Technical Report

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Suppression of Methane Gas Emission from Paddy Fields

Kimio ITO*

Abstract

Methane (CH_4) is the second largest greenhouse gas following to CO_2. Methane is produced by methanogen in anaerobic soil and water. About 11% of methane emission comes from paddy fields. Iron eluted from steelmaking slag has potential to improve soil environment from reductive to oxidized condition to suppress activities of methanogen. We examined effect of steelmaking slag on both methane emission suppression and rice grain yield in the actual paddy fields in Vietnam. Rice grain yield was increased in 12 of 17 crops and methane emission was suppressed in 9 of 10 crops by application of steelmaking slag.

1. Introduction

In March 2014, U.S. President Obama declared that the government would focus on cutting emissions of methane—a greenhouse gas—in the future.[1)] Of all the methane occurring on this earth, about 11% comes from paddy fields.[2)] In particular, emissions of methane from paddies in Southeast Asia are vast.[3)] Under the guidance of Professor Inubushi at Chiba University who had made a pioneering study on using steelmaking slag to restrain the emission of methane from paddies,[4, 5)] in 2009, the author et al. started a series of demonstration tests on restraining the emission of methane from paddies using a fertilizer made from steelmaking slag in paddies in Southeast Asia. Described below are how methane is produced and emitted from a paddy field, and why the application of fertilizer made from steelmaking slag is supposed to help restrain the methane emission, together with the relevant results of the demonstration test.

1.1 Global warming and methane emitted from paddy fields

Global warming is a very important problem that must be solved in the future. As one of the greenhouse gases, carbon dioxide (CO_2) is well known. Carbon dioxide is a greenhouse gas emitted due to the aerobic respiration of living things or oxidation by combustion of organic matter such as fossil fuels. Globally, about 34 500 million tons of carbon dioxide are emitted annually.[6)] Carbon dioxide is considered the greenhouse gas that contributes most to global warming, and CH_4 is considered to make the second largest contribution. Methane is produced by methanogens, which are anaerobic microorganisms living in an anaerobic environment (e.g., soil or water) or in the intestines of animals.

Globally, about 530 million tons of methane (converted in terms of carbon) are emitted annually.[2)] It should be noted, however, that the global warming potential of methane is 21 times that of carbon dioxide. Namely, compared in equimolecular terms, the greenhouse effect of methane is 21 times greater than that of carbon dioxide. Nitrous oxide (N_2O) is considered the greenhouse gas that makes the third largest contribution to global warming. N_2O is also produced by microorganisms living in soil or water environment or in the intestines of animals. On a global basis, 16 million tons of N_2O (converted in terms of nitrogen) are discharged annually.[2)] The global warming potential of N_2O is 310 times that of carbon dioxide.

Figure 1 illustrates how methane is produced and emitted from a paddy field. The methanogen that produces methane is an anaerobic microorganism. It produces CH_4 using HCO_3^-, CH_3COO^-, and so on, obtained by the decomposition of organic matter as electron acceptors and H_2 as the electron donor. Methane produced in anaerobic paddy soil is partly emitted directly to the atmosphere from the soil surface but mostly emitted to the atmosphere through the aerenchyma (ventilating system) in rice plant.[7)]

It is expected that economic activities, mainly in Asia, will become active in the years ahead. Reportedly, of the Asian population of about 4 200 million people, about 2 700 million (60%) live on rice.[8)] Since Asia's population is expected to continue increasing in the future, the total area of paddy fields in Asia will also increase. The paddy area in 2009 was 10 940 000 ha in Thailand, 4 410 000 ha in the Philippines, 7 420 000 ha in Vietnam, and 12 100 000 ha in Indonesia.[9)] In these warm regions, the production of methane by methanogens in paddies is very active.[3)]

Steelmaking slag made from the steelmaking process contains elements such as iron, silicon, and calcium, which are effective fertilizer components.[10)] Iron eluted into the soil is oxidized by air to become ferric ion, which can be expected to function as an oxidizer.

* Senior Researcher, Dr.Eng., Environment Research Lab., Advanced Technology Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

