3. Development and evaluation of new management options for improving GHG sink/source control in agricultural and forest ecosystems

(3a) Development and evaluation of mitigation technologies for CH_4 and N_2O emissions from agroecosystems（Abstract of the Final Report）

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I. Overview

Theme 3a consists of two sub-themes: the sub-theme (1) entitled ‘Development and regional evaluation of mitigation technologies for CH_4 and N_2O emissions from cultivated land in Asian countries’ targets on crop lands, and the sub-theme (2) entitled ‘Development and regional evaluation of mitigation technologies for CH_4 and N_2O emissions from animal industry in Asian countries’ targets on animal industry. The sub-theme (1) is further devised into 4 sub-sub themes and the sub-theme (2) into 2 sub-sub themes. The structure of the theme 3a is as follows:

II. Scientific outcome

Although various candidates of mitigation technologies for CH_4 and N_2O emissions from agricultural sources have been proposed and discussed, gaps in knowledge have pointed out including: 1) There are large uncertainty in quantitative evaluation of each technology due to the diversity of climate and ecosystems. 2) Most of the proposed technologies focus mainly on the mitigation efficiency of CH_4 and N_2O emissions, but little attention has been paid on the feasibility and the trade-offs with economy and production. 3) Developing the methods to scaling up the point data to regional or global evaluation is needed to estimate the mitigation effects of the technologies.

This study demonstrated feasible mitigation options for agricultural CH_4 and N_2O emissions from the experiments in crop lands and animal industry of Japan and other Asian countries. Those options include rice paddy management, fertilizer technologies, handling and feeding technologies of livestock, and animal waste management. Mitigation potentials of those options for CH_4 and N_2O emissions were quantitatively evaluated. The results indicated that those options have significant potentials to mitigate GHG emissions in Asian countries.

Compilation of GHG source databases and their analysis determined emission factors and quantitative influence of various controlling factors. These values revise the estimates of GHG emission rates at regional and global scales. In addition, a mixed ecosystem analysis and development of a process-based model enabled to make Tier 2 or 3 estimations of GHG emissions from agroecosystems.

III. Contribution to policy of global environmental issues for decision makers

The results of this study contribute to promote policies for global environmental conservation in Japan and other Asian countries through mitigating GHG emissions from agroecosystems. Most of the mitigation options demonstrated in this study were incorporated in 'the Strategies for mitigating and adapting agriculture, forestry and fisheries to global warming' (MAFF, 2007). The options for CH_4 from paddy fields by organic and water management and for N_2O emissions by fertilizer management were listed in the revised 'the Kyoto Protocol Target Achievement Plan' (Government of Japan, 2008).

Compilation of the inventories data improved both national and global inventories of agricultural emissions of CH_4 and N_2O. The results have contributed to revise the IPCC Guidelines (IPCC, 2006) and the latest National GHG Inventory Report of Japan (Ministry of the Environment, Japan, 2006).

1. Introduction

Agriculture contributes to about 40% of respective global emissions of methane (CH_4) and nitrous oxide (N_2O). These greenhouse gases are emitted to the atmosphere during agricultural production processes from soils and animals. As it is described in the IPCC assessment reports, CH_4 and N_2O emissions from agricultural sources can be reduced significantly through improved technologies of agronomic practices, animal nutrition, and animal waste management (IPCC, 2007). Although various candidates of mitigation technologies for CH_4 and N_2O emissions from agricultural sources have been proposed and discussed, there are gaps in knowledge that: 1) There are large uncertainty in quantitative evaluation of each technology due to the diversity of climate and ecosystems. 2) Most of the proposed technologies focus mainly on the mitigation efficiency of CH_4 and N_2O emissions, but little attention has been paid on the feasibility and the trade-offs with economy and production. 3) Developing the methods to scaling up the point data to regional or global evaluation is needed to estimate the mitigation effects of the technologies.

2. Research Objective

This research project, SSCP-3a, focuses on bridging the gaps in knowledge for CH_4 and N_2O mitigation in agricultural sector. The activities of the research project are based on field measurements of GHG exchange, laboratory experiments, GHG database compilation, and modeling, aiming at making a quantitative evaluation of the mitigation technologies for the emissions from cultivated land and animal industry in Asian countries. The studies have been developed to address scientifically and socially important questions related to the environmental impacts of agriculture.

3. Research Methods and Results

(1)-□ Development of feasible mitigation technologies for CH_4 and N_2O emissions from cultivated land in Asian countries

Field experiments for mitigating CH_4 and N_2O emissions from paddy fields and N_2O emissions by nitrogen application to crop fields were conducted at various sites in Japan, China, Indonesia, and Thailand (Fig. 1). The mitigation options tested include management of organic matter water, and land for paddy fields, whereas fertilizer management for N_2O. Methane and N_2O fluxes from the fields were measured using a closed chamber method at each site.

