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Contents

Preface to Symposium Papers on "Soil and Environment", 9th International Symposium on Integrated Field Sciences

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Sustainable food production is indispensable to meet the demand by the increasing human population on earth. Natural resources (soil, water, biodiversity, vegetation cover, renewable energy sources, climate, and ecosystem services) are fundamental capital in support of the food production. In other words, natural resource is environment. Our food production, agriculture, is blessed with the grace of environment.

However, the power of nature is far beyond the wisdom of human being. We realize this with 2011 Tohoku Earthquake followed by Tsunami. The tsunami seriously devastated not only the cities and villages but also a huge area of arable lands in the Pacific coastal areas of Tohoku region. The fertile arable soils were seriously devastated with saline water, thick mud deposition and so on.

Furthermore, the critical damage of Fukushima Daiichi nuclear power plant by the tsunami resulted in severe radiation leaks which extensively contaminated the environment. As a result, agriculture depending on the environment is also in danger of radioactive contamination. Nuclear power station has been believed to be one of the countermeasures against global warming, because CO_2 emission derived from nuclear power plant is lower than that from thermal power plants using fossil fuels. Global warming is the one of the most urgent environment issues. It is ironical that the nuclear power plant which was expected to contribute to mitigation of CO_2 emission deteriorated the environment, which is a basis for food production as well as life in this region.

Global warming is also the important issue in agriculture sector. Climate change due to global warming affects agriculture and may result in danger of food security. However, it should be noted that the relationship between climate change and agriculture (crops, livestock and forestry) is not a one-way street. Agriculture contributes to climate change in several major ways including emission of green house gasses (GHG) through land conversion, deforestation, use of fossil fuels for machinery and agro-chemicals, CH_4 from rice fields, N_2O from nitrogen fertilization, and so on.

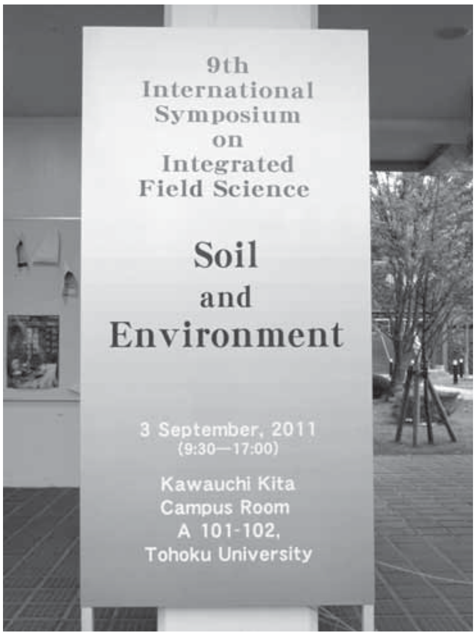
We, Field Science Center of Tohoku University, hold the international symposium for "Integrated Field Sciences" every year. In 2011 we had planned to organize the symposium which shed light on the relationship between soil and environment in terms of global warming. However, we are now in the face of the disaster by earthquake, tsunami and radioactive contamination. Therefore, we changed the program of the 9th symposium to discuss the current urgent issues under the conditions as stated above.

In the first part of symposium "Environmental Disaster caused by Earthquake", the problems in terms of Tsunami affected soil and the Fukushima nuclear power accident were discussed. In the second part of the symposium "Nitrogen, Green House Gasses and Agriculture -Global Warming and Soil-", the environmental issues caused by agricultural activities, such as water pollution with nitrogen and GHG emission, were discussed. In the poster session of the symposium, various papers relating to agro-environmental issues were presented.

The Symposium was held on 3 September, 2011, at the Kawauchi-Kita Campus, Tohoku University. On 4 September, to observe the damage by Tsunami, the field tour to the coastal arable area in Sendai city was conducted. Representative presentations are now included in this issue of Journal of Integrated Field Science. Abstracts of all papers including poster presentations are also included in this issue.

I hope that various scientific works presented in this issue will contribute to finding solutions for these agro-environmental problems not only in the region affected by the Tsunami and the Nuclear Power accident but globally as well.

Finally, I would like to express our sincere thanks for the following agencies to support the symposium: Strategic Japanese-Chinese Cooperative Program "Comparative study of nitrogen cycling and its impact on water quality in agricultural watersheds in Japan and China" (JST-NSFC), Tohoku University Global COE "Ecosystem Adaptability", National Institute for Agro-Environmental Sciences, and Project of Integrated Compost Science (PICS) of Tohoku University.



Impacts of Tsunami (March 11, 2011) on Paddy Field Soils in Miyagi Prefecture, Japan

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Keywords: Tsunami, paddy field, water-soluble cations, halite, gypsum

Abstract

A strong earthquake hit eastern Japan on March 11th, 2011. It triggered a huge tsunami that damaged not only houses, but also farmlands. There are several types of interactions between the tsunami and the farmlands. If there was a muddy (sometimes contains sulfidic materials) and/or sandy deposit under the shallow seawater or in the nearshore zone, it was transported inland. There are narrowly eroded places along a road and a ridge where the tsunami dropped from these micro-high sites. Moreover, the A_p horizon soil was at least partly lost. Thus, the deposits on the farmlands are mixtures of the eroded A_p horizon soil and transported materials from the nearshore zone. The chemical interactions include the exchange reaction between the Na^+ in the seawater and exchangeable cations in the A_p horizon soil, and precipitation of gypsum ($CaSO_4 \cdot 2H_2O$) as well as halite (NaCl) when the soils dry. The debris of at least various materials and halite must be removed to restore the damaged farmlands.

Introduction

A 9.0 magnitude earthquake hit eastern Japan on March 11th, 2011. It triggered a huge tsunami, and the farmland areas damaged by the tsunami are summarized in Table 1. The Miyagi prefecture was very extensively damaged. The tsunami penetrated up to several kilometers inland from the Miyagi prefecture coastline. The damaged farmlands were mainly the paddy fields (Table 1).

One paddy field soil was sampled at Arahama on March 25th, 2011, two weeks after the tsunami event. The soil survey and analytical data are presented focusing on the impact of the tsunami on the paddy field soil. A wide area covering almost all the farmlands on the Pacific coast of the Miyagi Prefecture was then surveyed from May 11th to 19th, 2011. The preliminary summary of these surveys is described. Results of survey by the UNESCO-IOC team are

Table 1. Estimated area damaged by Tsunami (March 11th, 2011).

Prefecture	Farmland (2010) ha	Area damaged by Tsunami			
		ha	%	Paddy field ha	Upland ha
Aomori	156,800	79	0.1	76	3
Iwate	153,900	1.838	1.2	1,172	666
Miyagi	136,300	15,002	11.0	12,685	2,317
Fukushima	149,900	5,923	4.0	5,588	335
Ibaraki	175,200	531	0.3	525	6
Chiba	128,800	227	0.2	105	122
Total	900,900	23,600	2.6	20,151	3,449

Ministry of Agriculture, Forestry and Fishery (March, 2011) available on the internet (Sugawara et al., 2011). This area has been repeatedly hit by a huge tsunami according to geological records (Minoura et al., 2001; Sawai et al., 2006).

Materials and methods

One point survey on March 25th, 2011

A study site was set up at Ipponsugi-Minami 49-50, Arahama, Wakabayashi-ku, Sendai, Miyagi Prefecture, Japan. After examining several points, a micro pedon was sampled from a paddy rice field on a roadside because rice stubbles were present which allowed us to identify the position of the original plow layer soil (Fig. 1). Five soil horizons were collected including a thin, newly-introduced layer on the soil surface. After determining the water content of each sample, a 1:5 water suspension (the weight of pure water was adjusted to be 5 times the oven-dried weight of each soil sample) of the field-moist soil sample was obtained to determine the electric conductivity (EC). A Horiba ES-12 conductivity meter was used to determine the EC of the soil suspension with temperature compensation to 25 degrees C. After centrifugation of the soil suspension and filtration, transparent water extracts were obtained. The precipitates were extracted twice with 1 M ammonium acetate ($AcONH_4$) to determine the exchangeable cations (Thomas, 1982). The amounts of entrapped solution after removal of the supernatant solution were calculated by subtracting the dry weight of the centrifuge tube and soil sample from the total weight before the addition of 1M $AcONH_4$. The concentrations of Na, K, Mg and Ca in the water extracts and the 1M $AcONH_4$ extracts were determined using a Hitachi A-2000 atomic absorption spectrophotometer. Using air-dried fine-earth fraction, the plant-available phosphorus (P) was determined by the Truog method (Truog, 1930). The pH(H_2O) values were determined at soil: water = 1:2.5 using the Horiba glass electrode.

From the air-dried fine earth fraction, the fraction of less than 0.05 mm (<0.05 mm) was separated from the 0-2 cm (tsunami deposit) and 9-13 cm (the lower plow layer soil) samples to determine the presence of evaporites. Using the air-dried samples, X-ray diffractograms were obtained by a Rigaku Miniflex (CuKα, 40kV, 15mA). For further examination of the evaporites, the surfaces of the mineral particles were observed using a scanning electron microscope (SEM, Hitachi SU8000) operated at 15 kV and energy dispersive X-ray analysis (EDX, EDAX Apollo 10). The mineral particles were fixed on a sample stage using a piece of double-sided sticky tape and then coated by evaporated carbon.

Survey over a wide area in Miyagi Prefecture (May 11th – 19th, 2011)

One to three fields of farmlands were selected from each 1 km^2 mesh in the tsunami-affected areas of the Miyagi Prefecture, Japan. Two micro pedons to the depth of about 30 cm were sampled in each field. Regarding the tsunami deposit, a mud layer and a sand layer (more than one set at a few sites) were separated if the thickness was 1 cm or more. The original soil layers were collected at the depth of 0 – 10 and 10 –

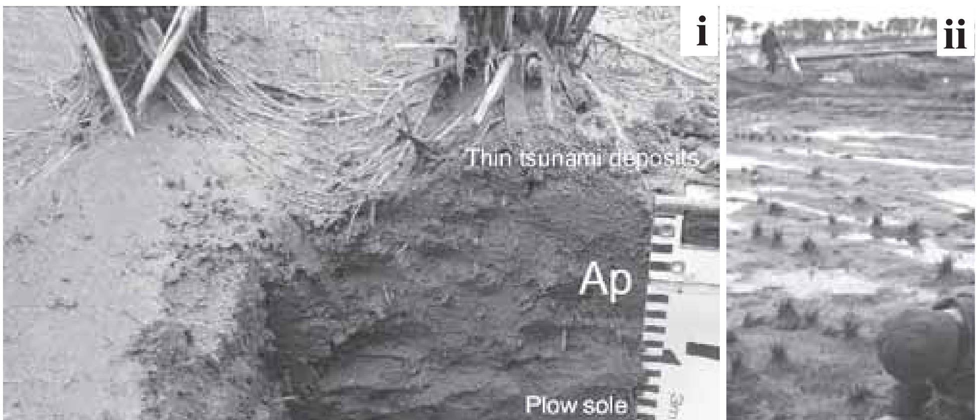


Fig. 1. Soil profile of micro pedon (i) and tsunami-affected paddy field (ii).

20 cm from the boundary between the tsunami deposit and the soil layer. Each corresponding layer from two micro pedons in one field was mixed to make a composite sample for the field. Regarding the mud and sand layers, the thickness of each layer, the EC values of soil:water = 1:5 suspension and pH(H_2O_2) values were obtained. To determine the pH(H_2O_2) values, the field moist soil equivalent to 2 g of oven-dried weight was treated with 20 mL of H_2O_2 solution in a hot water bath. After finishing vigorous bubbling, the pH value was measured at the soil: solution ratio = 1:10.

Results and discussion

One point survey on March 25th, 2011

Morphological properties

Fig. 1-i and Fig. 1-ii show the soil profile and the study site of the micro pedon, respectively. The study site was located 800 m from the seashore, and at the far end there were trees planted to protect against the tide. The sampling date was two weeks after the tsunami and there were puddles on the soil surface showing poor drainage of this site. Rice stubbles were present and the position of the Ap horizon soil was identified although the upper part of the rice roots was exposed suggesting that a few cm of the Ap horizon soil was carried away by the tsunami. In place of the lost thin soil, there were very thin (2 to 3 mm) mud on the top and a thin (2 cm) sand deposit below the very thin mud. The 2 – 4 cm layer was not sampled to avoid collapsing the loose tsunami deposit layer and mixing with the original soil. The Ap horizon was divided into two parts to examine the depth of the salt intrusion. No evident cracks were found in the soil profile. The plow sole having a firm consistency showed a readily positive reaction to the α, α'-dipyridyl testing solution showing the presence of ferrous iron. Thus, the downward movement of air and water is very slow suggesting that the seawater only slightly reached the deep horizons at this time.

Properties of the soil regarding the impact of the tsunami

The salt concentration was much higher in the 1:5 water extract of the tsunami deposit than those for the underlying horizons (Table 2). However, the impacts of the tsunami only slihgtly reached the deep horizons at this time (Table 2) as suggested from the morphological properties of the micro pedon. Such properties are shown in the vertical distribution of the EC(1:5) values and cation concentrations in the 1:5 water extract of the soil. The EC(1:5) values, and Na, K and Mg concentrations in the 1:5 water extract significantly decreased in the original soil horizons from the depth of 4 cm or deeper. The decreases in the EC(1:5) values and cation concentrations from the depth of 4 cm to that of 25 cm was rather gradual suggesting the weak intrusion of seawater.

The concentrations of the cations in the liquid phase of the tsunami deposit (0-2 cm) were not very different from that of the seawater. The concentrations of the major cations and the EC value of the mean seawater is shown in the bottom of Table 2 for reference (Stumm and Morgan, 1996). The ratios of the Na, K, Ca and Mg concentrations and the EC(1:5) value in the 1:5 water extract of the tsunami deposit are 0.091, 0.12, 0.16, 0.076, and 0.13, respectively. These values are around 0.104 that is the ratio of the weight of water in the field-moist tsunami deposit to the 1:5 water extract because the water content (the

Table 2. EC and cation concentrations in 1:5 water extract of soils.

Depth	EC(1:5)	Na	K	Ca	Mg	(Notes)
cm	dS m^{-1}	------------ mg L^{-1} -----------				
0-2	5.7	1000	46	67	99	Tsunami deposit, sand, loose. Overlain by very thin mud.
4-9*	0.67	100	3.5	28	6.5	Upper Ap horizon, sandy loam, many rice roots.
9-13	0.20	22	1.2	10	2.4	Lower Ap horizon, sandy loam, many rice roots.
13-17	0.094	7.8	0.90	6.6	1.5	Plow sole, dark olive gray, loamy sand, firm.
17-25	0.042	4.6	0.65	3.4	0.95	Subsoil, sandy loam.
Sea water	43	11000	400	410	1300	Average values for reference.

* The 2 – 4 cm layer was not sampled.

ratio of weight of water / weight of oven-dry soil) of the tsunami deposit and the 1:5 water extract are 0.52 (Table 3) and 5, respectively, and the value of 0.104 is obtained by 0.52/5. In general, the EC value of a diluted electrolyte is slightly higher than that calculated from the dilution factor.

The ratio of the Ca concentration in the 1:5 water extract of the tsunami deposit to that in the mean seawater is higher than the other cations calculated above. It is probable that Ca was partly released from the farmland soils through an exchange reaction with Na from the tsunami including the backwash process.

The impacts of the tsunami were also found in the exchangeable cations of the tsunami deposit (0-2 cm) and the original soil to a lesser extent (Table 3). These are the high values for the exchangeable Na, K and Mg and a low value for the exchangeable Ca in the tsunami deposit. An increase in the exchangeable Na and a decrease in the exchangeable Ca were found in the upper Ap horizon soil (4-9 cm). The ratio of charge calculated as Na/Σcation is 0.14 or less for this micro pedon. This charge ratio is slightly less than the exchangeable sodium percentage (ESP) calculated using the cation exchange capacity for the denominator. The ratios (Table 3) are less than the ESP value of 0.15 or more where physical soil degradation such as clay dispersion when wet, crust formation when dry, etc., becomes evident (Levy, 2000).

Agus et al. (2011) reported that the content of the plant-available phosphorus was abundant in the deposit from the Indian Ocean Tsunami in Ache, Indonesia. The Truog P value of the tsunami deposit (0-2 cm) was about one-half that of the Ap horizon soils (Table 3). However, this value is not very low considering that this tsunami deposit is sand-rich as will be discussed below.

Evaporites and other minerals in the tsunami deposit

The presence of halite (NaCl) was evident in the XRD pattern (Fig. 2i) of the <0.05 mm fraction from

Table 3. Selected properties of soil.

Depth	$pH(H_2O)$	Water content	1M ammonium acetate-extractable				Na ratio*	Truog extraction
			Na	K	Ca	Mg		
cm			-------- $cmol(+)\ kg^{-1}$--------					$mgP_2O_5\ kg^{-1}$
0-2	6.8	0.52	0.7	0.4	1.9	1.9	0.14	140
4-9	4.9	0.40	0.5	0.1	3.2	0.8	0.10	350
9-13	5.4	0.36	0.3	0.1	3.7	0.9	0.06	290
13-17	5.7	0.28	0.2	0.1	4.0	0.9	0.04	240
17-25	7.1	0.27	0.2	0.2	5.2	1.4	0.04	200

* The ratio of charge calculated as Na/Σcation.

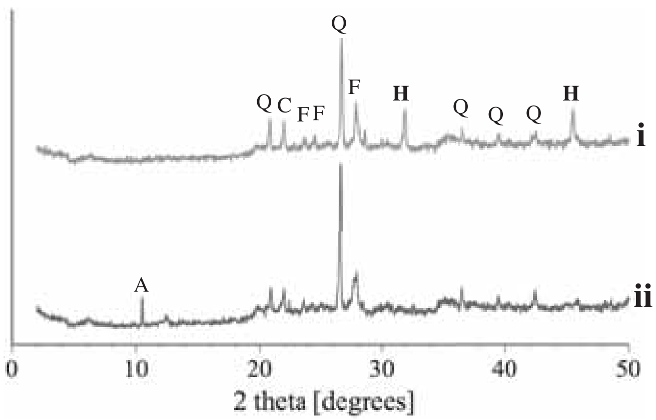


Fig. 2. X-ray diffactograms of the 0.05 mm or less fraction of the tsunami deposit (0-2 cm) (i) and that of the lower Ap horizon (9-13 cm) (ii). Q: quartz, C: cristobalite, F: feldspar, H: halite, and A: amphible.

the tsunami deposit. The content of the <0.05 mm fraction was 2% on an air-dry basis. Although significant XRD peaks from the halite were also detected in the >0.05 mm fraction (98%) after grinding, the intensity of the peaks were weak. The other major XRD peaks were from quartz, feldspar and cristobalite.

For comparison, the XRD pattern of the <0.05 mm fraction (14% on an air-dry basis) of the lower Ap horizon (9 – 13 cm) is shown in Fig. 2ii. The XRD peaks from halite were not evident while those from quartz, feldspar, cristobalite and also amphibole were present.

SEM observation of mineral surfaces

From the coarse sand particles of the tsunami deposit, quartz, feldspar and mica particles were observed using SEM and EDX. The presence of evaporites appeared more on mica particles than on the quartz and feldspar particles. An example of the mica surface is shown in Fig. 3.

Halite crystals tended to be present on the near-edge site of the mica particles (Fig. 3). Although the cubic shape is not very strong, halite crystals are evident from the element maps for Na and Cl (Fig. 3-ii and -iii) and the selected area analysis of Fig. 3-i-a and Fig. 3-iv-a.

On the surface of the mica particle, a gypsum particle was also found (Fig. 3-i-b, Fig. 3-iv-b). Although gypsum was not evident in the XRD pattern, the concentration of water-soluble Ca was relatively high in the 1:5 water extract of the tsunami deposit (Table 2). The SO_4 concentration in the average seawater is 2.71 g L^{-1} (28.2 mmol L^{-1}, Stumm and Morgan, 1996) and it can be postulated to be same in the field-moist tsunami deposit. On the other hand, the Ca concentration in the liquid phase of the field-moist tsunami deposit was calculated to be 0.64 g L^{-1} from Table 2. As dissolution of gypsum in water is 0.2 % at 25 degrees C, gypsum can precipitate in the field-moist tsunami deposit.

An apatite particle was found as an inclusion in the mica particle (Figs. 3-i-c, iv-c). The origin of this apatite appears to be the same as in the mica particle, possibly from an igneous origin. The Truog P value of the tsunami deposit was relatively high (Table 3) considering its sand-rich texture. As apatite is soluble in the Truog extracting solution (Nanzyo et al., 1997), apatite may be one of the reasons for the relatively high Truog P value.

The mica particle shown in Fig. 3-i appears to be the tri-octahedral type based on the EDX spectrum (Fig. 3-iv-d) that is rich in Mg and Fe. The K content appears low suggesting partial weathering.

Survey over a wide area in Miyagi Prefecture (May 11th – 19th, 2011)

This survey contributed to evaluating the total damages to the farmland soils of the Miyagi Prefecture by

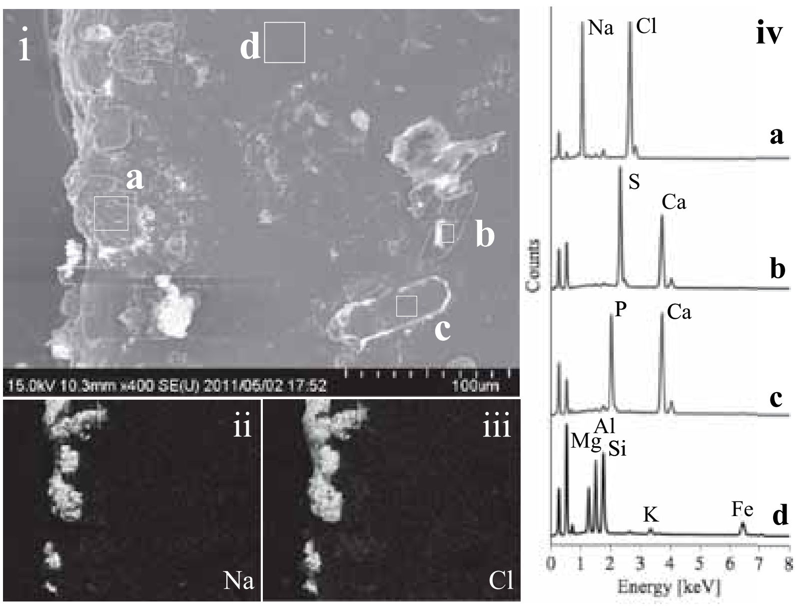


Fig. 3. SEM image of a mica particle found in the tsunami deposit (0-2 cm) (i), element maps for Na (ii) anad Cl (iii), and selected area (a, b, c and d in Fig. 3-i) analyses by EDX (iv).

the tsunami. The intensity of the damage was different from place to place. Removal of the Ap horizon soil, especially from the tilled farmlands, was more serious in the coastal area. If a paddy field is untilled like the example described above, severe water erosion was limited to the narrow area next to the micro-high places like roads or ridges. Various amounts of mud and/or sand were transported by the tsunami and deposited on the farmlands.

The properties of the tsunami deposit were announced by the researchers of the Miyagi Prefecture on July 21st, 2011. A part of the announcement is cited in Table 4.

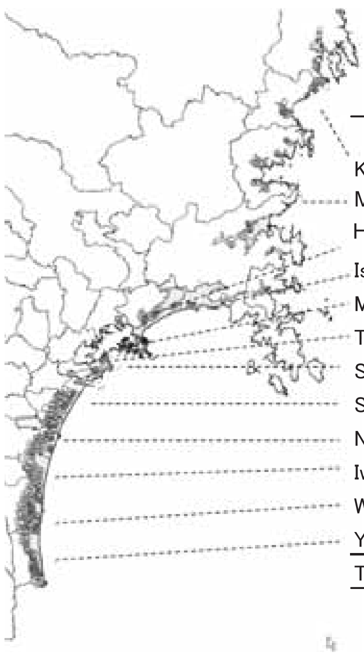
The frequency of the mud or sand layer having a thickness of 1 cm or more is not different between the northern and southern parts of the prefecture. The frequency of the low pH(H_2O_2) value of 3 or less appears higher in the southern part of the prefecture than in the northern part. Furthermore, the frequency of the low pH(H_2O_2) value of 3 or less is higher in the mud layer than the sand layer. The low pH(H_2O_2) value suggests a significant amount of sulfidic materials that may originate from the sediments under anoxic conditions. The EC(1:5) values of the mud layers tended to be higher than those of the sand layers. Harmful elements were not problematic in the tsunami deposit except only one site.

Other additional data such as the concentrations of the total-carbon, -nitrogen and -sulfur, water-soluble ions, and exchangeable cations will be reported elsewhere (Shima et al., 2012). It is probable that the reactions between the seawater and farmland soils widely took place.

Summary of overall impacts of the tsunami on farmlands

There are several types of interactions between the tsunami and the farmlands other than only scattering debris. They are erosion at the ①, ②, ③ sites and deposition on the farmlands (④, ⑤) as physical interactions, and also, ion exchange and precipitation reactions (④, ⑤, Fig. 4) as chemical interactions. If there was a muddy (sometimes contains sulfides) and/or sandy deposit under the shallow seawater or in the nearshore zone including the Teizan canal (①), they might be transported to the farmlands and deposited (④, ⑤). There are also small eroded sites at the ② and ③ sites where the tsunami dropped from the micro-high sites like roads or ridges. Moreover, the A_p horizon soil after tilling was at least partly lost. Thus, the deposits on the farmlands also contain the eroded A_p horizon soil. The chemical reactions of ④ and ⑤ include the exchange reaction between Na^+ in the seawater and exchangeable Ca^{2+} in the A_p horizon soil, and precipitation of $CaSO_4{\cdot}2H_2O$ as well as NaCl when the soils dry.

Table 4. Properties of Tsunami deposits in Miyagi Prefecture.



		Mud layer			Sand layer		
	Sample	1 cm or thicker	pH (H_2O_2) of 3 or less	Mean EC	1 cm or thicker	pH (H_2O_2) of 3 or less	Mean EC
	No. of sites			dS/m	No. of sites		dS/m
Kesennuma	23	10	0	4.5	13	0	2.1
Minamisanriku	15	7	0	0.8	11	0	0.5
Higashimatsushima	12	9	0	19.9	10	0	3.5
Ishinomaki	11	7	0	8.9	3	0	6.6
Matsushima	3	3	3	31.1	0	–	–
Tagajou	6	1	0	8.2	1	0	2.0
Shichigahama	5	5	0	29.7	5	0	5.3
Sendai	61	34	17	9.4	34	0	1.8
Natori	50	22	13	11.7	16	4	3.4
Iwanuma	31	17	3	14.3	16	1	5.0
Watari	88	39	16	15.9	32	2	3.6
Yamamoto	39	28	9	14.3	28	1	2.1
Total	344	182	61	av. 13.0	169	8	av.3.0

(Miyagi Pref.-Sendai City-Tohoku Univ.)

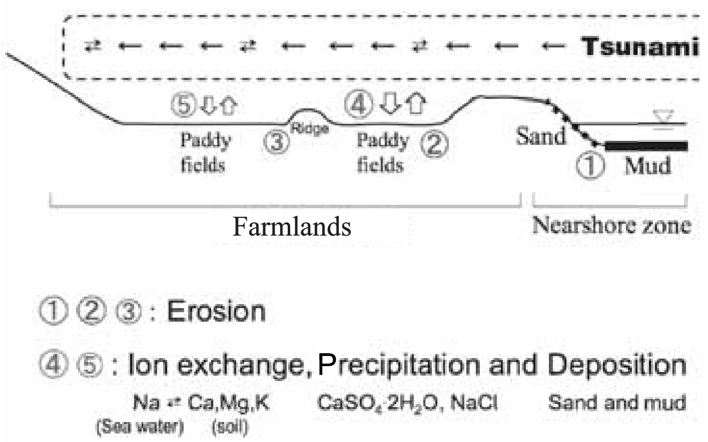


Fig. 4. Schematic diagram of interactions between Tsunami and farmlands.

Rehabiliation of damaged farmlands

The most important countermeasures are to remove the debris of destroyed houses, fallen trees, etc., and halite. Procedures to remove halite from the farmland soils are provided by the Ministry of Agriculture, Fishery and Forestry, Japan (June, 2011). They are expected to be successful. There are many other studies related to salt-affected farmlands by flood tide or tsunami and rehabilitation (Nakada, 2011; Nakaya et al., 2010; Agus and Tinning, 2008; Kida, et al., 2007a, b; Kumamoto Prefectural Agricultural Research Center, 2001). A drainage system including underground drainage plays an important role in removing the halite. Japan has a humid climate and a drainage system and rainwater may be sufficient for well-drained soils if they can have enough time. The ground has sunk by several tens of centimeters along the coastal areas due to the earthquake. For these areas, dikes, drainage and pumping system should be restored as soon as possible. The use of enough irrigation water will quicken the removal of the halite.

Acknowledgements

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The Dynamics of Tsunami Affected Soil Properties in Aceh, Indonesia

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Abstract

Understanding the dynamics of tsunami-affected soil properties is a key for reconstructing the local agriculture after tsunami events. We conducted a series of soil research after the 26 December 2004 Indian Ocean tsunami in the coastal areas of Nanggroe Aceh Darussalam (NAD) Province, Indonesia. The objectives of the study were to evaluate (i) the extent and types of soil damages, (ii) soil profiles of the affected area, (iii) changes in soil properties over time, and (iv) crop response. Survey of the extent and severity of soil damages was conducted from January 2005 to the end of 2007. Four soil profiles were evaluated in May 2005 and August 2007 in Aceh Besar District. Changes in soil salinity were evaluated at several monitoring sites using the electric conductivity (EC) meter based on soil samples and in the field using an electromagnetic induction soil conductivity instrument (EM38) from mid 2005 to the end of 2007. The tsunami waves affected the coastal areas up to 5 km inland. The damages ranged from permanent inundation, tsunami mud/sand deposition, surface crusting and soil salinity. Salinity level of up to 84 dS m^{-1} was measured a few weeks after the tsunami, but it decreased to <4 dS m^{-1} by October 2007 except in areas where lateral/vertical drainage is restricted. Soil pH, organic carbon content, exchangeable cations and total phosphorus were higher in the tsunami formed 'O' horizon than in the underlying layers. Yields of rice and dryland crops were lower in the first few seasons after the tsunami and empty pods of peanut and unfilled grain of rice were commonly observed. This could be attributed to either or combination of salinity, sodicity, cation imbalance and low micro nutrient availability. The tsunami effects were very variable and therefore management needs to be site-specific to be effective. In general, reconstruction of irrigation and drainage systems and application of organic matter speeded up the soil recovery.

Introduction

The earthquake of 9.1-9.3 of Richter scale that occurred southwest of Banda Aceh on Sunday 26 December 2004 was the third largest since 1900. It generated a large tsunami that killed 230,000 people on Indian Ocean coastlines, making it the worst tsunami in history in terms of lives lost. It devastated crops, buildings and infrastructure in low lying coastal areas around the Indian Ocean.

The forces of the waves and the mud brought by the waves changed the soil profile and nutrient balance in the upper soil layer. The affected land underwent either one or combination of the following problems: deposition of mud, silt, sand or coarser materials; increase in soil and water salinity; and desurfacing and compaction of topsoil (Hulugalle et al. 2009; Rachman et al., 2008a; McLeod et al. 2010; Slavich et al., 2008). The waves were up to 14.1 m height and devastated buildings, especially the simple constructed ones (Leone et al., 2011). Shofiyati et al., (2005), based on their estimation using Landsat ETM images, reported that the total area in Aceh flooded by the seawater was 120.295 ha.

The waves was higher on the west coast, facing the Indian Ocean epicenter and swept several kilometres inland, reducing the population of some villages by up to 80%. On the east coast of Aceh the wave heights varied from 2-6 m, population losses were generally lower (15-20%) and infrastructure damage was less. The erosive forces of the tsunami opened estuaries, transferred beach sands and coastal acid sulphate soils inland and reshaped wetlands. The tsunami also deposited sediments from the sea floor on the land. These transported terrestrial and marine deposits blocked drainage and irrigation systems. The impacts were most severe in low lands closest to the sea where landscape changes were greatest (Slavich et al., 2008).

Farming, one of the most important livelihoods of the people in the affected areas was practically stopped due to the failures of all enabling conditions. For several months to more than a year the local people's food supplies depended on food aids from other provinces as well as from national and international, government and non-government donations. In order to assist the local people in restarting agriculture, a series of soil related survey and research were conducted with the aim of (i) understanding the extent and level of damage on the soil, ii) evaluating soil profile of the affected area, (iii) understanding the temporal changes of soil properties, and (iv) evaluating crop responses to the problems.

MATERIALS AND METHODS

There were a few units of activities conducted in the West and East Coast of Aceh Province from 2005 to 2007, consisting of survey, evaluation of soil profile and construction of soil monolith, monitoring of soil salinity and evaluating crop responses.

Survey of extent and levels of damage

Initial measurement of soil salinity was conducted four weeks after the tsunami (January 2005) in Aceh Besar District. Soil salinity was measured using an Electric Conductivity (EC) meter using a 1:5 soil: water suspension at the soil laboratory of Indonesian Soil Research Institute in Bogor, Indonesia. EC 1:5 was then converted to effective EC (EC_e) using the conversion factor based on soil texture (Slavich and Peterson, 1990). The factor of 8.6 for soils with 30 –45% clay content was used as this represents the dominant soil in Aceh's lowland agriculture areas (McLeod et al., 2010; FAO, 2005).

A survey of the soil damage, covering the subject of inundation, salinity and mud accumulation was conducted in the districts of Banda Aceh, Aceh Besar, Aceh Jaya and Aceh Barat in the west coast of Nanggroe Aceh Darussalam (NAD) Province in May 2005. The damaged areas were assessed by comparing satellite images before and after the tsunami. Field survey was conducted on areas representing different levels of damages and different land use types as reflected by the satellite images, taking into account accessibility. The observations included thickness of mud and sand, the piling of debris, water table (including the level of inundation), soil texture, salinity (electric conductivity, EC), and soil pH. Classes of damage used the criteria as in Table 1.

Table 1. Class of damage of tsunami affected soil (Wahyunto dan Widagdo, 2005).

Class	Soil condition				Land condition	
	Decapping	Mud accumulation	Infiltration /texture*)	Salinity (EC) (ds/m)	Debris accumulation	Inundation
1. Light	*top soil* >10 cm	< 10 cm	Rapid, coarse	Low, < 2	Low <25%	None
2. Moderate	Top soil 5-10 cm	10 – 20 cm	Medium	Medium, 2 – < 4	Medium 25-50%	Drainable
3. Serious	Top soil <5 cm	>20 cm	Low, fine to very fine texture	High, 4 – 8 Very high >8	High >50	Seriously inundated
4. Inundated	Permanently inundated					

Soil profile properties

We described four soil profiles in May 2005 (five months after the tsunami) in Aceh Besar District, NAD Province. One of the pit (NAD 3) represented unaffected, while the other three (NAD 1, NAD 2, and NAD 4) represented the affected areas. In August 2007 (32 months after the tsunami) soil samples were taken with soil auger within 10 m distance from the initial profiles NAD 1, NAD 2, and NAD 4 using a soil auger at depth increments in accordance with the soil horizon depths. The site description of the four soil pits is provided in Agus et al. (2008). Soil properties evaluated included texture (pipette technique), pH (glass electrode), organic carbon (Walkley and Black), HCl 25% extractable phosphorous, exchangeable (and soluble) cations and cation exchange capacity (1M Ammonium acetate).

Dynamics of soil properties

Twenty permanent monitoring sites were established at selected areas to evaluate the changes in salinity and other soil properties. Soil samplings for laboratory analyses were collected in Sep. 2005, Nov. 2005, Jun. 2006, and Oct. 2007 from each site at 20 cm depth increment to 100 cm. The soil analyses included texture, pH (glass electrode), $EC_{1:5}$, organic C (Walkley and Black), and exchangeable cations and (1M Ammonium acetate). In line with the 20 plot monitoring using EC meter, twenty-three monitoring sites within 5 km of the east coast were selected across Aceh Besar, Banda Aceh, Pidie, and Bireuen districts for apparent EC_a measurement using electromagnetic induction soil conductivity instrument (EM38) (Slavich and Petterson, 1990). The ECa values were converted to EC_e using a linear relationship (McLeod et al., 2010). Most of the assessment sites were bunded lowland irrigated and rainfed rice fields (sawah), and some were more elevated and used for vegetables crops. In each site, 1–3 fixed transects of up to 100 m each were selected based on visual assessment of crop performance (poor, medium, and good) during the initial survey in August 2005 making a total of 38 transects across the 23 sites. The number of sites was reduced to 22 in January 2007 because one site was converted to housing. In December 2007 only 10 sites, where high salinity levels remained were measured.

Rainfall distribution in the study area is bi-modal with the annual average for Aceh Besar, Pidie, and Bireuen districts of 1668, 1889 and 1613 mm, respectively. The cumulative rainfall from 2005 to 2007 for these districts was 5205, 7779 and 7214 mm, respectively (McLeod et al., 2010).

Crop Response Soil Remediation

Evaluation of crop response included unstructured interview with the local stakeholders, visual observation and review of reports in the affected areas.

Results and Discussion

Extent and kinds of damages

The thickness of the mud in January 2005 observed in Aceh Besar area varied from 1 to 25 cm (Table 2) and in some pockets it was a few times deeper. These materials had grey to light green color, had a high clay content (mostly >40%), medium to high organic carbon (3 – 4%, except for Tanjung site), high 25% HCl extractable (potential phosphate) (300 – 1420 mg kg^{-1}) and available (Olsen) phosphate (>27 mg P kg^{-1}), high 25% HCl extractable potassium (200 – 2560 mg/kg), and high exchangeable Ca, Mg, K, and Na. The EC_e ranged from 20 in Mire to 84 dS m^{-1} in Keneuneu, Aceh Besar District. These mud characteristics reflected a potential for nutrient enrichment into the soil, despite the extremely high salinity and sodicity. The high sodium concentration caused soil dispersion and enhanced surface sealing and crusting as well as clogging of soil pores as clay particles leached down the profile during rainfall (Emerson and Bakker, 1973). Surface sealing and crusting which could be visualized every where in the mud deposited areas can cause a wide range of problems, such as delayed crop emergence due to lack of oxygen and surface hardness, waterlogging, increased runoff, and reduced microbial activities.

