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Comparison of Methane Emissions on Soil Texture in Korean Paddy Fields

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Rice paddy fields are the major source of methane emission, which is the decomposition product of organic matter under highly anaerobic condition. Methane emission from paddy fields is the results of biological and physicochemical processes affected by various factors such as agricultural techniques, climate, and soil properties. This study aimed to investigate the methane emissions from soils of varying textures in paddy soil. Soil clay content and particle distribution affect soil physicochemical properties and permeability. In addition, methane emission and soil texture are considered to be directly related. In this study, sandy loam (SL) and sandy clay loam (SCL) fields were investigated. The total cultivation period was 132 days and Shindongjin rice (Mid–late maturing one) was used as the test variety. Methane emission rates were monitored once weekly during rice cultivation using a closed chamber method. At the early growth stage, methane emission from SL soil was higher than that from SCL soil. After 100 days of growth, methane production under each condition almost undetectable. The average daily methane emissions were 5.41 and 6.16 kg ha^{-1} day^{-1} in SCL and SL soil, respectively.

Key words: methane emission, rice paddy, sandy loam, sandy clay loam, soil texture

INTRODUCTION

Compared to preindustrial levels, the current atmospheric methane concentration has doubled to a current value of 1.77 ppmv (Bodelier 2011). Methane is considered the second most potent greenhouse gas in the atmosphere after carbon dioxide (IPCC 2001). In addition, the global warming potential of methane is 21 times higher than that of carbon dioxide and, therefore, the reduction of methane emissions is very important.

In the soil, under anaerobic conditions (such as flooded soils, sediments, and landfills) methanogenic archaea convert acetate, methanol, or hydrogen combined with carbon dioxide to methane (Ferry and Kastead 2007; Thauer 1998). The methanogenic substrates are products of fermentative degradation of organic matter (e.g., dead roots) or photosynthates exuded by plant roots. Rice paddies have been identified as one of the most important sources of methane, contributing approximately 15–20% of the global anthropogenic methane emission in the atmosphere (Aulakh *et al.*, 2001). Although rice seedling transplantation in paddy soil has the advantage of considerably increasing the yield by effective weed control, this is problematic because methane is produced during the flooding period. Thus, rice is unique among crops because of its susceptibility to atmospheric methane emissions.

Factors affecting methane emission in rice paddies can be divided into non–artificial factors such as physical and chemical properties of paddy soils, and artificial factors such as organic matter, water management, and varieties (Kimura *et al.*, 1992; Minami 1993; Neue 1993). This study was carried out to investigate how the methane emission rate is affected by the particle distribution of paddy soil, which is one of the factors affecting methane production.

MATERIALS AND METHODS

Rice cultivation management

The experiment was conducted at the agronomy field of Juk–dong (36°22'20.4"N, 127°19'52.0"E) and Noeun–dong (36°22' 23.7"N, 127°19'39.5"E), Yuseonggu, Daejeon City, South Korea in 2016. Two fields with different soil textures (sandy loam [SL] and sandy clay loam [SCL]) were used as experimental plots (5 m×15 m). The total cultivation period was 132 days, and 21–day–old rice (Sindongjinbyeo cultivar, Mid–late maturing one) seedlings were transplanted in the flooded soil. Tillage was conducted before day 15 of the transplantation on the plow layer (0–15 cm). To keep the soil conditions in a reduced state, the irrigation water was controlled at a 5–7 cm depth during the cropping season and the flooding was continued until the harvest. During the fallow season, raw rice straw was applied at approximately 8 Mg ha^{-1}. During the rice cultivation season, chemical fertilizers (NPK treatment) were applied. The plots were treated with urea (90 kg N ha^{-1}), superphosphate (45 kg P_2O_5 ha^{-1}), and potassium chloride (58 kg K_2O ha^{-1}) following the recommended concentrations for Korean paddy fields (RDA 1999). Rice plants (72 hills under 3.3 m^2) were harvested to determine the grain

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yield in mid–October. The rice yield and yield components were analyzed in accordance with the Agricultural Science and Technology Research Survey of the Rural Development Administration (RDA 2003).