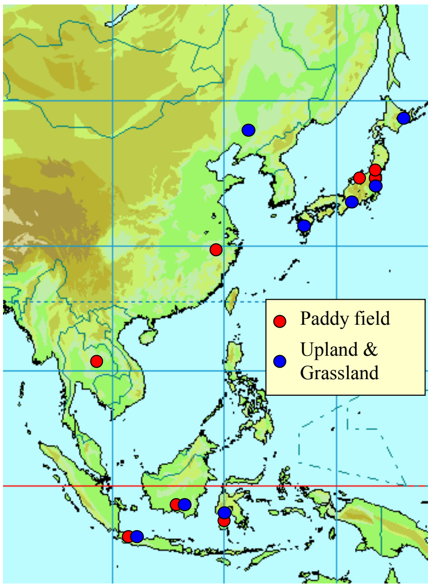

Fig. 1 Location of study sites

a. Management options in paddy fields in Japan

The impacts of application of livestock dung compost type on CH_4 emission from paddy fields were evaluated by applying different types of the compost (cattle dung compost: CAC, pig feces compost: PC, chicken dropping compost: CDC) in field and laboratory experiments in Yamagata. Methane flux in the PC plots increased early part of the cultivation season, late July and early August, while small increases in the flux in the CAC and CDC plots during the same periods were observed. In pot experiments, total amount of methane emission during a cultivation period in the CAC, PC and CDC plots were 1.16, 3.01 and 1.18 g CH_4 pot^{-1}, respectively. In the field experiments, total amount of methane emission during a cultivation period in the CAC and PC plots were 24.4 and 39.4 g CH_4 m^{-2}, respectively (Table 1). These experiments for the mitigating CH_4 emissions from paddy fields showed that application of cattle and pig manure instead of spring rice straw reduced the emission by about 50% and 30%, respectively.

Table 1 Methane emission rates from the paddy field in Yamagata during the investigation period

year	Plot	Methane emission※ (gCH_4m^{-2})			Methane emission ratio compared with RS (%)
		Cultivation period	After cultivation period	investigation period	
2004	CAC	24.41± 1.18	−0.02±0.01	24.39± 1.17	50
	RS	48.82± 5.54	−0.01±0.01	48.81± 5.53	100
2005	PC	39.27± 5.65	0.09±0.05	39.36± 5.70	72
	RS	54.60±15.47	0.06±0.06	54.66±15.53	100

※Numerical values indicate the mean of triplicate measurement and standard deviation.

Field experiments for mitigating CH_4 emissions from paddy fields tested various water management options in Fukushima. Extending midseason drainage from 2 week to 3 and 4 weeks reduced seasonal CH_4 emission rates by 53-72% and 26-51%, respectively. The difference in the period of midseason drainage did not show increase in N_2O emission rate. Rice yield at the 4 weeks plot decreased by 4-12%, whereas no difference in both yield and quality of rice at the 3 weeks plot. The results indicated that extending midseason drainage for 1 week is an effective mitigation option. Rice cultivation without puddling before transplanting rice reduced the emission of CH_4 by about 20%, but decreased rice yield by 4-5%.

Installing underground draining pipes in paddy fields also showed very large potential of mitigating CH_4 and N_2O emissions from paddy fields. However, a large scale monitoring for the effect of underground draining pipes resulted in large special variations due to the contents of humus in the sub-surface soil layer. Promoting field decomposition of wheat straw during the following rice cultivation period reduced the emission of CH_4 during the rice cultivation period by 29% in a Chinese paddy field. The control of flooded water table in Indonesian paddy fields reduced the emission of CH_4 by 39-51%.

Intensive field experiments were conducted to study effects of farmland improvement on CH_4 emission from two rice paddy fields in Niigata. Rice cultivation and field management was similar on both paddy fields, but whereas one field had a subsurface drainage system installed 0.6-0.8 m below the soil surface (drained paddy field), the other had no such system (non-drained paddy field). The subsurface drainage system lowered the groundwater level and top of gley soil layer to the drainage pipe level, enhanced soil permeability, and resulted in more oxidized soil conditions in the fallow season. Methane emissions from the drained paddy field during each rice-growing season were on 63% lower than those from the non-drained paddy field.

b. Management options in grass lands, upland fields, and greenhouse cultivation in Japan

The effect of alteration in the amount of nitrogen applied at each dressing in split application on N_2O emission was investigated at a grass land field in the eastern part of Hokkaido for 3 years. Furthermore, availability of nitrification inhibitors for decrease of N_2O emission was evaluated for 2 years. In swards for silage and hay production under traditional 2-cut system, it is customary to split the annual fertilizer rate into 2 applications (2/3 in early May for the first cut and 1/3 in early July for the second cut). This experiment showed that heavier nitrogen dressing supplied for the first cut (5/6 of annual rate) reduced annual N_2O emission. Dry matter yield in this treatment was nearly same as it was in the traditional system mentioned above. However, lodging risk was enlarged at first cut. Nitrification inhibitors decreased annual N_2O emission without any change in dry matter yield, but the materials were extravagant. In conclusion, assuming that nitrogen split application was changed for 104,000 ha of swards in Konsen district, 44 Mg N y^{-1} of N_2O could be reduced without changing in cost. On the contrary, when nitrification inhibitors applied on the same area of swards in this district, 33 Mg N y^{-1} of N_2O could be reduced with three or four times of material cost.

A long-term field experiment for cabbage cultivation on upland of an Andisol was conducted in Kumamoto to evaluate N_2O emissions. In spring-summer cultivation, N_2O emission was low at planting period but increased at harvesting period by comparatively high temperature and heavy rainfall. On the contrary, N_2O emission was high at application periods of basal and second dressing in autumn-winter cultivation. In order to reduce N_2O emission, combined application of cattle manure 20 t ha^{-1} and pig manure of 5 t ha^{-1} was the most effective method of fertilizer application, because the concentration of inorganic nitrogen of the soil by this combined application retained at lower level during growing period than conventional one. Additionally, single basal application of controlled release fertilizer was found to be the same effect but mulching little reduced N_2O emission. On the other hand, the effect of harvesting residue of cabbage on N_2O emission seems to be reduced by mixing with plowing layer of cultivating field.