Example of the map of Aceh Barat District, showing the level of damage, is in Fig. 1. Salinity problem extended to 4 km and in Aceh Besar District (not shown) to 6 km inland. This seems to be depended on the topography and presence of river channeling the water and the direction of the waves (Leone, 2011). Mud and sand accumulation was found along some parts of the coast and further inland in the flood plains. Thin, permanently inundated areas, stretched near the beaches.

Table 2. Characteristics of deposited mud measured in Aceh Besar District, January 2005.

Soil properties	Sites				
	Lamcot	Keneuneu	Lampineung	Tanjung	Mire
Thickness (cm)	10-20	15-25	15-25	2-5	2-5
Sand (%)	53	26	12	47	6
Clay (%)	8	43	42	25	42
ECe (dS m^{-1})	60.9	84.2	80.1	38.9	19.8
Salt (mg kg^{-1})	31,280	46,268	44,116	20,140	9,804
pH_{H2O}	7.4	7.8	7.7	7.7	8.1
Organic C (%)	2.9	4.1	2.3	1.0	2.8
$P_2O_{5(HCl\ 25\%)}$ (mg kg^{-1})	520	550	930	300	1420
$K_2O_{(HCl\ 25\%)}$ (mg kg^{-1})	300	1330	2560	730	2470
$P_2O_{5(Olsen)}$ (mg kg^{-1})	64	60	48	27	115
Ca (cmol(+)kg^{-1})	24.7	20.1	18.6	8.6	18.9
Mg (cmol(+)kg^{-1})	6.9	24.5	26.2	10.8	19.7
K (cmol (+) kg^{-1})	0.5	2.2	2.9	0.8	2.4
Na (cmol(+)kg^{-1})	13.6	59.7	56.9	18.9	13.8

Note: Exchangeable cations (Ca, Mg, K, Na) in this table are mixtures of soluble and exchangeable cations as there were no separation of soluble cations in the analysis.

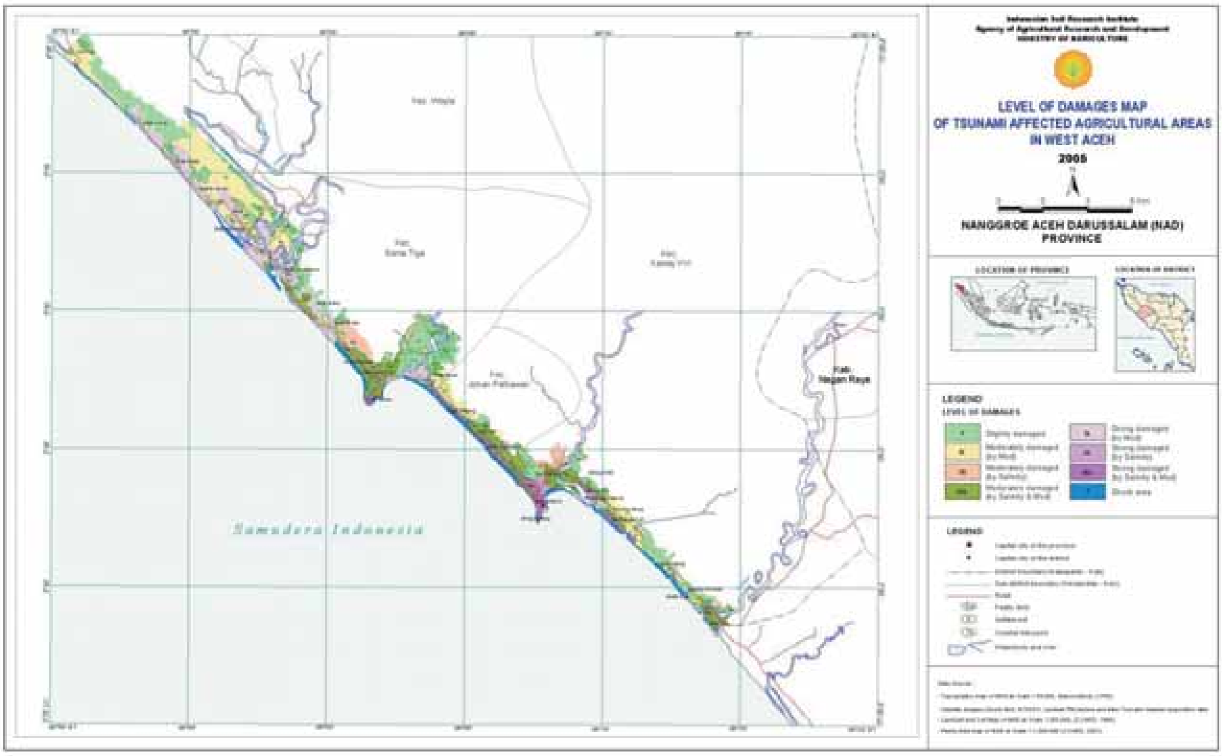

Fig. 1. Types and levels of damages of coastal area of West Aceh District, based on observation in May 2005, five months after the tsunami (Wahyunto and Widagdo, 2005).

Soil profile properties

The unaffected NAD 3 profile shows the typical characteristics of acid upland soils. Its organic matter, total nitrogen, phosphorus and exchangeable bases were only slightly higher in the Ap horizon compared with those in the lower horizons (Table 3). For the

Table 3. Selected soil profile properties, five and 32 months after tsunami.

Horizon	Depth (cm)	Texture		pH	Org	Total	Exchangeable cations (NH$_4$OAc 1N, pH 7)				
		Sand	Clay	H$_2$O	C	P	Ca	Mg	K	Na	CEC
		%			%	mg kg^{-1}	cmol(+) kg^{-1}				
NAD 3 (Beradeun village, 05˚30’09”N; 95˚16’28”E, Peneplain, 30 m asl; Unaffected soil, **May 2005**)											
Ap	0-16	47	20	5.2	1.3	90	4.0	1.2	0.07	0.1	11
Bw$_{1-2}$	16-40	52	19	5.2	0.4	30	1.8	0.7	0.00	0.2	9
2Bw$_{1-2}$	40-95	35	34	5.2	0.3	20	2.8	1.4	0.04	0.3	15
2BC$_{1-2}$	96-146	4	64	7.0	0.1	30	17.0	7.7	0.04	2.8	27
NAD 1 (Nusa Village; 05˚30’ 03”N; 95˚16’17”E; Fluvio marine plain; 5 m asl; **May 2005, five months after tsunami**)											
O1	*0-5*	*9*	*48*	*7.9*	*6.1*	*730*	*39.9*	*20.9*	*1.44*	*7.6*	*35*
O2	*5-11*	*84*	*10*	*8.0*	*0.8*	*390*	*33.8*	*5.6*	*0.28*	*7.4*	*10*
Ap	11-25	28	31	6.1	1.1	120	5.8	3.7	0.28	7.2	13
Bw	25-42	27	43	7.1	0.3	60	9.8	4.7	0.07	1.5	16
Bwg	42-98	31	41	7.7	0.2	50	8.2	4.5	0.06	1.1	15
BC	98-147	22	39	8.1	0.1	360	9.6	5.4	0.07	1.7	16
NAD 1 (Aug 2007; 32 months after tsunami)											
O	0-5	69	19	8.1	1.5	430	19.5	4.5	0.30	1.2	8
Ap	5.-20	28	43	7.6	0.7	90	7.4	3.5	0.12	2.3	10
Bw	20-37	17	51	7.6	0.4	60	10.5	4.7	0.12	3.2	9
Bwg	37-90	21	48	7.8	0.1	80	10.7	4.8	0.12	2.0	8
BC	90-142	21	48	8.2	0.1	170	9.4	4.2	0.09	1.5	12
NAD 2 (Beradeun village; 05˚30’ 06” N; 95˚16’ 21” E; Peneplain; 18 m asl.; **May 2005; five months after tsunami**)											
O1	*0-9*	*42*	*35*	*8.0*	*9.8*	*360*	*27.8*	*12.8*	*0.49*	*3.6*	*32*
Ap	9-29	22	37	5.8	1.5	80	7.6	2.6	0.09	2.1	16
Bw1	29-52	20	43	5.0	0.6	50	7.2	3.2	0.07	0.9	17
Bw2-3	52-83	17	59	6.0	0.3	20	14.8	6.7	0.09	1.4	28
BC	83-149	44	32	6.7	0.1	50	6.7	3.3	0.04	0.8	12
NAD 2 (Aug 2007; 32 months after tsunami)											
O1	0-2	33	28	7.8	3.0	270	27.4	4.5	0.32	1.1	16
Ap1	2.-16	25	29	7.2	1.9	110	9.8	2.8	0.12	0.7	11
Ap2	16-27	26	35	6.3	1.0	70	6.8	2.7	0.09	1.2	8
Bw1	27-50	30	35	5.9	0.6	50	6.1	3.1	0.09	1.4	9
Bw2-3	50-83	40	33	6.5	0.4	60	9.0	4.8	0.12	1.6	10
BC	83-140	49	30	6.5	0.4	60	8.5	4.5	0.11	1.5	9
NAD 4 (Surah village; 05˚32’ 25” N; 95˚16’05” E; Fluvio marine plain, 5 m asl.; **May 2005; five months after tsunami**)											
O	*0-17*	*93*	*5*	*8.4*	*0.1*	*1100*	*5.4*	*2.1*	*0.22*	*1.7*	*7*
Ap	17-24	21	37	6.3	1.1	450	11.0	11.9	0.45	8.0	27
Bwg1	24-43	17	31	6.6	0.4	840	18.6	16.5	0.15	1.5	26
Bwg2	43-83	30	20	7.4	0.2	950	16.9	15.6	0.11	0.5	25
NAD 4 (Aug 2007; 32 months after tsunami)											
O	0-5	73	14	7.7	1.1	890	10.3	4.5	0.88	0.5	10
Ap	5.-13	27	42	7.6	0.8	140	12.6	8.5	0.65	1.1	14
Bwg1	13-30	19	48	7.6	0.2	130	16.5	14.5	0.54	1.9	17
Bwg2	30-70	11	59	7.4	0.3	180	19.5	17.8	0.49	1.8	24

Note: Exchangeable cations (Ca, Mg, K, Na) in this table are mixtures of soluble and exchangeable cations as there were no separation of soluble cations in the analysis.

tsunami affected Profiles NAD 1 and NAD 2, soil pH, organic carbon content, exchangeable cations (potassium, calcium, magnesium and sodium) and total phosphorus were significantly higher in the tsunami formed 'O' horizon than in the underlying layers. However, for Profile NAD 4, where the O layer was dominated by sand fraction, this increase was not observed, except for soil pH. The Ap horizons of NAD 1 and NAD 4 were much higher in sodium up to 7.2 cmol (+) kg^{-1} compared to those in the underlying layer which were only <1.5 cmol (+) kg^{-1}. This elevated concentration is believed to be resulted from sodium leaching from the O horizon.

Thirty two months after the tsunami, the depth of the O horizon decreased because of incorporation into the Ap horizon and the difference in soil properties between the O and Ap horizons became rather unclear. Sodium concentration has practically returned to the pre-tsunami condition. Consistent with the soil profile data in Table 3, the concentration of exchangeable cations in other sites have also elevated in the first 20 cm and it also decreased over time (Fig. 2).

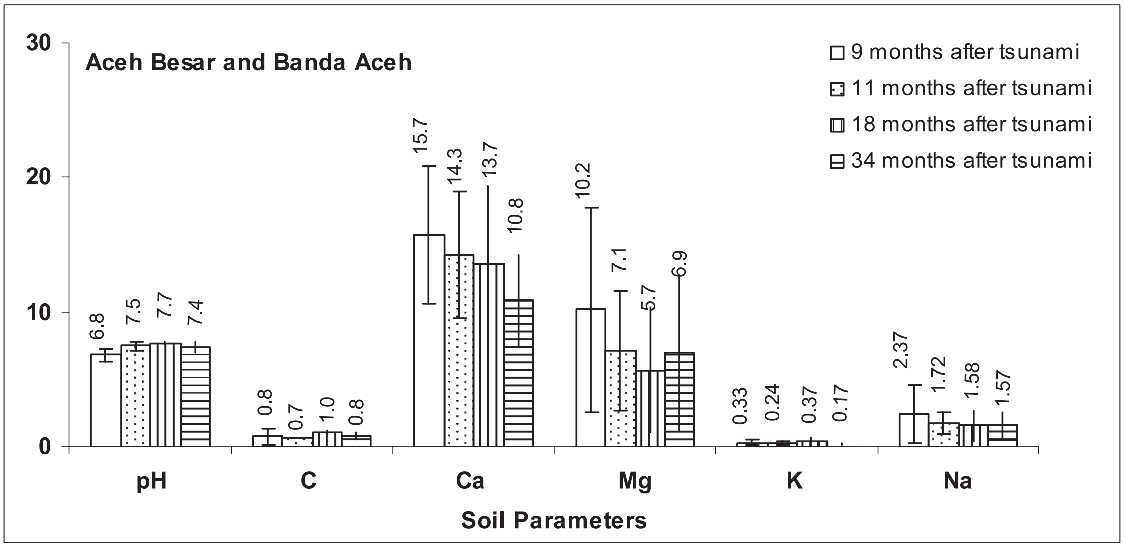

Fig. 2. Mean (histogram) and standard errors (bars) of 0-20 cm depth soil chemical properties over time in Aceh Besar and Banda Aceh Districs. C is in %, Ca, Mg, K, and Na are in cmol(+) kg^{-1}. Source: Rachman et al. (2008b)

Changes in soil salinity

Fig. 3 shows the EC_e by soil depth and Fig. 4 of average EC_e in the 1.2 m soil profile. EC_e varied spatially and decreased significantly with time due to natural leaching by rain water. Some of the soluble salts have been leached downward and increased the EC_e at the deeper depth to a higher level (>5 dS m^{-1}) such as in the cases Cot Lheu Rheng, C. Nusa, and D. Peuneung sites based on the Sep. 2005 and Nov. 2005 observations (Fig. 3). The downward movement of soluble salt may have occurred mostly during the first week after tsunami where standing sea water lasted for 1 to 6 days. The downward movement continues as rain water infiltrates into the soil. The four site measurement in the end of 2007, using EC meter, did not show any site and any soil layer with EC_e higher than 3 dS m^{-1}. The profile average EC_e, based on EM38 measurement, also decreased with time, but some sites still had ECe higher than 8 dS m^{-1} (Fig. 4). This is especially the case in paddy field areas where both lateral water movement is retarded by the dike, while vertical water movement is retarded by the plow pan (McLeod et al., 2010).

Crop responses

Productivity of rice decreased with increased salinity levels. In 2005 cropping most of rice (90%) died, the rest grew poorly with <2 t ha^{-1} yield. In the 2006/2007 cropping the growth recovered with reasonable yield of 3-4 ton ha^{-1}. In the end of 2007, most (70%) of rice field affected by tsunami regained normal yield of 5-6 ton ha^{-1}, especially in areas with good irrigation system (Irhas et al., 2008). There seems to be a complexity of extreme soil conditions affecting crop growth and production, including the low ratio of calcium to magnesium, increased uptake

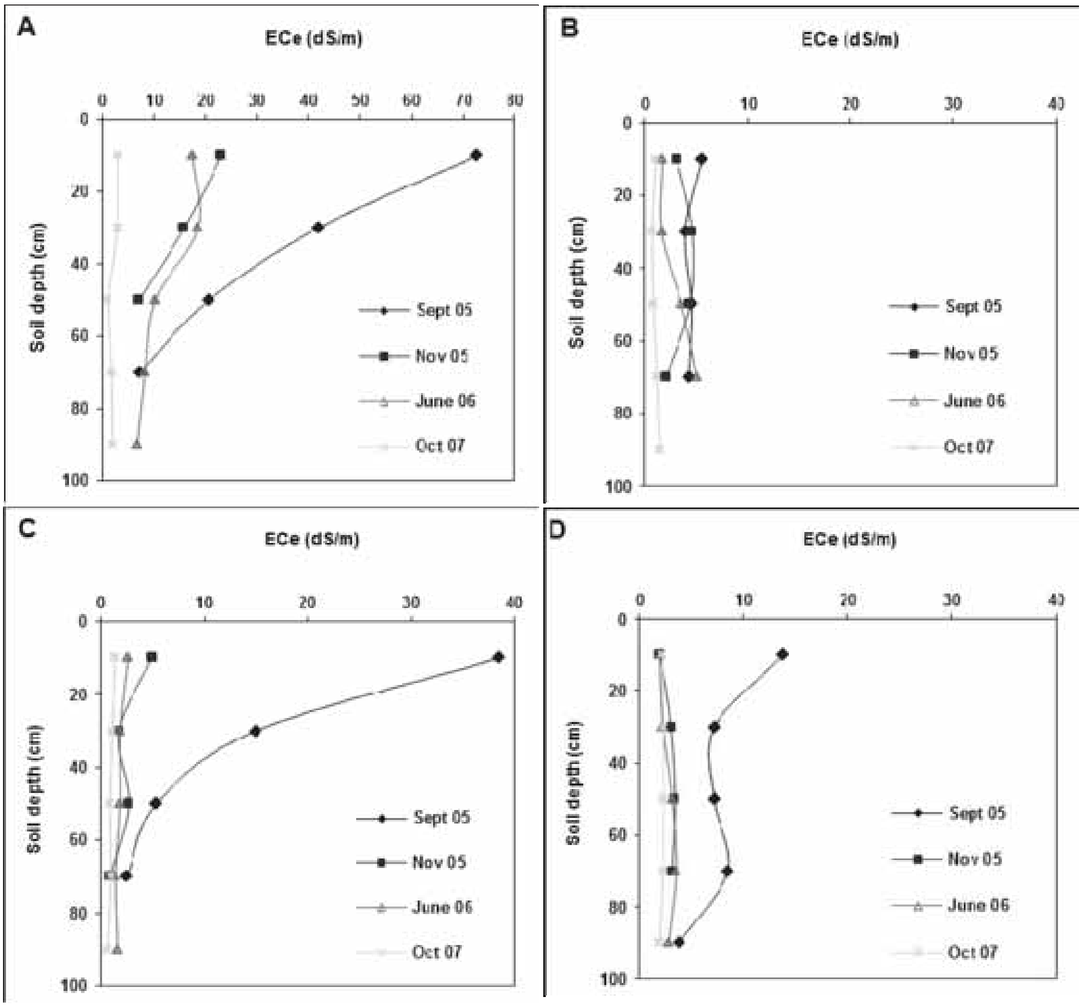

Fig. 3. Changes in EC_e values over time by soil depth at A. Cot Lheu Rheng, B. Panteraja, C. Nusa, and D. Peuneung sites. Source: Rachman et al. (2008a, b)

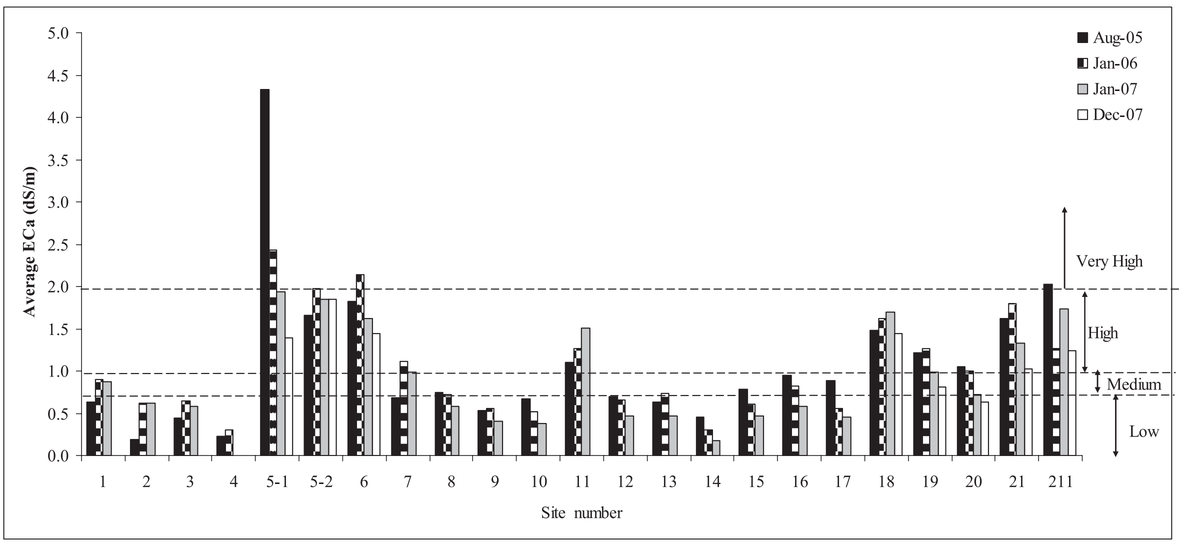

Fig. 4. Average profile effective electric conductivity, EC_e, across 23 assessment sites over time. The dotted line indicates soil salinity levels based on equivalent EC_e values following Slavich (2002). Reproduced from McLeod et al. (2010).

of sodium which affect the plant turgor, deficiency of micro nutrients, and surface sealing and crusting.

The local farmers observed a better crop performance for most crops, especially for the surviving tree crops, but empty seed of rice and pods of peanut was a concern. Most of the surviving tree crops in the affected areas seemed to benefit from the cation enrichment (Subiksa, 2006). Hybrid coconut, for example, yielded much higher in Aceh Barat District. Rachman et al. (2008a) reported the low ratio of calcium to magnesium of <1 for Panteraja, <1.5 for Cot Lheu Rheng, and <2 for Peuneung sites. The ideal calcium to magnesium ratio on the exchange complex for most crops is around 6 (McLean 1977). The relatively high proportion of Mg might have suppressed Ca uptake, the important element for pod filling, especially for peanut. Neumann et al. (2008), however, observed unhealthy performance of mango trees on tsunami affected sites. They found substantial increase of Na uptake in the trees while the uptakes of Ca, K and Mg did not seem to be suppressed by the elevated Na concentration. The authors attributed the unhealthy mango trees to elevated Na uptake.

Increased heavy metal concentrations were also documented by Wenzel et al., (2008).

In general, the heavy metal effects diminished after a few years and the remaining hot spots of pollution may be treated using phytoextraction of heavy metals and phytodegradation of organic pollutants. Arbuscular mycorrhizal fungi, a group of symbiotic soil microorganisms which may contribute to plant nutrient uptake, did not appear to be suppressed on tsunami affected soils. Roots of the halophyte 'kuda-kuda' (*Ipomoea pres-caprae*), which are very abundant on tsunami affected soils showed a particularly high degree of mycorrhizal root colonization (Neumann et al., 2008).

Possible management interventions include organic amendments such as compost or manure, and minimum tillage options such as permanent beds or zero tillage with retention of crop residues as *in situ* mulch together with suitable cover crops (Hulugalle et al., 2009; Lal, 1987; Roth et al., 2005). The relatively higher salinity level of paddy field areas for extended period of time (McLeod et al., 2010; Rachman et al. 2008b) because of low water percolation through the plowpan and blocking of the mud by the dykes suggests the importance of good irrigation and drainage systems.

Conclusions

Elevated soil salinity, very high sodium concentration on the tsunami deposit, land inundation, too sandy or too clayey mud, and surface crusting are among the extreme soil conditions in the tsunami affected area. Extremely high salinity level of >80 dS m^{-1} was measured a few weeks after the tsunami, but it decreased naturally relatively quickly. High soil salinity level (EC_e >4 dS m^{-1}) sustained in areas where lateral/vertical drainage is restricted. The yield of food crops such as rice in the poorly drained areas and peanuts in the severely affected areas has been affected until more than three years after tsunami.

The soil problem is more than just salinity. In areas where salinity had subsided to a negligible level, we observed poor peanut pod filling despite the seemingly thriving vegetative growth. Paddy areas with poor drainage also exhibited empty seeds. Other soil factors, singly or combination of more than one factor, may have caused the problems. These include elevated sodium uptake because of the soil sodicity, low ratio of calcium to magnesium, deficiency of micro nutrients and surface sealing and crusting. Fixing the irrigation and drainage systems to enable flushing of excessive salts and application of organic matter appears promising in remediation of these problem soils.

There are still researchable questions with respect to nutrient imbalance (dominance of Mg relative to K and Ca) and micro nutrients deficiency. These questions are more serious for annual crops than perennial crops. Perennial crops seem more resilient and able to cope with the complexity of the soil properties.

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"Na-no-hana Project" for Recovery from the Tsunami Disaster by Producing Salinity-Tolerant Oilseed Rape Lines: Selection of Salinity-Tolerant Lines of *Brassica* Crops

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Abstract

We tested salinity tolerance of 44 lines of *Brassica napus*, *Brassica juncea*, *Raphanus sativus*, and *Raphanus raphanistrum* using a *Brassica oleracea* line, which has been evaluated to be highly tolerant to salinity, as a control. Plants at the 3-4 leaf stage were cultured in pots containing perlite with liquid culture media containing 0 mM, 50 mM, 100 mM, and 200 mM NaCl for three weeks, and then the dry weight of the aerial part was compared. Since most of the lines showed a decrease of growth in the liquid media containing NaCl, salinity tolerance of each line was represented by a ratio of dry weights of plants grown with NaCl to those of plants grown without NaCl. Although the average dry weight ratio for *Raphanus* was slightly higher than that for *B. napus*, variation within species was much higher than the difference between species. In *B. napus*, N-343 and N-119 showed higher dry weight ratios than 'Kirariboshi', which is commonly grown in Japan, and N-343 had dry weights significantly higher than those of the salinity-sensitive lines in 200 mM NaCl, suggesting N-343 to be highly tolerant to salinity. J-105 in *B. juncea* and 'Izumoorochi' in *R. sativus* also showed high salinity tolerance. Use of these salinity-tolerant lines in oilseed production and as materials for plant breeding is herein discussed.

Introduction

More than 20,000 ha of agricultural land in the Tohoku region was damaged by the tsunami disaster in the wake of the Great East Japan Earthquake, making it difficult to grow crops in these fields without removal of salt from the soil. Until such time, salinity-tolerant plants are required for crop production.

Plants in the genus *Brassica* and closely related genera are distributed on the seashore of the Mediteranean Sea and in deserts in Africa and the Mideast, suggesting that they are tolerant to salinity. As expected, Brassicaceae vegetables including cabbage, Chinese cabbage, and radish have been revealed to be more tolerant than other vegetables tested (Osawa 1961). Wild Brassicaceae plants growing at the seashore have been reported to be highly tolerant to salinity (Takahata and Tshunoda 1981). However, Shimose and Sekiya (1991) have reported that salinity tolerances of Chinese cabbage and rape are low and that that of cabbage is intermediate. These differences may suggest the presence of high variation of salinity tolerance within species.

Since Tohoku University has unique genetic resources of *Brassica* crops and its wild relatives, we investigated the salinity tolerance of many lines in *Brassica napus*, *Brassica juncea*, and *Raphanus sativus* to use these genetic resources as materials for developing salinity-tolerant oilseed rape lines, which could be grown in these fields and used for oil production.

Materials and methods

Nine lines of *Brassica napus*, 30 lines of *Brassica juncea*, four lines of *Raphanus sativus*, one line of *Raphanus raphanistrum*, most of which are maintained as genetic resources in the Brassica Seed Bank in the laboratory of plant breeding and genetics in Tohoku University, were used for evaluating salinity tolerance (Table 1). A line of *Brassica olercea*, O-166, which has been reported to have high tolerance to

Table 1. Dry weights of aerial parts of plants cultured with liquid media containing 0 mM, 50 mM, 100 mM, and 200 mM NaCl

	Dry weight (g)			
Names of lines	0 mM	50 mM	100 mM	200 mM
Brassica napus				
N343	0.92	0.68	0.52	0.44*
N-119	0.77	0.56	0.48	0.32
Kirariboshi	0.85	0.45	0.27	0.23
Kizakinonatane	1.05	0.66	0.57	0.26
Brassica juncea				
J-105	0.52	0.53	0.46	0.26*
J-124	0.70	0.62	0.38	0.25*
J-130	0.50	0.35	0.33	0.28*
J-106	0.57	0.32	0.31	0.14
J-601	0.55	0.32	0.27	0.12
J-473	0.46	0.32	0.27	0.09
Raphanus sativus				
Izumoorochi	1.20	1.29	0.83	0.61
RAP-SAR-40	1.94	1.81	1.05	0.39

* indicates significant difference from dry weights of the salinity-sensitive cultivars at 5% level.

salinity (Takahata and Tsunoda 1981), was used for comparison.

Seeds were sown on wet filter paper in a Petri dish. After expansion of cotyledons, four plantlets were transplanted into a plastic pot with a diameter of 19 cm and a height of 14.4 cm (1.6 L capacity) containing perlite 1 to 3 mm in diameter. Plants were grown with a liquid culture medium containing 0.75 g Aminohouse No. 1, 0.5 g Otsuka House No. 2, and 0.025 g Otsuka House No. 5 (Otsuka AgriTecno Co. Ltd. Japan) per liter, which is estimated to contain 2.12 mM NO_3, 0.42 mM P_2O_5, 2.17 mM K_2O, 2.05 mM CaO, 0.74 mM MgO, 0.01 mM MnO, 0.05 mM Fe, 0.01 mM B_2O_3, 0.001 mM Zn, 0.0004 mM Cu, and 0.0003 mM Mo. When the surface of perlite was dry, the plants were supplied with 50 ml liquid culture medium. From the 3– to 4-leaf stage, plants were cultured with the liquid culture media containing 0, 50, 100, and 200 mM NaCl. When the surface became dry, 100 ml liquid culture media were supplied. Twenty-one days after treatment with the culture media containing NaCl, aerial parts were air-dried at 85 C for ten days and weighed.

Results

Although dry weights of J-105 in *B. juncea* and 'Izumoorochi' in *R. sativus* treated with 50 mM NaCl were slightly higher than those without NaCl, most of the lines showed a decrease of growth in the liquid media containing NaCl (Fig. 1). Salinity tolerance of each line was represented by the dry-weight ratio, i.e., the ratio of dry weights of plants grown with NaCl to those of plants grown without NaCl. Average dry-weight ratios of *B. napus* in the 50 mM, 100 mM, and 200 mM NaCl treatments were 0.64, 0.49, and 0.36, respectively. Average dry-weight ratios of *B. juncea* in 50 mM, 100 mM, and 200 mM NaCl treatments were 0.62, 0.51, and 0.31, respectively, and those of *Raphanus* in the 50 mM, 100 mM, and 200 mM NaCl treatments were 0.74, 0.53, and 0.40, respectively. In the 50 mM NaCl treatment, average dry-weight ratio of *Raphanus* was somewhat higher than that of *B. napus*, but the difference was not significant because of high varietal differences within these species. Dry-weight ratios of O-166 in *B. oleracea*, which has been evaluated to be highly salinity tolerant (Takahata and Tsunoda 1981), in 50 mM, 100 mM, and 200 mM NaCl treatments were 0.71, 0.52, and 0.32, respectively.

In *B. napus*, differences of dry-weight ratios among nine lines in the 200 mM NaCl treatment were significant ($p<0.05$). Among them, N-343 showed the highest dry-weight ratios of 0.74 and 0.48 in 50 mM and 200 mM NaCl, respectively. In 100 mM NaCl, N-119

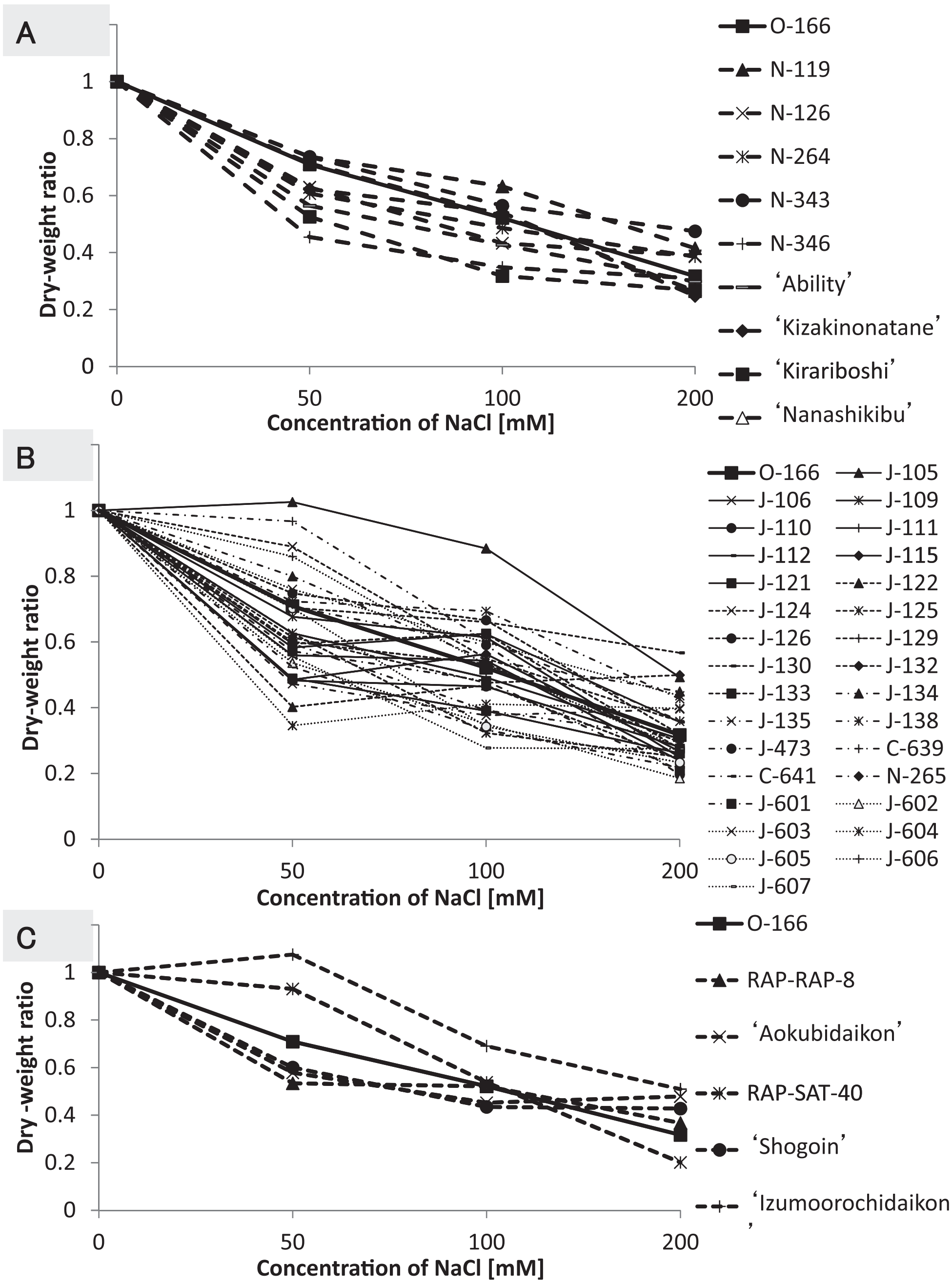

Fig. 1. Salinity tolerance of plants in *B. napus* (A), *B. juncea* (B), and *Raphanus* (C) represented by dry weight ratios of the aerial parts.
O-166 in *Brassica olercea*, which has been reported to have high tolerance to salinity, was used for comparison.

showed the highest value. The dry-weight ratios of these lines were higher than those of O-166 for all the concentrations of NaCl.

In *B. juncea*, significant differences ($p<0.05$) of dry-weight ratios among the tested lines were observed in the 100 mM and 200 mM NaCl treatments. In 200 mM NaCl, the difference between the highest and the lowest dry-weight ratios was quite large, i.e., 0.57 in J-130 and 0.21 in J-601. The line J-105, which showed slightly higher growth in 50 mM NaCl than that in 0 mM NaCl, showed the highest dry-weight ratio, 0.88, also in 100 mM NaCl and the third highest value, 0.50, in 200 mM NaCl. J-105 was considered to be the most salinity-tolerant line among the tested *B. juncea* lines.

'Izumoorochi' in *R. sativus* exhibited high dry-weight ratios in all the tested NaCl concentrations, i.e., 1.08, 0.69, and 0.51 in 50 mM, 100 mM, and 200 mM

NaCl, respectively. The average dry-weight ratios of 50 mM, 100 mM, and 200 mM NaCl were the highest in 'Izumoorochi' among all the examined lines of *B. napus*, *B. juncea*, and *Raphanus*. Significant differences of dry-weight ratios between lines in *Raphanus* were not observed in any tested NaCl concentrations.

Some lines showing high dry-weight ratios had low dry weights in the control with 0 mM NaCl. Therefore, dry weights of aerial parts of the selected lines were compared with those of lines with low salinity tolerance (Table 1). The dry weight of N-343 was comparable to those of the salinity-sensitive lines, i.e., 'Kirariboshi' and 'Kizakinonatane', in the control, and N-343 had a significantly higher dry weight ($p<0.05$) in 200 mM NaCl than those of the salinity-sensitive lines. On the other hand, the dry weights of N-119 in the control were lower than those of the salinity-sensitive lines. In *B. juncea*, J-105, J-124, and J-130 had significantly higher dry weights than those of salinity sensitive lines, i.e., J-106, J601, and J-473, in 200 mM NaCl, and dry weights of J-105, J-124, and J-130 in 0 mM NaCl were comparable to those of the salinity sensitive lines.

Discussion

Salinity tolerance evaluated with dry-weight ratios in *Raphanus* seemed to be higher than *B. napus*, as reported by Shimose and Sekiya (1990), but varietal differences within a species were too high to reveal the difference between these two species. Most of the Brassicaceae crops are allogomous plants, some of which have self-incompatibility (Kitashiba and Nishio 2010), and are therefore considered to have high variation in many genetic traits in a species. High variation within a species of *B. napus*, *B. juncea*, and *R. sativus* was found in the salinity tolerance trait. In *B. juncea*, high variation of salinity tolerance in a species has been revealed, and salinity tolerant lines have been developed in India (Purty et al. 2008). Data on salinity tolerances of different plant species without names of cultivars or lines in the Brassicaceae crops should be handled with care.