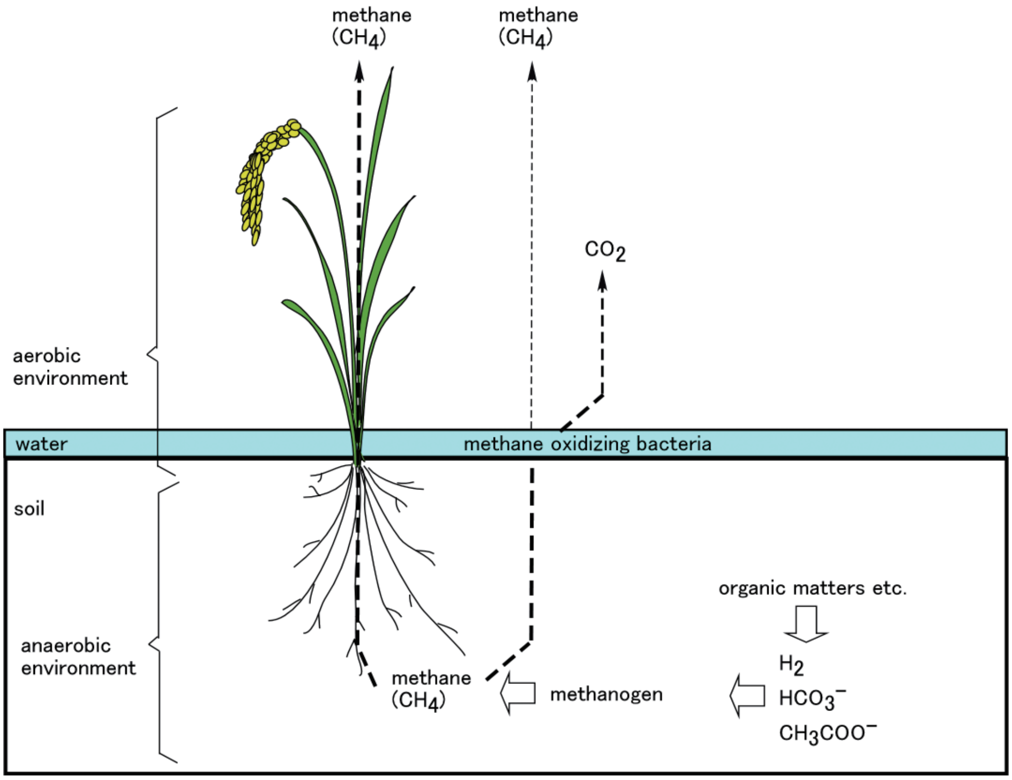

Fig. 1 Mechanism of methane gas emission from paddy field

Ferric ion increases the oxidation-reduction potential of the surrounding environment and hence, there is a possibility that it can restrain the functioning of methanogens, which like an oxygen-free anaerobic environment having a low oxidation-reduction potential. Although this was the result of a pot test, Furukawa and Inubushi reported that they could restrain the emission of methane from paddy soil by applying steelmaking slag 10–100 tons/ha.[4, 5)]

Thus, by applying steelmaking slag to paddy fields, it might become possible to restrain the emission of methane from the paddies and, at the same time, increase the yield and enhance the quality of rice, thanks to the silicon and calcium contained in the slag. Therefore, the author et al. applied steelmaking slag to paddies in Southeast Asia (Vietnam) to verify that it would in fact restrain the methane emission and increase the yield of rice. The results are described below.

2. Main Subject

2.1 Test procedure

2.1.1 Steelmaking slag fertilizer tested

The sample used in the test was silicate fertilizer made from slag that was produced in the hot-metal dephosphorization process of Nagoya Works. The composition of the fertilizer is shown in **Table 1**. Here, attention should be paid to the way the component elements of the fertilizer are indicated. For Ca, Si, Mg, P, and Al, it is customary to give their contents (mass%) converted in terms of oxides, CaO, SiO_2, MgO, P_2O_5, and Al_2O_3, respectively. For Mn and Fe, however, it is customary to directly give their contents (mass%). Conventionally, CaO is called lime, SiO_2 silicic acid, MgO magnesia, and P_2O_5 phosphoric acid.

As can be seen from Table 1, the fertilizer tested contained approximately 10% Fe, in addition to silicic acid, lime, magnesia, manganese, and so on, which are effective constituent elements.

Table 1 Compositions of tested fertilizer made of steelmaking slag

(%)

CaO	SiO_2	MgO	Mn	Fe	P_2O_5	Al_2O_3
47	24	4	3	10	2	4

Table 2 Research institutes and test sites in Vietnam

Research Institutes	Test sites	Soil type
Vietnam Academy of Agricultural Science (VAAS)	Tu Liem (Hanoi) Hiep Hoa (Bac Giang)	Fluvisols Acrisols
Hanoi University of Agriculture (HUA)	Gia Lam (Hanoi) Gia Loc (Hai Duong)	Eutric fluvisols Dystric fluvisols
Institute of Agriculture South Vietnam (IAS)	Go Dau (Tay Ninh)	Acrisols
Can Tho University (CTU)	Vin Hoa (Soc Trang)	Sand dune regosol

2.1.2 Test sites

The test was performed by two northern research institutes and two southern research institutes in Vietnam. The research institutes and test sites are detailed in **Table 2** and **Fig. 2**. The number of test sites was four in the north and two in the south.