Another long-term field experiment for cabbage cultivation was also conducted in Tsukuba. The residual leaves of a cabbage are incorporated into the field in Japan and can be a source of N_2O. The N_2O flux was different between the two cultivation systems (Fig. 2). The N_2O flux after the incorporation of residues was higher in the summer cultivation than in the winter cultivation. The N_2O flux after the basal fertilization was higher in the winter cultivation than in the summer cultivation. On the other hand, the N_2O flux after the topdressing was slightly or not at all increased in each cultivation system. In the summer cultivation, the N_2O flux was remarkably increased just before the harvest. A coated fertilizer was applied under the topsoil (0 to 10 cm in depth) to separate the incorporated residues and fertilizer nitrogen. The emission factor for N_2O from the cabbage residue was evaluated as 0.312% on the average of four cultivations and the application of coated fertilizer reduced the emission factor by 23.7%.

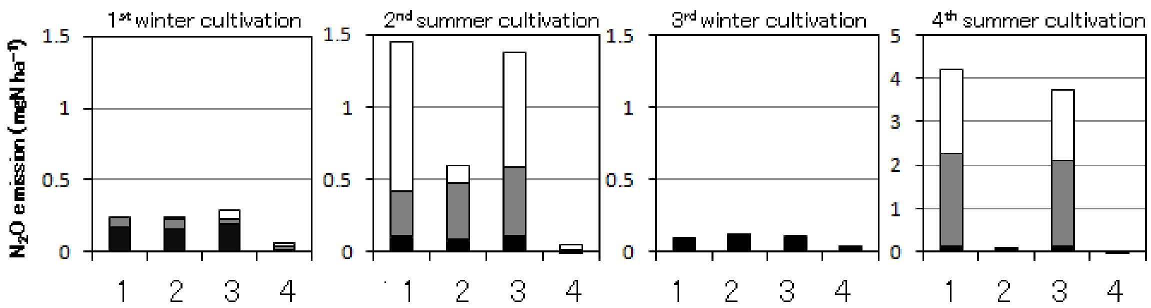

Fig. 2 N_2O emission from the cabbage fields during the distinct cultivation stages. Black bar indicates the amount of N_2O emitted during basal dressing to topdressing, gray bar indicates it during topdressing to incorporation of residue and white bar indicates it during incorporation of residues to next basal dressing.

Nitrous oxide (N_2O) and nitric oxide (NO) fluxes resulting during long-term tomato cultivation in planters in a glasshouse were continuously measured using the flow-through chamber method over the course of three cultivation periods. Total amounts of N_2O emission during the entire cultivation periods in the plot applied with a compound fertilizer containing nitrate-N and urea-N in drip fertigation plots (DF plot) were 0.8 times and 1.4 times of those in the conventional fertilization ploy (CF plot) in the first cultivation period which started in spring season and in the second cultivation period which started in winter season, respectively. Total amounts of NO emissions in the DF plots during the two cultivation periods were smaller than those in the CF plots by factors of 0.3 to 0.4. In the 3rd cultivation period which started in winter (December), the percentages of total applied N emitted as N_2O and NO in the plot applied with calcium nitrate (CN plot) were 1.3 times and 0.3 times compared with those in the control plot, respectively.

c. Management options in other Asian countries

Field measurements were conducted to asses CH_4 emission from paddy fields as affected by water management in several sites in Indonesia. In South Sulawesi site, seasonal CH_4 fluxes were the highest in the farmer's practice (>6 cm), followed by 6 cm and 3 cm water levels. Water management can reduce the emission of CH_4 by 51.4 % for 3 cm and 38.8 % for 6 cm to farmer's practice while no trade off emission as N_2O. In West Java site, CH_4 can reduce up to 80 % by intermitted drainage, however, N_2O increased to 99 % when rice soil field was water-saturated. In addition, CH_4 emission was reduced 17 kg ha^{-1} $season^{-1}$ by rotation of paddy and vegetation cultivations. In Thailand, crop establishment by direct seeded increased CH_4 emission from rice plant more than transplanted, while organic matter application had less increase to compare with chemical fertilizer.

To assess applicability of the key resource, water and organic matter, management options for mitigation of CH_4 emission from paddy field in Indonesia and to design a model implementing organization that could be the major player of Clean Development Mechanism (CDM) projects, cropping patterns and the Water Users' Association (WUA) were investigated in South Kalimantan and South Sulawesi with reference to water and organic matter management practices to compare them with the potential mitigation options.

N_2O and CH_4 flux from corn fields was also examined to see the effect of nitrification inhibitor (DCD) and controlled-release chemical fertilizer (CRF) in South Sulawesi and South Kalimantan, Indonesia. Fig. 3 shows N_2O flux from soils with combination of nitrogen fertilizer and DCD under the corn field experimental in Makassar, South Sulawesi. Urea + DCD reduced N_2O flux from the soil by 55.8% compared to the urea plot and by 11.7% compared to the CRF plot. Similar results were obtained from the experiment in Banjarmasin, South Kalimantan.

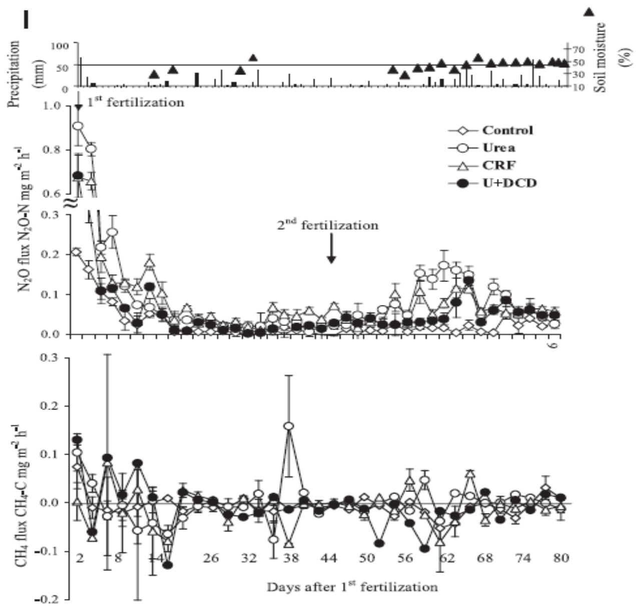

Fig. 3 Change of precipitation, soil moisture, N_2O, and CH_4 flux from the corn field affected by different nitrogen fertilizers during the cropping season (October 2005 to January 2006).