N-343 and N-119 in *B. napus* showed high dry-weight ratios. N-343 is a rutabaga cultivar, and not cultivated for rapeseed production. Evaluation of seed yield of N-343 is required. N-119 is an old Japanese cultivar of rape grown in the Tohoku region. Therefore, N-119 may be useful for rapeseed production in fields damaged by the tsunami. As a breeding material for salinity tolerance, N-343 is considered to be promising.

J-105 was found to be the most salinity-tolerant line among *B. juncea* lines examined in the present study. This line was provided to the Tohoku University Brassica Seed Bank by Takii Seed Co. under the name "long standing mustard" in 1943. There is no other description of this line. The plant looked like a leafy vegetable. Evaluation of seed yield is required for using it in oilseed production.

'Izumoorochi' was found to have the highest salinity tolerance among the lines examined in the present study. 'Izumoorochi' is a selected line having thick roots from a wild radish, "Hamadaikon", which grows on seashores in Japan (Ban et al. 2009). Some plants of Hamadaikon can grow on the beach near seawater. There is a possibility that a plant having much higher salinity tolerance than 'Izumoorochi' is found in Hamadaikon. However, *R. sativus* is mainly used as a root crop and not so much as an oil crop. It has strong self-incompatibility, and yield of seeds is much lower than *B. napus* and *B. juncea*. Salinity-tolerant *R. sativus* lines cannot be used directly for producing oil. Incorporation of salinity-tolerance genes of the salinity-tolerant *R. sativus* lines into *B. napus* or *B. juncea* is required. Since *R. sativus* can be crossed with *Brassica* species, genetic traits in *R. sativus* can be used in *Brassica* breeding by conventional cross breeding. Cytoplasm of *R. sativus* has been used for developing cytoplasmic male-sterile lines in *Brassica* (Koizuka et al. 2003), and single-chromosome addition lines in *B. napus* with *R. sativus* chromosomes have been developed (Akaba et al. 2009). Since genome research on *R. sativus* is actively performed (Li et al. 2011), DNA markers linked with a gene responsible for salinity tolerance will be eventually identified.

Salinity tolerance evaluated in the present study is of the young plant stage. Salinity tolerance of each line may change depending on plant stage. In fact, some accessions in *Arabidopsis thaliana* showing high salinity tolerance at the germination stage have been reported to be highly sensitive to salinity stress during vegetative growth (Quesada et al. 2002). Furthermore, lines with a low yield of seeds are not useful, even if they have high salinity tolerance. Therefore, field trials are indispensable for selecting salinity tolerant lines for oilseed production. We selected ten lines and are presently growing them in fields with high salinity. Assessing salinity tolerance, seed yield, adaptability, plant biomass, and uptake of salts, we will select a line usable as a rapeseed line for oil production in these fields and as a material for breeding of a more promising salinity-tolerant high-yield rapeseed line.

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Behaviour and Phytoavailability of Radiocaesium in Surface Soil

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Abstract

Large amounts of several radionuclides were released into the atmosphere from the Fukushima Daiichi Nuclear Power Plant (F-1NPP) in March 2011 and the ensuing months, and deposited onto the surface soil and vegetation in wide areas of eastern Japan. Among the released radionuclides, ^{137}Cs (half-life, 30.1 y) is the most important nuclide for assessment of the long-term radiation exposure for the public. The distribution of fallout ^{137}Cs, derived from past atmospheric nuclear weapons tests, in agricultural fields in Japan was well investigated and these studies are briefly reviewed here. The long-term monitoring data of ^{137}Cs in soils and crops can provide useful information to predict the behavior of radiocaesium released from the F-1NPP. Since Cs is irreversibly sorbed on frayed-edge sites (FESs) of illitic minerals, its mobility is quite low after its deposition onto surface soil. Behaviour and phytoavailability of Cs in soil is controlled by several factors including clay mineralogy, elapsed time since deposition and ion components in soil solution, especially NH_4^+ and K^+. Then, this paper also reviews studies on the behavior of Cs in soil-plant systems.

Introduction

Damage to reactor buildings of the Fukushima Daiichi Nuclear Power Plant (F-1NPP) due to the Great Eastern Japan Earthquake and the massive tsunami on March 11, 2011, coupled with the loss of electrical power that prevented cooling of the reactors and spent fuel pools and led to hydrogen explosions, resulted in the release of large amounts of radionuclides from the plant. Noble gases and volatile radionuclides predominated in releases to the terrestrial environment (Tagami et al., 2011) and they were deposited in wide areas of the Tohoku and Kanto districts. The amounts of released ^{131}I and ^{137}Cs have been estimated as 1.5×10^{17} Bq and 1.3×10^{16} Bq, respectively (Chino et al., 2011). Approximately 13 % of ^{131}I and 22% of ^{137}Cs of the total amounts released were estimated to be deposited over Japanese land areas (Morino et al., 2011). The degree of soil pollution has been gradually clarified by air borne monitoring and soil surveys. Iodine-131 has a short physical half-life (8 d), and it decayed rapidly after the accidental release. From a long-term viewpoint, ^{134}Cs (half-life, 2.1 y) and ^{137}Cs (half-life, 30.1 y) are important nuclides to assess radiation exposure of the public.

Shiozawa et al. (2011) reported the vertical distribution of radiocaesium (^{134}Cs and ^{137}Cs) in a paddy field in Fukushima Prefecture after the F-1NPP accident. They found 96% of the total radiocaesium was in a surface soil layer of 0-5 cm depth, and the radiocaesium was mixed within a depth of 0-15 cm after plowing. It is known that Cs is strongly retained by soil clay minerals. Therefore, the radiocaesium will remain in the surface soil for a long time.

The distribution of global fallout ^{137}Cs, derived from the atmospheric nuclear weapons testing, in agricultural soils and crops has been well investigated in Japan. Since the Chernobyl Nuclear Power Plant accident in 1986, the fate of ^{137}Cs in the terrestrial environment and the mechanism of its retention by clay minerals have been extensively studied, mainly in European countries. In this paper, scientific knowledge about the behaviour of Cs in soil-plant systems is reviewed.

Fate of global fallout ^{137}Cs in soils in Japan

Huge amounts of ^{137}Cs and some other radionuclides (e.g. ^{90}Sr and $^{239+240}$Pu) were released from atmospheric nuclear weapons tests in the late 1950s and early 1960s, leading to global fallout, mainly in the northern hemisphere (Aoyama et al., 2006). The deposition of fallout ^{137}Cs has been monitored since the 1950s in Japan. The maximum annual deposition was observed in 1963, after the large-scale atmospheric nuclear weapons tests of 1961–1962 (Hirose et al., 2008).

It is known that Cs is strongly retained on surface soil after deposition, and downward migration is very slow in soil (Rosén et al., 1999). Most of the fallout ^{137}Cs is within a depth of 30 cm from the surface several decades after the main deposition in undisturbed forest in Japan (Fukuyama and Takenaka, 2004). In agricultural fields, on the other hand, fallout ^{137}Cs is homogeneously mixed within the surface soil layer because soils in agricultural fields are generally mixed by plowing every year prior to planting of crops (Tsukada and Nakamura, 1999; Tsukada et al., 2002).

Long-term monitoring of radioactivity in 17 agricultural fields was carried out from 1959 by the National Institute for Agro-Environmental Sciences (Komamura et al., 2005). Maximum concentrations of ^{137}Cs in the plowed layer of paddy and upland field soils were observed in 1963 - 1966, which was an effect of the maximum annual fallout in 1963. Komamura et al. (2006) reported that the concentration of ^{137}Cs in the plowed layer was decreased by the half-times of 9 – 24 y in paddy fields and 8 – 26 y in upland fields. These monitoring data provide useful information to predict long-term behaviour of radiocaesium derived from the F-1NPP accident.

Retention of Cs by soil clay

It is known that radiocaesium is strongly sorbed by illitic minerals. The weathering fronts in the interlayers of illitic minerals expand into a wedge shape, known as frayed-edge sites (FESs) (Cremers et al., 1988). The contribution of FESs to the overall cation exchange capacity in soil is quite small, e.g. 0.001 – 6 % (Delvaux et al., 2000); however, they selectively sorb poorly hydrated cations including K^+, NH_4^+ and Cs^+. Radiocaesium deposited on surface soil is specifically sorbed by FESs, and the number of FESs affects Cs mobility in the soil.

The radiocaesium interception potential (RIP) was established as a quantitative indicator of FESs (Cremers et al., 1988). The RIP value is defined as the mathematical product of the trace Cs to K selectivity coefficient in the FESs and the FES capacity (Wauters et al. 1996). Vandebroek et al. (2009) compared the RIP among various soils collected worldwide and found that Andosols had one of the lowest RIP values among the soil groups. Nakamaru et al. (2007) also reported that the soil-soil solution distribution coefficient (Kd) of ^{137}Cs tracer in Andosols is relatively lower than that in other Japanese agricultural soil groups, and they suggested that soil organic matter could increase the mobility of Cs in soils. Ishikawa et al. (2007) investigated the relation between relative illite content and the strongly fixed proportion of ^{137}Cs tracer in Japanese paddy soils from which they suggested that the mobility of Cs was relatively higher in soils with lower content of illitic minerals.

Ammonium ion is more competitive than K for Cs adsorption on FESs. Therefore, a high concentration of NH_4^+ in soil solution can inhibit the Cs retention and increase Cs mobility in soil (Comans et al., 1989; Takeda et al. 2008). Ammonium salt solution can extract a relatively high amount of Cs from soil. For example, the mean extraction yield of stable Cs in 16 agricultural soils was 4.1 % with 1 M NH_4NO_3 solution, whereas it was 1.5 % with 1 M HNO_3 solution under the same extraction conditions (Takeda et al., 2006).

Mobility of radiocaesium decreases with time after its deposition in the soil due to an aging effect (Sanzharova et al., 1994; Absalom et al., 1995; Fesenko et al., 1997; Rigol et al., 1999; Roig et al., 2007; Takeda et al., 2009). A collapsing process of the interlayer space of phyllosilicates induces Cs fixation onto soil (Hird et al., 1996).

Soil-to-plant transfer of Cs

Concentration of radiocaesium in a crop plant (edible part) is estimated by using the soil-to-plant transfer factor (TF). The TF is generally defined as the concentration ratio of Cs in the edible part of crop plant (Bq kg^{-1} dry or wet plant) to that in the soil (Bq kg^{-1} dry soil), which is obtained by analysis of samples collected from agricultural fields or grown in pot experiments with radioisotope tracer. The TFs of many crops have been summarized by the IAEA (International Atomic Energy Agency, 2010). The TFs for crops in Japan were reported by measuring the fallout ^{137}Cs derived from atmospheric nuclear tests (Tsukada and Nakamura, 1999; Tsukada and Hasegawa, 2002; Tsukada et al. 2002; Komamura et al., 2005; Uchida et al., 2007; Uchida and Tagami, 2007; Kamei-Ishikawa et al., 2008). The reported TFs cover wide ranges with about two orders of magnitude in the same crop plant, because the availability of Cs in soil depends on many factors, including soil type, elapsed time after deposition, and coexisting ions.

Delvaux et al. (2000) conducted a cultivation experiment of ryegrass using a wide variety of soils containing ^{137}Cs tracer. The soil-to-grass transfer of Cs was negatively correlated with RIP values in soil, and larger TF values were observed in lower RIP soils. This result suggested that the number of FESs largely controls the availability of Cs in soil.

Soil-to-plant transfer of Cs generally decreased with time after deposition to the soil due to the aging effect as mentioned above. In a laboratory experiment for an allophanic Andosol, phytoavailability of Cs was determined to decline exponentially up to about 100 d after its addition to the soil, and was almost constant thereafter (Takeda et al., 2009).

The uptake of Cs by plant roots from soil solution is enhanced under the low K condition in soil solution (Shaw 1993; Smolders et al., 1997). Therefore application of K fertilizer reduces Cs uptake effectively in soils with a low amount of available K (Lembrechts, 1993; Nisbet et al., 1993; International Atomic Energy Agency, 1994)

Behaviour of Cs in paddy soil

Rice is the most important crop for estimation of internal exposure to the public in Japan. As noted above, long-term monitoring of fallout ^{137}Cs derived from nuclear weapons tests has been carried out for paddy soil and rice grain samples, providing useful information for prediction of radiocaesium concentration in rice. Although direct absorption of fallout ^{137}Cs from the atmosphere is the major pathway in rice before the 1980s, it became negligible after 1990 (Komamura et al., 2006). The concentration of ^{137}Cs from root uptake of rice plants varies by one order of magnitude among components (polished rice, rice bran, hull, straw and root). The highest and the lowest concentrations have been found in rice bran and in polished rice, respectively (Tsukada et al., 2002). Therefore, the concentration of ^{137}Cs in polished rice is lower than in brown rice (Komamura et al., 2006; Uchida et al., 2009). As well, 10% of the total ^{137}Cs in an entire rice plant was found in polished rice, and the remaining 90% was in non-edible parts. Only 0.003 % of ^{137}Cs in the plowed soil was transferred to the above ground biomass of rice plants (Tsukada et al. 2008).

Although behaviour of radiocaesium in contaminated agricultural fields in European countries has been well documented, particularly since the Chernobyl accident in 1986, the behaviour in paddy fields has not been studied much. Tensho et al. (1959) carried out a pot cultivation experiment using paddy and upland soils containing radioactive Cs tracer. Their results showed that about 20 times larger amount of Cs was absorbed by paddy rice than upland rice. Under the anoxic condition, the major form of N in paddy soils is NH_4^+, which can increase Cs mobility in soil. Higher availability of Cs in paddy soils would relate to higher concentrations of NH_4^+ in soil solution (Tensho et al. 1961). These studies indicate that availability of Cs is affected by the nitrogen cycle in paddy soil. In addition, Cs in irrigation water would affect its content in rice plant. Uptake of Cs by rice plant is much higher from solution than from soil when contaminated irrigation water is supplied to the paddy soil (Myttenaere et al., 1969).

Previously reported TFs of fallout ^{137}Cs for Japanese crops showed that the TFs of rice grain are relatively smaller than other crops including leafy and root vegetables (Tsukada and Nakamura, 1999; Tsukada et al., 2002; Tsukada and Hasegawa, 2002; Komamura et al., 2005; Uchida et al., 2007; Uchida and Tagami, 2007; Kamei-Ishikawa et al., 2008). However, the behaviour of Cs in paddy fields is complicated and knowledge is still insufficient for prediction of Cs transfer to rice plant and for setting countermeasures to reduce Cs uptake. Analysis of risk factors enhancing Cs uptake by rice is important for contaminated regions.

Conclusions

Behaviour and phytoavailability of radiocaesium in surface soil are affected by many factors including clay mineralogy, elapsed time since deposition, and major ions present in the soil solution. Radiocaesium is specifically and irreversibly sorbed by the FESs of illitic minerals. Therefore, its mobility as dissolved ions is quite low after deposition onto surface soil.

Phytoavailability of Cs partly depends on soil types. Caesium would be more labile in soils with a low number of FESs. Elapsed time after deposition is also an important factor controlling Cs partitioning between the soil solid and solution phase. Concentrations of major ions, especially K^+ and NH_4^+ in soil solution greatly affect Cs behaviour in soil. Since increasing the concentration of NH_4^+ in soil solution generally enhances Cs mobility in soil, the concentration of Cs in paddy soil can be elevated under the anoxic condition. Potassium depletion increases Cs root uptake from soil solution, therefore, fertilizer use should be checked carefully for management of contaminated agricultural soil.

Knowledge of the behaviour of radiocaesium in paddy fields and volcanic ash soils is still not sufficient. In addition, geomorphological effects on Cs behaviour in mountainous and catchment areas, such as northeastern Japan, are more complicated than in past contaminated areas such as around the Chernobyl nuclear power plant. Further investigations are needed for better management of contaminated soils for a long-term.

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Understanding Methane Emission from Rice Paddies in China

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Abstract

China is the largest rice-producing country in the world, accounting for about 30% of total rice production. Methane (CH_4), is produced and emitted in the rice fields under flooded conditions. There are very large temporal and spatial variations of CH_4 emissions from rice fields in China, with seasonal average fluxes in the range 0.14–58 mg CH_4 m^{-2} h^{-1}, mainly dependent on water regime in both off-rice and rice seasons, and availability of labile organic carbon. Based on field measurements, recent estimates of CH_4 emission from Chinese paddy fields, either by modeling or by scaling up, were mostly in the range 3.3–9.6 Tg CH_4 y^{-1}, with a more realistic value of around 8 Tg CH_4 y^{-1}. There is a large potential for mitigating CH_4 from rice paddies by improving water regimes and appropriate management of crop residues.

1.Introduction

China is the largest rice producer in the world. Its rice harvested area increased steadily from 27 Mha in 1961 to 36.97 Mha in 1976, decreased continuously to 26.78 Mha in 2003, and then increased again slowly to around 29.93 Mha in 2009. As rice fields are an important source of atmospheric methane (CH_4). China has been of particular concern in the past two decades as a source of CH_4. The research on CH_4 emissions from Chinese rice paddies started in the late 1980s and the first paper was published in 1988 (Winchester et al. 1988). Since CH_4 fluxes measured in a rice field in Tuzu, Sichuan Province of China were, on average, 60 mg m^{-2} h^{-1} (i.e. 4–10 times higher than emission rates from rice fields in the United States and Europe (Khalil et al. 1991), great attention was drawn to measurement and understanding of CH_4 emissions from rice fields in China. Up to the present, CH_4 and N_2O emissions from rice paddies in China have been intensively measured, the factors affecting their emissions investigated, and the annual emissions at the national and regional scales have been estimated by various approaches.

2. Factors influencing CH_4 emissions from rice fields

CH_4 emission from rice fields is the net result of three processes: production, oxidation and transport. Any factors that affect one or more of these processes may affect CH_4 emission. By analyzing field measurement data of CH_4 emission from rice paddies in Asia, Yan et al. (2005) found that organic amendment, water regime during the rice-growing season, water status in pre-season and soil properties were the main influencing factors.

2.1 Organic amendments

CH_4 is converted from substrate by methanogenic bacteria in strictly reduced environments. Organic amendments directly supply substrate for methanogenic bacteria. The decomposition of organic materials also helps develop a reduced environment for CH_4 generation. CH_4 emission from rice paddies is affected by the type, amount and timing of organic amendment.

A variety of organic fertilizers are used in China, including crop residues, green manure, animal manure, and compost from biogas reactors. The stimulating effect of all these organic fertilizers on CH_4 emission from Chinese rice paddies has been widely studied (Tao et al. 1994, Wang et al. 1995, Zou et al. 2003, Qin et al. 2006, Ma et al. 2007). Yan et al.

(2003) compiled 15 pairs of flux data, comparing CH_4 emissions from Chinese rice fields with and without organic amendment, controlling for other conditions (i.e. site, rice season and water regime). The ratios of CH_4 flux with organic amendment to flux without organic amendment were within the range 0.7–4.2, with an average of 2.08 and standard deviation of 1.16. However, there is a large difference in the effects of different types of organic materials on CH_4 emission. Generally, fresh crop straw shows the largest stimulating effect on CH_4 emission. A seasonal average CH_4 flux of 51.4 mg m^{-2} h^{-1} was reported for rice straw incorporation of 2.63 t ha^{-1}, compared to 10.3 mg m^{-2} h^{-1} without organic input (Qin et al. 2006). Decomposed manure from biogas reactors showed little stimulating effect (Tao et al., 1994). CH_4 emission induced from surface-applied organic materials was less than that from organic materials incorporated into soils, as the former had more chance to be decomposed aerobically than the latter (Xiao et al. 2007).

To prevent air pollution and increase soil fertility, the Chinese government banned field burning and encouraged field application of crop residues. This practice is likely to increase CH_4 emission from rice fields. To mitigate the straw-induced CH_4 emission, Ma et al.(2008) suggested that straw be piled in ridges between rice rows, high above the water layer and be covered with soil. CH_4 emission could be reduced by one third through this practice as compared with direct incorporation of straw into surface soil.

2.2 Water management during the rice-growing season

The water management practice during the rice-growing season is a critical factor influencing CH_4 emission. Mid-season drainage is widely practiced in Chinese rice cultivation. Yan et al. (2003) compiled 11 pairs of data that compared the effects of mid-season drainage and continuous flooding on CH_4 emission from Chinese rice fields, controlling for other conditions (i.e. organic input, rice season and site). On average, CH_4 flux from fields with mid-season drainage was 53% of that from continuously flooded fields. During mid-season drainage, the soil is exposed to air and the redox potential increases rapidly, which inhibits the activity of methanogenic bacteria and so lowers CH_4 production (Xu et al. 2000). The increase in soil redox potential also helps the oxidation of CH_4 (Jia et al. 2001). CH_4 emission may gradually resume when mid-season drainage ends and the rice field is re-flooded. However, if the mid-season drainage was performed until the soils becomes very dry, CH_4 emission may not resume even after an extended period of re-flooding, resulting in a greatly reduced seasonal CH_4 emission (Xu et al. 2000). The earlier the mid-season drainage is started, the greater is the mitigation effect (Li et al. 2007). However, if the mid-season drainage is performed too early, it damages rice growth.

It is worth noting that when drainage begins, the CH_4 trapped in soil may erupt, resulting in a short-term emission peak, which may be overlooked by observers (Xu et al. 2000).

2.3 Water status in preseason

In addition to water management, the water status of rice fields before the rice-growing season also has a strong influence on CH_4 emission in the rice-growing season. Extremely high CH_4 emission was found for rice fields flooded in the winter season (Cai et al. 2003). For four sites across south and southwest China, Kang et al. found that CH_4 fluxes in the rice-growing season from fields that had been flooded in the preceding winter season were 1.2–6.4 times those from fields that were drained in the preceding winter season (Kang et al. 2002).

If the soil is drained in the preseason, ions such as ammonium (NH_4^+), manganese (Mn_2^+) and iron (Fe_2^+) are oxidized. When the soil is flooded for rice-growing, the oxidized ions are gradually reduced, and it takes a long time for the methanogenic organisms to revive, therefore shortening the CH_4 emission period.

There are generally three rice crops in China: single, early and late rice. Single rice is planted on rice fields that are left fallow or planted with upland crops in the preceding season with the fields drained. Early rice is similar to single rice, but the preceding season is shorter. Late rice is usually planted immediately after early rice on the same field. Because the field is usually flooded or kept in moisture conditions suitable for CH_4 production before late rice transplanting, CH_4 fluxes increase sharply soon after transplanting; however, it takes a longer time for CH_4 emission to resume for early rice or single rice (Yan et al. 2003). Due to this difference in water status in preseason, the average CH_4 emission in late rice is 1.5 and 2.3 times that in early rice and single rice, respectively

(Yan et al. 2003). CH_4 emission from rice fields can be dramatically reduced when rice is planted after two consecutive upland crops as compared to the cases where rice is alternated with upland crops or rice is continuously cropped (Cai et al. 1998).

2.4 Chemical fertilizer

Application of chemical fertilizer, especially synthetic N, is necessary in Chinese rice cultivation. The effect of N-fertilizer on CH_4 emission from rice paddies has been studied in many field experiments and the results are mixed. Chen et al.found that the application of urea increased CH_4 emission, as urea increased root growth and root exudates, providing more substrate for methanogenesis (Chen et al. 1995). Another effect of urea application is that NH_4^+, the product of urea hydrolysis, inhibits CH_4 oxidation through competition for methanotrophs and thus increases CH_4 emission. Other studies, however, showed that the use of urea decreased CH_4 emission (Cai et al. 1997, Zou et al. 2005, Ma et al. 2007). It was argued that in an environment of high CH_4 concentration, NH_4^+-based N-fertilizer may inhibit CH_4 oxidation at the beginning, but the coexistence of high CH_4 concentration and NH_4^+ stimulates the growth of methanotrophs and/or their activity for oxidizing CH_4. With the gradual NH_4^+ uptake by rice plants, the increased methanotroph population and/or their activity may consume more CH_4, leading to lower CH_4 emission in later stages (Cai et al. 1997).

Compared to urea, the use of ammonium sulfate, $(NH_4)_2SO_4$, consistently decreased CH_4 emission from rice paddies in all studies that compared the effects of the two fertilizers (Tao et al. 1994, Cai et al. 1997, Lin et al. 2000). This was likely due to the inhibitory effect of SO_4^{2-} on methanogenesis.

3. Estimation of CH_4 emissions from rice fields

As the largest rice producer in the world, China's rice fields have been of particular concern in the past three decades as a source of CH_4, and various estimations have been made (Fig. 1). One of the earliest calculations was made by extrapolating a flux of 58 mg CH_4 m^{-2} h^{-1}, the average CH_4 emission flux for the rice-growing season of two consecutive years in Tuzu, Sichuan Province, to the whole of China. The resulting estimate was 30 Tg CH_4 y^{-1} (Khalil et al. 1991). Similarly, Wassmann et al. extrapolated the results of measurements in Hangzhou, Zhejiang Province to the entire country, and estimated an emission of 18–28 Tg CH_4 y^{-1} (Wassmann et al. 1993). As field measurements accumulated, more flux data were included in upscaling methods. Yao et al. used flux data from six sites to represent 10 agroecological zones, and estimated 15.3 Tg CH_4 y^{-1} (Yao et al. 1996). Evaluating results from 12 field sites, Cai concluded that emission was 8.05 Tg CH_4 y^{-1}, and considered the effects of water regime and organic fertilizer

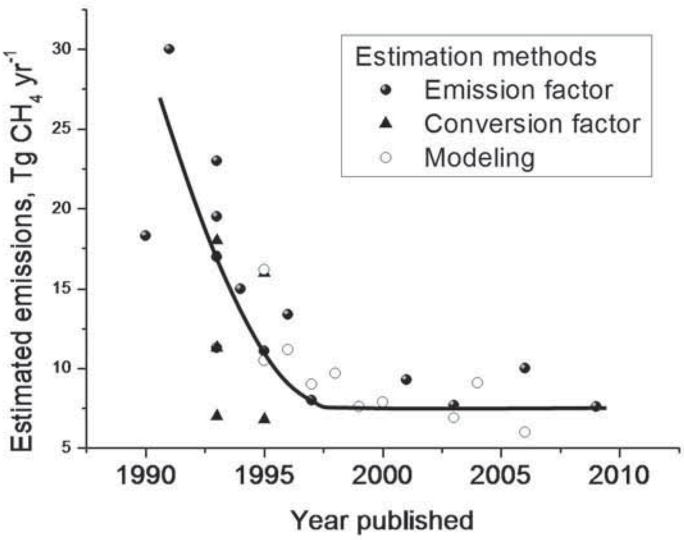

Fig. 1. Various estimations of CH_4 emission from Chinese rice fields, obtained by different methods, and published in different years. Figure was drawn with data from Cai et al. (Cai et al. 2009).

application (Cai 1997). With a total of 204 season-treatment measurements conducted on 23 sites, and considering the effect of water regime and organic amendment, Yan et al. estimated an emission of 7.67 Tg CH_4 y^{-1} (Yan et al. 2003).

Several process-based models of various levels of complexity have been developed to estimate CH_4 emission from rice fields in China. Cao et al. developed a simplified process-based CH_4 emission model. Taking rice primary production and soil organic degradation as supplies of carbon (C) substrate for methanogens, and considering environmental controls of methanogenesis, they estimated a total emission of 16.2 Tg y^{-1} for China (Cao et al. 1995). Huang et al. considered daily CH_4 emission flux as a function of photosynthetic activity, and incorporated the effects of organic matter, soil sand content, temperature and rice cultivar, and estimated the emission to be 9.66 Tg CH_4 y^{-1} (Huang et al. 1998). Based on a rice crop simulation model and integrating the effects of climate, soil, agricultural management and the growing of rice on CH_4 flux, Matthews et al. calculated an emission of 3.35–8.64 Tg CH_4 y^{-1} for China, and concluded that a more realistic estimate was 7.22–8.64 Tg CH_4 y^{-1} (Matthews et al. 2000).

Recently, we applied the tier 1 method of the 2006 IPCC (Intergovermental Panel on Climate Change) guidelines to estimate CH_4 emission from global rice fields – giving global total emission of 25.6 Tg y^{-1}, of which 7.6 Tg was estimated to be emitted from Chinese rice fields (Yan et al. 2009). We have compiled the most up-to-date dataset of CH_4 emissions from Chinese rice fields, with a total of 336 season-treatment measurements; the average of these seasonal measurements was 25.6 g m^{-2}. Simply multiplying this average flux by the total rice cultivation area of about 30 Mha, gives an estimate of 7.68 Tg CH_4 y^{-1}. Considering all the recent estimations obtained with different methods (Fig. 1), we are confident that CH_4 emission from Chinese rice fields is around 8 Tg y^{-1}.

4. Mitigation options for CH_4 emission from rice paddies

CH_4 is the terminal product of soil reduction in the succession of oxidation–reduction. In principle, any factors or practices able to retard soil reduction or reduce organic substrates will mitigate CH_4 emissions from rice fields. Among all factors, water regimes and organic substrates and their combination are crucial for controlling CH_4 emissions from rice fields.

Water regimes are important not only during the rice growing period, but also in the off-rice season, in determining CH_4 emissions from rice fields. Flooding, or at least water-saturation of soil, is a prerequisite but not sufficient condition for CH_4 production, since CH_4 is a terminal product of soil reduction. Only when active oxidants such as oxygen, NO_3^- , Mn_4^+, Fe_3^+ and SO_4^{2-} are consumed and anaerobic conditions have developed in soil (at least at microsites) is detectable amounts of CH_4 produced, given available organic substrates. The history of soil moisture before flooding for growing rice determines the duration of the development of anaerobic conditions after flooding (Xu et al. 2003), thus affecting CH_4 emissions from rice fields during the rice growing period. Since year-round flooding is the extreme water regime most favorable for CH_4 production, the largest CH_4 emissions were observed in rice fields in China that experienced these conditions (Cai et al. 2000). CH_4 emission also occurs if a rice field is flooded in the off-rice season (Cai et al. 2000). Therefore, draining rice fields sufficiently in the off-rice season will mitigate CH_4 emission in the off-rice season and also significantly during the rice growing period. Shiratori et al. (2007) found that subsurface drainage of waterlogged rice fields in Japan in the off-rice season mitigated CH_4 emissions significantly during the rice growing period. They established a linear relationship between soil moisture before flooding for rice transplanting and CH_4 emissions in the following rice-growing period. For various reasons, such as poor drainage in topographic depressions, lack of well-developed irrigation systems to ensure flooding of the rice field for rice transplanting, and poor management in the off-rice season, there is about 2.7–4.0 Mha of rice fields flooded year-round in China, and this is estimated to contribute CH_4 emission of 2.44 Tg y^{-1} (Cai et al. 2005). If flooding of some rice fields in the off-rice season is only due to poor management then lowering CH_4 emissions is relatively easy. For year-round flooded rice fields due to poor drainage and irrigation conditions, mainly distributed in hilly and mountainous areas in South and Southwest China, local farmers have developed a ridged cultivation system, in which ridges are built and maintained before rice transplanting every year. Rice is planted in both sides of the ridges, flooded water is kept in ditches, and the water level is raised to the top of ridges during the rice growing period and lowered to a certain level in the off-rice season. This practice raises soil redox-potential in the ridges and reduces CH_4 emissions by about 33% (Cai et al. 2003). Xu and Hosen demonstrated that keeping the soil water content in the range of 38–59% water holding capacity in the fallow season is important to lower CH_4 emissions (Xu and Hosen 2010).

It has been well documented that drainage in mid-season during the rice growing period mitigates CH_4 emission. As mentioned previously, Yan et al. found that, on average, CH_4 emission from rice fields with mid-season drainage was 53% that from continuously flooded fields. The effectiveness of mid-season drainage depends on the number of drainage events, and the timing and duration of each drainage event (Yan et al. 2003). Mid-season drainage has been widely practiced in China for > 30 years. The original objective of mid-season drainage was to control the number of rice tillers and promote root growth, and thus increase rice yield, rather than to mitigate CH_4 emission. The potential of this practice to mitigate CH_4 emissions from rice fields in China is expected to be limited since only for a small area of rice fields is mid-season drainage not currently practiced. Furthermore, a great attention is needed on the trade-off relationship between CH_4 and N_2O emissions from rice fields. Very large N_2O emissions were observed from rice fields with soil moisture close to water-saturation (Xu et al. 2004, Zheng et al. 2000), although this water regime significantly inhibited CH_4 emissions (Xu et al. 2004).

Increases in supplies of organic substrate under flooded conditions stimulates CH_4 emission. Therefore, amendments of organic manure, and incorporation of crop straw and green manure usually increase CH_4 emissions from rice fields. However, these practices may be essential for maintaining soil fertility. It has been demonstrated that at the same amount of organic C input, the CH_4 emissions induced by compost and biogas residues were less than that by crop straw (Wassmann et al. 2000). Incorporation of crop straw in the off-rice season when fields are drained stimulates CH_4 emissions less than incorporation just before rice transplanting (Cai and Xu 2004, Wassmann et al. 2000). CH_4 emissions induced by straw incorporation varies also with the patterns of straw incorporation (Ma et al. 2009). So, selecting an appropriate incorporation pattern should reduce the stimulation of CH_4 emissions. In the case of straw incorporation just before transplanting, practicing mid-season drainage earlier than usual can also reduce the stimulation of CH_4 emission (Cai et al. 2009).

CH_4 emissions from paddy fields are affected by planting density. Higher rice planting density leads to higher CH_4 emission fluxes because a high-density crop has more stems, leaves and roots, which speed up transmission and emission of CH_4. To ensure good crop yield, the rice planting density can be adjusted only within a very limited range, and hence there is limited potential of reducing planting density to reduce CH_4 emissions. The effect of rice variety on paddy CH_4 emissions varies. Ding et al. found that CH_4 emission was positively related to rice plant height, and the emission from paddy fields grown with tall-stalk rice (120-cm plant height) was 2.9 times that from fields sown with dwarf rice (90-cm height) (Ding et al. 1999). However, crop yield is the current priority for selection of rice varieties.

Application of electron acceptors such as NO_3^-- and SO_4^+-containing fertilizers, and Fe and Mn oxides mitigates CH_4 emissions from rice fields (Cai et al. 1997, Wassmann et al. 2000, Ali et al. 2009, Kara and Ozdilek 2010); however, they are less feasible. Chemicals that inhibit the activities of methanogenic bacteria depress CH_4 emissions during the rice growing period. Commonly used nitrification inhibitors can mitigate CH_4 emissions from rice fields (Li et al. 2009). It has also been reported that CH_4 emissions from rice–duck systems are less than from pure rice fields in south China (Zhan et al. 2011).

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Nitric Oxide Fluxes from Upland Soils in Central Hokkaido, Japan

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Abstract

Nitric oxide (NO) fluxes from soils were measured using the closed chamber method during the snow-free seasons (middle April to early November) for 3 years in a total of 11 upland crop fields in central Hokkaido, Japan. The annual mean NO fluxes ranged from 0.44 to 127 μg N m^{-2} hr^{-1} with the lowest observed in a grassland and the highest in a potato field. The instantaneous NO fluxes showed a large temporal variation with peak emissions generally occurring following fertilization and heavy rainfall events around harvesting in autumn. There was no clear common factor regulating instantaneous NO fluxes at all the study sites. Instead, instantaneous NO fluxes at different sites were affected by different soil variables. The cumulative NO emissions during the study period within each year varied from 0.02 to 5.11 kg N ha^{-1} for different sites, which accounted for 0.02% to 5.44% of the applied fertilizer N.

1. Introduction

Agricultural soils have been recognized as an important source of NO, making up 10% to 23% of the global atmospheric NO_x budget (Davidson and Kingerlee, 1997; Delmas et al., 1997). NO is produced in soil by both nitrification and denitrification (Conrad, 1996). Although nitrification is an aerobic process and denitrification is anaerobic, the two processes can occur simultaneously at aerobic and anaerobic microsites within the same soil aggregates (Azam *et al.*, 2002), and can be regulated by soil variables that influence microbial activity, such as the availability of NO_3^-, NH_4^+, O_2, and labile organic carbon, which, in turn, are controlled by a combination of soil properties (soil moisture, temperature, texture, structure) and soil management practices (Li *et al.*, 1992; Davidson *et al.*, 2000). Due to the complexity of interactions among soils, climate and land management driving the exchanges of NO between soils and the atmosphere, estimates of biogenic sources remain highly uncertain at regional and global scales (Rolland et al., 2010). National inventory of NO emissions from croplands are currently developed mainly by employing sets of emission factors derived from field-scale monitoring campaigns, assuming NO emission to be a fixed fraction of N inputs to soils. This clearly provides uncertainties in inventory calculations. Since agricultural activities play a significant role in the regional and global NO_x budget, precise estimates of NO emissions from arable land are being sought, along with possible means of abatement. Researchers have developed empirical and process models for this purpose (Li, 2000). However, more field measurements are still required to validate and improve the models, and to build regional or global inventories of NO from soils. Thus this study was carried out to quantify the magnitude of NO emissions from soils under different cropping systems in central Hokkaido.

2. Materials and methods

2.1 Site description

This study was conducted at Mikasa city, central Hokkaido, Japan (43˚14´N, 141˚50´E). In this area, snow cover usually begins in middle November and snowmelt completes around middle April. The mean annual air temperature and annual precipitation over 30 years (1971 to 2000) were, respectively, 7.4˚C and 1154 mm (Iwamizawa Meteorological Station Database, 2005). The mean annual air temperature in 2003, 2004, and 2005 was 7.4, 8.5, and 7.5˚C, respectively; the annual precipitation was 986, 1,295 and 1,398 mm, respectively.

