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Studies on the Interaction Between Upland Rice and Other Crops in Intercropping System

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Keywords: upland rice, intercropping, replacement series.

Abstract

The national rice requirement in Indonesia today is very high, and can not be fullfiled from irrigated lowland rice area only. However, the contribution of upland rice, which is grown in dryland and rainfed area, to national rice production is lower compared to lowland rice, although dryland area in Indonesia is much wider compared to lowland area. One of the advantages of upland rice culture compared to lowland rice is that it can be grown side by side with other crops under intercropping system. Studies on the interaction between upland rice and other crops is needed to get the crops suited to grow together.

This paper is a review of the results of a series of field experiments on the intercropping between upland rice and other (legume and horticultural) crops conducted in agriculture experiment station, Gadjah Mada University, in Kalitirto district, Yogyakarta, from 2000 up to 2005. The methodology used is based on the replacement series technique. Basically, there are three different types of interaction, i.e. (1) Mutual inhibitation, when the actual yield of each species is less than expected. (2) Mutual cooperation or complementation, when the actual yield of each species is greater than expected. (3) Compensation, one species yield is less and the other is more than expected.

The results of the experiments was classified into two groups i.e. (1) upland rice vs legume crops and (2) upland rice vs horticultural crops. Most of legume crops stimulated upland rice yield. However, the effect of upland rice on each legume was different, i.e. decreased yield such as in mung bean and groundnut, or no significant effect such as in velvet bean (*Mucuna sp.*). Thus a compensation type of interaction occurred. In horticultural crops, the results varied depending on the species of the crop. Complementary was shown on the interaction between upland rice and water melon. In intercropping upland rice-onion, upland rice stimulated onion yield while onion did not affect to upland rice yield. However, in intercropping upland rice-pineapple, both Cayenne and Queen types of pineapple gave positive effect (increased) to upland rice yield, while upland rice did not give harmful effect to pineapple.

I. Introduction

Formerly the Indonesian economic development was directed to industrial sector in which most of the resource materials were imported. Consequently the agricultural sector was left behind, and in 1998 the government imported 5.8 millions tons of rice which costed Rp. 10.44 trillions (Muhtadi, 1999; Karama, 2000). Today the food reserves policy is focused on to fulfils rice requirement based on national production i.e. equal to 54,259,400 tons paddy per year to fulfil the need of about 210 millions people. The efforts on fulfiling the rice requirement can not be reached by intensification in the irrigated area only. Especially in Java island, because of its high population pressure, many irrigated lands change to non agricultural land, which means the decrease of land with high productivity (Suyana, 2000).

There are about 7.5 millions hectares rainfed area in Indonesia, however only 2.5 millions hectares have been developed for rice culture, i.e. 293,960 hectares in West Java, 358,120 hectares in Central Java and 277,760 hectares in East Java and 1,6 millions hectares of the rest outside Java (Kasryno, 1996). The five millions hectares of the remainder become a long term upland rice intensification program target areas (Fagi, 1995).

Comparing to lowland rice, the contribution of upland rice to national rice production is still low, although its potential is high. This means that the role of upland rice in Indonesian rice production becomes more important in the future. On the average, upland rice production in Indonesia is about 2.5 tons per hectare. The development rate is slow. In the last 25 years upland rice production increased only 45% i.e. from 1,622,000 tons to 2,345,000 tons; compared to lowland rice which increased 140% i.e. 24,666,000 tons (Anonymous, 1995).

Rice production could be increased through (1) intensification, (2) extensification and (3) cropping systems improvement programs (Prajitno, 1992). Intercropping is one of the forms of cropping patterns in cropping systems program, i.e. growing two or more crops simultaneously on the same field, in the same time, usually planted in rows side by side (Prajitno, 1987). Consequently there is an interaction between crops grown in this system. The crops should be chosen so they can get the advantages on using time and space efficiently and able to press down the competition effect to minimum (Prajitno, 1988).

Unlike lowland rice, upland rice which is grown in the dryland or rainfed areas, could be intercropped with other crops, annually or perennially. This paper limits the discussion on the interaction between upland rice with legume crops and horticultural crops, as a result of multi years field experiments in Upland Rice Research Institute, Faculty of Agriculture, Gadjah Mada University. Each experiment is usually used by the graduate students for their master thesis under the guidance of the author.