Nitrous oxide (N_2O) fluxes from a maize field were monitored in Shenyang, northeast of China. Nitrous oxide fluxes from the urea plots without additives showed significant increases after basal and topdress applications in both the years. The fertilizer induced emission factor for N_2O was calculated to be the range between 0.34% and 0.73%. In the cases of applying fertilizer additives, N_2O fluxes remained much lower than the cases without the additives. Addition of an additive containing a nitrification inhibitor, DCD, reduced the seasonal N_2O emission rates by 54% on average. While, application of another additive containing both nitrification inhibitor and urease inhibitors reduced by 44%. The application of additives resulted in no significant difference in the crop yields compared with those in the plots without additives. The cost analysis showed that increase in the cost by applying the additives, 90 RMB ha^{-1}, almost compensated the labor cost for top-dress application of fertilizer (120 RMB ha^{-1}).

(1)-□ Compilation of inventories for mitigating CH_4 and N_2O emissions from cultivated land in Asian countries

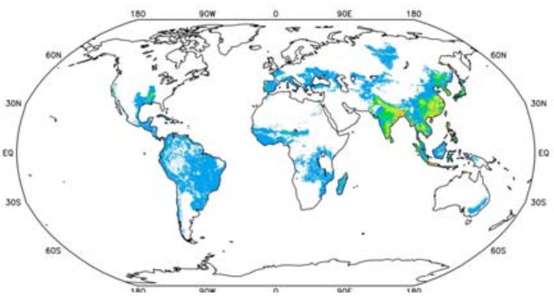

Fig. 4 Estimated global emission rates of CH_4 from paddy fields

We compiled a database of CH_4 emissions from rice fields in Asia from peer-reviewed journals, and developed a statistical model to estimate a baseline emission of 130 (with error range of 80-220) mg m^{-2} day^{-1}, and scaling factors. We then applied the Tier 1 method of the 2006 IPCC Guidelines to estimate CH_4 emission from global rice fields. The estimated global emission is 25.1 Tg yr^{-1} (Fig. 4). We calculated that if all those continuously flooded rice fields were drained once or more during rice-growing season, CH_4 emission would be reduced by 4 Tg yr^{-1}. If rice straw were applied off-season where and when applicable, there would be another emission reduction of 4 Tg yr^{-1} globally. When the two mitigation options were adopted simultaneously, global emission could be reduced by 7.5 Tg yr^{-1}.

Also, we analyzed data on N_2O emissions from rice fields reported in peer-reviewed journals. Mean fertilizer-induced emission factor during the rice-cropping season were 0.22 ± 0.24% for fertilized fields continuously flooded, 0.37 ± 0.35% for fertilized fields with midseason drainage, 0.31 ± 0.31% for all water regimes, respectively. N_2O emissions from Japanese agricultural fields were also analyzed, and was estimated as 0.62 ± 0.48 %, 2.82 ± 1.80 %, and 0.31 ± 0.31% for upland fields, tea fields, and paddy fields, respectively.

Default emission factors and scaling factors for CH_4 and default emission factor for N_2O derived from this work were contributed to revise 2006 IPCC Guidelines. Also, N_2O emission factors from Japanese agricultural fields were contributed to revise National

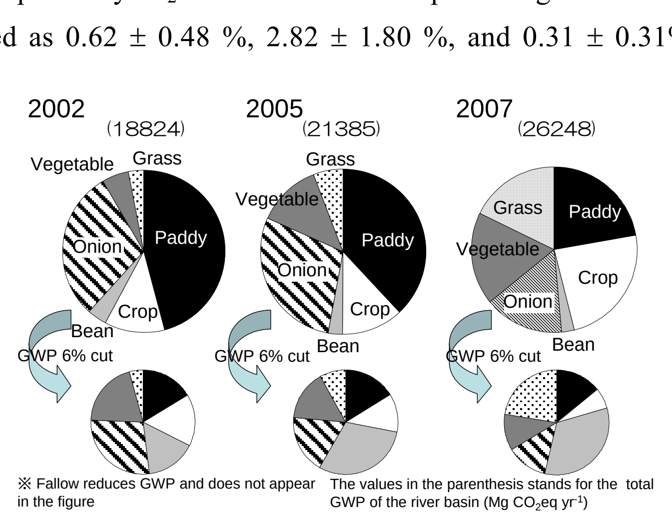

Fig. 5 Contribution of main land uses to GWP in 2002, 2005 and 2007 and to the reduction scenario by 6% in each year for the total agricultural land uses in the Ikushyunbetsu river watershed.

GHGs Inventory Report of Japan (2006).

A mixed ecosystem analysis for calculating carbon budget and GHG emission rates estimated net GWP in Ikushunbetsu catchment, Hokkaido. The N_2O emission from agricultural land use was described as sum of emissions induced by chemical fertilizer, applied organic matter and soil organic matter decomposition. Temporal variation of the N_2O emissions in onion filed could be explained by the relations between emission factors and meteorological factors. N_2O, CH_4 and CO_2 emissions in paddy rice filed was closely correlated to the amount of remained rice straw. Total GWP of the agricultural field increased from 18824 Mg CO_2eq yr^{-1} (2002) to 26248 Mg CO_2eq yr^{-1} (2007), because GWP of each land use as well as the area of vegetable and grassland, which had high GWP values, increased (Fig. 5). An eco-balance analysis for a scenario to reduce GWP by 6% showed that it was possible by increase in bean area and decrease in paddy rice area.