2.1.3 Test method

Before filling the paddy field with water, the fertilizer made from steelmaking slag was scattered over the field at a rate of 0.5–2 ton/ha (the common rate of fertilizer application in Japan) and mixed with the cultivated soil. About two weeks later, young rice plants of

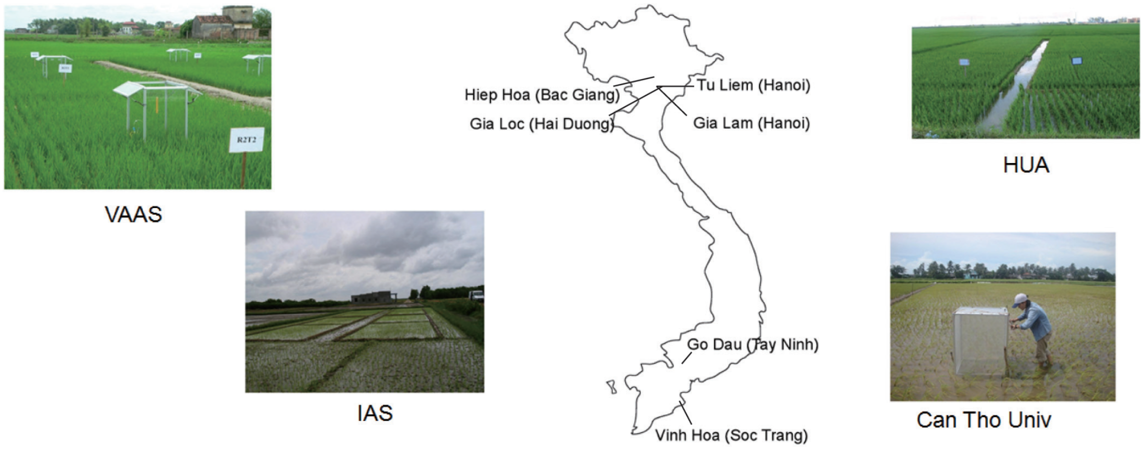

Fig. 2 Test sits for suppression of methane emission from paddy fields in Vietnam

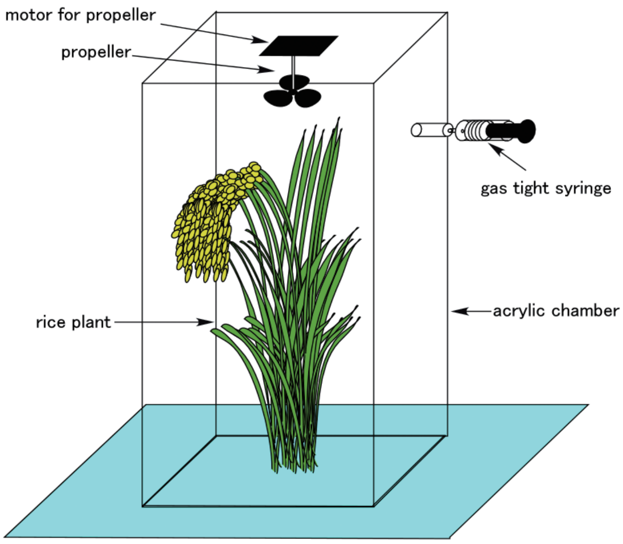

Fig. 3 Collection of methane gas by closed chamber method

varieties cultivated in various parts of the country were bedded out in the paddy field. With respect to NPK (nitrogen, phosphoric acid, potassium) fertilizers, they were applied in the same way as used by most of the local farmers. In addition to the test sections wherein both NPK and steelmaking slag fertilizers were applied, a control section wherein only NPK fertilizers were applied was tested. Every two weeks after the rice planting, methane emitted through the rice plant was collected by the closed chamber method, and its concentration was measured by gas chromatography-mass spectrometry (**Fig. 3**).[4, 5, 11)]

2.2 Test results and discussions

At six sites in Vietnam (four in the north and two in the south), a total of 17 crops of paddy rice were tested. **Figure 4** shows the relative rice yield in each of the test sections provided with the steelmaking slag fertilizer, with the rice yield in the control section without steelmaking slag fertilizer assumed to be 1. The favorable effect of the steelmaking slag fertilizer on the rice yield was confirmed for 9/12 crops in the northern part of Vietnam and for 3/5 crops in the southern part of the country.[12–14)]

Figure 5 shows the emission of methane for a given rice yield calculated for each of the 10 crops (eight in the north and two in the south) for which the methane emission was measured. In the figure, the amount of methane emission in each of the test sections is com-