Gas sampling and analysis

A closed–chamber method (Ali *et al.*, 2009; Kim *et al.*, 2012) was used to estimate methane flux from the soil during the entire cultivation period. The chambers had a base–area and height of 60 cm×60 cm and 120 cm, respectively and were placed in each plot. Two holes were created at the bottom of the chamber sides to ensure the water level inside was equal to the water level of the whole plot. The average daily methane emission during the rice cultivation season was observed around 11:00 am (Pramanik and Kim 2014). Based on these data, gas samples were collected using 60–mL syringes 0 and 30 min after covering the chamber between 11:00 am and 12:00 pm.

Methane concentrations in the gas samples were measured using gas chromatography with an Agilent 6890N system equipped with fused silica capillary column (30 m×0.53 mm) and a flame ionization detector (FID). The oven and detector temperature were adjusted to 100°C and 250°C, respectively. Hydrogen (H_2) and nitrogen (N_2) were used as the burning and carrier gases, respectively.

The Methane emission rate from the soil was calculated based on the increase in methane concentration per unit surface area of the chamber within a specific time interval. A closed–chamber equation (Rolston, 1986) was used to estimate the methane fluxes as follows.

$$F = \rho \times \left(\frac{V}{A} \times \frac{\Delta c}{\Delta t} \times \frac{273}{T} \right)$$

where, F is the methane flux (mg m^{-2} h^{-1}), ρ is the methane gas density (0.714 mg cm^{-3}), A is the area of the chamber (m^2), V is the volume of chamber (m^3), $\Delta c/\Delta t$ is the rate of increase in methane gas concentration (ppmv), T is the absolute temperature (273 + mean temperature in ˚C) of the chamber. The total methane flux for the entire cultivation period was computed using the following the equation (Singh *et al.*, 1999).

$$\text{Total methane flux} = \sum_{k}^{n} (R_i \times D_i)$$

where, R_i is the methane flux (g m^{-2} day^{-1}) in ith sampling interval, D_i is the number of days in ith sampling interval, and n is the number of sampling intervals.

Soil sampling and analyses

Soil samples were collected from the surface layer (0–15 cm) using a zigzag pathway on the plot. After air drying, the samples were homogenized by sieving (mesh size, < 2 mm). According to the Soil and Plant Analysis Method of the RDA (NIAST, 2000), soil pH and electrical conductivity (EC) were measured by using a pH meter and EC meter (ORION Versa Star Pro, Thermo Scientific Inc., USA) after diluting the soil with distilled water (1: 5, v/v). Furthermore, the available phosphate was measured using a UV–VIS spectrophotometer (Evolution 300, Thermo Scientific Inc., USA) by using the Lancaster method. Exchangeable cations were leached with 1 N ammonium acetate (NH_4OAc) and quantified using inductively coupled plasma spectrometer (ICP–OES, GBC Scientific, Australia). The total carbon (T–C) and total nitrogen (T–N) were analyzed using an elemental analyzer–TCD (Flash EA 1112 series, CE Instruments, Italy).

RESULTS AND DISCUSSIONS

Soil chemical properties

The chemical properties of the paddy soils are presented in Tables 1 and 2. The soil type distribution of the various test fields was composed of 21.44% clay, 21.50% silt, and 57.06% sand in the SCL and 16.39% clay, 17.33% silt, and 66.28% sand in the SL (analyzed using a hydrometer method). The organic C contents of

Table 1. Chemical properties in paddy soil before experiment

Soil Texture	pH (1:5)	EC (dS m^{-1})	T–C (g kg^{-1})	T–N (g kg^{-1})	Av. P_2O_5 (mg kg^{-1})	Ex. Cation ($cmol_c$ kg^{-1})		
						K^+	Ca^{2+}	Mg^{2+}
SCL	6.03	0.35	9.48	0.99	108.71	0.39	1.57	0.56
SL	5.84	0.21	8.66	0.92	122.45	0.51	1.62	0.69

Abbreviation: EC, electrical conductivity; T–C, total carbon; T–N, total nitrogen; Av. P_2O_5, available phosphate; Ex. Cations, Exchangeable cations; SCL; sandy clay loam; SL, Sandy loam