A process-based biogeochemical model (DNDC) was revised, tested and applied for assessing CH_4 mitigation potentials of alternative water regimes of rice fields. Using observed data from different sites of rice fields in Japan, revised DNDC was calibrated and validated under various conditions of soil, climate and farming practice. For assessment of CH_4 mitigation potentials, revised DNDC was run with a GIS database of 1 km×1 km mesh scale, containing rice field area, soil properties, daily weather and farming practices in Hokkaido. Average CH_4 emission with current water regime is estimated to be 4.2 Mg CO_2 ha^{-1} y^{-1}, and it could be reduced by 1.7 Mg CO_2 ha^{-1} y^{-1} by applying 2-week midseason drainage twice (Fig. 6).

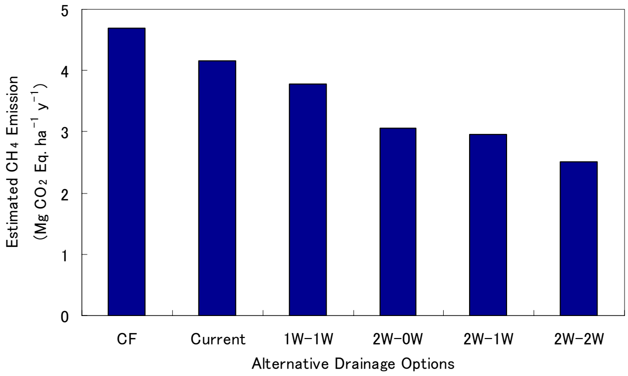

Fig. 6 Estimated average methane emissions from rice fields in Hokkaido with alternative midseason drainage (MSD) options. CF, continuous flooding; Current, current management; 1W-1W, MSD for 1 week and 1 week; 2W-0W, MSD for 2 weeks; 2W-1W, MSD for 2 weeks and 1 week; 2W-2W, MSD for 2 weeks and 2 weeks.

(1)-□ Parameterization of chemical properties of paddy soils for evaluating methane emissions from rice fields

For understanding which parameters are more important in soil properties for deciding the CH_4 production from rice paddies, ten kinds of rice soils were collected around Japan and anaerobically incubated at 30ºC for 16 weeks in laboratory condition, After 1, 2, 4, 8 and 16 weeks of incubation, CO_2, CH_4 and Fe^{2+} were measured for understanding soil organic matter decomposed and iron reduction. Available N also was measured at end of incubation. The results showed that decomposable C and reducible Fe are two key parameters to decide the CH_4 production (P_{CH4}). There was a significant relationship between decomposable C and available N (N_{ava}) (r^2=0.969**). Except a long time stored soil and a sand-gley soil samples, also, a significant relationship between total-Fe (Fe_{total}) and reducible Fe was found (r^2=0.837**). From this experiment, a simple CH_4

production model was pulled draw as:

$$P_{CH4} = 1.916N_{ava} - 2.395Fe_{total}/1000 \qquad \text{(each unit was μg g}^{-1}\text{ soil)}$$

(1)-□ Modeling CH_4 and N_2O emissions from agricultural land in Asian countries

This study applied the revised DNDC model to simulate the effects of various mitigation options on CH_4 emission from rice fields in Thailand. Validation of the model simulation with field observation data showed acceptable results. Rice straw incorporation into fields played an important role on CH_4 emission by adding additional organic carbon and lowered soil Eh, which is suitable for CH_4 production. The increasing rate of CH_4 emissions depends on amount of rice straw incorporated. Improving soil fertility by applying chemical fertilizer seemed to be influenced on CH_4 emission but was less effective on rice yield. Application of ammonium sulphate (AS) reduced CH_4 emission and preserve rice yield. In addition, it was shown that water management was one of the feasible mitigation choices to reduce CH_4 emission from flooded rice fields. Conducting field drainage at optimal rice growth stage is recommended.

(2)-□ Development of regulation technologies and compilation of inventories for mitigating CH_4 emissions from ruminant in Asian countries

We studied the following issues to achieve this investigational purpose.1) Analysis of a drifting factor of methane production of ruminant, 2) Measurement of methane production of ruminant in Asia, 3) Development of simple methane estimation method, 4) Estimation of methane production pf ruminant at a local level.

a. Analysis of a drifting factor of methane production of ruminant

The protein and non-structural carbohydrate source varying in degradability in rumen give to change methane production of Holstein cattle.

The following formula was obtained.

CH_4 (g/d)=-278*ME(MJ/kgDM)+900 r=0.73 in 30 degrees Celsius

When the contents of Metabolic energy, Crude protein and Ether extract increase, and neutral detergent fiber and acid detergent fiber decrease methane production decrease in high temperature.

b. Measurement of methane production of ruminant in Asia

The methane production from Brahman crossbred castrated cattle, Holstein crossbred heifers, Thailand native cattle, Thailand swamp Buffalo, Ongole crossbred young bulls, and Limousin crossbred young bulls in Southeast Asia were approximately 4.2-9.2% (MJCH_4/100MJ-Gross energy intake). Some of these values are higher than report of IPCC (6%:1996).

