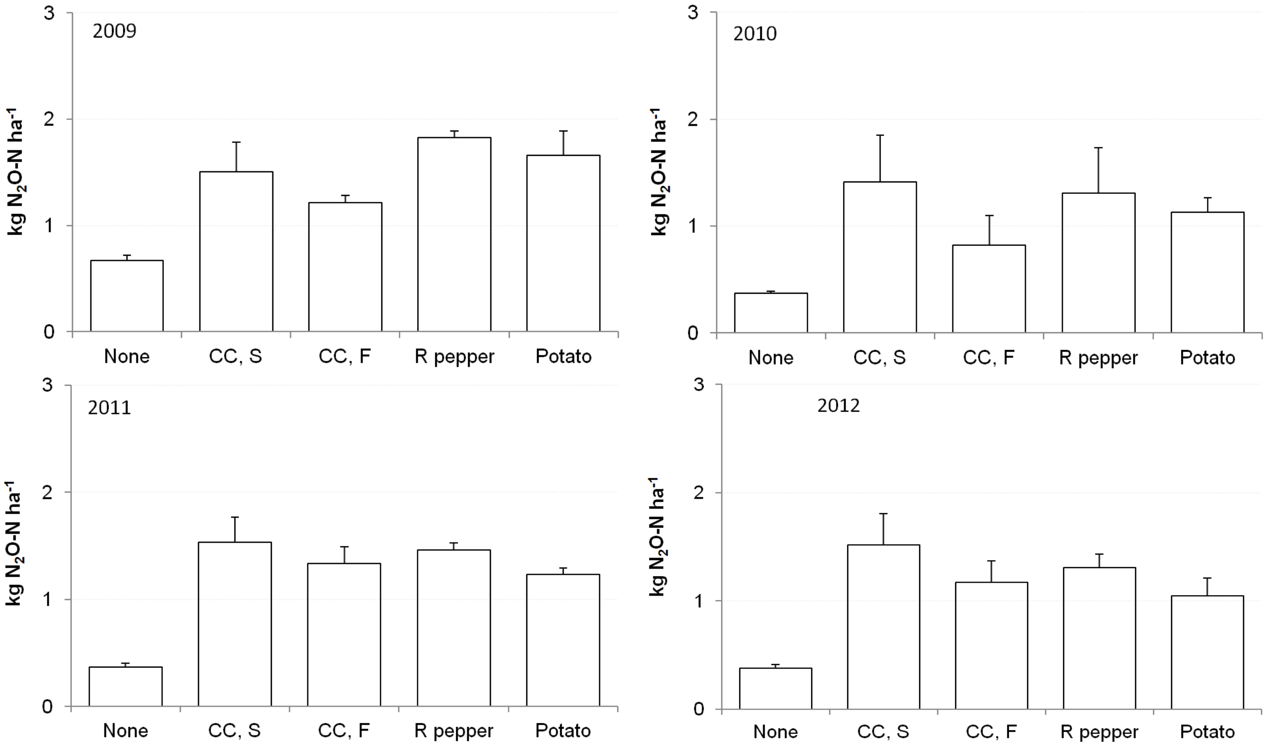

Fig. 4. Accumulated N_2O emission from cultivation of Chinese cabbage, red pepper, and potato from 2009 to 2012. CC, S and CC, F denote Chinese cabbage cultivated in spring and fall, respectively. Error bars indicate standard deviation.

in temperature and Kim et al. (2008) showed that mineral nitrogen level in soil greatly affected N_2O emission. Kim et al. (2010) reported that N_2O emission from soybean field was influenced by soil inorganic nitrogen (66%), soil moisture (19%), and temperature (15%). In addition, Akiyama et al. (2006) developed N_2O emission factor for Japan based on data measuring over 90 days by assuming that most N_2O resulted from fertilizer application is emitted in less

Table 2. N_2O emission factor[†], kg N_2O-N kg N^{-1}, for Chinese cabbage, red pepper, and potato from 2009 to 2012. CC, S and CC, F denote Chinese cabbage cultivated in spring and fall, respectively.

Crop	2009	2010	2011	2012	Mean±SD
Red pepper	0.00676	0.00548	0.00640	0.00545	0.00602±0.00066
Potato	0.00800	0.00616	0.00702	0.00541	0.00665±0.00112
CC, S	0.00405	0.00422	0.00483	0.00447	0.00439±0.00034
CC, F	0.00308	0.00226	0.00387	0.00355	0.00319±0.00070

[†] Emission factor = ((accumulated N_2O emission from cultivated plots)−(the background emission from un-fertilized plots)) / (unvolatilized portion of the applied nitrogen).

than 90 days, although Bouwman et al. (2002) reported significantly less N_2O emission for shorter than 120 days measurement compared with the data for 180~300 days. Background N_2O emission from non-fertilized field ranged from 0.37 to 0.67 kg N_2O-N ha^{-1}, which is relatively low level compared with 0.65 kg N_2O-N ha^{-1} in Japan (Akiyama et al., 2006), 1.06 kg N_2O-N ha^{-1} in China (Gu et al., 2009), and 1.0 kg N_2O-N ha^{-1} proposed by Bouwman (1996). Background N_2O emission is also influenced by many factors including soil properties, climate characteristics, and previous fertilization history.