Table 2. Chemical properties in paddy soil after experiment

Soil Texture	pH (1:5)	EC (dS m^{-1})	T–C (g kg^{-1})	T–N (g kg^{-1})	Av. P_2O_5 (mg kg^{-1})	Ex. Cation ($cmol_c$ kg^{-1})		
						K^+	Ca^{2+}	Mg^{2+}
SCL	5.91	0.64	11.45	1.37	90.76	0.45	1.74	0.79
SL	6.28	0.67	10.81	1.16	85.36	0.56	2.14	0.71

Abbreviation: EC, electrical conductivity; T–C, total carbon; T–N, total nitrogen; Av. P_2O_5, available phosphate; Ex. Cations, Exchangeable cations; SCL; sandy clay loam; SL, Sandy loam the soil were 9.45 and 7.66 g kg^{-1} in the SCL and SL, respectively. The soil pH was 5.84 and 6.03 in the SCL and SL, respectively (1:5 in water [H_2O]). The chemical properties of the two test soil with different textures were similar. The organic matter, magnesium, and calcium contents were slightly lower, and the available phosphate content was slightly higher. However, the values in both fields were within the range of soil conditions that support normal growth (Kang 2014).

Environmental factors

Methane production increases at high temperatures and on sunny days (Wang *et al.*, 1993). During the cultivation period, environmental factors affecting methane emissions such as precipitation, soil temperature, water temperature, and weather environment were investigated. The soil temperature was measured at approximately 5 cm from the topsoil. The changes in the environmental factors (temperature and precipitation) from the transplanting day to the harvesting day are shown in Fig. 1. The average atmospheric temperature was 24.5°C, and the total precipitation was 767 mm. The soil temperature pattern was similar to the atmospheric temperature, but it was approximately 2–5°C higher or lower than the atmospheric temperature was. The atmospheric and soil temperatures differed because irrigation was continuously carried out to maintain the freshwater condition and the shade condition was created by covering the ground surface where the rice was growing. The conspicuous temperature difference was observed 55–70 days after transplantation, which is the most vigorous stage of the plant growth period with atmospheric and geothermal differences of approximately 5°C. The overall temperature was between 20–30°C, which is suitable for methane production (Yamane and Sato 1964).

Comparison of methane emissions

(1) Methane emission trends during cultivation period

The change in methane emission rates during cultivation is shown in Fig. 2. The pattern of methane emission showed a gradual increase from 7 days after transplantation, and the maximum methane emission was observed approximately 20 days after transplantation.

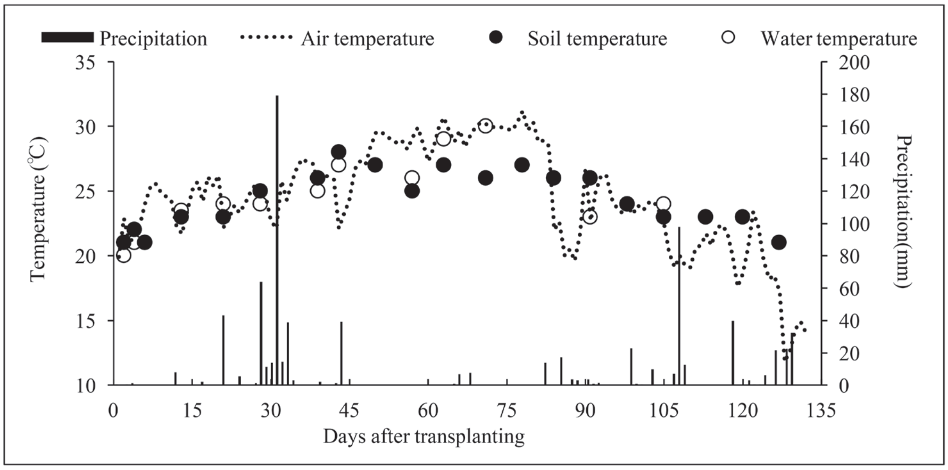
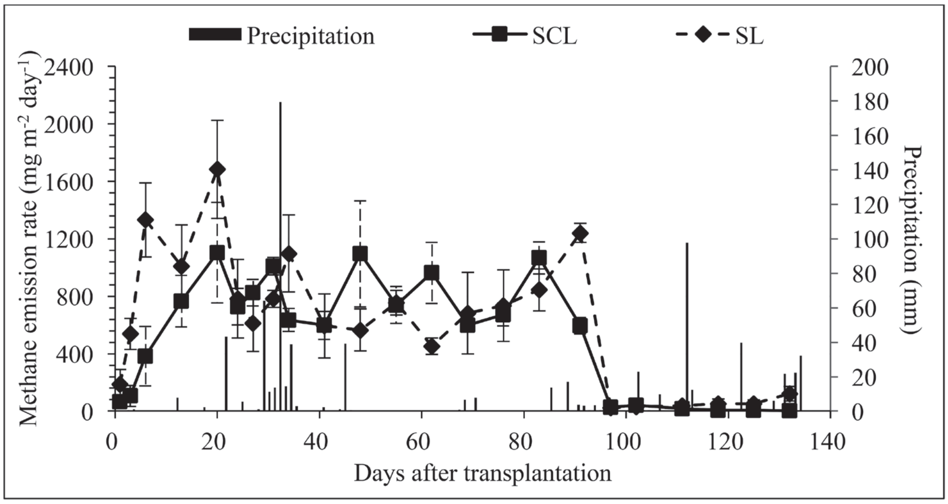