Table 2 Methane production of cattle in Thailand and Indonesia

	Brahman	Thailand native cattle	Holstein cross bred heifer	Tailand swamp buffalo	Ongole crossbred young bull	Limousin crossbred young bull
Body weight(kg)	411	166	375	430	78	91
Dry matter intake(kg/$BW^{0.75}$)	71.8	56.7	65	68	80.4	101.5
Dry matter digestbility(%)	58.8	57.1	55.3	54.2	-	-
Methane production						
g/day	121	40.8	110.3	88.1	46.9	66.2
g/Dry matter intake(kg)	18.4	15.5	20	13.6	22.8	22
%/Gross energy intake	5.7	4.8	6.2	4.2	9.2	8.7

c. Methane suppression technology of ruminant

(i)Additives

It was shown that CH_4 suppression effect of 10-30% with monensin and fumaric acid by *in vitro* studies.

(ii)By-product

The CH_4 production from Ongole crossbred young bulls could be reduced from 225 to 161 g-CH_4/kg-daily live weight gain by increasing concentrate feeding frequency.

The methane conversion rate of Holstein crossbred lactating cows fed on high concentrate diets in Thailand was 4.7 - 6.7 %(Mcal-CH4/100MJ-Gross energy intake). The methane production from swamp buffalos could be reduced from 443 to 295 g-CH4/kg-daily live weight gain by feeding soy-sauce by-product in Indonesia.

Twelve indigenous sheep were used to study the effect of rice bran supplementation on CH_4 production. The sheep were allocated into a completely randomized design with 3 treatments, namely RB0 (no supplementation), RB200 (rice bran 200g equaled to 1% body weight) and RB400 (rice bran 400g equaled to 2% body weight) .The sheep were fed Napier grass *ad libitum* as a basal diet. Rice bran increased the sheep productivity, and therefore rice bran produced fewer CH_4 production per unit product.

The CH_4 conversion rate (MJ0-CH4/100MJ-Gross energy intake) from Indonesia buffalo, Thailand Brahman crossbred castrated cattle were approximately 8-11, and beer cake and tofu cake could reduce CH_4 conversion rate. This study suggested that by-product (beer cake, tofu cake) could lead to a significant mitigation of CH_4 from ruminant.

Thailand Brahman crossbred castrated cattle were used to study the effect of coconut meal or palm kernel meal supplementation on CH_4 production. Coconut meal and palm kernel meal increased the cattle productivity, and therefore coconut meal and palm kernel meal produced fewer CH_4 per unit product.

These studies suggested that by-product could lead to a significant productivity and to a mitigation of CH_4 from sheep and cattle.

(iii) Polyphenol (tannin)

This study was carried out to study the effect of plant materials containing tannins on CH_4 production. six commercially available natural sources (plant) of tannins, which were available in the form of dry fine were procured. Samples containing both condensed tannin and hydrolysable tannin (HT) are more potent in this respect than those containing only HT. It is possible to reduce about 11% methane production of goat by addition of 2.5% of tannin to feed without decreasing digestibility.

d. Technologies for estimation of methane emission from ruminant.

CH_4 production in five diets estimated by SF6 (*in vivo*) method was compared with two in vitro techniques (RUSITEC and *in vitro* gas production method: IVGPT) for their potential to estimate the CH_4 production . It is recorded that the CH_4 production estimated by RUSITEC was lower as compared to that of SF6. It could be concluded that simplicity, low cost and high capacity of the IVGPT makes it ideal for estimating the CH_4 production in ruminant diets.

e. Estimation of methane production pf ruminant at a local level.

The CH_4 production from grazing goat and camel in Inner Mongolian were evaluated. The prediction model of the CH_4 production of grazing cashmere goats were estimated by equation between *in vitro* (X) and *in vivo* (Y) CH_4 production of the standard diets. *In vitro* CH_4 productions were measured by SF6 method were incubated in test bottle with rumen fluid collected thorough rumen fistula fitted to Cashmere goats.

$$Y \text{ (L/day: goat)} = 0.9311X + 13.966\text{、} (R^2=0.90)$$

It is estimated that the CH_4 production of grazing adult goats should be about 38.2 to 42.2 g/head/day, lamb goats should be about 10.48 to 19.7 g/head/day. According to the statistics year book (2005), It was estimated that CH_4 production in Inner Mongolia was 159400 to 267400 t/year in adult goats and 41000 to 77100 t/year in lamb goats.

The prediction model of the CH_4 production of grazing camel was estimated by formula. Five standard diets, which CH_4 productions were measured by SF_6 method, were incubated in test bottle with rumen fluid collected thorough rumen fistula fitted to Bactrian camel. A significant regression equation between *in vitro* (X) and *in vivo* (Y) CH_4 production of the standard diets was found;

$$Y \text{ (L/day: camel)} = 53.572X+12.311 \ (R^2=0.99)$$

The methane production of grazing Bactrian camels in varies growth phase was calculated and showed in the table 2. The CH_4 production in growing and grain-filling phase were significantly higher than that in maturing phase, because of dry matter intake was higher. The estimated the total amount of CH_4 production of the grazing mature Bactrian Camels was 137.7kg/year.

(2)-□ Development of regulation technologies and compilation of inventories for mitigating CH_4 and N_2O emissions from livestock waste management in Asian countries

Three research tasks were done for greenhouse gas control of the livestock manure management origin. The execution subject is as follows. : (a) Mitigation of the source materials of

GHG generating (C and N)by decrease discharge nitrogen and an organic matter per unit livestock (breeding improvement), (b) Mitigation during the manure treatment process by control of oxidization / reduction conditions in a reactor (manure processing control), (c) Mitigation at the application to the cropland as organic fertilizer by the pelletizing of chicken manure compost (pelletizing of a compost)

a. Breeding improvement

In the area of Mekong Delta in Vietnam, many pigs are breeding and the piggery conditions are considered as average in Asia. Thus, we made an investigation of pig farm conditions in this area. The results were as follows: the composition of pig diets was mainly with rice and rice bran. To supplement the essential amino acids, special concentrates, which was rich in protein, were used by many farmer. The scales of many piggeries were small and farmers were breeding only several to ten pigs. Feces and urine were discarded directly to the near pond, where fishes were breeding and they eat pig feces.