Emission factor of N_2O calculated from accumulated N_2O emission and nitrogen fertilization rate for each crop and background N_2O emission ranged from 0.00545 to 0.00676 kg N_2O-N kg^{-1} N for red pepper, from 0.00541 to 0.00800 kg N_2O-N kg^{-1} N for potato, from 0.00405 to 0.00483 kg N_2O-N kg^{-1} N for Chinese cabbage cultivated in spring, and from 0.00226 to 0.00387 kg N_2O-N kg^{-1} N for Chinese cabbage in fall (Table 2). Nitrous oxide emission factors from black volcanic ash soil in Jeju island were 0.0202 kg N_2O-N kg^{-1} N for soybean (Yang et al., 2012a), 0.0025 kg N_2O-N kg^{-1} N for carrot (Yang et al., 2012b), and 0.0040 kg N_2O-N kg^{-1} N for potato (Yang et al., 2012c). In Japan, N_2O emission factor is 0.0062±0.0045 kg N_2O-N kg^{-1} N because of 0.0032 kg N_2O-N kg^{-1} N for well-drained upland and 0.0140 kg N_2O-N kg^{-1} N for poor-drained upland (Akiyama et al., 2006). For tea tree, the N_2O emission factor is set to be 0.0282±0.0180 kg N_2O-N kg^{-1} N (Akiyama et al., 2006). It is generally reported large coefficients of variation for N_2O emissions measurements ranging from 100 to 300% (Thornton and Valente, 1996). An uncertainty for the Tier 1 method emission factor ranged from 0.003 to 0.03 (IPCC, 2006). Developing common N_2O emission factor for various upland crops except crops showing peculiar N_2O emission pattern is considered to be better than developing specific N_2O emission factor for each crop. The results obtained the study indicated that N_2O emission factor of 0.0051±0.0016 kg N_2O-N kg^{-1} N for red pepper, potato, and Chinese cabbage cultivated in Gangwon province, Korea. However, it should be noted that more extensive study is deserve to be conducted to develop N_2O emission factor for upland crops in Korea through examining the emission factors from various regions and crops because N_2O emission is influenced by many factors including climate, soil characteristics, nitrogen fertilization rate, nitrogen source, crop type, and agricultural practices.

Conclusion

Developing N_2O emission factor for agricultural field is essential to reduce greenhouse gas emission. Gas samples were collected from upland field cultivating red pepper, Chinese cabbage, and potato and N_2O emission was measured for four years. Accumulated N_2O emission was 1.48±0.25 kg N_2O-N ha^{-1} for red pepper, 1.27±0.27 kg N_2O-N ha^{-1} for potato, 1.49±0.06 kg N_2O-N ha^{-1} for Chinese cabbage cultivated in spring, and 1.14±0.22 kg N_2O-N ha^{-1} for Chinese cabbage in fall. Background N_2O emission from non-fertilized field was 0.45±0.15 kg N_2O-N ha^{-1}. Emission factor of N_2O calculated from accumulated N_2O emission and nitrogen fertilization rate for each crop and background N_2O emission was 0.0051±0.0016 kg N_2O-N kg^{-1} N for cropland in Gangwon province.

References

Akiyama, H., K. Yagi, and X. Yan. 2006. Estimations of emission factors for fertilizer-induced direct N2O emissions from agricultural soils in Japan: Summary of available data. Soil Sci. Plant Nutr., 52:774-787.

Australian Greenhouse Office. 2006. National Inventory Report 2004. Vol. 1. Australian Greenhouse Office. Canberra.

Bouwman, A.F. 1996. Direct emissions of nitrous oxide from agricultural soils. Nutr. Cycl. Agroecosyst. 46:53-70.

Bouwman, A.F., L.J.M. Boumans, and N.H. Batjes. 2002. Emissions of N_2O and NO from fertilized fields: Summary of available measurement data. Global Biogeochem. Cycles. 16:1058-1070.

Cantarel, A.A.M., J.M.G. Bloor, N. Deltro, and J.F. Soussana. 2011. Effects of climate change drivers on nitrous oxide fluxes in an upland temperate grassland. Ecosystems. 14:223-233.

Freney, J.R. 1997. Emission of nitrous oxide form soils used for agriculture. Nutrient Cycling Agroecosystem. 49:1-6.

Gu J, Zheng X, and Zhang W (2009) Background nitrous oxide emissions from croplands in China in the year 2000. Plant Soil. 320, 307-320.

Intergovernmental Panel on Climate Change (IPCC). 2001. Third Assessment Report. Working Group I. Cambridge University Press. Cambridge.