Fig. 1. Temperature change and precipitation during cultivation period.



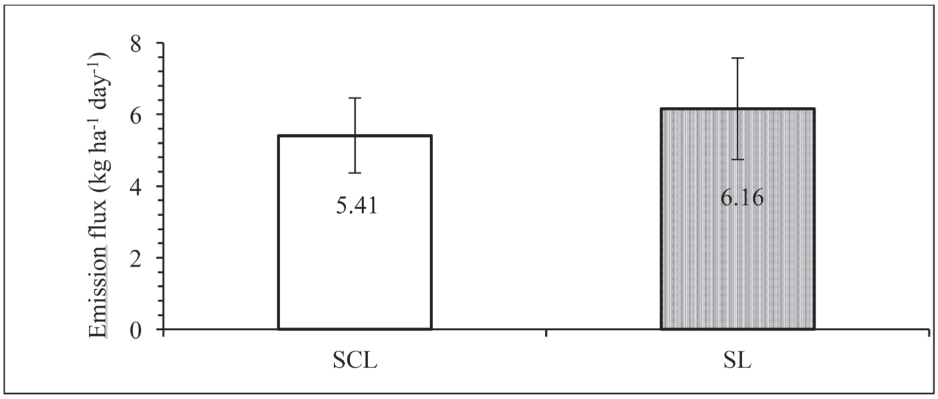
Abbreviation: SCL, sandy clay loam; SL, sandy loam

Fig. 2. Methane emission rates change by soil textures during cultivation period.

The peak methane emissions were observed within 90 days, after which it was rarely detected. Methane emission rates in the early stage were significantly different according to soil texture. The SL soil showed a rapidly increasing pattern, which subsequently decreased, but the SCL soil steadily maintained the peak level. The daily average methane flux is shown in Fig. 3 and the SCL, which contained more clay, produced less methane than the SL did. The emission rates were 5.41 and 6.16 kg ha^{-1} day^{-1} in the SCL and SL soils, respectively. Therefore, the flux per unit area of the SCL was 14% lower than that of the SL. This result was similar to that of a previous study showing more emissions occurred in the early stages of growth in sandy soil (Brye *et al.*, 2013). However, according to Wagnera (1999), the methane production rates increased in the soil types in the following order: sand < gravel < clayey silt ≤ clay, which differs from the results of this study. The results of each study are different, and the analysis error was large and, therefore, additional research is needed to improve the quantification of other known factors that affect methane emissions based on soil texture..