To conduct the nitrogen balance trial, GHG reduced diet was formulated with the similar composition based on that in Vietnam. The composition of GHG reduced diet was mainly rice bran. Nitrogen excretion in GHG reduced diet group was significantly lower than that of control, without no significant difference in nitrogen retention (Table 3).

Table 3 Nitrogen balance trial in pigs fed GHG reduced diet

	Control	GHG reduced diet
Initial body weight, kg	45.1±5.2	44.7±3.5
Feed intake, g/BW$^{0.75}$kg/d	107.5±6.4	109.0±1.8
Nitrogen balance, g/BW$^{0.75}$kg/d		
intake	3.02±0.18	2.63±0.04**
retention	1.07±0.11	1.01±0.13
excretion in feces	0.71±0.09	0.70±0.05
digestibility, %	75.8±2.0	73.7±1.8
excretion in urine	1.22±0.19	0.92±0.14*
total excretion in feces and urine	1.94±0.23	1.61±0.15*

Means±SD, n=6. *P<0.05, **P<0.01

In chick trial, new function of sugarcane extract (SCE) was examined. Diet was supplemented with SCE of0.25% or 0.5%. There were no significant differences in growth performance. However, nitrogen excretion ratio (excreted nitrogen/consumed nitrogen) was significantly lower in 0.5% of SCE group than in control group.

From overall the results, GHG reduced diet in pigs and SCE in chicks were considered for the effective techniques on GHG reduction.

Three corn-soybean meal based diets with different crude protein (CP) levels were formulated to investigate the effect of low-CP diets with amino acids on reducing nitrogen excretion. Pigs fed the 12.3% or 10.7% CP diet excreted less nitrogen in urine by 16 or 34 percentage units, respectively, than pigs fed the control diet with 14.4% CP. But pigs fed the both of low-CP diets retained less nitrogen than pigs fed the control diet.

Feeding trial was conducted to evaluate the effect of feeding molasses on the nitrogen excretion from the chicken. Body weight gain and retention of dry matter in the molasses group were tended to be higher than in control group. However, there was no significant difference in nitrogen excretion ratio (excreted N/intake N) between molasses and control groups.

The experiment in this year was conducted to confirm the previous results in which the nitrogen accumulation in pigs fed a low protein-amino acids supplemented diet was reduced, as well as the reduction of nitrogen excretion in urine. The results obtained here were similar with previous one, suggesting that the availability of free amino acids in diet was lower than that of amino acids derived from protein. This response was different from previous considerations in amino acid nutrition, although the mechanism underling is unknown.

Considering the previous results, the pig growth trial using the low protein-amino acids supplemented diets was conducted under the ad libitum feeding condition. Experimental groups contains three groups, one was conventional diet (control), second was low protein diet supplemented with amino acids, which was 100% of each requirement and third was low protein diet with 120% amino acids. The growth performance was not significantly different among the control and low protein diet groups (Table 4). Plasma urea nitrogen concentrations in low

Table 4 Growth performance of pigs fed low protein-amino acids supplemented diet

	Control （A）	low protein （B）	low protein （C）
CP content in diet (%)	12.7	10.4	10.4
Average weight gain (g/d)	1166±94	1096±128	1073±108
Average daily feed intake (g/d)	3976	3737	3616
Feed efficiency (gain/feed)	0.293	0.293	0.297
Plasma urea nitrogen (mg/100ml)	17.5±2.2a	12.3±2.4b	11.3±2.1b

n=8 in average weight gain, and n=2 in average daily feed intake and feed efficiency. a,b $P<0.01$. Ａ：Conventional diet、Ｂ：low protein-amino acids supplemented diet (100% of each requirement)、Ｃ：low protein-amino acids supplemented diet (120% of each requirement).

protein groups were significantly lower than in control group. Because of the high correlation between plasma urea nitrogen concentration and excreted urea nitrogen, it is suggested that excreted urea nitrogen in low protein diet groups was lower than in control group. However, average daily weight gains in low protein diet groups were slightly lower than in control group, although there were no significant differences.

Furthermore, some free essential amino acids concentrations in plasma except lysine were lower in low protein group compared with control. These results suggest that low protein-amino acids supplemented diet is a little lower nutritive value compared with conventional diet.

b. Manure processing control

Composting is a traditional treatment method

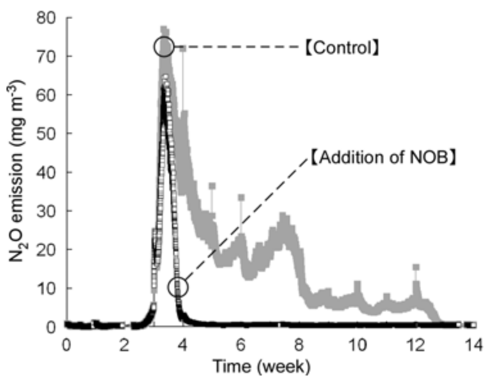

Fig. 7 Emission patterns of N_2O in the composting of swine feces.