Soil gas fluxes were measured at a total of 11 upland sites during the no snow cover seasons (middle April to early November) across 2003 to 2005. These sites were designated as A to G for 2003; A, D, E, and I for 2004; and A, D, P, Q, and R for 2005. These sites are distributed within an area of about 30 km^2 along with Ikushunbetsu River and have an altitude of 30 to 90 m a.s.l. The selected fields covered major upland soil-crop systems in the study area and were under local farmers' conventional management. The sites A and D have been converted from forest to agricultural use over 18 years at the initiation of this study. For other sites, the history of agricultural use ranged from about 40 to 100 years. The soil types were brown forest soils (Dystric Cambisols, FAO-UNESCO 1988) at sites A, D and R, gray lowland soils (Eutric Fluvisols) at sites B and P, brown lowland soils (Dystric Fluvisols) at sites C, E, F, G and I, and pseudogleys (Dystric Gleysols) at site Q.

The basic physical and chemical properties of soils and field management practices at the study sites have been detailed in the previous paper (Mu et al., 2008). The grassland site A was renovated in middle September 2002. *Dactylis glomerata* and *Phleum pratense* were the dominant species, and the aboveground biomass was harvested twice each year. The crop fields had been continuously managed under conventional tillage. Each year, the fields were generally plowed to a depth of roughly 25 cm before planting and after harvesting to incorporate crop residues. Winter wheat was generally sown in the previous September and harvested in the next late July or early August. Other crops were planted around May and harvested around September in the same year. The site D was planted with wheat in 2003, but was left fallow in 2004 and 2005 and ploughed frequently to control weed growth. Both of the sites E and P were under continuous onion (*Allium cepa* L.) for more than 10 years. The site R was subjected to a long-term pumpkin-potato rotation system. The total amount of chemical N application ranged from 0 kg N ha^{-1} at fallow site D to 300 kg N ha^{-1} at wheat site Q. Ammonium sulfate was the form of chemical N fertilizer except for the site Q to which 20% of N fertilizer was applied as urea. At site Q, the compost made from cow excreta mixed with wheat straw was also broadcast at a rate of 100 Mg ha^{-1} by wet basis and incorporated into the soil after wheat was harvested in late August. The organic carbon and total N applied with the compost were at the rates of 6543 kg C ha^{-1} and 339 kg N ha^{-1}, respectively.

2.2 Measurement of gas fluxes

The gas fluxes from the cultivated soils were measured using a closed chamber technique as described in the previous paper (Mu *et al.*, 2006). To determine NO fluxes, headspace samples of 200 ml were withdrawn from the chamber at 0 and 20 min, using a polypropylene syringe with a three-way stopcock, and transferred into a 500 ml Tedlar® bag. Concentrations of NO were analyzed using a chemiluminescence nitrogen-oxide analyzer (Model 265P, Kimoto Electric Co. Ltd., Japan). Sampling was conducted at a frequency of two to three times per month between 09:00 and 13:00 on each sampling date. The instantaneous gas fluxes from soils were calculated from the changes in gas concentrations in the chambers with time using a linear regression, and expressed as arithmetic means (n = 3). The cumulative gas emissions during the sampling period within each year were calculated assuming the existence of linear changes in gas fluxes between two successive sampling dates. The cumulative number of days was 200 for 2003 (i.e. from 10 April to 26 October), 213 for 2004 (i.e. from 10 April to 8 November), and 184 for 2005 (i.e. from 4 May to 3 November).

Triplicate measurements of soil temperature at 5 cm were recorded next to each chamber by a handy digital thermometer (CT-220, Custom Corp., Japan) at the time the gas flux was measured. The nine point soil temperature measurements at a site were averaged to produce a mean value for the site on each sampling date. Three disturbed soil samples were collected from 0-5 cm depth adjacent to each chamber at each site on each gas sampling date. Soil samples from the same sites were mixed and sieved (2 mm) to produce a homogeneous sample. Subsamples were used to determine soil moisture by oven drying at 105˚C for 24 hr. Soil moisture was expressed as the percentage of water-filled pore space (WFPS) using the measured soil bulk density (average of three measuring dates in

May, July, and September in each year) and assuming a particle density of 2.65 g/cm^3.

3. Results and Discussion

3.1 Soil temperature and moisture

Soil temperature generally increased from April through August and decreased after September (Fig. 1). Soil temperature was usually above 10˚C but rarely exceeded 30˚C from May through early November. The lowest temperatures were always measured from site A across the 3 years. The site D was left fallow in 2004 and 2005 and thus surface soil was directly exposed to sunlight, resulting in higher soil temperatures than other sites.

Soil moisture also responded to rainfall patterns over years (Fig. 1). Soil moisture usually ranged from 30% to 75% WFPS during April to May and September to November. Soil dry conditions prolonged from June across July in 2003. Some soil dry events also occurred during June to early August in 2004 and 2005, but each dry event was rapidly ameliorated by precipitation. Soil WFPS averaged for the sampling period varied from 38.0% at maize site C to 47.6% at grassland site A for 2003, from 40.6% at fallow site D to 62.0% at wheat site I for 2004, and from 36.4% at potato site R to 63.1% at grassland site A for 2005.

3.2 Soil NO flux

All soils were sources of NO, except for site A with several measurements showing a little uptake (-0.35 to -0.001 μg N m^{-2} hr^{-1}) (Fig. 2). In 2003, a pulse of higher NO emissions were observed in wheat soil D. On the first sampling date after snow melting (10 April), the NO fluxes in wheat soil D were 0.65 μg N m^{-2} hr^{-1}. Afterwards, the fluxes increased rapidly to higher emission levels (148 to 403 μg N m^{-2} hr^{-1}) with fertilization and lasted about 20 days. Through June to November 2003 the NO emissions in wheat soil D were lower than 21 μg N m^{-2} hr^{-1} (0.34 to 20.4). The seasonal pattern of NO emissions from other soils was characterized by low flux rates on most sampling dates and a few dates on which flux rates were higher than 20 μg N m^{-2} hr^{-1}. The lower rates were measured in grassland soil A (-0.35 to 2.25 μg N m^{-2} hr^{-1}). A slight increase in NO emissions followed fertilization or heavy rainfall during June to August for wheat soil B and F, maize soil C, onion soil E and soybean soil G, but few rates exceeded 50 μg N m^{-2} hr^{-1}. The emissions of NO from all soils were towards decrease in autumn in 2003. Seasonal patterns of soil NO fluxes in 2004 and 2005 were similar to that in 2003, with a pulse of higher emissions following fertilization observed in wheat soil I (41 to 117 μg N m^{-2} hr^{-1}),

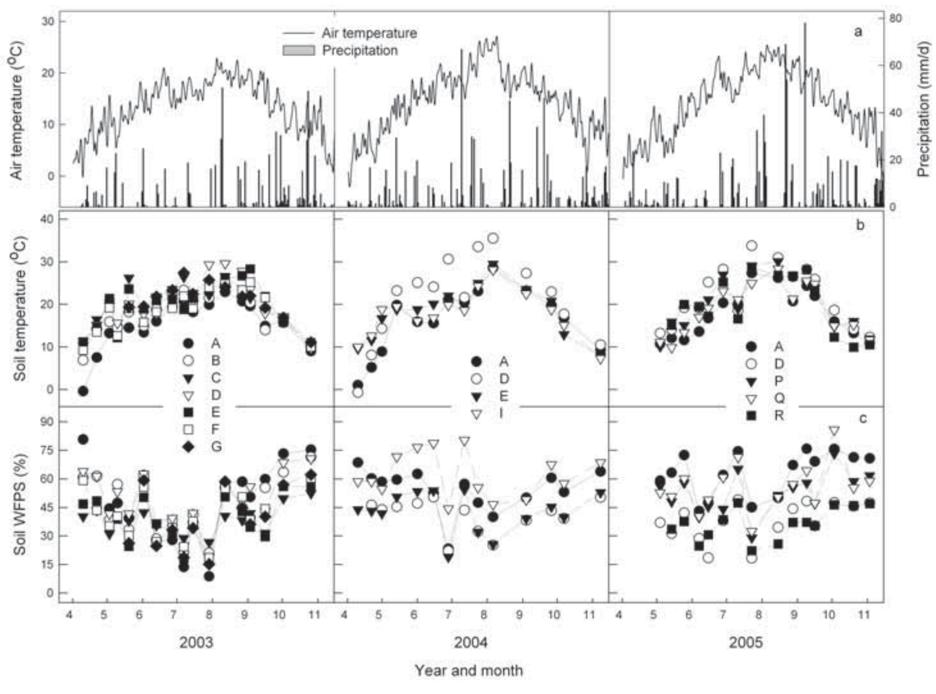

Fig. 1. Seasonal pattern of (a) local weather conditions, (b) soil temperature and (c) moisture at different fields. WFPS is water-filled pore space.

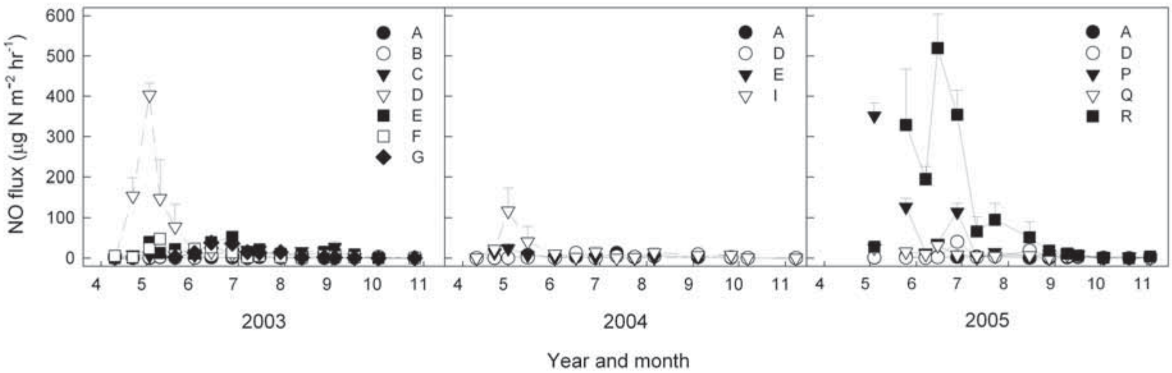

Fig. 2. Seasonal pattern of the NO fluxes from soils at different study sites.

onion soil P (127 to 352 μg N m^{-2} hr^{-1}) and potato soil R (195 to 520 μg N m^{-2} hr^{-1}) (Fig. 2). The lasting duration of the peak emissions for these sites were approximately 3 to 7 weeks. Previous studies have shown a strong stimulation of NO emission from agricultural soils just after nitrogen fertilization, lasting from a few days (Akiyama *et al.*, 2002) to 5 weeks (Akiyama and Tsuruta, 2003; Laville et al., 2009; Venterea et al., 2005). The reported peak values of NO fluxes ranged from 100 to 3960 μg N m^{-2} hr^{-1} (Akiyama and Tsuruta, 2002; Zhang et al., 2011). For this study, the maximum NO fluxes after fertilizer application ranged from 127 to 520 μg N m^{-2} hr^{-1}, which were well within the reported values.

The mean NO fluxes in 2003 varied greatly from 0.44 μg N m^{-2} hr^{-1} at grassland site A to 50.4 μg N m^{-2} hr^{-1} at wheat site D (Table 1). The mean NO fluxes from other soils ranged from 3.42 to 15.7 μg N m^{-2} hr^{-1}, and was not statistically different from grassland site A, but significantly lower than that from wheat

Table 1 Mean and cumulative fluxes of NO from different cultivated soils*

Year	Site	Land use	Mean flux (μg N m^{-2} hr^{-1})	Cumulative emission (kg N ha^{-1})	Fertilizer N rate (kg N ha^{-1})	Percentage of fertilized N (%)
2003	A	Grass	0.44 a	0.02 a	32	0.06
	B	Wheat	3.42 a	0.17 a	48	0.35
	C	Maize	10.61 a	0.48 a	196	0.24
	D	Wheat	50.44 b	2.04 b	140	1.46
	E	Onion	15.72 a	0.72 a	220	0.33
	F	Wheat	10.89 a	0.44 a	112	0.40
	G	Soybean	10.89 a	0.40 a	36	1.12
2004	A	Grass	2.86 a	0.15 a	50	0.30
	D	Fallow	2.85 a	0.17 a	0	-
	E	Onion	4.39 a	0.20 a	228	0.09
	I	Wheat	17.22 a	0.77 a	120	0.64
2005	A	Grass	1.83 a	0.08 a	100	0.08
	D	Fallow	6.01 a	0.28 a	0	-
	P	Onion	50.14 b	2.14 b	200	1.07
	Q	Wheat	9.57 a	0.41 a	300	0.14
	R	Potato	127.16 b	5.11 b	94	5.44

* The data followed by the same letters within a column and a parameter are not significantly different ($p > 0.05$) among sites in the same year. –: data not available.

soil D. In 2004, the mean NO fluxes ranged from 2.85 μg N m^{-2} hr^{-1} at fallow site D to 17.2 μg N m^{-2} hr^{-1} at wheat site I. In 2005, potato site R showed the highest mean NO flux (127 μg N m^{-2} hr^{-1}), and the mean flux for other soils ranged from 1.83 μg N m^{-2} hr^{-1} at grassland site A to 50.1 μg N m^{-2} hr^{-1} at onion site P.

3.3 Cumulative NO emission

Cumulative NO flux from soils during the sampling period within each year ranged from 0.02 kg N ha^{-1} at grassland site A in 2003 to 5.11 kg N ha^{-1} at potato site R in 2005 (Table 1). The pulse of higher NO fluxes following fertilization accounted for a large proportion of the total NO emission for wheat soil D (71%) and I (56%), onion soil P (59%) and potato soil R (71%). For other sites, no distinct peak emissions occurred after fertilization and the total NO emissions were evenly distributed to different cropping seasons.

3.4 Fertilizer N loss as NO

A few studies have reported a positive correlation between cumulative soil NO emission and fertilizer N rate (Liu et al., 2005; Mei et al., 2009; Veldkamp and Keller, 1997). Many other field studies, however, have failed to link soil NO emission directly to the application rate of fertilizer N. Similarly, no significant relationship existed between soil NO emission and fertilizer N rate in our study ($p > 0.6$). As an alternate approach, the emission factor is generally recommended to use for estimating regional NO emissions due to fertilizer application at annual or sub-decadal scales (IPCC, 2006). In this study, unfertilized or control plots were not established, therefore the fertilizer-induced NO emission factor could not be calculated as defined by IPCC (2006). Assuming that the NO emissions entirely came from the applied fertilizers, the fertilizer N loss rates as NO were estimated to be 0.06% to 5.44%, with an average of 0.84 ± 1.39% for all sites (Table 1). Our observed NO loss rates were mainly within the range of 0.01% to 4.0% reported for the agricultural soils over the world (Mei et al., 2009; Stehfest and Bouwman, 2006; Yao et al., 2010). The sites with peak emissions occurring after fertilization showed a consistently high NO loss rates when compared to other sites without distinct peak emissions. There might be some uncertainties in the estimates of NO loss rates due to the lower sampling frequency that might miss some peaks of NO flux. Soybean site G in 2003 was not observed for peak emissions after fertilization, but its NO loss rate was approximately 3 to 20 times higher than grassland site A and wheat site B to which a comparable amount of fertilizer N was applied. Leguminous crops such as soybean can transfer N from the atmosphere to soil, so the NO emissions from site G might partly be from fixed N and accordingly the fertilizer loss rates be exaggerated.

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N_2O and CH_4 Emissions from Andosols in an Intensive Dairy Farming Region, Japan

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Abstract

To investigate the effects of manure application, land uses and soil textures on N_2O and CH_4 fluxes on Andosol, We selected eight farmer's fields covering three cropping systems (rice, maize-fallow, and grass-maize) and four soil textures in an agriculture catchment of central Japan. The amount of applied N from chemical or organic amendments (i.e., compost, urine, and slurry) ranged from 200 to 800 kg N ha^{-1}. Field gas samples were conducted by static chamber method. The N_2O flux varied from -0.03 to 1.61 g N m^{-2} h^{-1} over all of the fields through whole year and the annual emission ranged from 1.28 to 9.26 kg N $ha^{-1}yr^{-1}$ which account for 0.21−1.08% of applied manure N. The winter crop season showed higher value than summer crop season. Fertilization and rainfall significantly stimulate soil N_2O fluxes. Manure types and land uses significantly affect soil N_2O emission and high values were observed in slurry and upland fields. The fluxes of CH_4 were -24.8− 29.1 μg C m^{-2} h^{-1} for upland fields and -57.5– 546 μg C m^{-2} h^{-1} for paddy rice, respectively. In this study region, CH_4 emission is mainly found in paddy rice field (0.39 – 6.67 kg C $ha^{-1}yr^{-1}$) rather than upland fields (- 0.03 − 0.02 kg C $ha^{-1}yr^{-1}$). For paddy rice fields, the CH_4 might be underestimated due to the limited sampling. No significant difference of CH_4 emissions were found in different soil texture, different fertilizer rate and fertilizer type.

Introduction

The increasing anthropogenic emissions of greenhouse gases (GHG), such as CO_2, CH_4 and N_2O are the major concern for global climate change. Agriculture was one of important sources of CH_4 and N_2O emissions (IPCC 2007). Estimates of agricultural nitrous oxide (N_2O) and methane (CH_4) emissions are needed to develop economical efficiency as well as effective policies in mitigating and reducing greenhouse gas emissions in farming systems. In Japan compared with the beginning of 70's, the livestock sector grew two times in recent years to meet the increasing demand in meat and dairy productions (Shindo et al. 2009). As a result, the increased manure applied to soil became one of the most important sources of green house gas (GHG) emission from agricultural soils, which mainly depends on land uses and management methods (Mosier, et al. 1998; Li, et al, 2004). However, the potential of alternative management practices to reduce soil N_2O and CH_4 emissions has been poorly studies, and quantitative estimates across fields remain uncertain.

Furthermore, Japan is an active volcanic country, where Andosol covers 16.4% of the land surface and 46.5% of arable upland fields (Ministry of Agriculture, Fishery and Forestry, 1991). These volcanic soils are originally acidic and have high friability, high porosity and high content of Al and Fe with high humus accumulated ability (Shindo and Honma, 2001). Consequently, those unique physical and chemical characteristics in Andosols can lead to different C and N cycles compared to other soil orders. Hayashi et al. (2011) reported that Anosols showed the limited ammonia volatilization loss from upland fields. So far, GHG emissions from Andosols under intensive application of dairy manure have been hardly studied.

In this study, N_2O and CH_4 has been measured in an intensive dairy farming system across different manure type (slurry or compost), four soil textures (loam, silt loam, sandy loam and loam sand) and different land uses (paddy rice and uplands). The aims are (i) to investigate the effects of intensive manure application, land uses and soil textures on N_2O and CH_4 fluxes on Andosol. (ii) to estimate N_2O and CH_4 emissions from an intensive dairy farming region.

Materials and Methods

This study was conducted from May 2009 to April 2010 at upstream of Naka River watershed in Japan (36˚49`- 37˚01`N, 139˚54`-139˚59`W). In this region, major crop systems are one season cultivation of rice (R), maize (M), and a rotation of grass and maize (G/M). Dairy cow manure is the main fertilizer source, which ranges from 200kg N $ha^{-1}yr^{-1}$ to 800kg N $ha^{-1}yr^{-1}$. Five sampling sites (marked with I-V) were chosen according to different land uses (uplands and paddy rice), soil textures (loam, silt loam, sandy loam and loam sand) and location (Fig. 1). There are 8 sampling fields in total and the soils are Andosol. Three samples were taken at each field randomly. In G/M system, Italian ryegrass (Lolium multiflorum L.) was planted in October and harvested in May, immediately followed by the planting of maize, which was harvested in September. For R system, the field was flooded from May to late August; the rice seedlings were transplanted in May and harvested in October. The detail soil and fertilizer information could be found in Deng et al. (2011).

Nitrous oxide (N_2O) and methane (CH_4) gas samples were carried out in intensive monitoring and intermitted monitoring using static chamber method. In intensive monitoring, N_2O flux and CH_4 was measured after applied manure, during harvest time and snow time, every 2 days one sampling time. It will not be stopped until the flux becomes very stable (about 2 weeks). For intermitted monitoring: gas measurements were conducted bimonthly. Soil mineralization N, moisture, temperature and soil dissolved organic matter of topsoil will be measured at same time. N_2O concentrations were measured using a gas chromatograph equipped with an electron capture detector (GC-2014, Porapak Q column, Shimadzu). The carrier gas was a CH_4 and Ar gas mixture with the volume ratio of 5:95. The oven and detector temperatures were 80 and 340˚C. The contents of CH_4 were tested by a thermal conductivity detector. The N_2, H_2 and air were used as the carrier, fuel and supporting gas, respectively. The column, injector and detector temperature were 55, 100 and 200˚C.

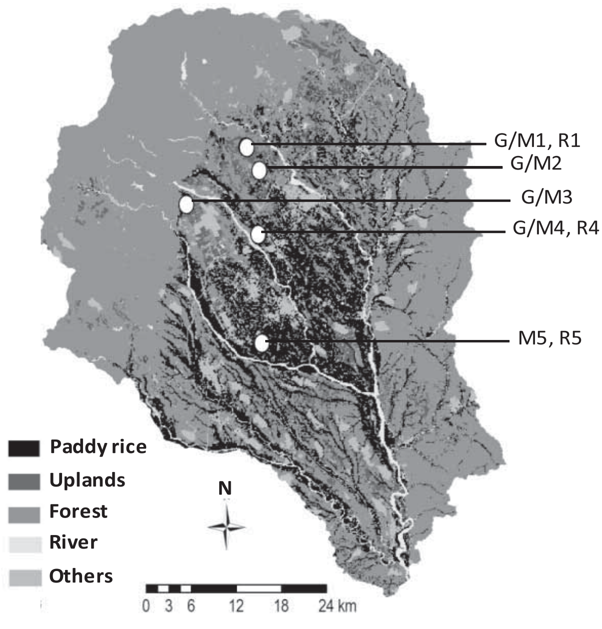

Fig. 1. The sampling sites in the Upper Naka River Watershed, Tochigi, Japan. G/M and R indicate the grass/maize rotation and paddy rice land.

Results and discussion

N_2O emissions

The N_2O fluxes in soil ranged from -0.03 to 1.61 g N m^{-2} h^{-1} through the whole year. Fertilization events significantly stimulated N_2O emission and the high flux can maintain 2 weeks to 1 month after the application of manure. The cumulative emissions were 0.06−1.33 kg N ha^{-1} in summer season (May-Sep) and 0.91−8.30 kg N ha^{-1} in winter period (Oct-Apr) and winter season showed significantly higher values ($p < 0.5$) than summer season (Fig. 2). This might be resulted from the lower N requirement of crops, and consequently soil has higher content of available N for nitrifies/denitrifies in winter season compared with summer crops. Heavy rainfall was found significantly stimulated N_2O fluxes in all fields and high flux was observed on 27 October 2009. Similar observations have been reported by many researches (Dambreville et al. 2008; Li et al. 1992). This significant N_2O flux could be generated by the rainfall which stimulates the soil anaerobic condition which was suitable for denitrifies. During snowing period, no significant N_2O emission was observed. Generally, during freezing and thawing season, some N_2O peaks occurred (De Bruijin et al. 2009). The difference might be explained by that there was no thawing to stimulate the anaerobic condition (Koponan et al. 2006) or the slow N_2O diffusion processes (Müller et al. 2002).

Overall, the cumulative N_2O emission from soils varied 1.28− 9.26 kg N ha^{-1} yr^{-1} which accounts the 0.21-1.08% of applied manure N (Fig. 2). The highest emission was found in the field with high clay and silt content and slurry application which provide a good anaerobic condition for denitrification process (G/M3) (Paul and Beauchamp, 1989). Farm managements also significantly influenced N_2O emission, the farmer's practice of the plowing immediately after composted manure application can significant decrease the N_2O emission (G/M1). Mixing manure and soil could stimulate crop uptake N and make soil with high porosity which was not suitable for denitrification process. Paddy fields showed significantly lower N_2O emission (0.89−1.91 kg N ha^{-1} yr^{-1}) than uplands (1.91 – 9.26 kg N ha^{-1} yr^{-1}). This result could be attributed to the highly anaerobic condition in paddy rice fields which contributes to denitrification process producing more N_2 rather than N_2O compared with uplands (Deng et al. 2011).

CH_4 emissions

The daily methane flux was ranged from -24.8 to 29.1 μg C $m^{-2}h^{-1}$ for uplands. Most of the values were very low and negative which was less than 1.59 μg C $m^{-2}h^{-1}$, except fields G/M2 and G/M3 at 31st May 2009 and G/M4 on 10th May with 29.1, 25.6 and 10.5 μg C $m^{-2}h^{-1}$. Those high values could be stimulated by the heavy rainfall after the fertilizer application (Mori, et al. 2008). No significant CH_4 fluxes were found after manure application. Similarly, Chadwick and Pain (1997) suggested that CH_4 emissions from soil were unaffected by manure application with high dry-matter content. Considering the different of seasons, no significant difference was observed between CH_4 emission in winter crop season (from -0.26 to 0.02 kg C ha^{-1}) and summer crop season (from -

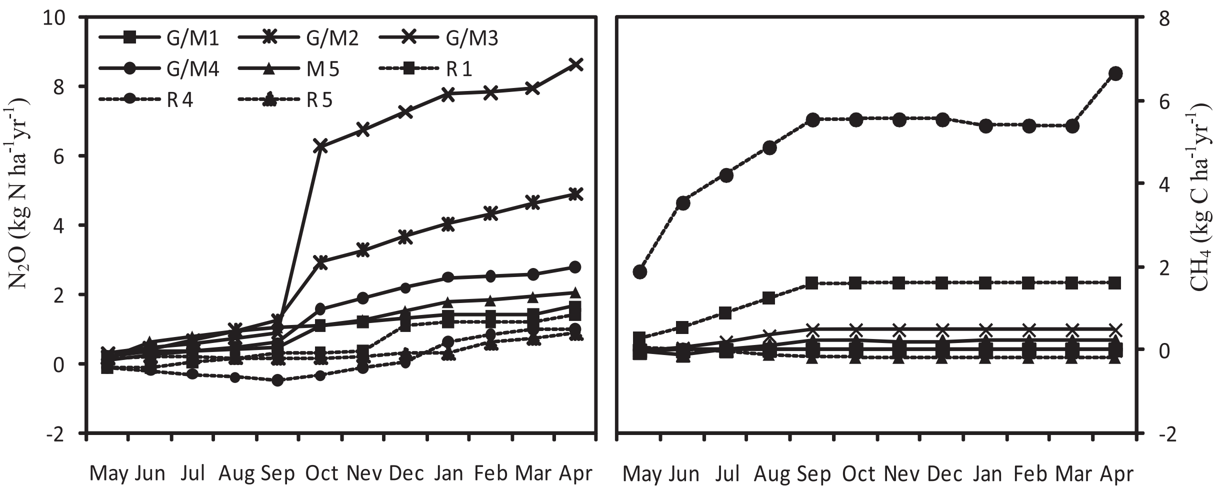

Fig.2. The cumulative N_2O and CH_4 emissions across all of the fields through a whole year

0.002 to 0 kg C ha^{-1}) ($p>0.05$). Thus, the annual CH_4 emissions varied from -0.026 to 0.02 kg C ha^{-1} yr^{-1} and no significant difference was found over all of the upland fields.

In paddy rice fields, the CH_4 fluxes changed from -57.5 to 546 µg C m^{-2} h^{-1} in paddy rice fields. During flooding season, CH_4 fluxes were maintaining high level (0.18 – 546µg C m^{-2} h^{-1}). However, some high peaks of CH_4 emission might be missed due to the limited sampling time in rice flooding season and also those measurements only included soil CH_4 emissions while no rice plant CH_4 emissions. For un-flooding season, most of values were negative and the emissions were nearly ignored.

Conclusion

The current results suggested that land uses are the main factors to influence N_2O and CH_4 emissions. Paddy rice can significantly reduce the amount of N_2O emission whilst obviously stimulate CH_4 fluxes during flooding season. Fertilization and rainfall was the main factor to influence soil N_2O emissions. Greater N_2O emission could be produced by the application of slurry than that of dry compost. In winter season due to the lower crop N uptake, the N_2O emission was significantly higher than summer crop season. The cultivation immediately after manure application showed lower N_2O emissions than other farming practices. Regarding the CH_4 in the un-flooding soils, most of the value was negative and unaffected by fertilization and soil textures. But, heavy rainfall also can stimulate CH_4 emission.

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Possible Nitrogen Removal through Denitrification in the Watershed Scale

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Abstract

Large apparent N loss has often been observed between the anthropogenic N input and the riverine N export in river basin, but few persuasive results are available to verify its cause. Here, both a hilly agricultural area and an upland-lowland transect are studied to clarify the implication of groundwater denitrification that could account for the NO_3^- removal during discharge process. In a sloping highland used for cabbage agriculture, the estimated NO_3^- concentration calculated from the N and hydrological budgets agreed well with observed NO_3^- concentration in streams, indicating that the stream NO_3^- concentration can be simply accounted for by the N and water balance and negligible denitrification in this hilly region. In contrast, decreased NO_3^- concentrations are invariably observed in lower sites of slope, where more humid condition prevails. A transect study in an agricultural region showed marked decreases in NO_3^-/Cl^- ratio and dissolved oxygen concentration and significant increases in dissolved N_2/Ar ratio in ground water in lowland sites, clearly indicating NO_3^- removal by denitrification. Forest sites having a groundwater table shallower than ca. 1m also tend to have evidence of denitrification and other reductive processes. Except sloping areas, water is due to move through the groundwater in the lowland before flowing out to rivers, where reductive condition prevails. From the reasons raised here, it is highly likely that a large part of nitrogen discharged from land surface may be removed by denitrification especially in the river basin scale.

Introduction

The increase of N loading from anthropogenic sources such as agriculture, sewage, and atmospheric deposition have resulted in the increase in nitrogen concentration in river discharge. Increased riverine N export is expected for catchments having large N load such as in European and Eastern Asian countries (Seitzinger and Kroeze, 1998). A linear relationship has often been shown between the net areal N input and the riverine N flux even for large river basins (Howarth et al., 1996).

But importantly, the observed N output by river discharge is much less than the calculated N input: regional nitrogen fluxes in rivers are only 16% to 25% of the total of anthropogenically derived nitrogen inputs (Howarth et al., 1996; Caraco and Cole, 1999; Howarth et al., 2006). The discrepancy between N load and riverine N export suggests a significant sink in river basins. Denitrification in wetlands and aquatic ecosystem has been considered important, but it is also thought that other mechanisms such as storage in soil and forests could be of importance as well. Large uncertainty remains as to the cause of this nitrogen loss with little robust evidence showing the contribution of denitrification in the watershed scale. It is essential to understand the biogeochemical behavior of N after anthropogenic loading to environments including this large possible sink. The present paper discusses the potential importance of denitrification, which likely acts as a significant sink to remove dissolved nitrogen during the process of discharge especially in lower reaches of rivers.

Materials and method

N budget was studied in an agricultural highland area, Tsumagoi, Gumma Prefecture, where agricultural field, mostly for cabbage, is distributed in hilly landscapes around 1000 – 1400 m asl. It is conceivable that groundwater would be mostly well-oxygenated due to relatively fast flowing in this sloping region. River water sampling was conducted in June, August and October, 2005, at 28 fixed tributaries and 10 fixed mainstream points of the Agatuma River. Concentration of nitrate and total dissolved nitrogen was measured by an ion chromatography (Dionex, DX-120) and a total nitrogen analyzer (Mitsubishi Chemical Analytech, TN-100), respectively. The average concentration was used for the analysis.

The watersheds have variable land coverages of cabbage field, forest, and others. The nitrogen loading into a watershed was calculated from the following equation, on the assumption that the leaching from cabbage fields is the sole source of dissolved nitrogen.

$$L = (F - H) \times A$$

where L, F, H, and A are N loading into a watershed (kg N $ha^{-1}year^{-1}$), the fertilizer application rate to cabbage field (180 kg N $ha^{-1}year^{-1}$; Japan Agricultural Cooperatives at Tsumagoi village), N recovery due to cabbage harvest, and the areal coverage of cabbage field in a watershed, respectively. The N recovery by cabbage harvest (H) was calculated from the typical cabbage yield (6.23×10^4 kg ha^{-1} yr^{-1}; Japan Agricultural Cooperatives at Tsumagoi village) and the nitrogen content of cabbage, which was measured as 1.70×10^{-3} N kg kg^{-1}. The whole area and agricultural area in a watershed were estimated from a 1:25,000 land use map of Tsumagoi Village (Tumagoi Village Office, 2004) by a weighing technique. The area of cabbage field was assumed to be equivalent to the agricultural area because 93% of the agriculture area is covered by cabbage field (Tumagoi Village Office, 2004). The water discharge from a watershed was estimated from the water budget, calculated from the difference between annual precipitation (1664 mm) and evapotranspiration (this was assumed to be 700 mm in the present calculation). Nitrogen export by river (10^6 g N $year^{-1}$ per watershed) was estimated from measured nitrogen concentration in river water and this water discharge.

In Kamagaya city, Chiba prefecture, ground water sampling was conducted from wells along an upland-lowland transect in agricultural area. Orchard and vegetable fields dominate in upland sites, while orchard, vegetable fields and rice paddy in lowland site. Dissolved gas was extracted from sample water in a vial by a headspace method. Gas analysis was made by a GC-system, which enables simultaneous measurement of N_2, O_2, Ar, CO_2 and CH_4 with a sufficient accuracy (Yoh et al., 1998).

Results and Discussion

(1) The balance of fertilizer N input and riverine N export in Tsumagoi highland agricultural region

Concnentration of TDN (total dissolved nitrogen) or nitrate in the whole rivers studied in Tsumagoi showed a variation of more than one order of magnitude ranging from 12 to 223 μ mol L^{-1} and 7 to 195 μ mol L^{-1}, respectively. They showed positive correlations against the percentage of cabbage field coverage in the watershed (data not shown), suggesting that the leaching from cabbage fields is a dominant factor to control the concentration of TDN or nitrate.

Riverine export of TDN is plotted as a function of the estimated nitrogen loading into a watershed in Fig. 1. An excellent linear relationship was found between them with a slope close to 1, implying that the output of nitrogen by rivers is almost equivalent to the input of nitrogen into the watershed. Discharge of inorganic nitrogen proved to be satisfactorily accounted for by the N and hydrological budgets. The results demonstrate a negligible loss of nitrogen within the watersheds, in a striking contrast to previous studies reporting nitrogen removal of large proportions as described above. It is evident that little denitrification is occurring in case of such a sloping highland. The results suggest that nitrogen storage in soil and forests that is presumed in previous studies to be partly responsible for the decreased riverine N fluxes relative to the total anthropogenic nitrogen inputs may contribute little if any.

(2) Importance of lowland as the site of nitrogen removal by denitrification

The study of groundwater showed a distinct difference in NO_3^- concentration along a upland - lowland transect; 930-2000 μ mol L^{-1} (mostly more than the drinking water standard of 10 mg N L^{-1}) in upland site but 0-114 μ mol L^{-1} in lowland sites. Decrease in NO_3^-/Cl^- ratio and decrease in dissolved oxygen concentration were generally observed in lowland sites in comparison with upland sites (Fig. 2). The measurement of dissolved gases showed remarkable increases in relative N_2/Ar ratio in dissolved gases especially in the lowland region, demonstrating N_2 production in

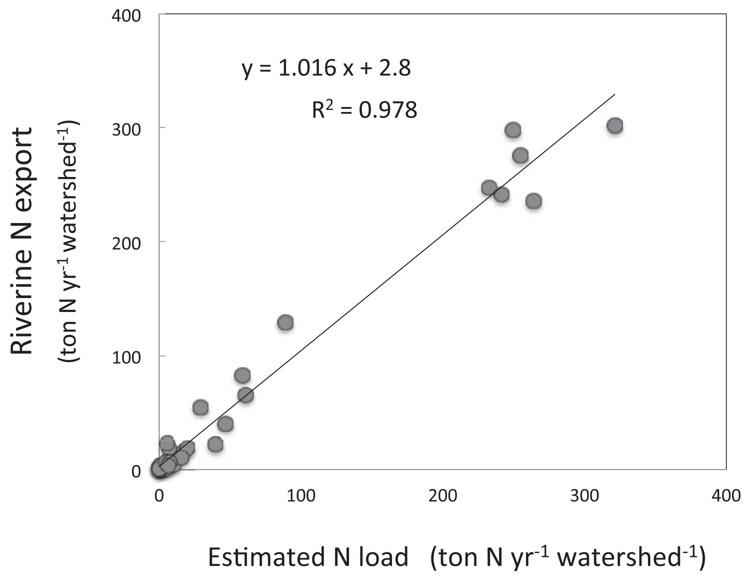

Fig. 1. The relationship between calculated riverine export of dissolved nitrogen and estimated nitrogen loading for watersheds in Tsumagoi highland agricultural region. See text for details to calculate both variables. The equation of linear regression and correlation coefficient is shown in the figure.