(2) Rice grain yield and methane emission per grain production

Rice grain yield and yield components differed significantly between the two soils (Table 3). Rice grain yields were 6.19 and 5.57 Mg ha^{-1} in the SCL and SL soils, respectively. The SCL performed better than the SL did in overall crop growth, including an 11% higher grain yield. Regarding methane emissions per grain yield, the methane flux was 115 and 145 g kg^{-1} in the SCL and SL,



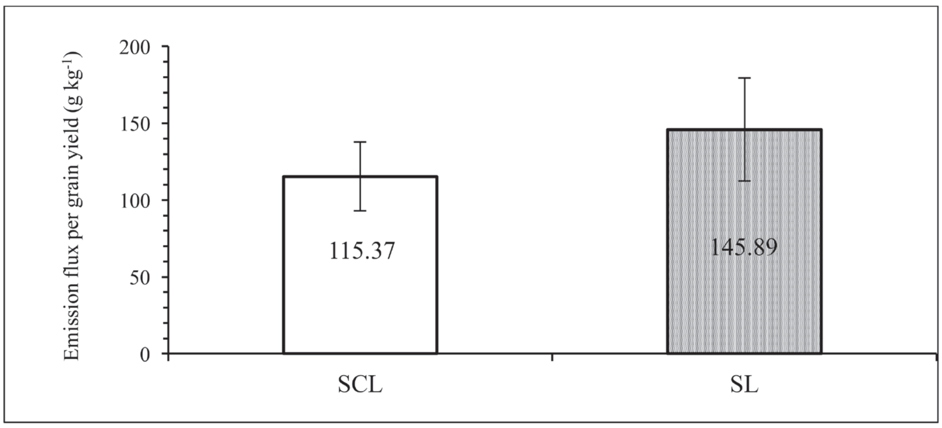
Abbreviation: SCL, sandy clay loam; SL, sandy loam

Fig. 3. Daily average methane flux per hectare during cultivation period.

Table 3. Yield components and grain yields

Soil Texture	Grain yield (Mg ha^{-1})	Weight of rice straw (Mg ha^{-1})	1000 grain weight (g)	Ripened rate (%)	Culm length (cm)	No. of tillers per hill
SCL	6.19	9.60	34.32	94.58	99.1	15.5
SL	5.57	9.20	34.13	90.10	91.3	14.6

Abbreviation: SCL; sandy clay loam; SL, Sandy loam



Abbreviation: SCL, sandy clay loam; SL, sandy loam

Fig. 4. Total methane flux per grain yield.

indicating the levels in the SCL were 26% lower than those in the SL were. Therefore, the differences were clearer than those observed with the unit emission per unit area analyses (Fig. 4).

CONCLUSIONS

To compare methane emissions based on soil texture, the rates were monitored during rice cultivation and were found to differ significantly at the early stage of growth. Furthermore, 90 days post–transplantation, the methane production in each plot was almost undetectable. Relatively, the SCL field, which had a finer soil particle distribution, showed low emissions. The average daily emission rates were 5.41 and 6.16 kg ha^{-1} day^{-1} in the SCL and SL soils, respectively. In addition, there were significant differences in rice productivities. However, the error range was so large because of the characteristics of the atmospheric sample analysis, and the similar or different results of the previous study might have been attributable to external factors. Therefore, the results would be difficult to compare because of the differences. The significant effects of soil texture on methane emissions clearly demonstrate that additional research is needed to improve the quantification of other known factors affecting methane emissions from soil samples of varying textures.

AUTHOR CONTRIBUTIONS

Su–Hun KIM, Ji–Sun LIM and Jae–Han LEE carried out analysis and interpretation of data. Yoshiyuki SHINOGI verified the data. Taek–Keun OH and Chang–Hoon Lee supervised the project and wrote the paper. All authors commented on the manuscript.