II. Theoretical framework

Interaction between two species can be studied with a "replacement series". A replacement series is the result of generating a range of mixtures by starting with a monoculture of one species and progressively replacing crop of that species with crop of the other species, until a monoculture of the latter is produced. The results of such an experiment are presented in a "replacement diagram", where for each species the yield per unit area is plotted against the proportion of the total number of seeds sowed. Competitive effects can be examined by the type of diagram illustrated in Figure 1.

In the figure, actual yields are given by solid lines and expected yields by broken lines. Expected yields are those that would be obtained if each species experienced the same degree of competition in mixture as in pure stand i.e. if interspecific competition is equal to intraspecific competition. Though this is unlikely in practice, this provides a useful basis for comparison. Three broad categories of interaction can be recognized. (1) The actual yield of each species is less than expected, which is called mutual inhibitation (figure 1a.). (2) The yield of each species is greater than expected. This can be termed mutual cooperation or complementation (figure 1b.). (3) One species yields less and the other more than expected. This can be termed compensation (figure 1c).

However since the physical units of the yield of each crop is not equal, for example ton/ha of upland rice vs ton/ha watermelon in intercropping is difficult to combine, de Wit (1960) proposed a physical unit to measure a combined yield of different species i.e. the relative yield :

$$\text{Relative Yield (RY)} = \frac{\text{Yield in intercropping}}{\text{Yield in monoculture}} \qquad (1)$$

The "Relative Yield Total" (RYT) of a two component intercropping system may be represented as follows :

$$RYT = \frac{Yab}{Yaa} + \frac{Yba}{Ybb} \qquad (2)$$

Where :

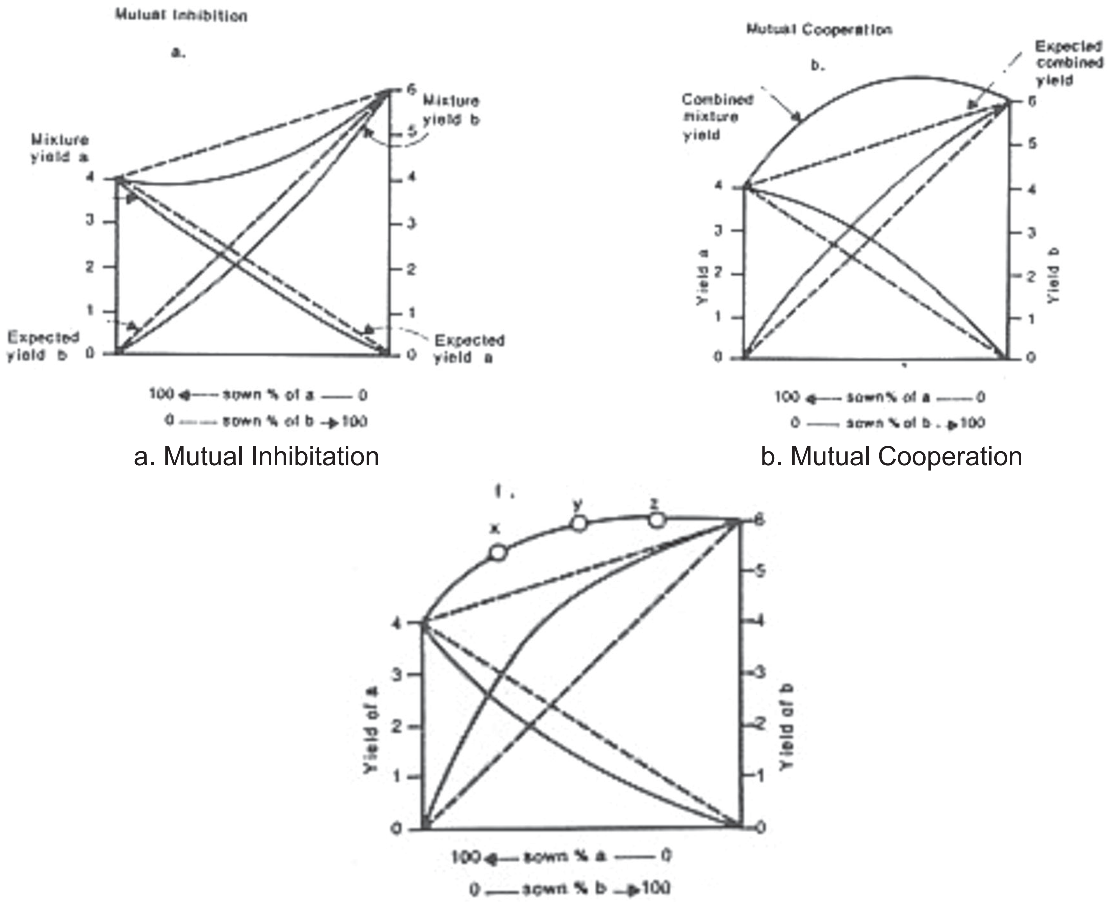
Yaa = yield of crop A as monoculture
Yab = yield of crop A as intercrop with crop B
Ybb = yield of crop B as mono culture
Yba = yield of crop B as intercrop with crop A