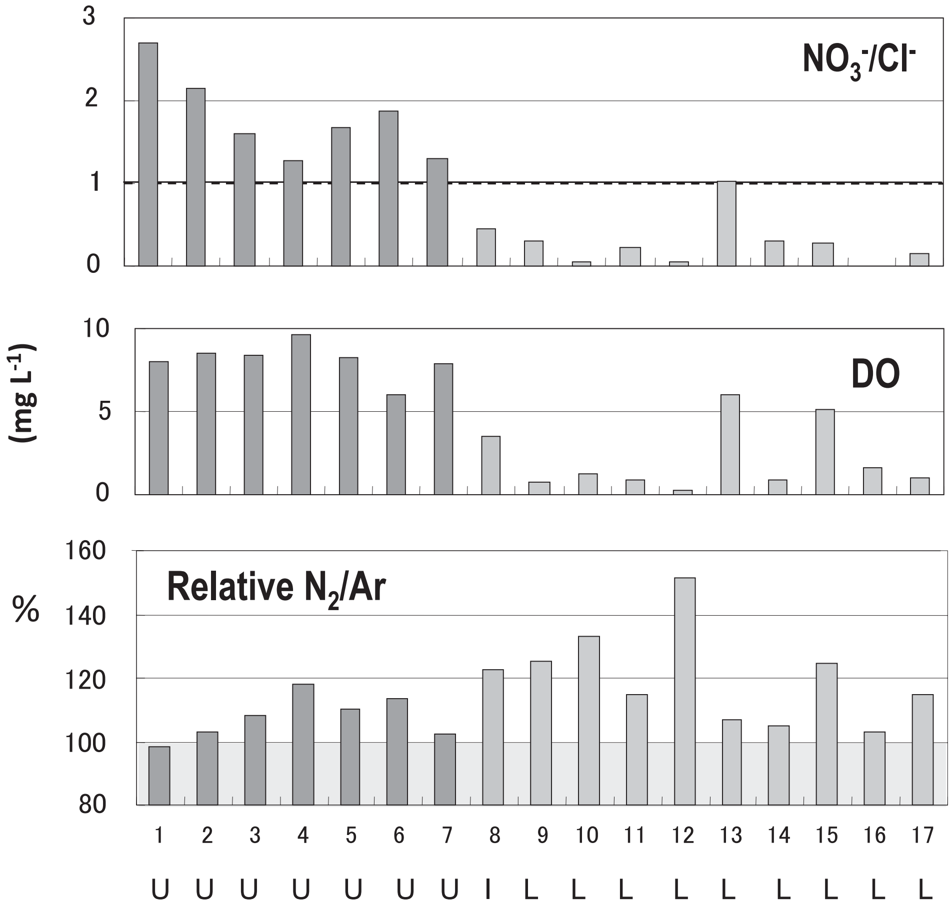

Fig. 2. Change in NO_3^-/Cl^- ratio (top), dissolved oxygen concentration (middle) and relative N_2/Ar ratio in dissolved gases (bottom) along a upland - lowland transect in Kamagaya, Chiba prefecture. Relative N_2/Ar ratio represents the percentage of measured N_2/Ar ratio relative to the theoretical value calculated from in situ temperatures. U, L and I in the figure denote upland sites, lowland sites and intermediate site, respectively.

groundwater. The results demonstrate denitrification largely contributes to the removal of nitrate especially in lowland area, where more humid and deoxygenated condition prevails due to lower position of slope. The prevalence of reductive condition and denitrification has also been observed in riparian zone and in sub-soil deeper than 1m even in forested watersheds (Konohira et al., 1997).

It is reasonable to assume that the ground water at a certain site comes not only from a vertical flow at the same location but also from the upstream area by a lateral flow of ground water in aquifer; namely, it is supplied from the whole upper watershed. In the light of this hydrological connection between upland and lowland, upstream groundwater (sometimes of high NO_3^- concentration) would never go to a river without passing through the lowland zone, where denitrification takes place. It is thus likely that nitrate of elevated concentration in aquifer has a chance to be removed during the process of transport to a surface runoff. The molar ratio of NO_3^- /Cl^- observed in groundwater in the present study was 1.7 and 0.3 in upland sites and lowland sites in average, respectively. On the assumption that the decrease in this ratio in lowlands is due to denitrification and that negligible denitrification is occurring in upland sites, then it is estimated that nitrogen concentration was lowered to 18 % by denitrification, equivalent to the ratio of observed riverine N export to calculated N input in the river basin of 16% to 25% (Howarth et al., 1996; Caraco and Cole, 1999; Howarth et al., 2006).

In addition to a lateral topographical importance addressed above, a longitudinal aspect in landscape is of another significant implication regarding to the nitrogen sink in lands. The longitudinal section of a river, and accordingly the land surface, generally has a shape approximated by an exponential curve. A significant drop in NO_3^- concentration has been observed in stream waters in forest areas of lower elevation in Tama River system, where dissolved Mn, NH_4^+ and the evidence of sulfate reduction are also found in stream waters indicative of reductive condition in these areas (Yoh et al., 2004). Increase in dissolved Fe concentration has also been shown in streams of lower reaches in a forested watershed of the Amur River basin (Yoh et al., 2010). It is thus likely that reductive condition and denitrifying zone would be usually prevailing under the soil in lower reaches, probably according to a gentle slope and a shallow ground water table.

The results raised here suggest that nitrogen leached out from agricultural lands could be substantially removed by denitrification in the river basin in general, which has not been unambiguously recognized. Further systematic researches are required to know the actual quantitative importance of denitrification and the boundary conditions regulating this process to contribute to nitrogen removal during the discharge process.

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Effect of Toposequence Position on Soil Properties and Crop Yield of Paddy Rice in Northern Mountainous Region, Vietnam

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Abstract

In tropical mountainous regions of Northern Vietnam, intensive cultivation of upland crops enhances large nutrient losses through erosion in the upland areas. However, in the valley areas, sediment deposition can enhance soil fertility depending on the quality of the sediments, and influence the crop productivity. To access the spatial differences in soil properties and crop yield at cascade level affected by either sediment induced or farmers' fertility practice, field experiment was conducted in Cheing Khoi watershed area during the spring crop season (February to July, 2011) with two different cascades (one cascade consists of 5 different toposequence fields) wherein half of each cascade was fertilized with farmer recommendation practice.

Total nitrogen and carbon contents were significantly higher in middle field than others. Number of effective tillers, panicle length, grains per panicle, filled grain % and 1000 grain weight varied significantly due to different toposequence position. Rice yield in the middle of toposequence showed better performance than the other field positions in fertilized and unfertilized fields in both cascades. The observed grain yields for non-fertilized fields averaged over both cascades, accounted for 0.55, 0.64 and 0.47 kgm^{-2} in top, middle and bottom fields, respectively, while for fertilized fields, grain yield of 0.72, 0.79 and 0.63 kgm^{-2} were obtained. The larger toposequential differences in crop yield require different crop management practices for each toposequential position, in order to improve rice production in this watershed area.

Introduction

In Northern mountainous region of Vietnam, the topography is characterized by mountains with partly steep slopes with altitudes between 300 and 1000 m. In this region, an important agro-ecosystem is a composite swidden agriculture which integrates annual food crops, such as maize, cassava and upland rice, and fallow in the uplands and permanent wet rice fields in valley bottoms of the catchment (Lam et al., 2005) to form a single household resource system (Rambo, 1998). More recently, traditional agriculture methods involving fallows are more and more replaced by market oriented land use annual monocropping systems that have a low soil cover during their establishment phase (eg. Maize), inducing severe erosion on steep slopes. Such land use alterations have dramatic environmental effects (Wezel et al., 2002) and high precipitation will lead to accelerate soil degradation due to erosion of the steep slopes used for agriculture.

Soil erosion is considered to have serious impacts on the current productivity and sustainability of the land. Upstream erosion will lead to sedimentation and siltation of downstream water bodies and paddy fields as well as to nutrient transportation within sediments and irrigation water. During erosion events, nutrients are removed and, attached to eroded sediments, reallocating in the watershed (Dung et al., 2008; Pansak et al., 2008). Sediment rich water will flow into the paddy fields at the upper side and flow out at the lower side so that the distribution of the sediments is unequal throughout the rice fields. The deposited sediments create patterns of spatial variability in soil fertility of downstream watershed (Gao et al., 2007; Mingzhou et al., 2007).

Rice fields are located on the gently sloping land with differences in elevation for a few meters in an undulating topography. These differences in toposequence position may lead to differentiation in soil properties and hydrological conditions (Hseu and Chen, 2001; Tsubo et al., 2006) and therefore crop yield. Topography directly affects soil-forming processes through erosion and deposition, and variation has been observed in soil texture (Eshett et al., 1989; Posner and Crawford 1992; and Yamauchi, 1992), nitrogen (N), phosphorus (P) and potassium (K) content (Moormann et al., 1977; Eshett et al., 1989; Posner and Crawford, 1992, and Yamauchi, 1992) among the toposequence position. Furthermore, organic compounds present in the water also will influence soil fertility in paddy rice fields. However, redistribution of nutrients through erosion-sedimentation processes in upland-lowland areas and its impact on soil fertility in the lowland are too often neglected (Mochizuki et al., 2006; Ruth and Lennartz, 2008).

There have been studies about spatial variability of yield, crop growth performance and soil but the knowledge about sediment inducing spatial variation in soil properties and crop yield among the toposequence position due to upland soil erosion is still limited. Therefore, the experiment was conducted with the objective of (1) to access the sediment inducing toposequential variability of soil properties and crop yield at cascade level and (2) to distinguish between the inherent spatial variability in soil fertility induced by sediment deposits and soil fertility induced by farmers' fertilization practice.

Materials and Methods

The study watershed area (2 km^2) is located in the ChiengKhoi commune (350 masl, 21˚ 7′60″N, 105˚ 40′0″E) situated in the Yen Chau district, Northwest Vietnam. The climate is characterized by tropical monsoons with very hot and rainy summers (May-October) and cool and dry winters (November-April) with average annual rainfall of 1200 mm and average annual temperature of 24˚C.

Two rice cascades (series of paddy terraces) were selected for this experiment. Cascade 1 (C-1) was 83 m long with height difference of 7 m, and cascade 2 (C-2) was 87 m long with height difference of 5 m among the toposequence position. Both cascades contained 5-6 successive paddy fields, covering a total of 0.8 ha. The uppermost field of cascades received water directly from the irrigation channel. All other fields received water from single inlet from above lying field and drain via single outlet to the lower situated field.

The experiment was laid out in a split plot design with three replications at each site. Two sets of factors included in this experiment are as follows: different toposequence position (top, middle and bottom) as the main plot and with (+F) and without (-F) fertilizer application as the subplot. The applied chemical fertilizers were 213 kg N ha^{-1}, 150 kg P ha^{-1} and 93 kg K ha^{-1}according to the local recommendations by extension service.

Soil type was Gleysols (silty loam in the different horizons). Seed of variety Nep 87 was raised in seed bed on 12 February 2011. Seedlings of 17 days old were transplanted on 28 February 2011 in the well-puddled experimental fields. Fertilizer was applied three times: basal, active tillering stage and heading stage. All other managements were the same in both cascades.

Top soil samples at 0-5 cm depth were taken before rice transplanting and after harvest for total N (TN) and total carbon (TC) content. Seven samples hills were collected from each plot for collection of data on plant characters and yield components. Grain yield was determined from 1 m^2 sampling area at harvest and was expressed as rough (unhulled) rice at 14% moisture content. All the data were evaluated by an analysis of variance (ANOVA) by using CropStat 7.0 statistical software. Treatment means were compared by least significant test ($LSD_{0.05}$).

Results

Soil TN and TC contents were significantly different ($P<0.01$) among the field position (Table 1). The C-1 and C-2 contained average value of 0.25 gkg^{-1} and 0.24 gkg^{-1} TN whereas TC was 4.75 g kg^{-1} and 3.89 g kg^{-1}, respectively. When compared with different toposequence position, TN content was significantly higher at the middle field followed by bottom and the lowest was found at the top field. The same trend like TN was also found in TC content in C-1, but bottom field of NF was the highest after trans-

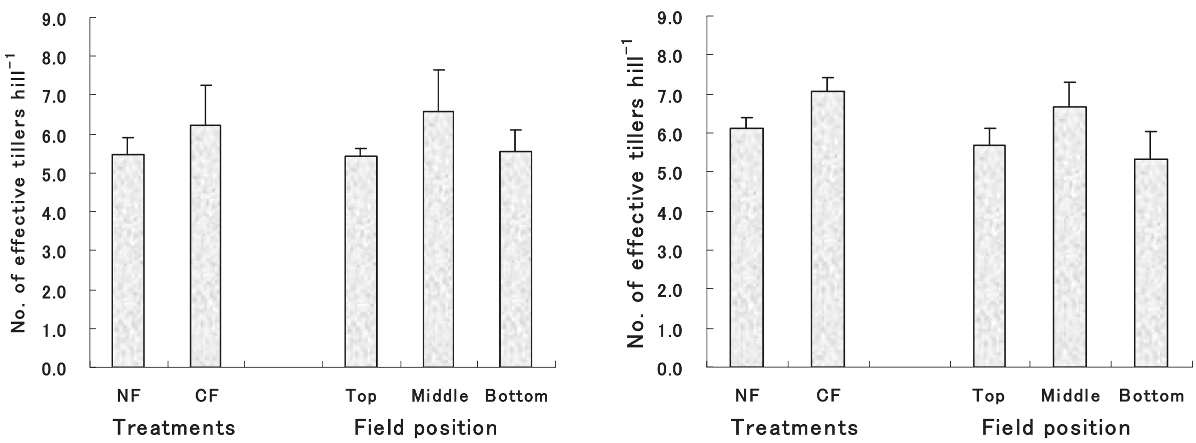
Table 1. Soil total nitrogen and carbon content after harvest of the spring crop

Cascade	Field position	Fertilizer	TN (gkg^{-1})	TC (gkg^{-1})
C-1	Top	NF	0.17	3.08
		CF	0.17	3.31
	Middle	NF	0.33	5.94
		CF	0.30	5.44
	Bottom	NF	0.28	5.52
		CF	0.29	5.22
		CV(%)	11.2	11.6
		$LSD_{(0.05)}$	0.05	1.0
C-2	Top	NF	0.18	2.55
		CF	0.17	2.42
	Middle	NF	0.25	4.48
		CF	0.32	4.27
	Bottom	NF	0.31	5.67
		CF	0.21	3.96
		CV(%)	10.9	10.8
		$LSD_{(0.05)}$	0.04	0.8

planting in C-2. There were no significant differences in TN and TC content between the two sampling times (before transplanting and after harvest) for C-1 (data not shown).

Significance differences in effective tiller per hill ($P<0.05$) were observed among the different toposequence position in both cascades (Fig. 1). For the effect of field position on average, the highest number of effective tillers per hill was found in the middle field than other fields. The lowest number of effective tillers was observed at top field (5.5) in C-1 and at bottom field (5.3) in C-2. Number of effective tillers in top and bottom fields showed no significant differences in both cascades. Significant variation in number of effective tillers per hill ($P<0.05$) was observed due to fertilization (Fig. 1). Application of fertilizer produced higher number of effective tillers with 6.2 and 7.0 in C-1 and C-2 while those in non-fertilized plots were 5.5 and 6.1, respectively.

Fertilizer treatment did not show any significant variation in respect of panicle length and filled grain proportion (Table 2). The overall mean values were



(a) Cascade 1 **(b) Cascade 2**

Fig. 1. Effect of fertilizer and field position on no. of effective tillers $hill^{-1}$. Error bar indicates standard deviation

Table 2. Effect of fertilizer and toposequence position yield components of spring rice in Cascade 1 and 2

		Treatment	Panicle length (cm)	Grains panicle^{-1}(no)	Filled grains%	1000-grain weight (g)
C-1	Fertilizer	NF	21.7	136.1	78.9	24.1
		CF	22.5	154.4	80.6	25.0
	CV(%)		3.9	15.6	14.7	3.7
	$LSD_{(0.05)}$		1.2	13.2	4.5	0.9
	Field position	Top	23.3	167.0	76.5	22.4
		Middle	21.5	185.8	82.7	25.3
		Bottom	20.1	95.9	80.0	24.0
	CV(%)		4.0	16.2	15.4	4.3
	$LSD_{(0.05)}$		1.4	13.2	5.5	1.12
C-2						
	Fertilizer	NF	21.5	132.1	72.4	24.2
		CF	22.1	153.7	76.8	25.3
	CV(%)		5.7	15.5	10.2	3.7
	$LSD_{(0.05)}$		0.8	16.1	4.7	0.8
	Field position	Top	23.3	129.3	68.3	25.5
		Middle	22.3	189.3	80.6	25.7
		Bottom	19.7	110.0	74.9	22.3
	CV(%)		5.7	15.7	9.4	2.7
	$LSD_{(0.05)}$		0.9	19.8	5.8	1.0

higher in fertilized part than in the non-fertilized part. Regarding the effect of different toposequence position, significant differences ($p<0.05$) in panicle length were observed with the longest in the top field (23.3 cm and 23.3 cm) followed by middle (21.5 cm and 22.1 cm) and the lowest was in the bottom field (20.1 cm and 19.7 cm) in C-1 and C-2, respectively. Filled grains proportion was the highest in middle field than other fields in both cascades.

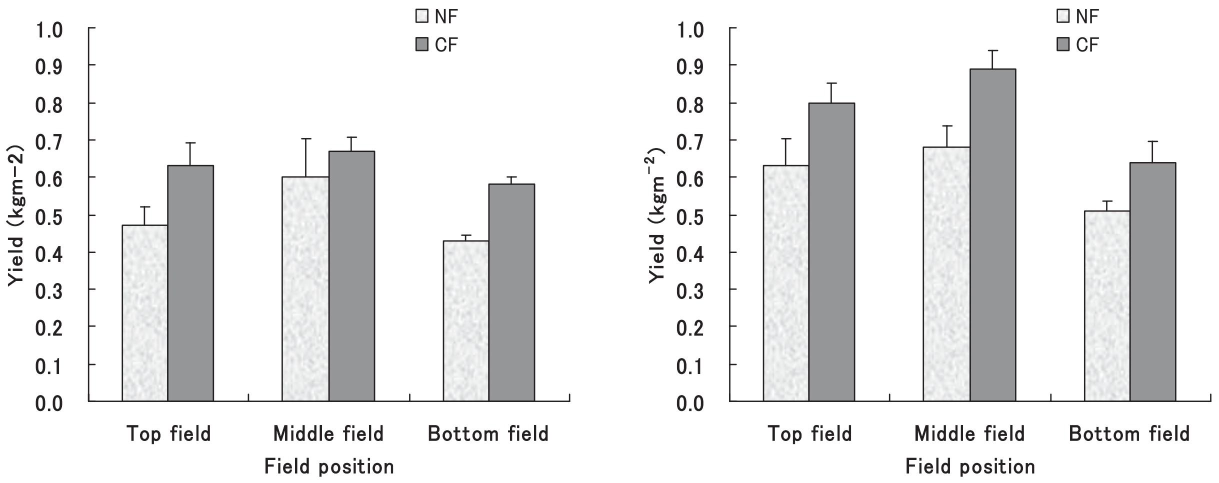
Significant differences in grains per panicle and 1000 grain weight were observed due to fertilizer ($p<0.05$) and different toposequence position ($p<0.01$, Table 2). Fertilization increased grain per panicle and 1000 grain weight than non-fertilized part in C-1 and C-2. The middle field position showed the highest value of grains per panicle and 1000 grain weight in average of both cascades 187.6 and 25.5, respectively.

The grain yield of rice differently responded to the different toposequence position of the fields and to the different fertilizer treatment (Fig. 2). A significant difference ($p<0.01$) of grain yield was observed between the fertilizer treatments with fertilizer application showing a higher value of yield (+F: 0.65 kgm^{-2}) than non-fertilizer plot (–F: 0.55 kg m^{-2}) in the average of both cascades.

The effect of different field position along the toposequence was significant as well ($p<0.01$) and the highest yield was achieved by the middle in C-1 and C-2. On average the middle field produced the highest grain yield of 0.71 kg m^{-2} followed by the first field (0.63 kg m^{-2}) and last field (0.54 kg m^{-2}). Yield differences in non-fertilized plots were observed among the different toposequence positions with the highest yield in the middle field position in both cascades. The interaction of fertilizer and different field positions was also observed where higher yields were shown in the three field positions of the fertilized plot than in the non-fertilized part.

Discussion

The result showed that there was a high degree of spatial variability related with TN and TC content among the different toposequence position in both cascades (Table 1). This indicated that different sediment sources contributed to an enrichment or depletion of soil fertility explaining spatial variability patterns on landscape level (Schmitter et al. 2010). The



(a) Cascade 1 (b) Cascade 2

Fig. 2. Grain yield in non-fertilized and fertilized plots at different field positions. Error bar indicates standard deviation.

result showed that mostly the first field in the cascade had lower TN and TC content than the lower fields. Increases in soil TN and TC were related to the different toposequence position, which was influenced by irrigation and runoff water from the upper fields. This result was in agreement with Tsubo et al. (2007) who examined rainfed rice terraces and analyzed the downward movement of finer nutrient in soil. Spatial variation in TN and TC contents occurs due to transportation and deposition of sediment during irrigation. Our finding was in agreement with Hartel et al. (2007). They reported that the maximum distance sediment coming from irrigation water was obviously until the middle field positions while the irrigation water velocity at the bottom fields was low, and those fields mainly derived the water from rain.

This study showed that the number of effective tillers must be related to higher content of TN in both cascades (Fig. 2). Furthermore, both cascades showed generally higher number of effective tillers in the fertilized fields than in the unfertilized ones (Table 2). This corresponds to the findings of Hertel et al. (2007) in Cheing Khoi area. Hertel et al. (2007) reported significant higher number of effective tiller due to increasing N levels in soil. Significant higher grains per panicle, filled grain proportion and 1000 grain weight were the highest in the middle field but only the panicle length was the highest in the first field. All other fields, the fertilized as well, were not significantly different from each other.

In both cascades, the highest yield was observed in the middle fertilized fields (Fig. 2). Grains per panicle, effective tillers, filled grain % and 1000 grain weight were also highest in these fields. The same trend was observed in both cascades, where for example the last non-fertilized field showed the lowest yield which correlated with grain per panicle, panicle length and 1000 grain weight. Pantuwan et al. (2002) discussed that this might be due to runoff and seepage, the water availability in the paddy fields constantly changes which lead to water stress in different time scales and severities and this affects the nutrient availability. The effect of sedimentation can be seen clearly in the unfertilized part where the middle field produced the highest grain yields than other fields (Fig. 2). The fertilizer management did not mitigate this trend in this experiment. Hertel et al. (2007) reported that the middle field of the unfertilized part produced the highest grain yield, but fertilizer mitigated this effect. Mochizuki et al. (2006) reported that combining chemical fertilizer with the incorporation of the sediment soil into the paddy soil increased the grain yield significantly while without fertilizer the sediments had no effect. This result was in contrast to the findings of our research, where fertilized plots produced higher yield but in non-fertilized part, there was a significant difference in grain yield among the different field position. No significant differences were found in the middle field of C-1 between the fertilized and unfertilized parts where nutritious soil particle should be settling down. The observed average grain yields for the fertilizer strips in both cascades (0.70 kg m^{-2}) were of similar magnitude as those reported by Schmitter et al. (2011) who cited an average grain yield of 0.68 kg m^{-2} in Chieng Khoi in 2011. Most of the spatial variations observed among the different toposequence position are likely to be contributing to the continuous flow, transportation and deposition of sediment during irrigation. The top field in the cascade produced higher grain yield than the bottom field. This could be due to some water inputs other than rainfall in the higher positions on the toposequence. This result was in agreement with Tsubo et al. (2006). They stated that in Chapassk Province, the grain yield was 66% higher in the top field than bottom field. This could be due to run-on of water from the catchment above the top field or irrigation water in the top field and also due to flood in the fields lower on the toposquence.

Conclusion

This study showed clearly that there were spatially differences in all measured parameters due to the effect of different toposequence position. In non-fertilized part of the cascades, the middle field produced a better growth performance than the other fields of the toposequence. The spatial variability of the non-fertilized plots represented the different sediment deposition along the fields and can be assumed that fine textured clay and nutrients and organic matter will be flushed from the irrigation channel into the field and deposited at the middle field. In fertilized plots, the spatial variability along the toposequence position might be due to different sediment deposition due to irrigation. The results point out that farmer management practice of fertilization as toposequence specific management should be no longer suitable for this area and by practicing site specific fertilizer management. Site specific managements would save money, contribute to higher yield and lead to sustainable agricultural production.

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Influence of Different Calcium Amendments upon Methane Emission under Na-salinized Paddy Soil

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Abstract

About 30% of world's rice areas are affected by salinity. Salinity is among the soil factors suggested to influence methane (CH_4) emission from rice fields. The amendment of calcium (Ca) has been widely adopted to ameliorate the negative impact of salinity, while its impact on CH_4 emission is unknown. Therefore, the impact of salinity and Ca amendment upon CH_4 production was investigated in this study. The salinity levels were 0, 10(S10), 30(S30), 60(S60) and 90(S90) mmol L^{-1}NaCl. Methane production potential was higher in S30 level than control while S90 showed the minimum production by incubation. As the influence of Ca amendments, gypsum (GM) and poultry manure (PM) was analyzed in a pot experiment with rice plants, CH_4 emission in control and PM was not significant different but GM showed significantly lower value (about 56%) than control and PM. In saline treatments, all treatments in S90 levels showed minimum emission. Methane emission in S30 without amendments was lower than non-saline control and PM, but it was not significantly different. The CH_4 emission was closely related to the amount of dead leaves. These results showed that lower CH_4 emission in S30 was not due to suppression of CH_4 production potential, but lower above plant biomass yield under saline condition, while the lower CH_4 emission in S90 was due to both lower CH_4 production potential and lower above plant biomass yield.

Introduction

Methane (CH_4) is a powerful greenhouse gas that has profound impact on the physico-chemical properties in atmosphere leading to global climate change. Methane is produced under anaerobic environments by obligate anaerobic microorganisms through either CO_2 reduction or transmethylation processes (Hou et al., 2000). Because of the flooding condition required for the cultivation, paddy fields are known to be one of the main anthropogenic sources of CH_4 gas (Dubey, 2005). In rice soil, acetate and hydrogen/carbon dioxide are the major substrates for CH_4 production. These substrates are primarily from rice plants via root exudation, root senescence and plant litter (Lu et al., 1999). Moreover, CH_4 produced during the rice cropping season is emitted to the atmosphere by plant mediated transport system, ebullition and diffusion. Out of these three systems, plant-mediated transport is the primary mechanism for the emission of CH_4 from rice paddies, with as much as 90% of CH_4 transported to the atmosphere through the aerenchymal system of the rice plants. Therefore, flooded rice paddies fields play a significant role of CH_4 emission and it occupies 10% of global anthropogenic CH_4 emission.

However, the amount of CH_4 emission depends upon several parameters such as water management, soil type and cultivars etc. (Purkait et al., 2007). Salinity is one of the soil factors influencing soil microbial activities including methanogenisis (Pattnaik et al. 2000). Of the 130 million hectares of land where rice is grown, about 30% contain too high level of salts to allow normal rice yield (Mishra, 2004). And also rice is mainly grown in delta and coastal region of the tropics. In these regions, salinity is the major limiting factors of the rice production due to periodic sea water intrusion and irrigation water salinity in summer rice cultivation. Therefore, the objective of this study was to study the influence of irrigation water salinity levels on CH_4 emission and to evaluate CH_4 emission by applying different Ca amendments to Na-salinized paddy soil under rice cultivation.

Materials and Methods

1. Laboratory Incubation Experiment

A composite soil sample was collected from 0-15 cm depth at Field Museum Fuchu Honmachi, Field Science Center, Tokyo University of Agriculture and Technology. The soil was put in refrigerator until the incubation experiment. There were 5 salinity levels; control, 10(S10), 30(S30), 60(S60) and 90(S90) mmol L^{-1} NaCl with 4 replications. Wet soil (20g) was put in to 100 ml conical flasks and then flooded with 20 ml of tap water or different levels saline water according to the treatments. The conical flasks were fitted with rubber stoppers that have two tubes to facilitate for flushing with N_2 gas, collecting gas samples. These flasks were kept in an incubator at 30 ·C for a period of 21 days and gas samples were collected 2, 4, 7, 14, and 21 days after incubation. The nitrogen gas flushes were carried out one day before and immediately after the sampling at 250 ml min^{-1} for 3 min. Just before sampling, the conical flasks were shaken to drive out the CH_4 entrapped within the soil.

2. Pot Experiment

To confirm and evaluate the impact of salinity upon CH_4 emission, salinity levels 30 mmol L^{-1} and 90 mmol L^{-1} NaCl were selected from incubation experiment and studied under rice cultivation with pot experiment. It was conducted at Field Museum Fuchu Honmachi. There were 9 treatments and 3 replications; control, 30 mmol L^{-1} NaCl (S30), 90 mmol L^{-1} NaCl (S90), gypsum 1 ton/ha (GM), poultry manure 2.08 ton/ha (PM), 30 mmol L^{-1} NaCl plus gypsum (S30-GM), 30 mmol L^{-1} NaCl plus poultry manure (S30-PM), 90mmol L^{-1} NaCl plus gypsum (S90-GM) and 90 mmol L^{-1} NaCl plus poultry manure (S90-PM). All treatments were arranged in randomized complete block design. About 21 days old seedlings were transplanted in plastic pots with a diameter of 30 cm and 20 cm height, which were filled with (8kg) soil. Puddling was done by irrigating the pots twice on alternate days with salt solutions (30 and 90 mmol L^{-1} NaCl) or with tap water (control). About 40 kg P/ha and 70 kg K/ha were applied at the time of final pot preparation.70 kg N/ha was applied in 3 equal splits at active tillering, panicle initiation and flowering stage. Equal amount of nutrient levels were adjusted in all treatments. About 2-3 cm of water will be maintained in the pots until crop maturity by irrigating regularly with assigned NaCl concentration.

Results and Discussion

1. Laboratory incubation Experiment

The addition of NaCl up to 30 mmol L^{-1} increased in methane production (Fig. 1). The increase of CH_4 production in salinity S10 and S30 was 1.2 times and 2 times higher than control, respectively. At higher salinity levels (S60 and S90), CH_4 production was 19 to 33% lower than control. It might be due to the sodium requirement of methanogens. Ramakrishnan et al. (1998) also observed that addition of 27mM NaCl to illuvial soil caused almost a two-fold increase in methane production over that of control and higher addition of NaCl (54, 135 and 274 mM) causing about 50% reduction in CH_4 production. According to the report of Jarrell and Kalmokoff (1988), sodium is required for amino acid transport, growth, methanogenesis, and internal pH regulation in methanogenic bacteria. However, the quantum of sodium requirement varies widely among methanogens. In this experiment, the addition of 30 mmol L^{-1} NaCl provided the methanogenesis for the highest CH_4 production among the treatments.

2. Pot Experiment

(a) Changes of Soil Environments under irrigation water salinity and Ca amendments

The range of soil temperature was 20.7 to 35 ˚C and there was no big difference in soil temperature values among the treatments. Eh values lay in the range of -280 to -417 mV. Wang et al., (1993) demonstrated that the critical Eh value for CH_4 production is below -150 mV. The differences in pH values can be found only until 3 weeks after transplanting

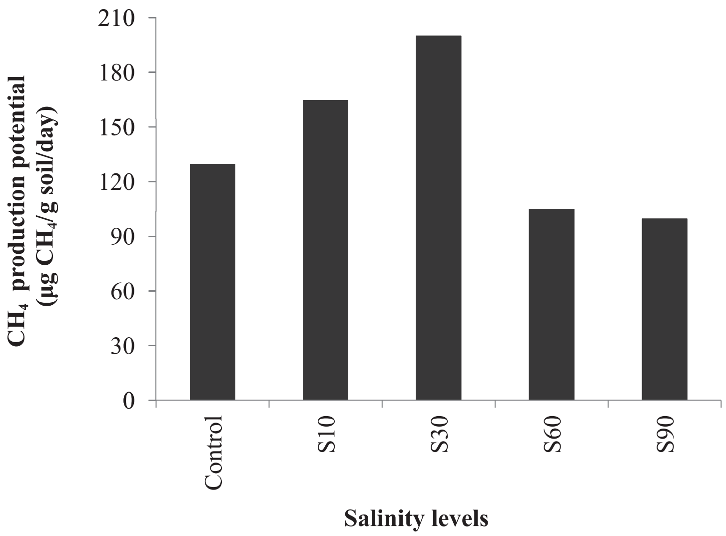

Fig.1. CH_4 production potential of soil under different salinity levels

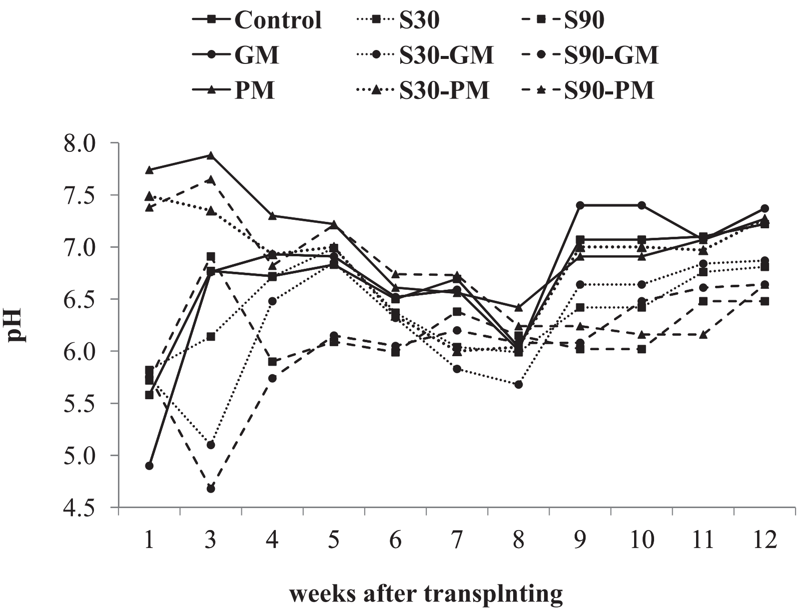

Fig.2. Changes of soil pH during the rice growing season

as shown in Fig. 2. After that there was no big difference in pH values and it remained in the range of 5.3 to 7. 4. Generally, methanogens grow best in neutral or slightly acidic medium (Oremland et al., 1982). Therefore, soil environmental factors were favorable for methane production.

(b) Influence of Salinity and Ca amendments upon above plant biomass yield

Total numbers of dead leaves were higher in saline treatments than non-saline treatments (Fig. 3a). In non-saline treatments, there was no significant difference in total number of dead leaves among the treatments. In saline treatment, total number of dead leaves for all treatments in S90 was significantly lower than those in S30. This lower number of dead leaves in S90 was due to shorter duration of growth period than other treatments. There was no significant difference in S30 with and without amendments.

Generally dry matter yields in non-saline treatments were higher than those in saline treatments (Fig. 3b). In non-saline treatments, dry matter yield in PM was significantly lower than control and GM. Poultry manure has high N content (about3gN/100g PM). Inorganic fertilizer Nitrogen was not added in PM treatment. Therefore, lower dry matter yield in PM might

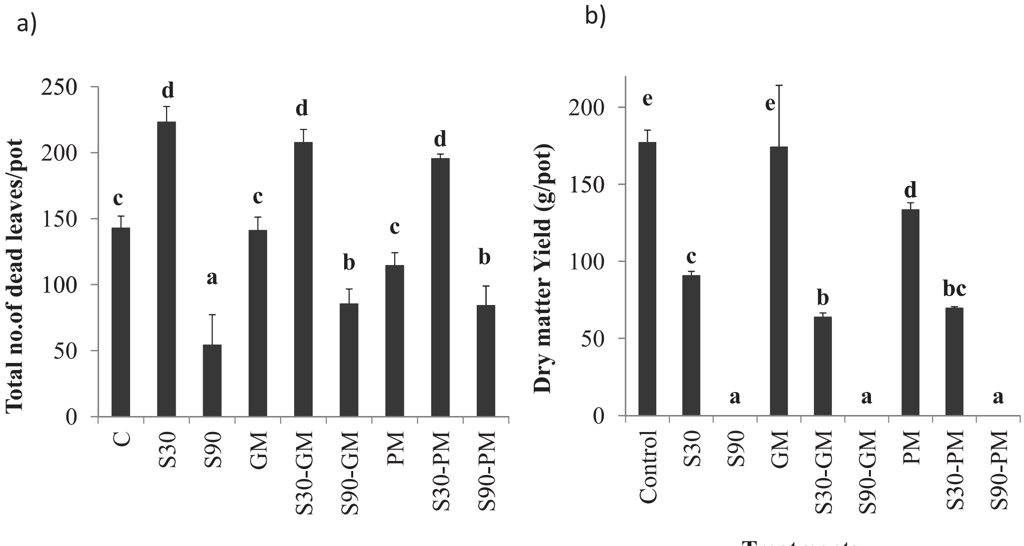

Fig.3. Effect of salinity and Ca amendments upon above plant biomass yield; (a) total number of dead leaves, (b) dry matter yield
Means followed by a common letter are not significantly different at $p < 0.05$ by Duncan's multiple range test (DMRT).Error Bars indicate Standard Deviation.

be due to the lower availability of inorganic N from the mineralization of organic manure (PM) at vegetative stage.

Addition of amendment did not improve the dry matter yield in saline treatments. Suriyan Cha-um et.al, (2011) observed that the remediation of saline soil (ECe 12.5 dSm^{-1}) with gypsum 65 g/m^2 improved the paddy yield compared with control (saline soil without amendment) in a field trial. However, in case of irrigation water salinity with pot experiment, continuous application of saline irrigation water resulted in accumulation of NaCl salts in the root zone day after day. Moreover, it was impossible for leaching of NaCl salts from the pots. Therefore, addition of amendments has little effect upon rice growth under irrigation water salinity in this pot experiment

(c) CH_4 emission under salinity and different Ca amendments

The addition of GM ($CaSO_4.2H_2O$) reduced CH_4 emission by 56% compared with control (Fig. 4). Gypsum contains sulphur, which suppresses CH_4 production in rice paddies as shown by laboratory studies (Van Bodegom and Stams 1999) and field experiments (Denier van der Gon and Neue 1994). The extent of suppression depends on both acetate (CH_3COO^-, Ac) and SO_4 concentrations (Gupta et al. 1994). In non-saline treatments, CH_4 emission in control and PM was not statistically significant different. Corton et al. (2000) also observed that the application of poultry manure with urea fertilizer could not increase CH_4 emission because of its narrow C/N ratio which was about 5 to 6.

In saline-treatments, minimum CH_4 emission was found at S90 with or without amendments. It might be due to the low methanogenic activity, shorter growth duration and lower above plant biomass yield under very high saline condition.

The amount of CH_4 emission in S30 without amendment was 6%lower than control and PM, but was not significantly different. However, the above plant biomass yield in S30 was 49% lower than control. According to the result that was observed in the incubation experiment, CH_4 production in S30 was higher than control. Therefore, S30 did not suppress CH_4 production potential but the lower amount of emission was might be due to lower above plant biomass yield which led to fewer organic material as C source. In addition, the path way of CH_4 was limited in S30 because rice plants are the main conduct for CH_4 transport from soil to atmosphere and more than 90% of the CH_4 is emitted through plant transport in temperate rice fields (Dubey, 2005).