changing odoriferous and unsanitary animal waste to odorless, sanitary and marketable organic fertilizer. However, the emission of harmful gases from composting of animal waste has been the cause of serious environmental problems such as complaints from residents around farms about odor, and destruction of the natural ecosystem by greenhouse gases (GHGs). N_2O emission from composting swine feces has a good correlation with nitrite (NO_2^-) accumulation in the composting material. We attempted to add nitrite-oxidizing bacteria (NOB) into the composting material for promoting NO_2^- oxidization. As the sauce of NOB for bioaugmentation, we used the mature swine feces compost containing NOB at 10^6 cell g^{-1}. After the thermophilic phase of swine feces composting, 10% (w/w) of mature compost was added. In the control (no addition), chronic NO_2^- accumulation derived from delayed growth of indigenous NOB guild was occurred. On the other hand, the addition of mature compost could prevent NO_2^- accumulation by promoting oxidation to nitrate (NO_3^-) (Fig. 7). Emission pattern of N_2O from the compost heap was similar to that of NO_2^- concentration in the material: therefore, N_2O emission was ceased rapidly in the treatment with mature compost addition. Emission rates of N_2O were 88.5 (control) and 17.5 (addition of mature compost) g N_2O-N kg^{-1} T-$N_{initial}$, respectively. Improving composition of nitrifying communities for complete nitrification promotion is useful to establish a composting method with low N_2O emission.

c. Pelletizing of a compost

The greenhouse gas which occurs in the case of the compost application to the cropland is important for greenhouse gas control from agriculture sector.GHG generated from the pelletized compost may be low. The regulation efficiency at the time of application by pelletizing manure were examined both a small scale and a field experiment. Result of observation using the experimental apparatus, when fertilized the pellet of chicken manure compost, N2O emission increased more than the cases to fertilize chicken manure compost (powder).

A field experiment was conducted to measuring the N_2O emissions from a cabbage-harvested field applied with the chicken manure compost. As a result, N_2O emission was greater from the pellet of chicken manure compost, compare to that of chicken manure compost (powder).

5. Discussion

The experiments for the effect of agricultural management, including rice cultivation, fertilizer, animal diet, and animal wastes, on mitigating the emissions of CH_4 and N_2O were conducted in cultivated lands and animal industry at various sites of Japan and other Asian countries. They determined the potentials of mitigation by each option. Some of the options, such as water management in paddy fields, application of slow-release fertilizers, improved diets and additives for livestock, were identified as promising options having large potentials for mitigating GHG emissions with relatively low cost. Therefore, there are large possibilities to be adopted in agriculture of different Asian countries and to make significant contribution to mitigating GHG emissions from agriculture.

Compilations of source databases and their analysis presented a number of new emission factors for global standard and country specific ones. Those values revise the previous ones or fill gaps of knowledge and can be utilized for revising GHG emission inventories in various countries. Actually the emission and scaling factors for CH_4 and N_2O emissions from rice cultivation have introduced in the revised 2006 IPCC Guidelines, and the emission factors for N_2O emissions from nitrogen input to crop lands and CH_4 and N_2O emissions from animal wastes treatment in the latest National Greenhouse Gas Inventory Report of Japan.

Further studies for crop lands and animal industry are expected to conduct additional field experiments to evaluate the effects of mitigation options at current sites and other sites in monsoon Asia. LCA and economical analysis are also expected to be incorporated. A compilation of the N_2O emission database and a through analysis of the data will be further promoted in order to understand the variability of the fluxes and to evaluate the effectiveness of mitigation options. Field data of soil emissions are used to validate and improve process based biogeochemical models for scaling-up. The DNDC model is being modified to adapt the processes in paddy soils and Andisols. Further networking amongst research communities for agricultural greenhouse gas emissions in monsoon Asia will be conducted with the object of launching a regional cooperative research program. Possible linkages to other regional and international programmes, such as IGBP-iLEAPS, -GLP, -IGAC, WCRP-GEWEX, ESSP-MAIRS are also expected.

Major Publications

1) H. Akiyama, K. Yagi and Yan, X.: Global Biogeochem. Cycle, 19, GB1005, doi:10.1029/2004GB002378 (2005) “Direct N_2O emissions from rice paddy fields: summary of available data”

2) X. Yan, K. Yagi, H. Akiyama and H. Akimoto: Global Change Biol., 11(7), 1311-1141 (2005) “Statistical analysis of the major variables controlling methane emission from rice fields”

3) Y.Fukumoto, K.Suzuki, T. Osada, K. Kuroda, D. Hanajima, T.Yasuda and K.Haga: Environ. Sci. Technol., 40(21), 6787-6791 (2006) “Reduction of nitrous oxide emission from pig manure composting by addition of nitrite-oxidizing bacteria”

4) S.D. Kimura, Z. Mu, Y. Toma and R. Hatano: R.: Soil Sci. Plant Nutr., 53, 373-386 (2007) “An Eco-Balance Analysis of Six Agricultural Land Uses in the Ikushunbetsu Watershed”

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7) Enishi, N. Takusari, K. Higuchi, I. Nonaka, M. Kurihara and F. Terada: Energy Protein Metabolism Nutr., 619-620 (2007) “Enteric methane emission of Japanese native goats”

8) Purnomoadi, F.Y. Devi, R. Adiwinari, E. Rianto, O. Enishi and M. Kurihara : Energy Protein Metabolism Nutr., 611-612 (2007) “Energy utilisation and methane conversion rate in Indonesian indigenous sheep fed Napier grass supplemented with pollard. Energy and protein

metabolism and nutrition"

9) T. Fumoto, K. Kobayashi, C. Li, K. Yagi and T. Hasegawa: Global Change Biol., 14, 382-402 (2008) "Revising a process-based biogeochemistry model (DNDC) to simulate methane emission from rice paddy fields under various residue management and fertilizer regimes"

10) A. Hadi, O. Jumadi, K. Inubushi and K. Yagi: Soil Sci. Plant Nutr., 54 (in press) "Mitigation options for N_2O emission from a corn field in Kalimantan, Indonesia: A case study"