When the RYT is equal to or less than 1, there is no advantage to intercropping.

If we take into account the duration of the crop i.e. the time it occupies from planting to harvesting, we use the Area Time Equivalent Ratio (ATER) which was proposed by Hiebsch (1980) (*cit.* Ofori and Stern. 1987) :

$$ATER = \frac{RYa.\ ta + RYb.\ tb}{T} \qquad (3)$$

Where RYa and RYb are relative yield of crop A and B, ta and tb are the durations (days) for crop A and



a. Mutual Inhibitation

b. Mutual Cooperation

c. Compensation

Fig. 1. Types of inter-species interaction.

crop B, and T is the duration (days) of the whole intercrop system.

III. Some experimental results

As mentioned earlier, the experiments were conducted in Gadjah Mada Agricultural Experiment Station, Kalitirto, Yogyakarta. The altitude is about 146 m above sea level, with regosol soil type and C3 type of Oldeman agroclimatic classification. Yearly air temperature ranges from 27°C up to 35°C.

3.1. Interaction between upland rice and legumes

3.1.1. Upland rice vs velvet bean (*Mucuna pruriens*. L. DC.). (Kalis, 2001).

Weeds are one of the major problems in growing upland rice. The field experiment was aimed to study the effect of velvet bean on the growth and production of upland rice, and its associated weeds. The experiments was conducted in the wet season of 2000/2001. Two factors were considered, (1) upland rice varieties (Dodokan and Cirata), (2) proportion of upland rice: velvet bean, arranged in replacement series from 0% to 100% at 25% interval. Each plot size was 6x 4 m, giving 400 plants per plot under spacing of 30 x 20 cm. The design was 2 x 5 factorial arranged in split plot with upland rice varieties as main plot; with three replications.

The results of the experiment showed that the best upland rice yield was reached by the combination of 75% upland rice-25% velvet bean, i.e. 1.41 tons and 1.92 tons per hectare for dodokan and cirata varieties (table 1). It should be noted here, that the yield is relatively low, because dodokan and cirata are lowland rice which can be adapted to upland condition . The highest relative yield total (RYT) was reached by the proportion of 50% upland rice-50% velvet bean, i.e. 1.19 and 1.16 for dodokan and cirata respectively. The interaction of both crops belongs to the categories of mutual cooperation or complementary, as the RYT values of every mixture was above 1 (see figure

2.).

As an additional result the proportion of 25% upland rice and 75% velvet bean gave the greatest growth suppression of sedges, grasses and broad leaved weeds.