The addition of GM or PM at S30 reduced in CH_4 emission about 53 to 33% respectively compared with control. The difference in the extent of reduc-

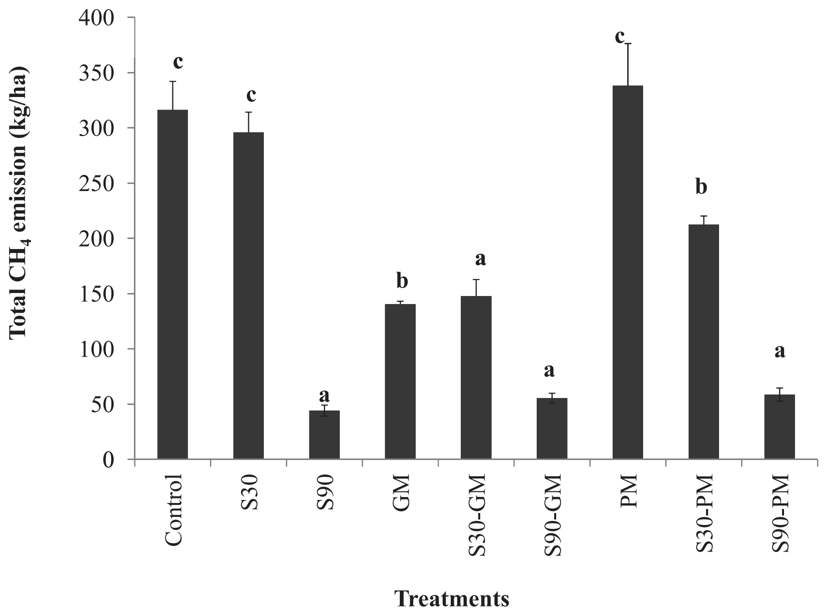

Fig.4. Effect of salinity and Ca amendments upon total CH_4 emission for whole crop season
Means followed by a common letter are not significantly different at $p < 0.05$ by Duncan's multiple range test (DMRT). Error Bars indicate Standard Error.

tion in CH_4 emission might depend upon the extent of SO_4 content and the availability of organic carbon substrate for the growth of methanogens.

Conclusion

The continuous application of saline irrigation water inhibited the rice growth for both salinity levels; S30 and S90 with or without amendment. Salinity 90 mmol L^{-1} NaCl (S90) could suppress CH_4 emission by lower CH_4 production potential and lower biomass. The addition of saline irrigation water up to salinity 30 mmol L^{-1} NaCl level was more favorable for methane production as found by the incubation experiment. However, the lower amount of CH_4 emission in S30 compared with control under rice cultivation is due to the lower above plant biomass yield. Therefore, the reduction of CH_4 emission from rice cultivation under saline condition did not depend only upon salinity level but also above plant biomass yield. The application of sulfate containing amendment; GM and low C/N ratio organic manure; PM under saline condition did not enhance CH_4 emission. However, the extent of reduction in CH_4 emission depends upon sulfate content and the organic carbon availability of each amendment.

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Mitigation of Impact of Nitrogen Cycling Associated with Agriculture and Food Consumption on Regional Environments

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Abstract

Concerns about environmental problems such as water pollution, eutrophication, acidification, air pollution, global warming, ozone layer depletion associated with nitrogen (N) load are increasing. Global N load associated with agriculture and food consumption is supposed to account for 90% of the total increased N load during the 100-year period, and there is a large N load in Asian countries with the remarkable growth of the population.

Using the inventory data concerning the flows and stocks of N in the systems of agriculture and food consumption, and the census data in each prefecture of Japan, the export (E), cycling (C), loss (L) and purification in sewage plants (P) were estimated, and their total is obtained as a total system throughput (TST). The L increased with the increase of TST and accounted for 50% of the TST. The L increased with the increase of proportions of urban area and upland crop field significantly. And the L also increased with the increase of population, livestock excreta, and chemical N fertilizer application, and decreased with the increase of N fixation significantly.

Stream TN concentration in each prefecture in Japan was estimated by assuming the ratio of stream runoff to net N input (NNI) of 0.27 and the ratio of stream water discharge to precipitation of 0.75. The NNI is defined as the difference between the input and the output of N in the region, and equals to L+P. The area with the estimated TN concentration higher than 1 mg N L^{-1}, which is the Japanese environmental standard for stream TN concentration, was 66% of the total area of Japan. In that case, 66.7% of NNI was derived from agriculture, and disposed livestock excreta accounted for 14% of L. If all the livestock disposal excreta N were used to alter chemical N fertilizer application, total NNI was reduced by 10.8 % and NNI derived from agriculture decreased to 62.7% of the total NNI, and the area with the nitrogen concentration higher than 1 mg N L^{-1} reduced to 31%.

N_2O emission in each prefecture in Japan was estimated by assuming that NNI not discharged to river is denitrified as N_2O+N_2 (based on the significant increase of stream bicarbonate runoff with the increase of NNI not discharged to river), and the ratio of $N_2O/(N_2O+N_2)$ of 0.71±0.26 (which was measured for the 84 soil samples with pH of 4.3 to 6.6). The result showed 51% of NNI was estimated to be emitted as N_2O. However, this estimation is considerably larger than the estimation in National Inventory Japan 2011. This might be due to the methodological problem in the estimation of $N_2O/(N_2O+N_2)$ ratio. By alteration of chemical N fertilizer to disposed livestock excreta N, regional N_2O emission can be reduced by 10.8%.

These findings suggest that reduction of regional N import is effective to mitigate N loss from agriculture. Further improvement of self-sufficiency of food to reduce the loss from sewage plants should be discussed more carefully.

1. Introduction

By chemical nitrogen (N) fixation developed by Haber-Bosch in 1913, human beings obtain a chemical N fertilizer and can perform stable food production now. However, distinct N load to environment has been increasing through the processes of agriculture and food consumption. The amount of global N cycling becomes increase very much. There are increasing evidences that global N cycling is seriously unbalanced by human activities. Galloway and Cowling (2002) estimates that during a 100 year period from 1890 to 1990, the input of anthropogenic N in the earth's terrestrial area increased from 15 Mt N to 118 Mt N due to increase of chemical N fertilizer use and legume crops cultivation. Total N input including atmospheric N deposition was doubled from 131 Mt N in 1890 to 283 Mt N in 1990. About 90% of the total increasing N load is caused by agriculture and food consumption. The increasing N load to environment results in the following various problems: 1) freshwater pollution by nitrate (NO_3^-); 2) air pollution by nitrogen oxide gas; 3) coastal eutrophication by stream N runoff; 4) N saturation of a forest by atmospheric N deposition; 5) influence on biodiversity by the invasion of high nitrogen reactivity plant; 6) acidification by nitrification of applied ammonium N in the soil; 7) global warming enhanced by N_2O emission from the soil.

There is a large N load in Asian countries with the remarkable growth of the population. The consumption of chemical N fertilizer in East Asian and South East Asian countries is estimated as 31.5 Mt N, which accounts for 37% of the world consumption (FAO, 2011). The area of these countries is 1.46×10^9 ha, which is 11% of the world's land area. Therefore, there is concern about the severe impact of N load on the environment in those countries, and the need for mitigating impacts is strong. Thus, the prevalent situation over a wide area must be evaluated. Current trends suggest that N-related problems are likely to worsen. Increase of food demand is likely to increase fertilizer use. Essential improvement for N cycling associated with food production and consumption is needed.

The N flows associated with agriculture and food consumption occur regionally. Regional surplus N is resulted from the unbalance between the N input (I) into the region, associated with atmospheric N deposition, chemical N fertilizer application, legume crop N fixation, and import of food and feed, and the N output from the region, associated with the export of agricultural production (E). The surplus N is equal to the net N input (NNI) for N discharge from the region which was defined by Howarth et al. (1996). If there is no N stock in the region, most of NNI discharges to stream and atmosphere (Howarth et al., 1996). If denitrification in the sewage plant and in farmlands is defined as purification (P), N loss to environment can be approximate as difference of NNI and P. That is, NNI can be written as;

$$NNI = I - E = L + P \quad (1)$$

The L includes stream N runoff, N_2O emission and NH_3 volatilization. From the equation (1), it is clear that in order to reduce the N loss, decrease of N input is required. However, in the agricultural system, N cycling (C) associated with application of manure and residue occurs during N input and N output. The N cycling elongates N flow through the system. The N flow through the whole system is called total system throughflow (TST) and is defined as the sum of N cycling, export, loss, and purification. That is,

$$TST = C + E + L + P \quad (2)$$

Finn (1980) defined the ratio of the C to TST as the cycling index (CI) and indicated that an increase of CI increased the production in the natural ecosystem. In the same manner, the ratios of export, loss, and purification to TST as export index (EI), loss index (LI), and purification index (PI), respectively (Hatano et al., 2005). The purpose of the agriculture is the increase of the E. From the equation (2), in order to increase E, TST should increase. However, the increase of TST may increase L.

Watershed scale including all kind of land uses is the proper scale of the analysis of N flows, regional activity data are most often available for municipal units (Kimura et al., 2009).

On the other hand, stream N discharge from the watershed can be measured, and previous results (Howarth et al., 1996; Boyer et al., 2002 and Hayakawa et al., 2009) show that the stream N discharge is significantly correlated to the NNI in the watershed. Therefore, regional stream N runoff can be estimated from the NNI calculated using the municipal units.

Concerning N_2O emission, usually the emission factors related to N application rate and stream NO_3^- leaching have been used (Mosier et al., 1998). However, the emission factors include a lot of uncertainties due to soil type (Akiyama et al., 2006) or climatic condition (Toma et al., 2007). Therefore, in order to estimate regional N_2O emission, more comprehensive approach is required. The source of regional N_2O emission is NNI. Based on the equation (1), NNI composed of two parts, one is stream N runoff and another one is the emissions of N compound gases including N_2, N_2O and NH_3. Therefore, difference of NNI and stream N runoff is an approximate of denitrification. Based on the chemical reaction of denitrification, denitrifers produce bicarbonate (HCO_3^-) equivalent to NO_3^- denitrified according to the following equation (Bolt and Bruggenwert, 1978):

$$NO_3^- + 1.25CH_2O \rightarrow 0.5N_2 + HCO_3^- + 0.25CO_2 + 0.75H_2O \quad (3)$$

However, the chemical weathering of the soil and rock minerals also produces HCO_3^- as follows:

$$CO_2 + 5.5H_2O + KAlSi_3O_8 \rightarrow 0.5Al_2Si_2O_5(OH)_4 + K^+ + HCO_3^- + 2H_4SiO_4 \quad (4)$$

$$CO_2 + H_2O + 0.25Mg_2SiO_4 \rightarrow 0.5Mg^{2+} + HCO_3^- + 0.25H_4SiO_4 \quad (5)$$

$$CO_2 + H_2O + 0.5CaMg(CO_3)_2 \rightarrow 0.5Ca^{2+} + 0.5Mg^{2+} + 2HCO_3^- \quad (6)$$

Therefore, the denitrification and the chemical weathering are the sources of the stream HCO_3^- runoff. Denitrification in the agricultural watershed can be estimated by comparing the HCO_3^- runoffs in the watersheds with and without agricultural activities. For the estimation of N_2O emission from the watershed, the ratio of $N_2O/(N_2O+N_2)$ can be used, because denitrification produces N_2+N_2O and denitrification is the major process of N_2O production in the soil (Hatano, 2010). Usually, potential denitrification of the soil is measured by the acetylene block method in a laboratory incubation under the condition of addition of NO_3^--N of 200 mg N L^{-1} (Tiedje, 1994). Acetylene concentration of 10% in the head space air of incubation bottle inhibits the transformation from N_2O to N_2. Therefore, when the acetylene is not applied, potential N_2O production can be measured. N_2O production ability of soil in the denitrification is obtained as the ratio of $N_2O/(N_2O+N_2)$. However, Weier et al., (1993) mentioned that high NO_3^- concentration (100 kg N ha^{-1}) and high oxygen concentration (WFPS less than 90%) inhibited the transformation from N_2O to N_2. Cuhel et al. (2010) showed that $N_2O/(N_2O+N_2)$ ratio increased from 15 to 30 % with decreasing pH from 7.67 to 5.52 in the incubation study adding the NO_3^- of 10 kg N ha^{-1} yr^{-1} under the anoxic condition.

The purpose of this study is to evaluate the effect of improvement of the N managements in agriculture and food consumption by analyzing the structure of regional N flows concerning C, E, L and P using the activity data and inventory data, and by estimating the amount of stream N runoff and regional N_2O emission based on the field observations related to the NNI.

2. Materials and Methods

1) Characterization of regional N flows in Japan

Amount of chemical N fertilizer consumption in Japan has been slightly decreased from the peak of 0.8 million t in 1980 to 0.5 million t, with the decrease of arable land from 5.2 million ha in 1961 to 4.3 million ha. Self-sufficiency of cereal crops has decreased from 80% in 1961 to 30% (FAO, 2011). Those values are almost stable after 1995. Regional N flows concerning C, E, L and P were calculated using the census data of all prefectures of Japan in 1997 organized by Mishima et al. (2004). The census data include human and livestock populations, arable land area, chemical fertilizer consumption, livestock excreta utilization rate and agricultural products in each prefecture. Forested land area and urban area were obtained from the web sites of Japanese government (http://www.rinya.maff.go.jp/ and http://www.stat.go.jp/, respectively).

The N fixation rate in the fields of grassland, rice paddy, soybean, red bean and other legume crops was used as 45, 40, 100, 45 and 20 kg N ha^{-1} yr^{-1} (Yatazawa, 1978). For other agricultural crops, the fixation rate of 5 kg N ha^{-1} yr^{-1} was used (Yoshida, 1981). Crop residue N was estimated using N content of residues and a dry-weight mass ratio of residue : yield (Nagumo and Hatano, 1999). Amounts of livestock N demand and N excreta were calculated based on the dietary needs for their intake. Livestock N products were estimated as livestock N demand - livestock N excreta. Self-supported feed N was estimated assuming that all yields of grass and maize were for livestocks. The rest of the livestock N demand was assumed to be supplied by imported feed N. Livestock excreta N application rate was calculated as livestock N excreta production - ammonia volatilization from livestock excreta - disposal N of livestock excreta. Ammonia volatilization from livestock excreta and chemical fertilizer was estimated by multiplying the excreta N by ammonia emission factor for each livestock (25.5, 25.5, 17.3, 36.0, 36.0 and 16.9 for dairy cattle, young cattle, beef cattle, pig, poultry and horse, respectively) (Bouwman et al., 1997) and was estimated to be 7% of the applied chemical N fertilizer (Bouwman and Bowmans, 2002). Ammonia volatilized was assumed to deposit into farmland.

Human N demand was used as 3.14 kg N $person^{-1}$ yr^{-1}, which was divided into excretion (2.61 kg N $person^{-1}$ yr^{-1}) and sewage (0.53 kg N $person^{-1}$ yr^{-1}) (Kunimatsu and Muraoka, 1997). The self-supported food was estimated assuming that the self-sufficiency rate of the farmer's food was 37% of the total N demand and that of non-farmers was 0% (Nagumo and Hatano, 1999). The imported food was calculated as the difference between human N demand and self-supported food.

Denitrification in the sewage plant was estimated using popularization rate of sewage plant (Japan Sewage Works Association 2007), human disposal N (assumed to be the same as human N demand), and N removal efficiency as 60% (Kunimatsu and Muraoka, 1997).

Denitrification in the farmland soil was used as 70 kg N ha^{-1} yr^{-1} in paddy field and 30 kg N ha^{-1} yr^{-1} in other fields (Yatazawa, 1978). The export of food and feed was calculated as the total production of N minus the amounts N consumed by humans or livestock.

The NNI was calculated as:

NNI= atmospheric N deposition + chemical N fertilizer + N fixation + imported food and feed N - exported food and feed N (7)

The NNI was also expressed as:

NNI= field surplus N + human disposal N + livestock disposal N + denitrification in sewage plant and farmland (8)

As human excreta N + waste N (equal to imported food N + self-supplied food N) is the source of NNI derived from food consumption, therefore, NNI from food consumption and NNI from agriculture can be expressed as:

NNI from food consumption = imported food N+ self-supplied food N (9)

NNI from agriculture = NNI – NNI from food consumption (10)

The P was obtained as:

P= denitrifications in sewage plant and farmland (11)

The L was calculated as:

L= NNI - denitrification (12)

The C was calculated as:

C= applied livestock excreta N + self- supported food and feed N (13)

The E was obtained as:

E= exported product N of crop and livestock (14)

Total system throughput (TST, equation (2)) and CI, EI, LI and PI were calculated.

In order to investigate the major cause of the L, multiple regression analysis was conducted for L using the proportions of land uses (urban, paddy rice field, upland field and forest proportion) and the sources of N flows (human population, livestock excreta production, chemical N fertilizer consumption and N fixation).

2) Estimation of stream N runoff and TN concentration

Regression analysis using the 52 data set of stream total N (TN) runoff and NNI in the watersheds of various countries, obtained by previous studies (Boyer et al., 2002; Filoso et al., 2003; Hayakawa et al., 2009; Howarth et al., 1996; Jordan et al., 1996; McIsaac et al., 2004), showed the significant regression equation as

TN runoff = 0.266′ NNI + 3.34, R^2= 0.344 ($P<0.01$) (15)

The data set included TN ranging from 1 to 46 kg N ha^{-1} yr^{-1} and NNI ranging from 2 to 96 kg N ha^{-1} yr^{-1}. The result indicates that 27% of NNI in the watershed would discharge to the river. Using the discharge factor of 27%, regional stream TN runoff was calculated from the NNI obtained for each prefecture in Japan. In Japan, the water quality standard for TN concentration in streams, lakes, and marshes for the preservation of life and environmental quality is less than 1 mg N L^{-1} (Ministry of the Environment, 2005). The TN concentration of each prefecture was estimated by dividing the stream TN runoff by water discharge in each prefecture. Water discharge rate was assumed to be 75% of precipitation (Oshima et al., 2003). The regional precipitation data were obtained from web site of Japan Meteorological Agency.

3) Estimation of regional N_2O emission

Although denitrification in the sewage plant and the soil was defined as purification, N_2O can emit during the denitrification (Mosier et al., 1998). The regional N_2O emission was estimated from the stream HCO_3^- runoff and $N_2O/(N_2O+N_2)$ ratio. HCO_3^- runoff was measured in five sub-watersheds of Shibetsu watershed, where relationship between NNI and stream TN runoff was obtained (Hayakawa et al., 2009). The NNI of the sub-watersheds estimated in 2003 and 2004 ranged from 1.6 to 99.3 kg N ha^{-1}. The HCO_3^- runoff was caused by denitrification and chemical weathering of soil minerals. The source of the denitrification was assumed as the N of NNI left from stream TN runoff in the watersheds [NNI - TN runoff] and the relationship between HCO_3^- runoff (kmol ha^{-1} y^{-1}) and [NNI - TN runoff] (kmol ha^{-1} y^{-1}) was investigated (Hatano, 2008). The regression equation was obtained as follows:

HCO_3^- runoff = 0.980´ [NNI-TN] + 3.704, R^2= 0.751 (P<0.01) (16)

Assuming that the value of 3.704 kmol ha^{-1} y^{-1} when [NNI-TN runoff] equal 0 was derived from chemical weathering and the chemical weathering was maintained in all the watersheds, HCO_3^- runoff derived from denirification can be calculated as:

HCO_3^- runoff from denitrification = 0.980´ [NNI-TN] (17)

This indicates that almost all the NNI left from not discharging to river was denitrified.

The ratio of $N_2O/(N_2O+N_2)$ was determined for the 84 soil samples with pH of 4.3 to 6.6 collected from the soil layers of 0-5 cm, 20-25 cm and 45-50 cm depth at three land uses, grassland, wind breaking forest and riparian forest, in the 11 sub-watersheds with different soil types (Valcanogeneous Regosol, Regosolic Andosol, Ordinary Andosol, Acid Brown Forest soil, Brown Lowland soil, Gray Lowland soil and Peat soil) in Shibetsu watershed (Hayakawa et al., 2009). Potential denitrification activity (N_2O+N_2) was measured at three replicates under anaerobic conditions with abundant NO_3^--N (200 mg-N L^{-1} as KNO_3) at 25˚C by using acetylene block technique which inhibits the final conversion of N_2O to N_2 gas (Tiedje, 1994). Samples of fresh, homogenized soil (15 g) were placed into 100 mL serum bottles. An aliquot of 15 mL solution treated with NO_3^--N (200 mg N L^{-1} as KNO_3) and chloramphenicol (1 g L^{-1}) was added to the bottles. The serum bottles were evacuated and flushed four times with O_2-free N_2 to ensure anaerobic conditions, and acetylene gas was added to a final concentration of 10% (10 kPa) in the headspace. Production of N_2O was measured by the same procedure but without addition of acetylene gas. Headspace gas was sampled by syringe at 2 and 4 h and denitrification and N_2O production rates were calculated from the linear portion of N_2O produced over time. Adjustments were made for soluble N_2O in the bottles using a Bunsen absorption coefficient of 0.54 at 25˚C. Nitrous oxide was determined using a gas chromatograph with an electron capture detector (GC-14B; Shimadzu, Kyoto). However, regional denitrification includes those derived from the sewage plant and from the soil. The ratio of $N_2O/(N_2O+N_2)$ of the denitrification in the sewage plants was assumed to be the same as that in the soil. In this study, average of $N_2O/(N_2O+N_2)$ ratio was used for the estimation of regional N_2O emission.

Regional N_2O emission was estimated as:

Regional N_2O emission = $[N_2O/(N_2O+N_2)] \times$ [HCO_3^- runoff from denitrification] (18)

3. Results and Discussion

1) Characteristics of regional N flows in Japan

Fig. 1 shows the relationship between TST and C, E, L and P. The value is expressed as kg N per ha of prefecture per year. Significant linear relationship was found between TST and C for the plots of all prefectures other than the metropolitans of Tokyo, Osaka and Kanagawa where TST was larger than 230 kg N ha^{-1} yr^{-1}. From the slope of the regression equation, CI was obtained as 0.23, and CI became approximately 0 in the metropolitans (Fig. 1a). The E and P were also significantly correlated with TST for all prefectures other than metropolitans. From the slops of the regression equations, EI and PI were obtained as 0.10 and 0.13(Fig. 1b and d). In the metropolitans, the EI decreased to 0, while the PI increased to 0.5. On the other hand, in all prefectures including the metropolitans, L was significantly correlated with TST. From the slope of the regression equation, LI was obtained as 0.50 (Fig. 1c). Vasconcellos et al. (1997) suggested that CI is an indicator for stability of the ecosystem

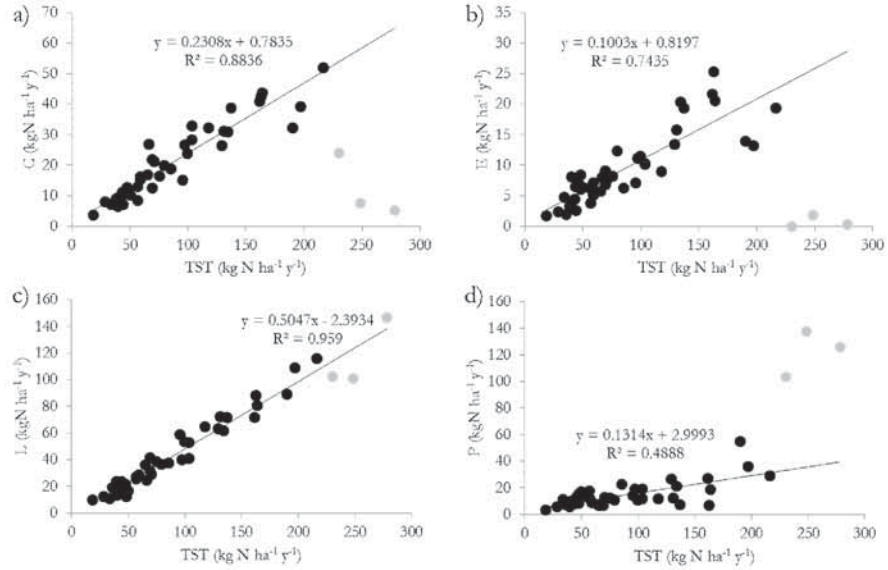

Fig. 1. Relationship between total system throughput (TST) and cycling (C) (a), export (E) (b), loss (L) (c) and purification (P) (d) related to the N flows associated with agriculture and food consumption in Japanese prefectures. Symbol with light color indicates metropolitans.

by preventing overshoots due to external impacts. The CI increases with maturity of the ecosystem. The CI of the system with complete food self-sufficiency is 1. In the metropolitans, the CI was 0, and the L and P accounted for TST, indicating vulnerable food security and pollution tendency. In other prefectures, CI was 0.23, and the L was larger than the sum of C + E, indicating that basically Japanese agriculture and food consumption system is on the trend of increasing pollution.

Fig. 2 shows the composition of L. Human disposal N accounted for more than 90% of L in the metropolitan. Human disposal N, livestock disposal N, and field surplus N accounted for 35%, 14%, and 51% of the L, respectively.

The result of multiple regression analysis showed that L was significantly correlated with urban area and upland area. Equation was as follows:

L = 3.47 × urban area % + 4.12 × upland field % + 5.1053, $R^2 = 0.834$ ($P < 0.01$) (19)

Increase of the proportions of urban area and upland field increases L significantly. On the other hand, L was significantly correlated with human population density, livestock excreta N production, chemical N fertilizer consumption and N fixation.

L = 0.0226 × human population density + 0.914 ×

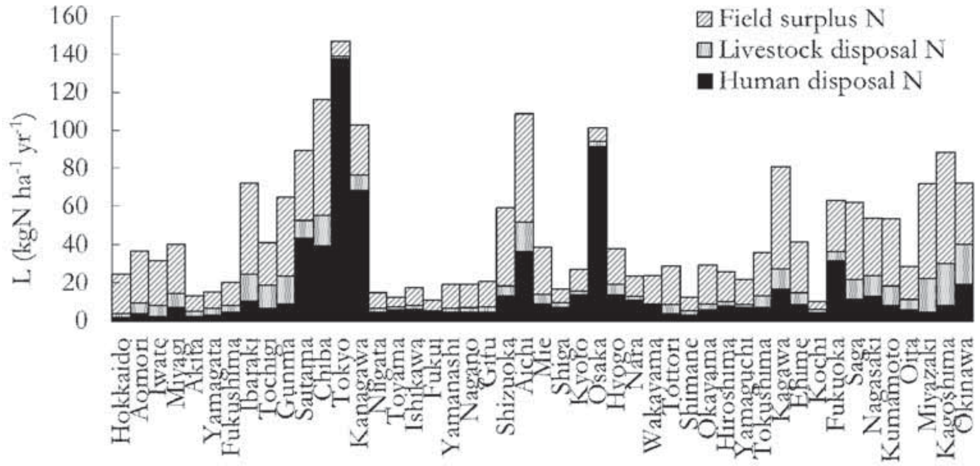

Fig. 2. Contributions of human disposal N, livestock disposal N, and field surplus N to L in Japanese prefectures.

livestock excreta N production + 0.873 × chemical fertilizer consumption – 1.08 × N fixation – 1.57, $R^2 = 0.975$ ($P < 0.01$) (20).

The equation indicates that increase of human population density, livestock excreta, and chemical N fertilizer application increases L while N fixation decreases L.

2) Net nitrogen input

Fig. 3 shows N flows constituting NNI in each prefecture. The value is expressed as kg N per ha of prefecture per year. In metropolitans, imported food N was extremely high, which was more than 200 kg N ha^{-1} yr^{-1}. Chemical N fertilizer and imported feed ranged from 5 to 47 kg N ha^{-1} yr^{-1} and 2 to 78 kg N ha^{-1} yr^{-1}, respectively. Sum of N deposition and N fixation did not exceed 10 kg N ha^{-1} yr^{-1}. Exported crop N and livestock product N were smaller than chemical N fertilizer application and imported feed N, respectively. The NNI ranged from 13 to 272 kg N ha^{-1} yr^{-1}. Total NNI was 1.84 Mt N yr^{-1}. In which chemical N fertilizer and imported food and feed N accounted for 35.8, 32.4 and 40.2, respectively.

3) Estimated regional stream TN concentration in Japan

Fig. 4 shows the regional stream TN concentration. The stream TN concentration in 29 prefectures of total 47 prefectures in Japan exceeded the Japanese environmental standard of 1 mg N L^{-1}. The stream TN concentration in the region of 66 % of total area of Japan exceeded 1 mg N L^{-1}. The stream TN con-

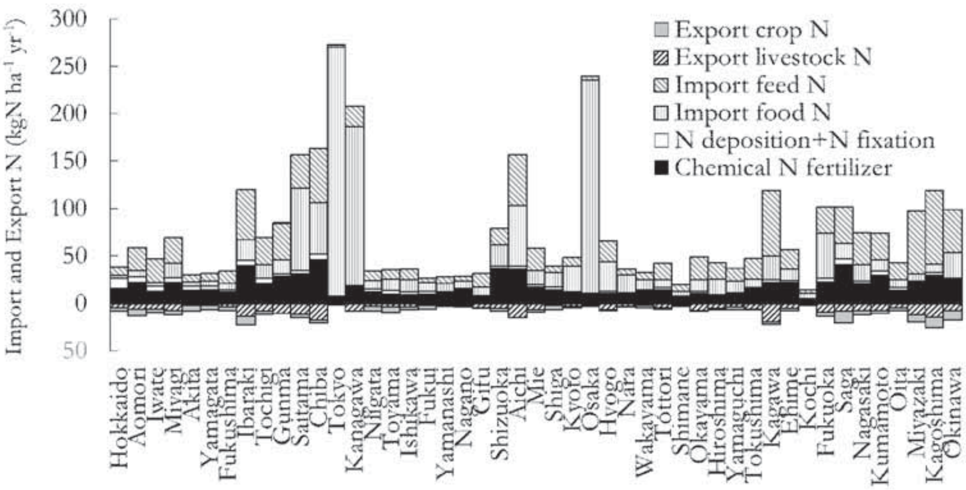

Fig. 3. N flows constituting regional NNI in Japanese prefectures.

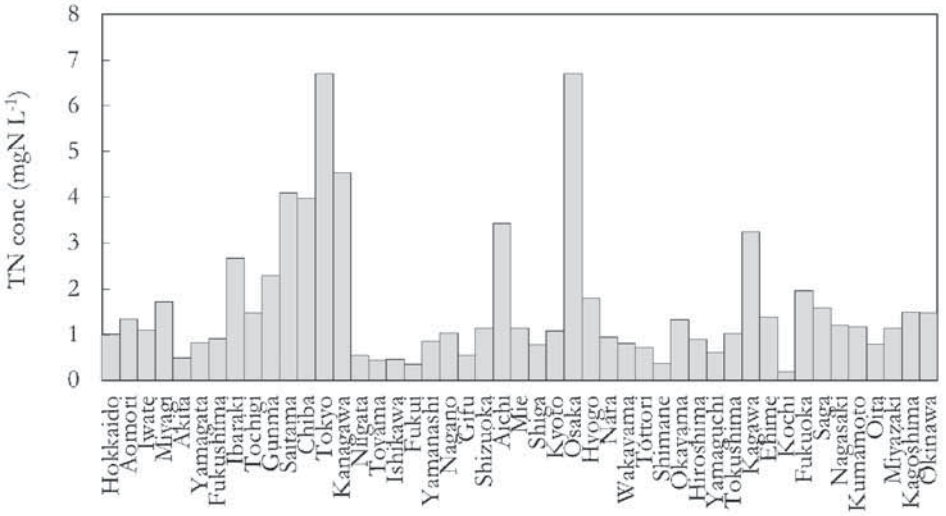

Fig. 4. Estimated regional stream TN concentration in Japanese prefectures.

centration was lower in agricultural prefecture than in urban prefecture. Metropolitans showed remarkably high TN concentration up to 7 mg N L^{-1}.

The stream N runoff ranged from 3.6-73.6 kgN ha^{-1} yr^{-1} in which 2.1 to 24.2 kg N ha^{-1} yr^{-1} was derived from agricultural field and 1.0 to 70.9 kg N ha^{-1} yr^{-1} was derived from sewage plant (Fig. 5). In the metropolitans, the stream N runoff from sewage plant was extremely high. Total stream N runoff in Japan was estimated as 0.50 Mt N, which was 27 % of NNI, in which 0.33 Mt N yr^{-1} from agricultural field (66.7%) and 0.17 Mt yr^{-1} from sewage plant (33.3%).

4) Estimated regional N_2O emission in Japan

Fig. 6 shows that mean potential denitrification activity (N_2O+N_2) measured by the acetylene blocking method was significantly higher in top 0-5 cm soil layer than in sub layers in all land uses of wind breaking forest, grassland and riparian forest. The denitrification activity was higher in riparian forests (571±1602 mg N kg^{-1} day^{-1}) than in wind breaking forests (246±337 mg N kg^{-1} day^{-1}) and in grassland (67±112 mg N kg^{-1} day^{-1}). Fig. 7 shows that mean $N_2O/(N_2O+N_2)$ ratio was not significant difference among the soil depths in land uses. The average of the ratio was 0.71±0.256 (n=84). Čuhel et al. (2010) shows the ratio decrease with increase of pH. The soil pH in this study ranged from 4.3 to 6.6. However, there was no significant relationship between pH and the ratio of $N_2O/(N_2O+N_2)$. Čuhel et al. (2010) also showed the ratio of 0.8 in the soil with pH 5.5. The mean soil pH of this study was 5.6. Taking into con-

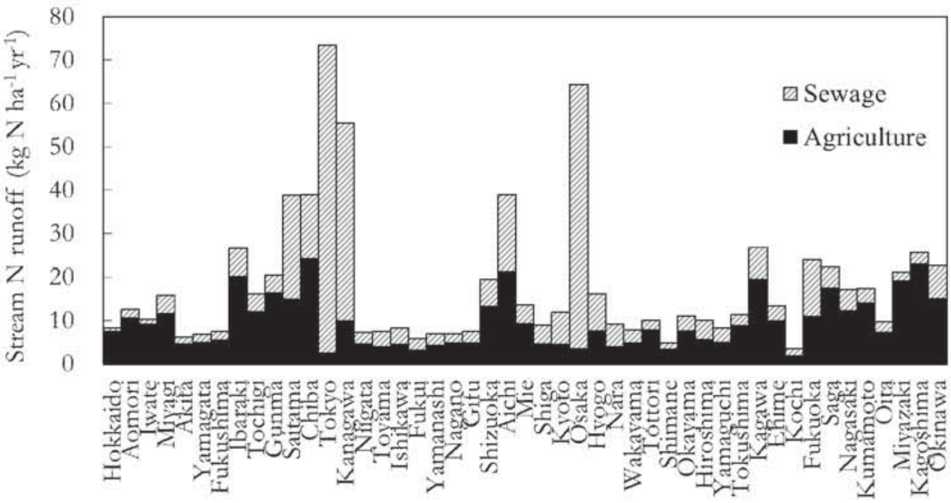

Fig. 5. Regional stream N runoff derived from agricultural field and sewage plant in Japanese prefectures.

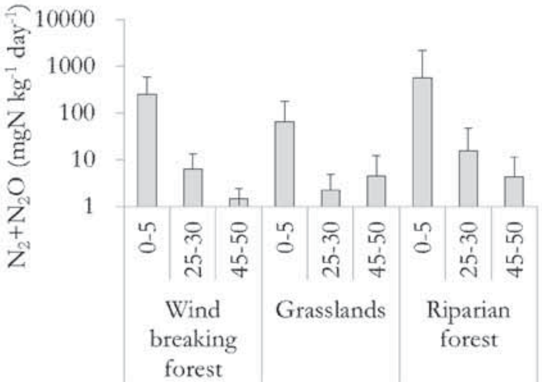

Fig. 6. Denitrification activity (N_2O+N_2) of the soil sampled from different depths in wind breaking forest, grassland and riparian forest in Shibetsu watershed.

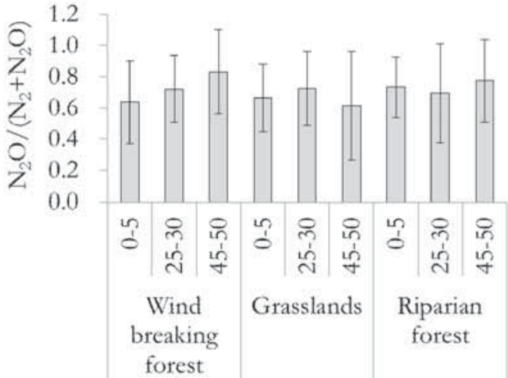

Fig. 7. $N_2O/(N_2O+N_2)$ ratio of the soil in wind breaking forest, grassland and riparian forest in Shibetsu watershed.

sideration that top layer showed high denitrification activity, the $N_2O/(N_2O+N_2)$ ratio of 0.71 was able to be acceptable.

Table 1 shows an example of the calculation of N_2O emission based on the NNI, stream N runoff, stream HCO_3^- runoff and $N_2O/(N_2O+N_2)$ ratio using the data obtained in Shibetsu watershed. Source of the stream HCO_3^- runoff was estimated by equation (16) and (17). Denitirification (N_2O+N_2) (weight base) was obtained by (14/12) × HCO_3^- runoff from denitrification (weight base) based on the equation (3). Regional N_2O emission was calculated by equation (18) using the $N_2O/(N_2O+N_2)$ ratio of 0.71. The regional N_2O emission was estimated as 31.6 kg N ha^{-1} yr^{-1}, corresponded to 58.1 % of NNI and more than three times of stream N runoff. However, the N_2O emission seemed to be large compared to the N_2O emission from grassland soil in the watershed, which was less than 10 kg N ha^{-1} yr^{-1} (Hatano et al., 2011). The regional N_2O emission may include indirect emission through water soluble N_2O. However, several studies showed indirect N_2O emission was lower than direct emission. The ratio of indirect emission to direct N_2O emission was 4.6 % in a onion field in Hokkaido (Sawamoto et al., 2003) and 50.3 - 67.3% from soybean, wheat and upland rice plots and 273 - 341 % in paddy rice plot in Tsukuba (Minamikawa et al., 2010). The watershed includes some wet spots like riparian zone although the area is less than 10% and sub-soils may be always wet although the denitrification activity is low due to low available water soluble organic carbon. Therefore, it may be possible to produce the larger N_2O in the watershed although further research is required. N_2O emission in each prefecture in Japan was estimated using the estimated NNI and regional N runoff.