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REFERENCES

Ali, M. A., Lee, C. H., Lee, Y. B., Kim, P. J. 2009 Silicate fertilization in no–tillage rice farming for mitigation of methane emission and increasing rice productivity. *Agr Ecosyst Environ* **132**: 16–22

Aulakh, M. S., Wassmann, R., Bueno, C., Kreuzwieser, J., Rennenberg, H. 2001 Characterization of root exudates at different growth stages on ten rice cultivars. *Plant Biol* **3**: 139–148

Bodelier 2011 Interactions between nitrogenous fertilizers and methane cycling in wetland and upland soils. *Curr Opin Environ Sustain* **3**: 379–388

Brye, Kristofor, R., Rogers, Christopher, W., Smartt, Alden, D., Norman, Richard J. 2013 Soil Texture Effects on Methane Emissions From Direct–Seeded, Delayed–Flood Rice Production in Arkansas. *Soil Science Issue* **10**: 519–529

Cho, H. S., Seo, M. C., Kim, J. H., Sang, W. G., Shin, P., Lee, G. H. 2016 Effect of Soil Texture and Tillage Method on Rice Yield and Methane Emission during Rice Cultivation in Paddy Soil. *Korean J Soil Sci Fert* **49**(5): 564–571

Wagnera, D. 1999 Methane production in aerated marshland and model soils: effects of microflora and soil texture. *Soil Biol Biochem* p. 999–1006

Ferry, J. G., Kastead, K. A. 2007 Methanogenesis. In: Cavicchioli, R. (Ed.), *Archaea: Molecular and Cellular Biology*. ASM Press Washington DC p. 288–314

IPCC (Intergovernmental Panel on Climate Change), 2001 In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (Eds.), *Climate Change Impacts, Adaptation and Vulnerability*. Cambridge Universitiy Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change), 2007 *Climate Change: Mitigation of Climate Change – Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Kang, S. S., Kim, M. S., Kong, M. S., Chae, M. J., Sonn, Y. K., Lee, C. H., Kim, Y. H., Lee, D. B. 2014 Setting up the optimum ranges of soil chemical properties according to agricultural land use. *Korean Soil Sci Fert* p. 120 [in Korean]

Kim, S. Y., Gutierrez, J, Kim, P. J. 2012 Considering winter cover crop selection as green manure to control methane emission during rice cultivation in paddy soil. *Agr Ecosyst Environ* **161**: 130–136

Kimura, M., Miura, Y., Watanabe, A., Murase, J., Kuwatsuka, S. 1992 Methane production and its fate in paddy fields. I. Effects of rice straw application and percolation rate on the leaching of methane and other soil components into the subsoil. *Soil Sci Plant Nutr* **38**: 665–672

Ko, J. Y., Lee, J. S., Woo, K. S., Song, S. B., Kang, J. R., Seo, M. C., Kwak, D. Y., Oh, B. G., Nam, M. H. 2011 Effects of Soil Organic Matter Contents, Paddy Types and Agricultural Climatic Zone on CH4 Emissions from Rice Paddy Field. *Korean J Soil Sci Fert* **44**(5): 887–894 [in Korean]

Minami, K. 1993 Methane from rice production. *Res Rep Div Environ Planning* **9**: 243–258

Neue, H. U. 1993 Methane emission from rice fields. *Biosciences* **43**: 466–474

NIAST(National Institute of Agricultural Science and Technology) 2000 *Analytical methods of soil and plant*. RDA. Korea

Pramanik, P., Kim, P. J. 2014 Evaluating changes inn cellulolytic bacterial population to explain methane emissions from air–dried and composted manure treated rice paddy soils. *Sci Total Environ* **470–471**: 1307–1312

RDA (Rural Development Administration) 1999 *Fertilization standard of crop plants*. Korea. p. 148

RDA (Rural Development Administration) 2003 *Standard measurement and analysis in agricultural research and development*. Korea

Rolston, D. E, 1986 *Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods*, Soil Science Society of America, Madison. p. 1103–1119

Singh, S., Singh, J. S., Kashyap, A. K. 1999 Methane flux from irrigated rice fields in relation to crop growth and N–fertilization. *Soil Biol, Biochem* **31**: 1219–1228

Thauer, R. K. 1998 Biochemistry of methanogenesis: a tribute to Marjory Stephenson. *Microbiol. – UK* **144**: 2377–2406

Wang, Z. P., R. D. Delaune, P. H. Masscheleyn, Jr. W. H. Patrick 1993 Soil redox and pH effects on methane production in a flooded rice soil. *Soil Sci Soc Am. J.* **57**: 382–385

Yamana, I, K. Sato 1964 Decomposition of glucose and gas formation in flooded soil. *Soil Sci Plant Nutri* **10**: 27–133