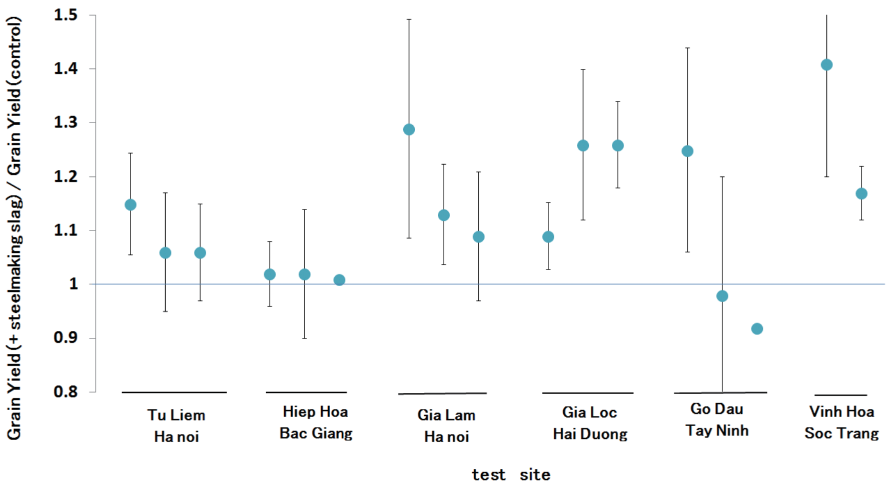

Fig. 4 Effect of fertilizer made of steelmaking slag on rice grain yield

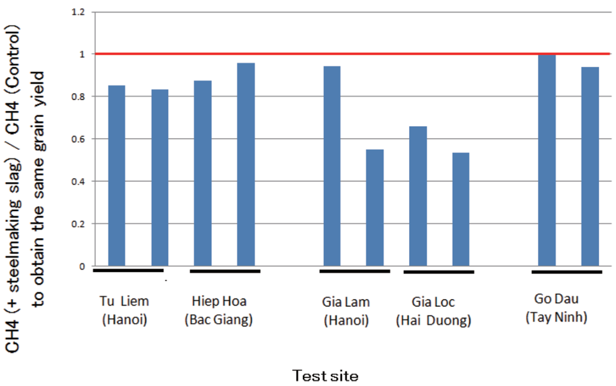

Fig. 5 Effect of fertilizer made of steelmaking slag on methane emission from paddies

pared with that in the control section (rice yield assumed to be 1) in which steelmaking slag fertilizer was not applied. The reduction of methane emission for a given rice yield by the steelmaking slag fertilizer was confirmed for all the eight crops in the northern part of Vietnam and for one crop out of two in the southern part of the country.[12–14)]

From the results shown in Figs. 4 and 5, applying the fertilizer made from steelmaking slag is considered effective to not only increase the yield of rice but also reduce the emission of methane.

In the present test, a fertilizer made from steelmaking slag that was produced in the hot-metal dephosphorization process was used. As shown in Table 1, the fertilizer contained a relatively large proportion of silicic acid (about 24%), whereas the content of iron was about 10%. Conversely, a fertilizer made from basic oxygen furnace slag contains a larger proportion of iron (about 20%) than that made from hot-metal dephosphorization slag.

In view of the fact that the supply of iron to the soil helps reduce the emission of methane from the soil, the fertilizer made from basic oxygen furnace slag containing more iron than the fertilizer made from hot-metal dephosphorization slag is considered to be able to more efficiently restrain the emission of methane. Singla and Inubushi reported that in a paddy rice pot test using paddy soil of Kujukuri, Chiba Prefecture, they measured the emission of methane from soil with a fertilizer made from slag obtained from the hot-metal dephosphorization process and a fertilizer made from basic oxygen furnace slag, and found that the fertilizer made from basic oxygen furnace slag more efficiently restrained the emission of methane.[15)]

3. Conclusion

In a test conducted at paddy fields in Vietnam, it was found that applying a fertilizer made from steelmaking slag to a paddy field was effective in reducing the emission of methane and increasing the yield of rice. The measure of reducing emissions of methane as a means of curbing global warming, as in the United States, will ever increase in importance in the future. Since the emission of methane from paddy fields accounts for some 11% of the total amount of methane emissions on earth, it is hoped that the application of a fertilizer made from steelmaking slag that is capable of reducing the emission of methane and increasing the yield of rice at the same time will become widespread in the rice-producing countries of Southeast Asia in the future.

The results of the test on reducing the methane emissions from paddy fields in Vietnam described in this study are based on the joint research "Verification of the Effects of Steelmaking Slag on the Reduction of Methane Emissions from Rice Paddies and on the Improvement of Rice Yield" (2009–2011) conducted by former Nippon Steel Corporation, Chiba University, Sumitomo Corporation, and Vietnamese research institutes (Vietnam Academy of Agricultural Science (VAAS), Hanoi University of Agriculture (HUA), Institute of Agriculture South Vietnam (IAS), Institute of Tropical Biology (ITB), and Can Tho University (CTU)).

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Kimio ITO
Senior Researcher, Dr.Eng.
Environment Research Lab.
Advanced Technology Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511