Table 1. Fate of NNI and source of HCO_3^- runoff estimated based on the data obtained in Shibetsu watershed in 2003 and 2004

NNI	N runoff	N_2O emission	N_2 emission	Other losses
kgN ha^{-1} yr^{-1}				
54.5	9.0	31.6	12.9	0.9
100%	16.5%	58.1%	23.7%	1.7%

HCO_3^- runoff	from denitrification	from weathering
kgC ha^{-1} yr^{-1}		
82.6	38.2	44.4
100%	46.2%	53.8%

Fig. 8 shows the estimated regional N_2O emission in each prefecture in Japan. The N_2O emission ranged from 6.7 to 138.5 kg N ha^{-1} yr^{-1} in which 3.9 to 45.5 kg N ha^{-1} yr^{-1} was derived from agricultural field and 1.8 to 133.4 kg N ha^{-1} yr^{-1} was derived from sewage plant.

In the metropolitans, the N_2O emission from sewage plant was extremely high. Total N_2O emission in Japan was estimated as 0.94 Mt N yr^{-1}, which was 51 % of NNI, in which 0.63 Mt N yr^{-1} from agricultural field (66.7 %) and 0.31 Mt N y^{-1} from sewage plant (33.3 %). However, there was a significant gap between the estimates of this study (0.94 Mt N y^{-1}) and National Inventory (0.03 Mt N yr^{-1}) (Ministry of Environment, 2011). Most significant problem in the estimation of N_2O emission in this study is that the value of $N_2O/(N_2+N_2O)$ ratio (0.71) may be too high. The NO_3 concentration (200 ppm) in added solution for DEA measurement in conventional method used in this study may be too high. Increase of the NO_3 concentration increases N_2O production (Weier et al., 1994). Combining the data of Weier et al. and this study, significant relationship between the NO_3 concentration in added solution and $N_2O/(N_2O+N_2)$ ratio and the ratio at the no NO_3 addition was 0.21. Using the value of 0.21 for the ratio, N_2O emission in Japan was estimated as 0.24 Mt N yr^{-1}. But, this value is still higher than National Inventory. It is necessary to improve the methodology for the ratio and to prepare the ratio for the representative soils in the countries.

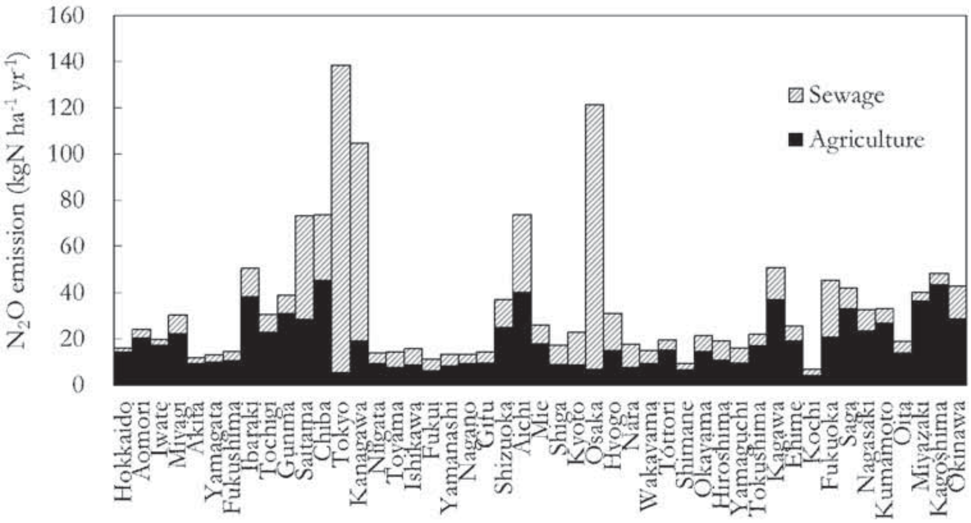

Fig. 8. Regional N_2O emission from agricultural field and sewage treatment in Japanese prefectures.

Another problem is that National Inventory did not include the increase of background N_2O emission associated with N mineralization from SOM decomposition. N_2O emission in Japanese forest is 0.16 ±0.16 kg N ha^{-1} yr^{-1} (Morishita et al., 2007). On the other hand, background N_2O emission in upland crop was 1 to 5 kg N ha^{-1} yr^{-1} associated with N mineralization of SOM decomposition (Mu, et al., 2009). But, increase of N_2O emission was only 0.004 to 0.02 Mt N yr^{-1}. Further research is needed to solve the gap.

5) Improvement of N flows

As mentioned above, livestock disposal N was 14% of L, which was 0.198 Mt N yr^{-1}. Fig. 9 shows the comparison of NNI, N_2O emission and stream N runoff in actual status and the status with reuse of all livestock excreta. When the livestock disposal N was used to alter chemical N fertilizer application, total NNI was reduced from 1.84 to 1.65 Mt N yr^{-1} (by 10.8 %), and NNI derived from agriculture decreased from 66.7 to 62.7 % of the total NNI. Total regional

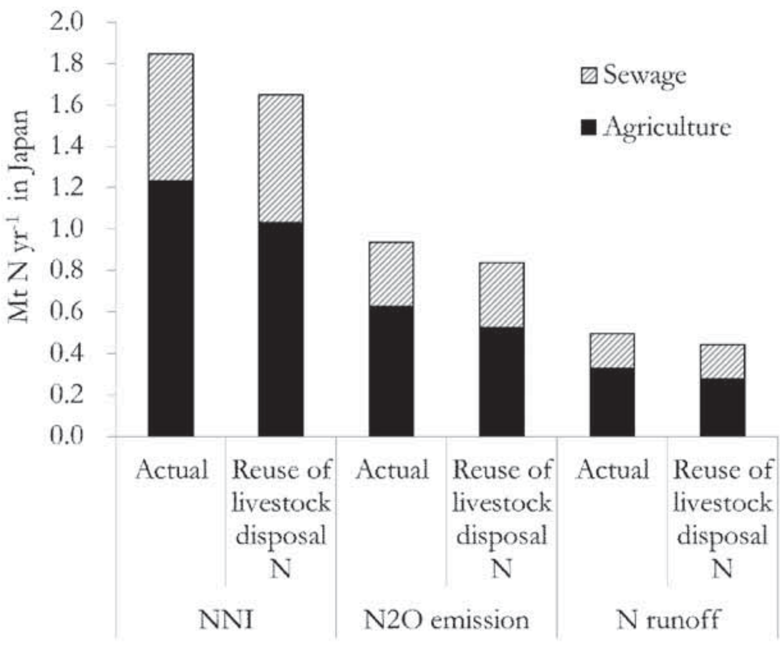

Fig. 9. Comparison of regional NNI, N2O emission and N runoff from agriculture and sewage treatment in actual status and status with reuse of livestock disposal N in Japan.

N_2O emission decreased from 0.94 to 0.84 Mt N yr^{-1} and total stream N runoff decreased from 0.50 to 0.44 Mt N yr^{-1}. This would make a reduction of the regional area and the number of the prefectures, where stream TN concentration exceeded 1 mg N L^{-1}, from 66 % to 31% of total area of Japan and from 29 to 22 of total 47 prefectures, respectively.

Table 2 shows the characteristics of mean regional N flows in Japan. Reuse of livestock disposal N increased C and reduced L, but did not change E, P and TST. Cycling index increased and loss index decreased with reuse of livestock disposal N. Reuse of livestock disposal N decreases chemical N fertilizer application, resulting in the decrease of I (= E+L+P) and NNI as shown in Fig. 9. However, reuse of livestock disposal N increases C and compensates the decrease of chemical N fertilizer application. Due to this, TST is maintained although L is reduced. That is, cycling plays a role of N stock to be supplied to crops, consequently which is the same role as imported chemical N fertilizer.

Furthermore, reuse of human disposal N accounting for 36 % of total NNI decreases L and P and increases C, which reduce chemical N fertilizer application. In fact, human induced N treated in sewage plant was 0.61 Mt N yr^{-1} which was almost same as chemical N fertilizer application (0.66 Mt N yr^{-1}) and imported food N (0.59 Mt N yr^{-1}). Reuse of human disposal N can compensate chemical N fertilizer and imported food N. However, in order to reduce the imported food N (increase of self-sufficiency), farmland area should be increased. Increase of upland field may increase N loss (equation 19). Careful discussion including conservation of the land with high denitrification activity, such as riparian forests or wetland is necessary. High denitrification activity increases N_2O production, and N_2O production is enhanced by soil acidification stimulated by chemical N fertilizer application. Further research to elucidate the balance between the food production and environment conservation is necessary. And Model prediction is required to assess for development and application of mitigation technology. However, field observation is also important to elucidate controlling factors of environmental pollutions and to determine the values.

Conclusion

Reducing the regional N import associated with the imports of food and feed N and chemical N fertilizer by the application of human and livestock disposal N is required to mitigate environmental loss from agriculture. Application of the disposal N to the farmland increases N cycling to maintain crop production and reduces N loss as stream N runoff and N_2O emissions. However, improvement of self-sufficiency of food requires the increase of farmland area. This often increases N loss. Further study is required to balance between food production and environment conservation.

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Table 2. Comparison of mean regional N flows of cycling (C), export (E), loss (L), purification (P) and total system throughput (TST), and the flow indexes of cycling (CI), export (EI), loss (LI), purification (PI) in actual status and status with reuse of livestock disposal N in Japan.

	C	E	L	P	TST
Actual	19.7	8.7	45.5	21.0	95.0
Reuse of livestock disposal N	26.2	8.7	39.1	21.0	95.0
	CI	EI	LI	PI	Total
Actual	0.23	0.10	0.47	0.20	1
Reuse of livestock disposal N	0.29	0.10	0.40	0.20	1

thor also appreciates that Dr. Shin-ichiro Mishima of National Institute of Agro-Environmental Sciences could allow us to use of digital data for estimation of nitrogen flow and nitrogen balance in the districts.

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9th International Symposium on Integrated Field Science

"Soil and Environment"

Purpose of the symposium:

An understanding of the interactions between agricultural activities and environment is central for sustainable agriculture. Especially, soil which supports crop productions has a crucial role in these interactions.

The aim of this international symposium is to provide a multidisciplinary forum for exchanging innovative ideas and methods for studying the interactions between agricultural activities and soil, understanding its complexity and its functioning.

In the present symposium, the special session on environmental disaster caused by the catastrophic earthquake followed by Tsunami will be held with reference to sustainability of soil. Another disaster by Tsunami in Indonesia, 2004, and its effect on soils will be presented by Dr. F. Agus in this session. In the second session, we will focus on green house gases (GHG) and nitrogen which may cause global warming and water pollution. Poster session is open for those who are interested in these topics.

Date: 3 September, 2011 (9:30 – 17:00)

Venue: Kawauchi Kita Campus Room A101-102, Tohoku University

Organized by

Field Science Center, Graduate School of Agricultural Science, Tohoku University

Co-organized by

Strategic Japanese-Chinese Cooperative Program "Comparative study of nitrogen cycling and its impact on water quality in agricultural watersheds in Japan and China" (JST-NSFC)
Tohoku University Global COE "Ecosystem Adaptability"

Supported by

National Institute for Agro-Environmental Sciences
Project of Integrated Compost Science (PICS), Tohoku University

Secretary General:

Masanori SAITO
Professor,
Laboratory of Environmental Crop Science,
Field Science Center,
Graduate School of Agricultural Science,
Tohoku University

Program

9:30	Saito, M.	Opening address

Session 1. Environmental Disaster caused by Earthquakes

9:40	Nanzyo, M.	Impacts of Tsunami (March 11, 2011) on paddy field soils in Miyagi Prefecture, Japan
10:05	Agus, F. et al.	Soils affected by Tsunami - The effect of Tsunami on arable fields in Aceh, Indonesia in 2004
10:35	Nishio, T.	"Na-no-Hana Project" for recovery from the Tsunami disaster by producing salinity-tolerant oilseed rape lines
11:00	Takeda, A.	Behavior and phytoavailability of radiocaesium in surface soil

Session 2: Nitrogen, Green House Gasses and Agriculture

11:25	Cai, A., Yan, X.	A Great Challenge to Solve Nitrogen Pollution from Intensive Agriculture
11:50		Lunch
13:00		Poster presentation
14:00	Yan, X., Cai, Z.	Integrated greenhouse gas emissions from Chinese rice paddies
14:25	Yagi, K.	Analysis of research stocktaking in the Paddy Rice Research Group of the Global Research Alliance on agricultural greenhouse gases
14:50	Mu, ZJ. et al.	Soil greenhouse gas fluxes and net global warming potential from intensively cultivated vegetable fields in southwestern China
15:10	Deng, M. et al.	Modeling N_2O emission from Andosols in an intensive dairy farming region, Japan
15:25		Coffee Break
15:40	You, M.	Possible nitrogen removal through denitrification in the watershed scale
16:05	Oo, A. Z. et al.	Spatial differences in soil properties, crop yield and methane emission from paddy rice cascade
16:20	Theint, E. E. et al.	Influence of different Ca amendments on CH_4 emission under Na-salinized paddy soil
16:35	Hatano, R.	Mitigation of impact of nitrogen cycling associated with agriculture and food consumption on regional environment
16:50		Closing remark

Chair Persons: M. Saito, T. Takahashi, M. Nanzyo,

Poster Session

P1	Kimura, S. et al.	Comparison of Nitrogen Budgets in Agricultural Watersheds
P2	Hayakawa, A. et al.	Spatio-temporal variation of riverine N and P concentration in the Lake Hachiro watershed.
P3	Kohyama. K. et al.	The relationship between Nitrogen load and river water quality in several catchments in different area sizes
P4	Itahashi, S. et al.	Risk evaluation of the groundwater pollution by the agriculture origin nitrogen in a middle-sized agricultural watershed
P5	Tsushima, K. et al.	Effects of silicate fertilizer application on growth and yield of rice with organic culture
P6	Akita, K. et al.	Aquatic Biota in Winter Flooded Paddy Field with Organic Farming-Case Study in Field Science Center, Tohoku University, Japan-
P7	Xia, Y. et al.	Diurnal pattern of nitrous oxide emissions from a sewage-enriched river: references to IPCC indirect emission factor
P8	Liu, X. et al.	Effect of long-term fertilization on greenhouse gases emission in paddy soils, China
P9	Azuma, J., Saito, M.	Determination of phytase labile organic phosphate in organic manures
P10	Kusunoki, A. et al.	Effect of water management on vivianite crystallization on rice roots
P11	Yoshimoto, R. et al.	Effect of soil components on adsorption of Pepper Mild Mottle Virus by Japanese soils
P12	Yamamoto, T. et al.	Isolation of plant growth-inhibiting compounds from acidulocompost; a garbage compost processed under thermoacidophilic conditions
P13	Miyazawa, M. et al.	Effect of chemical treatment on mineralization of C and N in Andosols rich in Al-humus complexes
P15	Enami, M. et al.	Andosols-Cambisols sequence on the Ohira Hills in central Miyagi Prefecture, northeastern Japan
P16	Nishiue, A. et al.	Studies on faint podozolization observed in the Andosols around Kuwanuma on the eastern footslope of Funagata Volcano in midwestern Miyagi Prefecture, Japan
P17	Goto, T.	Experience as a member of JOCV in Caoson village, Vietnam
P18	Nakai, Y. et al.	Report on Agri- Reconstruction Project (ARP).

Welcome Reception will be held at “Kita no Kazoku”, Dai-Ichi Seimei Tower Build. from 18:30.

Impacts of Tsunami (March 11, 2011) on paddy field soils in Miyagi Prefecture, Japan

Masami NANZYO

Graduate School of Agricultural Science, Tohoku University, Sedai, 981-8555, Japan

A 9.0 magnitude earthquake hit eastern Japan on March 11th, 2011. It triggered huge tsunami and the area of the damaged agricultural land by the tsunami was summarized in Table 1. The Miyagi prefecture has been damaged most extensively. The tsunami penetrated up to several kilometers inland from a coastline of the Miyagi prefecture. The damaged agricultural lands were mainly the paddy fields (Table 1).

Table 1. Estimated area damaged by Tsunami (March 11th, 2011).

Prefecture	Agricultural land (2010) ha	Area damaged by Tsunami			
		ha	%	Paddy field ha	Upland ha
Aomori	156,800	79	0.1	76	3
Iwate	153,900	1.838	1.2	1,172	666
Miyagi	136,300	15,002	11.0	12,685	2,317
Fukushima	149,900	5,923	4.0	5,588	335
Ibaraki	175,200	531	0.3	525	6
Chiba	128,800	227	0.2	105	122
Total	900,900	23,600	2.6	20,151	3,449

Ministry of Agriculture, Forestry and Fishery (March, 2011)

There are several types of interactions between tsunami and the agricultural lands not only scattering debris. They are erosion at the ①, ②, ③ sites and deposition on the agricultural lands as physical interactions (④, ⑤), and also, ion exchange and precipitation reactions as chemical interactions (④, ⑤, Fig. 1). If there was a muddy (sometimes contains sulfides) and/or sandy deposit under the shallow seawater or in the nearshore zone (①), it was transported to the agricultural land and deposited (④, ⑤). As there are small eroded sites also at the ② and ③ sites where tsunami fell down from micro-high sites like a road and a ridge. Moreover, the A_p horizon soil after tilling was lost at least partly. Thus, the deposits on the agricultural lands contain the eroded A_p horizon soil also. The chemical reactions of ④ and ⑤ include the exchange reaction between Na^+ in seawater and exchangeable Ca^{2+} in the A_p horizon soil, and precipitation of $CaSO_4 \cdot 2H_2O$ as well as NaCl when the soils dry.

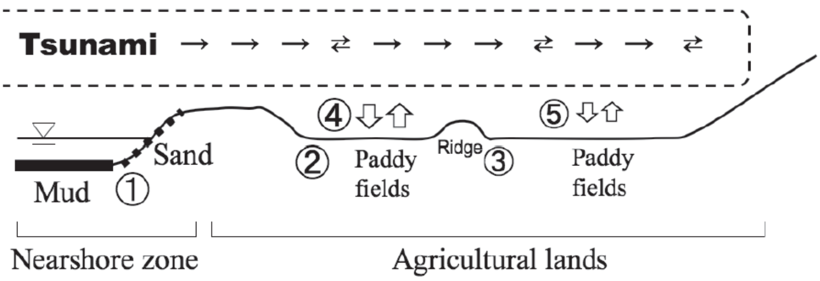

Fig. 1. Schematic diagram of interactions between Tsunami and agricultural lands.

The dynamics of tsunami affected soil properties in Aceh, Indonesia

Fahmuddin AGUS[1*], Achmad RACHMAN[2], Wahyunto[3], Sofyan RITUNG[3], Malem MCLOID[4] and Peter SLAVICH[4]

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Understanding the dynamics of tsunami-affected soil properties is a key for reconstructing the local agriculture after tsunami events. We conducted a series of soil research after the 26 December 2004 Indian Ocean tsunami in the coastal areas of Nanggroe Aceh Darussalam (NAD) Province, Indonesia. The objectives of the study were to evaluate (i) the extent and types of soil damages, (ii) soil profiles of the affected area, (iii) changes in soil properties over time, and (iv) crop response. Survey of the extent and severity of soil damages from January 2005 to the end of 2007. Four soil profiles were evaluated in May 2005 and August 2007 in Aceh Besar District. Changes in soil salinity were evaluated at several monitoring sites using the electric conductivity (EC) meter based on soil samples and in the field using an electromagnetic induction soil conductivity instrument (EM38) from mid 2005 to the end of 2007. The tsunami waves affected the coastal areas up to 5 km inland. The damages ranged from permanent inundation, tsunami mud/sand accumulation and surface crusting and salinity. Salinity level of up to 84 dS m^{-1} was measured a few weeks after the tsunami, but it decreased to <4 dS m^{-1} by October 2007 except in areas where lateral/vertical drainage is retarded. Soil pH, organic carbon content, exchangeable cations and total phosphorus were higher in the tsunami formed 'O' horizon than in the underlying layers. Yields of rice and dryland crops were lower in the first few seasons after the tsunami and empty pods of peanut and unfilled grain of rice were commonly observed. This could be attributed to either or combination of salinity, sodicity, cation imbalance and low micro nutrient availability. The tsunami effects were very variable and therefore management needs to be site-specific to be effective. In general, reconstruction of irrigation and drainage systems and application of organic matter speeded up the soil recovery.

"Na-no-hana Project" for recovery from the Tsunami disaster by producing salinity-tolerant oilseed rape lines

T. NISHIO

Graduate School of Agricultural Science, Tohoku University

Fields of more than 20,000 ha in Tohoku region have suffered the Tsunami disaster by the Higashinippon earthquake, and it may be difficult to grow crops in these fields for several years because of high salinity. *Brassica* crops, e.g., oilseed rape, cabbage, radish, and mustard, are known to have relatively high tolerance to salinity and to absorb much salt. However, most of the *Brassica* crops are outcrossing plants, and have high variation of salinity tolerance within a species. Since Tohoku University has unique genetic resources of *Brassica* crops and its wild relatives, we planned to use these genetic resources as materials for developing salinity-tolerant oilseed rape lines and oil production in these fields. We are testing salinity tolerance of more than 50 lines *in vitro* and in pots. After selection of ten salinity-tolerant lines, we plant them in the high salinity fields. Assessing salinity tolerance, seed yield, adaptability, plant biomass, and uptake of salts, we will select a line usable as a rapeseed line for oil production in these fields and as a material for breeding of a more promising salinity-tolerant high-yielding rapeseed line. In our preliminary investigation, we identified salinity tolerant lines in *Brassica napus*, *Brassica juncea*, and *Raphanus sativus*.

Behavior and phytoavailability of radiocaesium in surface soil

A. TAKEDA

Institute for Environmental Science

Large-scale Tsunami on 11 March 2011 triggered the accident of Fukushima Daiichi Nuclear Power Plant. Large amount of several radionuclides was released into the atmosphere and deposited onto the surface soil and vegetation in the wide area in eastern Japan. Among the released radionuclides, ^{137}Cs is one of the most important nuclides for estimating long-term public exposure to radiation, because of its long half-life (30.1 y). Therefore countermeasures are required for its reduction in agricultural products in contaminated regions.

The distribution of fallout ^{137}Cs, derived from atmospheric nuclear weapon testings carried out mainly in 1950s - 60s, in agricultural soil and crops has been investigated. After the Chernobyl Nuclear Power Plant accident in 1986, fate of ^{137}Cs in terrestrial environment and mechanism of its retention to clay minerals have been extensively studied. In this presentation, the behavior of Cs in soil and its transfer from soil to plant will be reviewed briefly.

It is well known that Cs is specifically sorbed on frayed-edge sites (FES) of illitic minerals. A major form of nitrogen in soil solution under anoxic condition is NH_4^+, which acts as a competitive ion for Cs^+ on sorption into FES. Therefore, mobility of radiocaesium can be influenced by nitrogen cycle in paddy soil. Potentially effective soil management to reduce Cs transfer to crop will be also discussed.

A Great Challenge to Solve Nitrogen Pollution from Intensive Agriculture

Zucong CAI[1] and Xiaoyuan YAN[2]

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[2]Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008

The huge population and the small arable land area per person determine that intensive agriculture, which is characterized by high ratio of cultivated land to territory, high multiple cropping indices, and large input of agro-chemicals, is an inevitable choice for food security in China. Although the researches were continuously strenthened for good management practices for raising nitrogen use efficiency (NUE), minimizing N losses from croplands, and thus mitigating adverse impacts of N application on environment and the knowledge on rational application of N fertilizers was improved greatly in China in the last three decades, the total consumption of N fertilizers continuously increased and NUE, on the national average, decreased from about 30-35% in 1980s to around 20-30% in 2000s. This is because the top priority for food security drove the increase in consumption of N fertilizers, thus leading to the decrease in NUE. The driving force for producing food as much as possible will continue and potential is available for enhancing crop production through raising multiple cropping indices and increasing N application in China, while, the NUE is unlikely to reach the levels achieved in some developed countries because it decreases with the increases in multiple cropping indices and nitrogen application rate. All of these factors determines that the N consumption will increase in China in future. Therefore, while we should continue to struggling for higher NUE, we have to realize that nitrogen pollution from crop production could not be controlled by raising NUE alone under intensive agriculture. In order to protect our environment and sustain development, we have to face a challenge to solve nitrogen pollution under the condition of high nitrogen application rate. Research should be strengthened for the control of nitrogen pollution through establishedment of theories, principles, technologies, and policies under the intensive agriculture.

Integrated Greenhouse gas emission from paddy fields in China

Xiaoyuan YAN[1] and Zucong CAI[2]

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[2]Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008

Rice is the crop with the biggest production in China, but the sowing area of rice showed a declining trend since middle 1970s and was outweighed by maize in 2007. The current sowing area is about 29 million ha, with half being single rice, one quarter being early rice and remaining being late rice. Methane (CH_4) emission has been measured on over 30 sites, with varying duration since late 1980s. Measured seasonal emissions were extremely variable, ranging from 3.4 to 1274 kg CH_4 ha^{-1}. Except the widely acknowledged influencing factors such as organic amendment, water regime during rice growing season, it was found that seasonal emission from late rice is higher than that from early rice, and the latter is higher than that from single rice, likely due to the difference in the water regimes before these rice seasons. A number of estimations have been made for the total CH_4 emission from Chinese rice fields, with more recent ones being around 7.6 Tg CH_4 $year^{-1}$.

Nitrous oxide (N_2O) emission from paddy fields in China has been measured on over 20 sites, with seasonal emissions ranging from 0.02 to 12.6 kg N ha^{-1}. Estimated annual emission ranged from 29 to 37 Gg N.

While emitting CH_4, paddy fields in China acted as a sink of atmospheric carbon dioxide (CO_2). Average soil organic carbon content of paddy fields increased by 2.5% from 1980 to 2007, which translates to a carbon sequestration of 74 Tg for the paddy fields nationwide. The sequestrated carbon equals 5.3% of the CH_4 emitted during the same time period in terms of global warming potential (GWP).

In summary, Chinese paddy fields emit CH_4 and N_2O at 190 and 9.8 Tg CO_2-eq year^{-1}, respectively, and sequestrate carbon at 10 Tg CO_2-eq year^{-1}. Thus the GWP of paddy fields is absolutely dominated by CH_4 emission.

Analysis of research stocktaking in the Paddy Rice Research Group of the Global Research Alliance on Agricultural Greenhouse Gases

K. YAGI

National Institute for Agro-Environmental Sciences

The Global Research Alliance on Agricultural Greenhouse Gases, which was launched in December 2009, brings countries together to find ways to grow more food without increasing GHG emissions (Global Research Alliance; Shafer et al., 2011). As an initial activity in the Alliance, research stocktaking was conducted within participating countries to identify current research activities, opportunities, gaps and areas of overlap. The results for the Paddy Rice Research Group are presented.

A detailed spreadsheet that captures information on each country's research projects and programmes in agricultural greenhouse gas emissions was prepared and distributed to each contact point of the Alliance member countries. The questions on the spreadsheet include research target, topic, outcome, structure, etc. as well as key equipment, facilities, and databases. As at 1 March 2011, 68 projects from 16 countries (China, Denmark, Ghana, Indonesia, Japan, Korea, Malaysia, Netherlands, Pakistan, Peru, Philippines, Russian Federation, Spain, Thailand, Uruguay and US) had been listed in the stocktake of the Paddy Rice Research Group.

Most of the research is being undertaken into irrigated rice production systems, with little on rain-fed production systems. The lack of data for rain-fed systems may cause difficulties when one tries to develop country specific emission factors. Projects focusing on methane accounted just over 50%, and the percentages for nitrous oxide and soil carbon sinks/sources were 30% and 20%, respectively. This result suggests that possible trade-off between different GHGs and the importance of evaluating the net global warming potential are well understood in many research projects.

There were two areas of research that predominated: GHG accounting/life cycle assessment and agronomy. While much smaller, the third focus for research was farming systems. In terms of research outcomes, the key primary outcomes were included: testing of mitigation, low greenhouse gas emitting varieties, improved national inventory and investigation of mitigation options. Most of the current research can be described as "applied" or "tactical" and is primarily funded from governments. The results indicate the general need for research progress on developing mitigation options and improving national inventories for GHG emissions from paddy fields in many countries.

The Paddy Rice Research Group of the Alliance will continue to compile databases on research projects, experts and literature related to GHG emissions from paddy fields in each member country. Those processes will be conducted through the contact point of each country. The Group also plans to develop and publish a manual of standardised measurement techniques for GHG emissions from paddy fields through identification of "good practice" and gaps in current methodology. As a plan for longer term action, it is discussing to develop a simple project protocol for evaluating promising mitigation options, such as water management practices, that would be undertaken in a number of rice producing countries.

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Soil greenhouse gas fluxes and net global warming potential from intensively cultivated vegetable fields in southwestern China

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Vegetable cropland in China has increased from 3 million ha in 1980 to 18.4 million ha in 2009, and the field management has been characterized with intensive fertilization and high density of cultivation. Therefore, the net effect of vegetable production on global warming deserves attention. Greenhouse gas fluxes were thus measured over approximately 18 months in two typical subtropical vegetable fields with intensive management and contrasting soil properties. Intensive fertilization consistently stimulated N_2O emission, while imposed complicated impact on soil respiration with CO_2 emission enhanced in one field and suppressed in the other field. The fertilizer-induced N_2O emission factors averaged 1.4 to 3.1% with large seasonal variations which could be explained by the interaction of soil temperature and moisture up to 71 to 94%. All the vegetable cropping systems were net sources of atmospheric radiative forcing, and the net global warming potential over the entire study period ranged from 1786 to 3569 g CO_2 equivalence m^{-2} for fertilized soils with net CO_2 emission contributing 53 to 67% and N_2O emission occupying the remaining 33 to 47%. The result suggests that sustainable management practices are pressingly needed to explore for vegetable farming to satisfy the increasing demand for vegetable while to mitigate its global warming effect through reducing fertilizer-induced N_2O emission as well as increasing carbon sequestration in vegetable fields.

Modelling N_2O emissions from Andosols in an intensive dairy farming region, Japan

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[2]Field Science Center, Kitasato University, Nasushiobara, Japan

Estimates of agricultural Nitrous oxide (N_2O) emissions are needed to develop economical efficient as well as effective policies in mitigating and reducing greenhouse gas emissions in farming systems. In Japan compared with the beginning of 70's, the livestock sector grew two times in recent years to meet the increasing demand in meat and dairy productions and the N_2O emission related to manure increased However, the potential of alter-

native management practices to reduce soil N_2O emissions has been poorly studies, and quantitative estimates across fields remain uncertain. In addition, Japan is an active volcanic country, where Andosol covers 16.4% of the land surface and 46.5% of arable upland fields. These volcanic soils are originally acidic and have high friability, high porosity and high content of Al and Fe with high humus accumulated ability (Shindo and Honma, 2001). Consequently, those unique physical and chemical characteristics in Andosols can lead to different C and N cycles compare to other soil orders. So far, C and N cycles in those specific soils have not been modeled.

The objectives of this study were (i) to calibrate and validate the DNDC model for N_2O emission on Andosols under intensive dairy manure application, (ii) to estimate N_2O emissions in this agriculture system, (iii) to suggest potential N_2O mitigation solutions for managing dairy manure on Andosol.

Compared to summer crop season, winter crop season showed higher N_2O fluxes (Fig 1). The cumulative emissions were 0−1.22 kg N ha^{-1} in summer season (May-Sep) and 0.73−7.73 kg N ha^{-1} in winter period (Oct-Apr). The highest emission was found in the field with high clay and silt content and slurry application which provide a good condition for denitrification process (G/M3). Farm managements also significantly influenced N_2O emission, the farmer's practice the plowing immediately after composted manure application can significant decrease the N_2O emission (G/M1). Paddy fields showed significantly lower N_2O emission (0.89−1.43 kg N ha^{-1} yr^{-1}) than uplands (1.66 – 8.62 kg N ha^{-1} yr^{-1}). This result could be attributed to the highly anaerobic condition in paddy rice fields which lead to denitrification process producing more N_2 rather than N_2O compared with uplands.

After calibration, modelled crop parameters and soil parameters were comparable with the observed values and the typical values found in the literature. Mean yields of grass and maize were predicted reasonably well. But the rice yields have been significantly under estimated by DNDC. It suggested that the performance of DNDC was not good for low fertilizer application rates. Over estimate the soil moisture condition from DNDC was the main reason for the N_2O emissions.

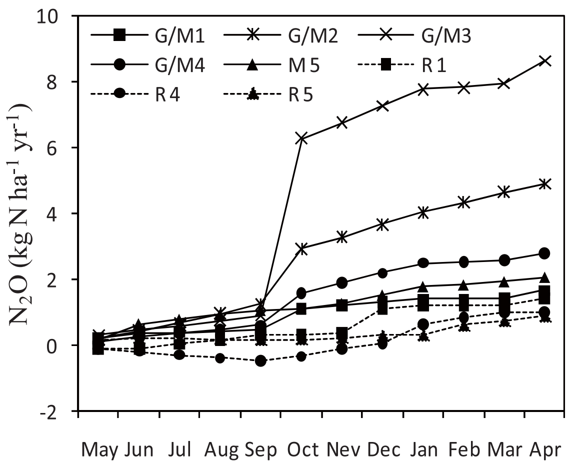

Fig. 1. Cumulative N2O emission of field through a whole year

Possible nitrogen removal through denitrification in the watershed scale

Muneoki YOH

Tokyo University of Agriculture and Technology, Japan

The increase of N loading from anthropogenic sources such as agriculture, sewage, and atmospheric deposition have resulted in the increase in nitrogen concentration in river discharge, with a linear relationship often observed between riverine N flux per area and the net N input per area (Howarth et al., 1996). But importantly, the N output by river discharge is much less than the N input, suggesting a significant sink in river basin such as denitrification, accumulation to soil and vegetation, etc.. It is important to understand these potential nitrogen sinks to evaluate the impact of N input and N cycling in watershed scales.

Here, I discuss the potential importance of denitrification, which may significantly contribute to NO_3^- removal during the process of discharge especially lower reaches of rivers, on the basis of several preliminary results about ground water denitrification.

In a highland slope used for cabbage agriculture, the estimated NO_3^- concentration calculated from the N and hydrological budgets agreed well with observed NO_3^- concentration in streams, indicating that the stream NO_3^- concentration is regulated simply by the N and water balance with negligible denitrification in this district. In contrast, decreased NO_3^- concentrations are invariably observed in lowlands; the lower position of slope, where more humid condition prevails. A transect study in an agricultural region showed marked decreases in NO_3^-/Cl^- ratio and dissolved oxygen concentration and significant increases in dissolved N_2/Ar ratio in ground water in lowland regions, strongly suggesting NO_3^- removal by denitrification. Forest sites having a groundwater table shallower than ca. 1m also tend to have evidence of denitrification.

Water discharge almost always passes through the groundwater in lowland before flowing out to rivers, where denitrification is probably active in common. In the light of this fact, it is highly likely that a large part of nitrogen discharged from land surface may be removed by denitrification in the river basin scale. Detailed and systematic researches are required to know the actual quantitative importance of denitrification and the boundary conditions regulating this process.

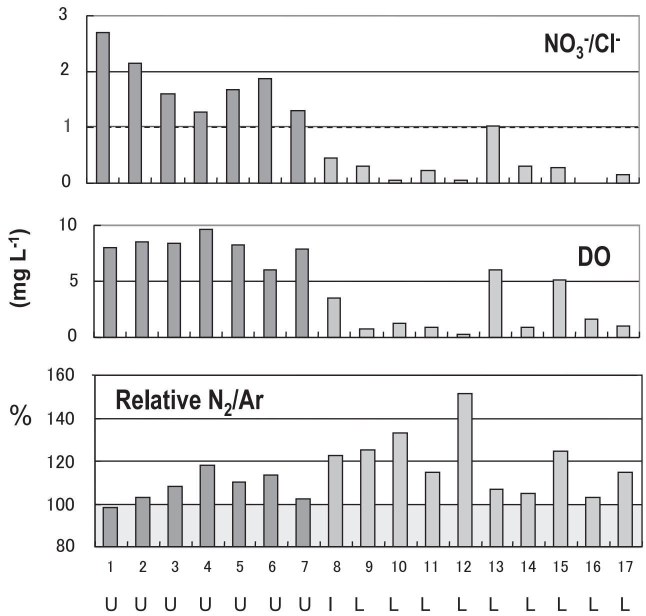

Fig. 1: NO_3^-/Cl^- ratio, dissolved oxygen, and dissolved N_2/Ar ratio in groundwater for the sites along an upland-lowland transect in an agricultural region (Kamagaya, Chiba), Japan.

The notation of U, I and L in the x-axis denote upland, intermediate, and lowland zones, respectively.

Spatial differences in soil properties, crop yield and methane emission from paddy rice cascade, Northwest Vietnam

Aung Zaw OO[1], Kimura Sonoko DOROTHEA[1], Khin Thuzar WIN[1], Nguyen Xuan HUU[2], Lam NGUYEN[2] and Georg CADISCH[3]

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[2]Hanoi University of Agriculture, Vietnam
[3]University of Hohenheim, Germany

In tropical mountainous regions of Northern Vietnam, most of the population depends on the cultivation of paddy rice in lowlands and crops such as maize and cassava in upland areas with relatively steep slopes. Intensive cultivation of upland crops enhances large nutrient losses through erosion in the upland areas. However, in the lowland areas, sediment deposition can enhance soil fertility depending on the quality of the sediments, and influence the crop productivity. To access the spatial differences in soil properties, crop yield and methane (CH_4) emission at cascade level affected by either sediment induced or farmers' fertility practice, field experiment was conducted in Cheing Khoi watershed, Son La Region, North Vietnam. The experiment was conducted during the spring crop season (February to July, 2011) with two different cascades (one cascade consists of 5 different paddy rice fields) wherein half of each cascade was fertilized with farmer recommendation practice, while no fertilizer was applied on the other half each. Methane gas emission was measured at 3 replication in each field weekly and paddy rice growth (tiller number and height), water quality was measured monthly. At the final harvest, yield component parameters were determined with 3 replications.