Intergovernmental Panel on Climate Change (IPCC). 2006. 2006 IPCC guidelines for national greenhouse gas inventories. Vol. 4. Agriculture, forestry and other land use. Eggleston H. S., Buendia L., Miwa K., Ngara T., Tanabe K. (eds.) Hayama, Japan, 682p.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007. Mitigation of climate change: Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Metz B., Davidson O., Bosch P., Dave R., Meyer L. (eds) Cambridge University Press, New York, 851p.

Kim, G.Y., B.H. Song, B.K. Hyun, K.M. Shim, J.T. Lee, J.S. Lee, W.I. Kim, and J.D. Shin. 2006. Predicting N_2O emission from upland cultivated with pepper through related soil parameters. Korean J. Soil Sci. Fert. 39:253-258.

Kim, G.Y., B.H. Song, K.A. Roh, S.Y. Hong, B.G. Ko, K.M. Shim, and K.H. So. 2008. Evaluation of greenhouse gases emissions according to changes of soil water content, soil temperature and mineral N with different soil texture in pepper cultivation. Korean J. Soil Sci. Fert. 41:399-407.

Kim, G.Y., K.H. So, H.C. Jeong, K.M. Shim, S.B. Lee, and D.B. Lee. 2010. Assessment of greenhouse gases emissions using global warming potential in upland soil during pepper cultivation. Korean J. Soil Sci. Fert. 43:886-891.

Netherlands Environmental Assessment Agency. 2006. Greenhouse Gas Emissions in the Netherlands 1990-2004: National Inventory Report 2006. Netherlands Environmental Assessment Agency. Bilthoven.

Park, S., P. Croteau, K.A. Boering, D.M. Etheridge, D. Ferretti, P.J. Fraser, K.R. Kim, P.B. Krummel, R.L. Langenfelds, T.D. van Ommen, L.P. Steele, and C.M. Trudinger. 2012. Trends and seasonal cycles in the isotopic composition of nitrous oxide since 1940. Nature Geosci. 5:261-265.

Parkin, T.B. 2008. Effect of sampling frequency on estimates of cumulative nitrous oxide emissions. J. Environ. Qual. 37: 1390-1395.

Parkin, T.B., R.T. Venterea, and S.K. Hargreaves. 2012. Calculating the detection limits of chamber-based soil greenhouse gas flux measurements. J. Environ. Qual. 41:705-715.

Saggar, S., J. Luo, D.L. Giltrap, and M. Maddena. 2009. Nitrous oxide emissions from temperate grasslands: Processes, measurements, modelling and mitigation. In Sheldon A. I., Barnhart E. P. (eds.): Nitrous oxide emissions research progress. Nova Science Publishers, Inc., New York, p. 1-66.

Seo, Y.H., S.W. Kim, S.C. Choi, B.C. Jeong, and Y.S. Jung. 2012. Nitrous oxide emission from livestock compost applied arable land in Gangwon-do. Korean J. Soil Sci. Fert. 45:25-29.

Shin, Y.K., J.W. Ahn, M.H. Koh, and J.C. Shim. 2003. Emissions of greenhouse gases from upland rice and soybean. Korean J. Soil Sci. Fert. 36:256-262.

Singh, S.N. and L. Tyagi. 2009. Nitrous oxide: Sources, sinks and mitigation strategies. In Sheldon A. I., Barnhart E. P. (eds.): Nitrous oxide emissions research progress. Nova Science Publishers, Inc., New York, p. 127-150.

Stauffer, B.R. and A. Neftel. 1988. What we have learnt from the ice cores about the atmospheric changes in the concentrations of nitrous oxide, hydrogen peroxide and other trace species. In The Changing Atmosphere. Edited by R. FS and I. ISA. John Wiley & Sons Ltd. Chichester.

Stehfest, E. 2008. Modelling of Global Crop Production and Resulting N_2O Emissions. VDM Verlag Dr. Müller, Saarbrüken, Germany.

Swedish Environmental Protection Agency. 2006. Sweden's National Inventory Report 2006. Swedish Environmental Protection Agency. Bromma.

Thornton, F.C. and R.J. Valente. 1996. Soil emissions of nitric oxide and nitrous oxide from no-till corn. Soil Sci. Soc. Am. J. 60:1127-1133.

Yang, S.H., H.J. Kang, S.C. Lee, H.J. Oh, and G.Y. Kim. 2012a. Influence of N fertilization level, rainfall, and temperature on the emission of N_2O in the Jeju black volcanic ash soil with soybean cultivation. Korean J. Soil Sci. Fert. 45:451-458.

Yang, S.H., H.J. Kang, S.C. Lee, H.J. Oh, and G.Y. Kim. 2012b. Influence of N fertilization level, rainfall, and temperature on the emission of N_2O in the Jeju black volcanic ash soil with carrot cultivation. Korean J. Soil Sci. Fert. 45:459-465.

Yang, S.H., H.J. Kang, S.C. Lee, H.J. Oh, and G.Y. Kim. 2012c. Influence of N fertilization level, rainfall, and temperature on the emission of N_2O in the Jeju black volcanic ash soil with potato cultivation. Korean J. Soil Sci. Fert. 45:544-550.