The results of the analysis of variance showed that the effect of farmer practices with fertilizer application and different cascade position as well as by their interaction had significantly differences on all yield, yield component parameters and CH_4 emissions in both cascades. Rice yield in the middle of cascade showed better performance than the other field positions in fertilized and unfertilized fields in both cascades. The observed grain yields for non-fertilized fields averaged over both cascades, accounted for 0.55, 0.64 and 0.47 kg m^{-2} in top, middle and bottom fields, respectively, while for fertilized fields, grain yield of 0.72, 0.79 and 0.63 kg m^{-2} were obtained. Higher rate of CH_4 emission was found in middle field of cascade 1 (2.3 and 2.96 mg CH_4 m^{-2} h^{-1}, in non-fertilized and fertilized plot, respectively) and higher in bottom field of cascade 2 (2.36 and 3.71 mg CH_4 m^{-2} h^{-1}) until active tillering stage. The differences in crop yield and CH_4 emission requires different crop management practices for each cascade position in order to improve rice production in this watershed area.

Influence of different Ca amendments on CH_4 emission under Na-salinized paddy soil

Ei Ei THEINT, Aung Zaw OO, Suzuki MAI, Motobayashi TAKASHI and Kimura Sonoko DOROTHEA

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Salinity is among the factors suggested to influence methane (CH_4) emission from rice fields. Rice fields represent one of the main sources of greenhouse gas CH_4, occupying 10% of global anthropogenic CH_4 emission. About 30% of world's rice areas are affected by salinity. Therefore the objectives of this study were to evaluate the influence of salinity and different Ca amendments upon CH_4 emission under Na-salinized soil. Pot experiment was conducted in RCB design with 3 replications. There were three levels of salinity; 0, 30 (S30) and 90 (S90) mmol L^{-1} NaCl and two Ca amendments; gypsum (GM) and poultry manure (PM) with 230 kg Ca/ha. A salt tolerant Indica variety Dolfak was used in this experiment. For all plots, nutrient level was adjusted to 70 kg N/ha, 40 kg P/ha and 70 kg K/ha. To confirm the effect of different salinity levels on CH_4 emission, 20 g of soils were incubated with 0, 10(S10), 30(S30), 60(S60) and 90(S90) mmol L^{-1} NaCl for 3 weeks at 30 ˚C.

The incubation eperiment showed higher CH_4 emission in S10 and S30 than in control, while that of S60 and S90 was lower than control, though it was not statistically significant.

In the pot experiment, there was no significant difference in CH_4 emission between control (316 kg CH_4 ha^{-1} $season^{-1}$) and PM (338 kg CH_4 ha^{-1} $season^{-1}$) but significantly different compared to GM (140 kg CH_4 ha^{-1} $season^{-1}$) for the non-salinity treatments. GM showed 56% lower in CH_4 emission than control and PM. In salinity treatments, S30 without amendments was not significantly different from control and PM. All treatments in S90 showed minimal CH_4 emission. Plant growth was significantly suppressed due to the saline treatment, especially at S90 no grain could be harvested. As different salitiny level was compared, CH_4 emission of S30 was lower than control but not significantly different, while S90 was significantly lower than control and S30. 90% of CH_4 emission in rice fields are transported by plants mediated transport system. Since CH_4 production was not significantly inhibited at the incubaiton experiment, the growth inhibition due to salinity was strongly influencing the CH_4 emission and led to suppression of CH_4 emission. Therefore, from these results, it can be concluded that salinity up to 30 mmol L^{-1} NaCl is more favorable for CH_4 emission. The application of gypsum can suppress CH_4 emission either in saline or non-saline condition.

Mitigation of impact of nitrogen cycling associated with agriculture and food consumption on regional environments

R. HATANO

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Concerns about environmental problems such as water pollution, eutrophication, acidification, air pollution, global warming, ozone layer depletion associated with nitrogen load is increasing. Global nitrogen load associated with agriculture and food consumption is supposed to account for 90% of the total, and there is a large nitrogen load in Asian countries with the remarkable growth of the population.

Using the inventory data concerning the flows and stocks of nitrogen in the systems of agriculture and food consumption, and the census data in each province of Japan, the export (E), cycling (C), loss (L) and purification in sewage plants (P) were estimated, and their total is obtained as a total system throughput (TST). The L increased with the increase of TST and accounted for 50% of the TST. The L increased with the increase of proportions of urban area and upland crop field significantly. And the L also increased with the increase of population, animal excreta, and chemical fertilizer application, and decreased with the increase of nitrogen fixation significantly.

Stream nitrogen concentration in each province in Japan was estimated by assuming the ratio of stream runoff to net nitrogen input (NNI) of 0.27 and the ratio of stream water discharge to precipitation of 0.75. The NNI is defined as the difference between the input and the output of nitrogen in the region, and equals to L+P. The area with the estimated nitrogen concentration higher than 1 mg N L^{-1}, which is the Japanese environmental standard for stream nitrogen concentration, was 66% of the total area of Japan. In that case, 55% of NNI was derived from agriculture, and disposed animal excreta accounted for 14% of L. If all the disposed animal excreta were used to alter chemical fertilizer application, NNI derived from agriculture decreased to 50%, and the area with the nitrogen concentration higher than 1 mg N L^{-1} reduced to 31%.

N_2O emission in each province in Japan was estimated by assuming that NNI not discharged to river is denitrified as N_2O+N_2 (based on the significant increase of stream bicarbonate runoff with the increase of NNI not discharged to river), and the ratio of $N_2O/(N_2O+N_2)$ of 0.71±0.26 (which was measured for the 84 soil samples with pH of 4.3 to 6.6). The result showed 41% of NNI was estimated to be emitted as N_2O. The estimated N_2O emissions derived from agricultural fields and sewage plants in each province ranged from 2.3 to 32.7 and from 3.0 to 107.1 kgN ha^{-1} yr^{-1}, respectively. By alteration of chemical fertilizer to disposed animal excreta, the N_2O emission was reduced by 19%.

These findings suggest that reduction of nitrogen input into agriculture is effectively influencing the mitigation of environmental loss from agriculture, and further improvement of self-sufficiency of food to reduce the loss from sewage plants is required.

Comparison of Nitrogen Budgets in Agricultural Watersheds

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To analyze the effect of agricultural activity on nitrogen (N) budget at watershed scale, a watershed-scale analysis was conducted at two Japanese and one Chinese watersheds. The study sites are the Shibetsu River watershed (SRW) and Upper-Naka River watershed (UNRW) in Japan, and the Jurong Reservoir watershed (JRW) in China. The total area and the proportion of agricultural area (in brackets) of the watershed was 685 km^2 (51%), 1299 km^2 (21%) and 46 km^2 (55%) for SRW, UNRW and JRW, respectively. The main agricultural land use in SRW was forage grass, while paddy rice fields occupied the highest proportion in UNRW and JRW with values of 11% and 31% of total land area, respectively. The farmland surplus N was 61, 48 and 205 kg N ha-1 yr-1 for SRW, UNRW and JRW, respectively. The total input and output for the whole watershed was 89 and 76, 83 and 61, and 353 and 176 kg N ha^{-1} yr^{-1} for SRW, UNRW and JRW, respectively. The proportion of discharged N to net anthropogenic N inputs was 31%, 37% and 1.7% for SRW, UNRW and JRW, respectively. The two watersheds in Japan showed similar relation to the previous reports, while the JRW showed a totally different characteristic compared to the proceeding studies. The high proportion of paddy rice fields and the water bodies in the landscape was an underestimated N sink in this area.

Spatio-temporal variation of riverine N and P concentration in the Lake Hachiro watershed

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Water quality in the Lake Hachiro is degraded as a result of nutrient pollution such as N and P, which can cause harmful algal bloom during summer. The relative availability of N and P in an lake water determines which nutrient is more limiting: P tends to be limiting for algal bloom when the N:P is over the Redfield ratio of 16:1 (moler). The balance of N and P delivering from rivers to the lake, therefore, can control algal bloom. This study evaluated a spatio-temporal variation of riverine N and P concentration in the Lake Hachiro watershed. River water sampling was conducted at 28 points in the BBM river catchment and at 20 points in the MTN river catchment once a month in 2008. Lake water sampling was also conducted once at 45 points in August 2010 (Hayakawa et al., 2011). The temporal variation of riverine DIN and DIP concentrations showed a reverse trend. During summer, NO_3-N concentration decreased while PO_4-P concentration increased, resulting the decrease of DIN:

DIP below 16:1, especially in the agricultural catchments. During winter, NO_3-N tended to increase while PO_4-P decreased, resulting the increase of DIN:DIP above 16:1. The lower DIN:DIP during summer indicated a high rate of denitrification and a release of PO_4-P from paddy soils or sediments in an anoxic condition. Chl.a concentrations in the lake water were higher in the southeast area (max 1190 mg L^{-1}) where the DIN:DIP were relatively low. Therefore, P limiting for algal bloom would be removed in the southeast area, and the lower DIN:DIP water from rivers during summer may trigger harmful algal bloom in the Lake Hachiro. This study suggested we should focus on the balance of N and P cycles in the watershed, and the input nutrients especially P should be managed carefully in the Lake Hachiro watershed.

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The relationship between Nitrogen load and river water quality in several catchments in different area sizes

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In comparative research on water quality in watersheds, the issue of size of watershed area is often discussed. In this research, several catchments in different area size were set up and relationship between properties of catchment and potential nitrogen load in whole watershed and/or catchments was explored.

In the study, potential nitrogen load concentration (PNC) in the catchments were calculated and each catchments were categorized using land use types that were set based on ratio of urban, ratio of forest, ratio of cultivated land, ratio of paddy field in cultivated land and ratio of livestock load. In case of Upper Naka river watershed, there were 134 catchments and they were categorized into 7 land use types. Less than 20 % of catchments were same land use type as whole watershed. As a result, similarity of land use type in whole watershed and small catchments is one of the important factors. It is considered that the small catchment that has similar land use type of watershed represents property of river water quality of watershed.

Risk evaluation of the groundwater pollution by nitrate-nitrogen leached from farmlands in a middle-sized agricultural watershed

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Groundwater pollution by nitrate-nitrogen (NO_3-N) is widespread in Japan. Nitrogen (N) in chemical fertilizer and manure can be a source of the pollution but site vulnerability to the pollution cannot be determined in a wide area due to difficulties in understanding water and N movements in the soil-groundwater system. We developed a

PC system for evaluating groundwater pollution by agricultural activities in a wide area by a combination of statistical and GIS data, modified existing numerical model (LEACHM, Leaching Estimation And Chemistry Model, Hutson, 2003; Asada et al., 2011) and a newly developed GIS model (MacT, Mixing areal chemical Transport, Itahashi et al., 2011).

The application of the system to an agricultural watershed where standard cultivation methods were supposed to be adopted for each crop types revealed almost 100 % risk to groundwater pollution below farmlands. Two alternative treatments were suggested to reduce such groundwater pollution effectively while maintaining desired crop production; that is introduction of cleaning crops after harvest of the major crops to recover excess N still remaining in the soil, and reduction of total N inputs by both chemical fertilizer and manure with a careful look at carbon and nitrogen dynamics in soil-plant systems using LEACHM.

Although the groundwater pollution by NO_3-N is one of the persistent environmental problems in Japan, this system will help constructing more environmental friendly fertilization systems, and moreover conserving healthy water environment.

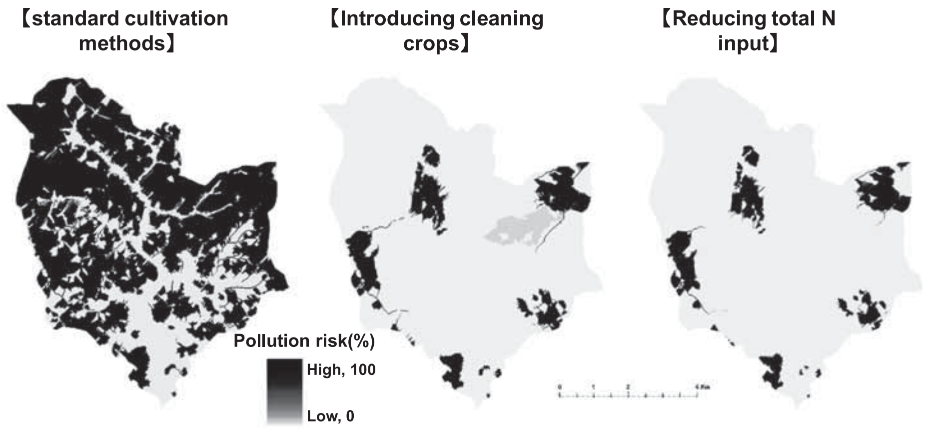

Fig. Risk evaluation maps to groundwater pollution by agriculture in an agricultural watershed.

Effects of silicate fertilizer application on growth and yield of organically managed rice

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Organic rice farming without chemical fertilizer and agrochemicals is expected to have merits of ecosystem conservation and reduction of environment pollution, but the yield level is low. It has a number of technically problems, for example, unestablishment of weed control technique and low yield by low nitrogen nutrient. In previous studies, it was shown that silicon (Si) can enhance photosynthetic ability and increase growth and yield of rice with conventional farming. In this study, we examine effects of silicate fertilizer application on growth and yield of organically managed rice.

Material and Methods: The field experiment was conducted in 2010 in the paddy field of the Field Science Center, Graduate School of Agricultural Science, Tohoku University, Miyagi prefecture, Japan. We use three silicate fertilizers; calcium silicate (CS), silica gel (SG), Poly-Silicate Iron sludge (PSI). PSI sludge includes large amount of silicon and iron derived from the flocculant. Main treatment was organic farming and four treatments were composed by no silicate fertilizer (control, CON), CS, SG, and PSI application. Application rate of each silicate fertilizers were decided to correspond to 200g m^{-2} of CS, which is conventional application rate in Japan. All of three silicate fertilizer treatments can supply same amount of 0.5 HCl soluble silicate.

Number of tiller was measured periodically during the growing season. Rice yield and yield components were determined at harvest time. Then concentration of nitrogen and silicate in rice plant was measured.

Results and Discussion: Number of tiller of organically managed rice was lower than that of rice with conventional culture. Brown rice yield of organically managed rice reduced. Compared with CON, silicate fertilizer (CS, SG, PSI) increased percentages of ripened grain and brown rice yield by 4 to 8%. Silicate fertilizer application did not increased nitrogen uptake, but concentration of silicate in rice plant in silicate fertilizer plots was higher than that in CON plots. These results suggest that increase of silicate uptake enhanced photosynthetic ability and rice ripening. From these results, it is suggested that silicate fertilizer application can increase rice yield in organic farming system.

Aquatic Biota in Winter Flooded Paddy Field with Organic Farming -Case Study in Field Science Center, Tohoku University, Japan-

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In Japan, more than a half of natural wetlands have been lost in the last century primarily due to land reclamation by drainge (Geographical Survey Institute, 2000). On the other hands, waterfowl, for example white-fronted goose (*Anser albifrons* Scopoli) migrating to Japan are increasing. Waterfowl habitat environments are getting worse and may increase risks of food shortage and disease infection.

Winter flooded rice fields have potential as alternative wetlands for waterfowl. Winter flooding is conducted worldwide, for example, in Sichuan province in China (Qiu, 1962), California in the United States (Day and Colwell, 1998), Ebro delta in Spain (Serra *et al.*, 2007), Cheonsu bay in South Korea, Oosaki City, Sado and Toyooka City are famous for scarce water bird conservation using winter flooded rice fields, in Japan. Winter flooding is often conducted in combination with organic farming and is expected to increase biodiversity of aquatic life. We researched the effects of winter-flooded and organic farming on the aquatic biota in paddy field.

Material and Methods

The field experiment was conducted in 2009 and 2010 in the paddy fields of the Field Science Center, Tohoku University. In 2009, treatments were organic farming without winter flooding (OF plot) and conventional farming (CF plot) with chemical fertilizers and pesticides. Organic farming is characterized by no use of chemical fertilizer and pesticides and use of organic fertilizer. In 2010, the OF plots were shifted to organic farming with winter flooding (WF plot). These experiments were conducted with three replications with area of 900 to 1200 m^2.

To determine the data on aquatic animal density, aquatic animals were collected using a square sampler (1×1m) and a sample net (mesh size: 2 mm) with three times in each year.

Results and Discussion

A total of 15,867 individuals and 32 taxa of aquatic animals were found in all fields in two years. The density and taxa number of aquatic animals were higher in OF and WF fields than CF fields throughout the growing season, but the biodiversity index of OF and WF plots were sometimes lower than CF plots, mainly due to large number of Chironomidae larvae in OF and WF plots.

The densities of 18 taxa were higher in OF or WF plots than in CF plots. The density of only one taxon was higher in CF plot. The possible reasons for the aquatic biota richness in the fields with organic and/or winter-flooded farming are no use of insecticide (Mesleard *et al.*, 2005), Lemnaceae richness due to no use of herbicide that increase hiding space for some Pyralidae, and applyication of organic fertilizer supplying nutrients to Chironomidae and Culicidae (Ikeshoji *et al.*, 1980; Simpson *et al.*, 1994).

Diurnal pattern of nitrous oxide emissions from a sewage-enriched river: references to IPCC indirect emission factor

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There remains considerable uncertainty in the magnitude of indirect nitrous oxide (N_2O) emitted from streams or rivers by the Intergovernmental Panel on Climate Change's (IPCC) methodology. The uncertainty is partially due to a lack of onsite data and great variability of N_2O production, especially on high temporal pattern. Therefore, we measured the N_2O emission rates, concentrations of dissolved N_2O, and potential controlling variables on an hourly basis over one site in a typical sewage enriched river in the Taihu Lake region, China. Results showed that distinct diurnal patterns were observed in N_2O emission, concentrations of dissolved N_2O, and river physicals and chemicals during a 72 h period. N_2O emission and dissolved N_2O saturation averaged 56.1μg N_2O-N m^{-2} h^{-1} (ranged from 41.1 to 87.7μg N_2O-N m^{-2} h^{-1}) and 813% (ranged from 597% to 1 372%), respectively. Correlative analysis indicate that dissolved N_2O, pH, DO, NH_4^+, SO_4^{2-}, air temperature, and water temperature operate as important controls on N_2O production, while TN, Cl^-, DOC, and NO_3^- seems less important. The patterns of N_2O production may contribute to coupled nitrification-denitrification processes and the rates might be greater during day than those at night. The results suggested the compounds of salinity such as SO_4^{2-} concentration would expect to be a more reliable factor than salinity in accounting for N_2O variation in aquatic systems.

To include individually explicit N_2O emission in rivers or river sections, we suggest a more constrained emission factor considering river length (EFL):

$$EFL = \frac{N_2O}{Nr \times L}$$

where EFL is the mean emission factor of N_2O from river surface water per unit length of river (kg N_2O-N kg inorganic-N km^{-1}); Nr is inorganic N inputs (kg N yr^{-1}); L is river length (km); Using the EFL metholodogy, we calculated that 0.28 Tg yr^{-1} of reactive N inputs to N_2O-N in river networks globally, lower than the results of the IPCC methodology and a global river network model.

Our resulting emission factor was 0.24%, very close to the revised IPCC value of 0.25% .Thus our study strongly support the recent revision of EF5-r from 0.75% to 0.25%. Although the revised value of EF5-r agrees well with our results, our EFL methodology is more applicable in reducing uncertainty and simplifying calculation and validation.

Effect of long-term fertilization on greenhouse gases emission in paddy soils, China

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Two long-term fertilizer experiments initiated in 1980s were used in this study to investigate the effect of rice straw or organic manure application on greenhouse gases (GHGs) emission and soil carbon sequestration. The experiment sites are in Hunan and Jiangxi province with double rice-cropping systems. Methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) fluxes were measured in situ using closed chamber method during early rice growing season. Flux of greenhouse gases was monitored at about 7 day's interval. Soil water regime was flooding after seedling transplantation till panicling and drainage during spiking followed by a subsequent moist condition without irrigation till harvest. Treatments in Hunan include CK (no fertilizer), chemical fertilizer only (CF), chemical fertilizer plus pig manure (CFM) and chemical fertilizer plus rice straw (CFS). Jiangxi has the same treatments with Hunan excluding CFS.

Comparing with no fertilizer treatment, fertilization increased soil organic carbon (SOC) content and GHGs emission in both sites. Furthermore, SOC contents in CFM and CFS were significantly higher than CF treatment. In Hunan, total emission of CH_4, N_2O and CO_2 ranged from 45.61 kg CH_4-C/ha to 133.45 kg CH_4-C/ha, from 0.16 kg N_2O-N/ha to 2.11 kg N_2O-N/ha, from 1354.92 kg CO_2-C/ha to 1731.54 kg CO_2-C/ha, respectively. Long-term rice straw return and pig manure application did not increase the total emission of GHGs compared to chemical fertilizer only plot. However, application of pig manure significantly enhanced GHGs emission compared to CF plot in Jiangxi. These results suggest that rice straw return with chemical fertilizer has the potential to mitigate climate change during rice production in Hunan; the effect of organic manure application is highly dependent on soil fertility and climatic conditions.

Determination of phytase labile organic phosphate in organic manure

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In Japan, almost half of the cropland soil is Andosol which is characterized by strong phosphate adsorption capacity. Therefore, crops can't use phosphorus fertilizer efficiently. According to previous research, phosphate in compost is more likely to be efficiently used by crops than chemical fertilizer. This may partly ascribed to mineralization of organic phosphate by micro-organisms. Mineralization of organic phosphate may increase availability of phosphate by crops. Major organic phosphate in organic manure is assumed to be phytic acid, but few report has been analyzed the concentration of the phytic acid in organic manure.

In this study, we tried to determine phytic acid in organic manure using phytic acid hydrolysis enzyme; phytase. Using a commercial wheat phytase, we examined incubation conditions including enzyme concentration, incubation temperature and incubation time, and following method was selected. Finely ground sample (100mg) in a test tube was incubated in 5 ml of 0.04 unit / ml enzyme solution for 12 hours at 30˚C. The enzymatic reaction was terminated with trichloro acid. Inorganic phosphate in the solution was determined by modified malachite green method.

Phytic acids concentrations in some organic manures were determined. Proportions of phitic acid (phytase labile phosphorus) in total phosphate were 5 % in a poultry manure from egg farm, 46 % in a poultry manure from a broiler house, 10 % in a green manure made by above-ground part of buck-wheat and 55 % in a rice bran. Most of the organic phosphate in seeds; soybean and buck-wheat, was phytase labile.

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Effects of water management on vivianite crystallization on paddy rice roots

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【Introduction】The availability of phosphate (P) for paddy rice plants is higher than that for upland plants because of enhanced P solubility under reducing conditions. In recent years, vivianite aggregates, ferrous phosphate crystals, have been identified on thin roots of paddy rice (Nanzyo et al.,2010). Recognition of vivianite will improve understanding P dynamics under reducing condition like paddy fields. In this article, we describe (i) effects of water management on vivianite crystallization and (ii) a quantitative method to estimate the content of vivianite.

【Materials & methods】(i) Rice plants (Oryza sativa, L.) were grown in three small paddy field plots (1m×1m). Water management for each was (1) intermittent irrigation after mid-summer drainage, (2) continuous flooding during cultivation, and (3) re-flooding after mid-summer drainage. Rice roots were separated from soil blocks by washing with fresh water, and air-dried. After drying, we observed vivianite attached to roots by optical microscope and scanning electron microscope (SEM)-energy dispersive X-ray analysis (EDX).

(ii) After rapid oxidation with heating, vivianite dissolves little in dilute hydrochloric acid. The difference in P solubility between before and after heating at 105˚C was used for estimation of the quantity of vivianite aggregate.

【Results & Discussion】The longer the term of flooding, the more vivianite aggregates are observed by optical microscope. The aggregates crystallized mainly on the thin roots, and were identified to be vivianite by EDX. The crystal aggregates appeared like laminae from the root surface to bulk soils by SEM, and they suggests mobilization of P in soil. On the other hand, the amount of the crystal aggregates reduced after drainage under oxidizing conditions. These observations suggest the changes in redox status by water management affect crystallization and dissolution of vivianite.

Synthetic vivianite dissolve little after heating at 105˚C for 48h. The decrement of P in the root extractant after heating showed a correlation with the abundance of vivianite found by optical microscope observation.

Effect of soil components on adsorption of *Pepper Mild Mottle Virus* by Japanese soils

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The *Pepper Mild Mottle Virus* (PMMoV) is a soil-borne virus that causes the mosaic disease to *Capsicum* ssp. This virus disease had been controlled by soil fumigation using methyl bromide, but the method was banned in 2005. Therefore, a new management and control technology that replaces methyl bromide is required. In the present study, the adsorption of PMMoV by soils that is considered to be one of the most important factors of the virus inactivation was examined.

Five Andosols (three soils with a high humus content and two soils with a low humus content), a gray low land soil, a yellow soil, and an allophanic mineral sample were used. Two hundred milligrams of soil and mineral samples were mixed with 2 mL of phosphate buffer containing 100μg of PMMoV. The suspensions were shaken for 2 h then they were stored overnight at 4˚C, and were centrifuged at 20,000×g for 20 min at 4˚C. The concentration of PMMoV in the supernatant was determined by double antibody sandwich enzyme linked immuno solvent assay (DAS-ELISA) method and calculated adsorption rate. To evaluate the charge characteristics of the soil and clay samples on the adsorption of PMMoV, the adsorption experiments were also performed at pHs 4 and 5.

Large amounts of PMMoV particles were adsorbed by the soil samples with a low humus content at the low pH. This was attributed to the increase in the positive charges of the soil samples. On the other hand, low virus adsorptions were observed at any pH levels in the soils with a high organic matter content. There were close negative correlations ($P < 0.05$) between the PMMoV adsorption by the soils and the humus content of the soil samples. There was no significant relationship between the rate and Si_o or Fe_d contents. The present study suggests that the inhibitory effect of humus against the PMMoV adsorption by soils is rather important in Japan because the country is extensively covered by soils with a high organic matter content.

Isolation of plant growth-inhibiting compounds from acidulocompost; a garbage compost processed under thermoacidophilic conditions

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The use of garbage composts for agricultural production is essential for a sustainable society in the viewpoint of environmental conservation and resources protection. We have tested the agricultural use of acidulocompost (AC); a unique garbage compost processed under thermoacidophilic conditions (Nishino et al., 2003). We clarified that the garbage AC was more effective for potato production than cattle manure compost and showed a function of weed growth suppression (Tatenai et al., 2006).

In order to identify a plant growth-inhibiting compounds derived from garbage AC, we examined the followings; 1) the extracting method to effectively recover the active compounds from AC, 2) the effects on plant growth of the law material (cedar-wood saw material with a starter microorganism) used for acidulocomposting process, and 3) isolation of the active compounds from AC. The plant growth inhibiting activity was evaluated from the germination and the hypocotyl and radicle elongations of lettuce (*Lactuca sativa* L.) after 48 hours' incubation at 25˚C.

Most of the plant growth-inhibiting compounds in garbage AC were collected with three extractions using a mixture of methanol: chloroform: water = 2:1:0.8. The hypocotyl and radicle elongations of lettuce were severely inhibited with the extracted materials from AC, but the extracts from the law material had no activity on plant growth inhibition. This result suggests that the inhibition activity of AC is attributed to the compounds produced or modified during the composting process. The extracts were subjected to reverse-phase column chromatography on C18-coated silica gel and the major activity was fractionated into the Hexane-EtOAc (6:4) eluted fraction. The active fraction was then subjected to preparative HPLC and active compound was isolated at 2.4 min in retention time. We are currently promoting the identification of the inhibitory compound.

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Effect of chemical treatment on mineralization of C and N in Andosols rich in Al-humus complexes

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Andosols accumulate soil organic matter (SOM) in large amounts mainly due to stabilization of SOC by formation of Al-humus complexes, low soil pH and high Al toxicity. In this study, we changed these factors by chemical treatments and investigated their effects on mineralization of C and N.

We used three soil samples: Mukaiyama A1, Mukaiyama 3A3 (Miyagi Prefecture), and Utsunomiya (Tochigi Prefecture). Soils were treated with chemical reagents such as $CaCO_3$ (increasing soil pH and decreasing soluble Al), KH_2PO_4 (decreasing soluble Al with minimum change of soil pH), and H_2SO_4 (decreasing soil pH and increasing soluble Al). For measurement of soil respiration, we put fresh soils (30 g dry soil equivalent) into conical flasks (500 mL) and incubated the soil samples under lighting condition (25˚C) and dark condition (16˚C). Then we flew fresh air to flasks and sealed them for 1 h. The concentration of CO_2 in the flasks was measured by IR spectroscopy. For inorganic N measurement, we put fresh soils (150 g dry soil equivalent) into plastic pot (500 mL) and incubated them under dark condition (30˚C). Inorganic N (ammonium N plus nitrate N) was periodically measured. We extracted soil DNA from soil samples and investigated microbial community by PCR-denaturing gradient gel electrophoresis with specific 16S rDNA.

The $CaCO_3$ treatment increased soil respiration in all the soil samples. This was considered to be due to the increase in soil pH and the decrease in soluble Al. The apparent soil respiration may include CO_2 derived from $CaCO_3$. The $CaCO_3$ treatment did not increase amounts of inorganic N as compared to control. In Mukaiyama A1 soil, the treatment even decreased mineralization of N, suggesting the intense immobilization of N. The KH_2PO_4 treatment largely increased soil respiration and N mineralization in all the soils. This may be due to solubilization of soil organic matter in addition to the decrease of Al toxicity. While the H_2SO_4 treatment decreased the amounts of soil respiration and N mineralization in Mukaiyama A1 soil, this treatment did not affect in other soils. In comparison among the three soil samples, the amounts of soil respiration and N mineralization of Mukaiyama

3A3 soil were much lower than those of the others. This was possibly due to the lower content of decomposable organic matter because the soil sample was derived from a buried humus horizon. Results of analysis of microbial community indicated that the KH_2PO_4 and H_2SO_4 treatments remarkably changed soil microflora.

Andosols-Cambisols sequence on the Ohira Hills in central Miyagi Prefecture, northeastern Japan

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Andosols often accumulate a large amount of humus, and contribute to the soil carbon storage. Brown forest soils, accounted for 53% of the land in Japan, consist mainly of cambisols, but include some Andosols and Cambisols with inadequate andic properties. They could form the transition of Cambisols to Andosols as to the expression of andic characters. In the present study, the soil of the Ohira Hills located on the east edge of Andosols area in the central Miyagi Prefecture was investigated to examine the distribution of Andosols and Cambisols with andic characters.

Materials and Methods: Soil samples: Soil samples were taken at two points of the ridge and slope areas and one point of foot area on the Ohira Hills in the Miyagi Prefectural Forestry Technology Institute (Ohira-mura, Kurokawa-gun) . Soil analysis: Al, Fe and Si extracted by ammonium oxalate, Al and Fe extracted by sodium pyrophosphate, phosphate absorption coefficient, P retention, pH(NaF), bulk density, volcanic glasses content.

Soil classification: Unified Soil Classification System of Japan-2nd Approximation(2002)- and World reference base for soil resources 2006 (WRB 2006) .

Results and Discussion: Andic characters at the soil profiles of ridge and foot areas well developed near surface horizons and gradually decreased with depth. On the other hand, those of slope area weakly developed at all horizons. These suggest that the immixture of volcanic ash on the parent material of the study sites was comparatively small and depending on the topographical features. Although the soil profiles of ridge and foot areas showed Andosols-like characteristics, they were classified as Cambisols or Regosols due to the inadequacy of the horizon thickness with andic or vitric properties. The soil profiles of slope area were classified as Cambisols with weak andic characters. Despite the nonexistense of Andosols in the study sites, the soils of the Ohira Hills would be a part of Andosols-Cambisols sequence which includes Cambisols with various degree of andic characters as a function of topographic factor.

Studies on faint podozolization observed in the Andosols around Kuwanuma on the eastern footslope of Funagata Volcano in Midwestern Miyagi Prefecture, Japan

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【Introduction】Close distribution of Ando soils, Browon forest soils, and Podzolic soils is shown in the soil map in National Land Survey around Kuanuma in Taiwa-cho, Kurokawa-gun, Miyagi prefecture. Various soils are developed from volcanic ash in response to climate, time, biota, geography and human activities, suggesting that the soils around Kuwanua are affected by different pedogenic processes in a small area. We considered podozolisation in the soils around the Kuwanuma in addition to Andosolization.

【Materials and methods】Three pedons at approximately 800m above sea level (ASL) and 3 pedons at approximately 1000m ASL, 6 pedons in total, were surveyed and sampled according to the genetic horizons around Kuwanuma. In addition to some general physicochemical study, sodium-pyrophosphate extractable organic carbon (C_p) and fulvic acid carbon (C_f) were determined by the dichromate oxidation method. The extent of podozolisation was also examined by using the C_p/(organic carbon) and C_f/C_p ratioes.

【Results and discussions】Although all 6 pedons surveyed in this study are classified as Andosols, weak differences were found between the 800m ASL sites and the 1000m ASL sites. As a podozolisation trend, the vertical distribution of C_p and C_f of 3 pedons at the 1000m ASL sites showed high values between the upper part to the middle part of the soil profiles and they decreased gradually to the lower part. In contrast, 3 pedons located at the 800m ASL sites showed the highest value in the upper part of the soil profiles and the value decreased steeply to the lower part. These results suggest that the Andosols at the 1000m ASL sites are affected by faint podozolisation and podozolisation of the Andosols at the 800m ASL sites is almost negligible. However, no horizons met the criteria of $C_p/OC \geq 0.5$ and $C_f/C_p \geq 0.5$. Thus, mobilization and accumulation of humic substances were not evident according to the method used to differenciate spodic horizons from buried andic A horizons in the World Reference Base for Soil Resources. All horizons of the pedons surveyed in this study showed low C_p/OC and high C_f/C_p values that are the fulvic properties.

Experience as a member of JOCV in Caoson village, Vietnam

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From June 2009 to June 2011, I worked as a rural development extension worker in Vietnam, which was supported by JOCV (Japan Overseas Corporative Volunteers) program, JICA. My office was belonging to Department of Agriculture and Rural Development at Hoabinh Province. The objectives of my job were for improving living conditions and for helping to increase residents' income in the village.

My first activity was to know farmers and their living status and to build friendship up with farmers. So, I tried to talk with many farmers in the village as frequently as possible, and I sometimes stayed in the village for 3-5 days to deepen friendship with them. However, it took a long time, about 1 year, to understand Vietnamese, so it was not easy to hear farmer's opinion and to understand feelings of Vietnamese people.

I conducted 3 activities. One was to introduce Japanese agricultural technology about natural agrichemical, compost, raising seedlings, and so on. Another was to produce furnace made by dirt and manure. And the last was to construct a model farm for producing organic vegetable. What I did for 2 years was limited so that I couldn't get any actual achievements in these activities. However, my experiences for the 2 years were so precious. I am pleased if my modest activities may contribute to improvement of living status of farmers in Caoson village.

Report on Agri- Reconstruction Project (ARP).

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After 11^{th} March 2011, all of us made every effort to find foods, water and energy for life. Almost of all train and bus service were stopped running. There was no available gasoline in gas stations at Sendai. However, Graduate school of agriculture, Tohoku University started action for support stricken area, and Agri- Reconstruction Project (ARP) was established.

11^{th} May, first symposium on ARP was held. 11 specialists who were belonging ARP reported suggestion from their knowledge. About 120 people participated. According to these reports, damages in stricken area were very serious. However, the support for those areas would become more and more important.

300 pamphlet of symposium were printed, and sent to local governments in stricken areas. Simultaneously, web site of ARP activities has been available.

27^{th} and 28^{th} in July, poster session was held in annex library in our faculty. Data of those posters are also available in web site.

Several researches are conducted by specialists from marine biology, soil science, plant breeding/genetics, animal welfare and forestry.

Dr. Osada, who is professor of aquacultural biology laboratory, is researching about artificial high speed raising of oyster seed. These artificial seeds are expected to be supplement for shortage of natural seeds.

Dr. Nanjyo, Dr. Takahashi, Dr. Kanno, Dr. Saito and Dr. Ito, who are member of soil science laboratory and environmental crop science laboratory, have been collecting soil samples from stricken areas. Researchers are suggesting several reconstruction ways which respond to damage level.

Dr.Nishio and Dr. Kitashiba, who are from laboratory of plant breeding and genetics, now selecting rapeseed which could endure the soil damage from salt water. Those rapeseeds will use in "The Rapeseed Project" which is conducted by Dr. Nakai.

Dr. Sato is professor of animal welfare laboratory, take part in the live cow protection project which is carrying out inside 20km area from Fukushima nuclear power plant.

Dr. Seiwa is professor of forest ecology laboratory, planning to reconstruction of domestic forestry. There are large areas which is not appropriate to be paddy field or farm. New style forestry can apply these stricken areas, and it might be creating some chance of employment.

Tohoku University is the nearest and the largest university beside the stricken areas. Graduate school of agriculture is one of the most important cores of support activity in stricken areas. ARP will conduct new support activities for reconstructing agriculture even from now, and send massages for all the countries of the world.

References

Web site of ARP is available at http://www.agri.tohoku.ac.jp/agri-revival/ (in Japanese)

Information to Authors from Journal of Integrated Field Science (JIFS)

The Journal publishes articles in all areas of field science in agricultural science. The journal is an English magazine started in 2003 fiscal year when Integrative Field Science Center, Graduate School of Agricultural Science, Tohoku University, has started.

Our journal places the edit committee. Under the committee, an original paper including short paper, proceedings, a review, description, and data are published. An original paper undergoes two reviser's (referee) examination.

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