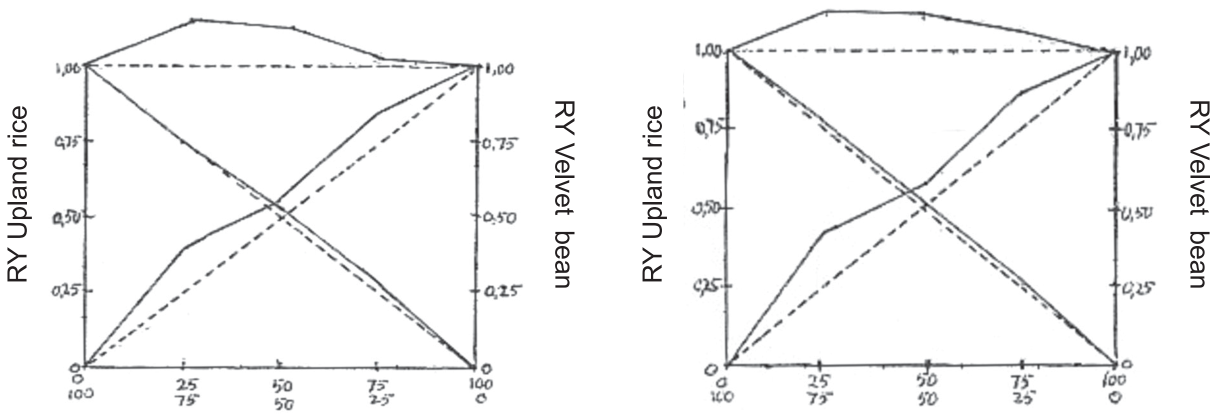
3.1.2. Upland rice vs mung bean (Nina, 2003).

The experiment was intended to find out the type of interaction exhibited when mung bean intercropped to upland rice at different planting time and population ratio. It was done during the wet season of 2002/2003. The design was 3 x 3 factorial of intercropping treatments with two augmented monoculture treatments arranged in randomized complete block design. The first factor was mung bean planting time, i.e. 10 days prior to upland rice (K1), at the same time (K2) and 10 days after planting upland rice (K3). The second factor was population ratio of mung bean to upland rice, i.e. 25%mung bean, 75% upland rice (P1), 50% mung bean, 50% upland rice (K2) and 75% mung bean, 25% upland rice (K3). Varieties used was Limboto for upland rice and Walet for mung bean.

The results revealed that combination of mung bean and upland rice in intercropping system led to an increase of upland rice yield but accompanied with a decrease of mung bean, thus a compensation type of interaction (figure 3). Mung bean planting time did

Table 1. Upland rice and velvet bean yields (ton/ha) in intercropping system and their relative yield (RY)

Proportion of Upland rive vs Velvet bean (%)	Yield		Relative Yield		RYT
	UR	VB	UR	VB	
Dodokan					
UR100	1.30	-	1.00	0.00	1.00
UR75VB100	1.06	2.29	0.81	0.27	1.08
UR50VB50	0.86	4.44	0.67	0.52	1.19
UR25VB75	0.62	6.36	0.47	0.35	1.22
VB100	-	8.49	0.00	1.00	1.00
Cirata					
UR100	1.73	-	1.00	0.00	1.00
UR75VB100	1.44	2.73	0.84	0.26	1.10
UR50VB50	1.04	5.77	0.64	0.56	1.16
UR25VB75	0.68	8.01	0.41	0.18	1.17
VB100	-	10.28	0.00	1.00	1.00



a. Dodokan b. Cirata

Fig. 2. Replacement diagram of upland rice-velvet bean intercropping

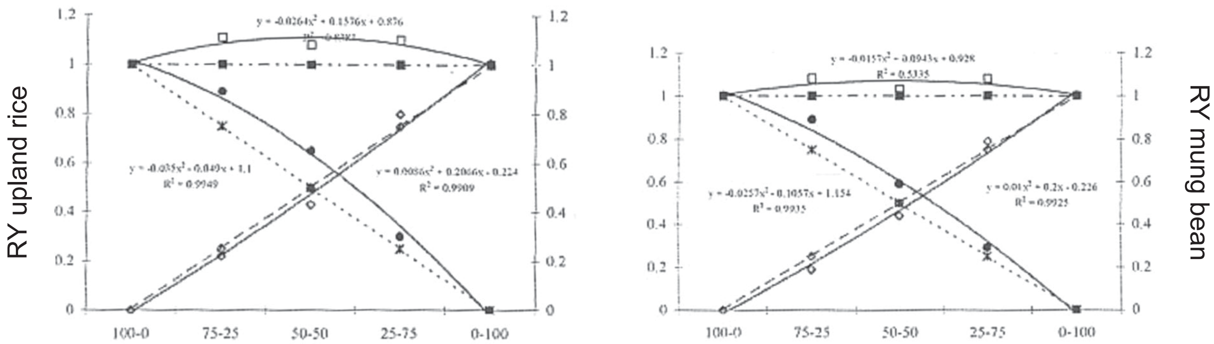
not give significant effect to the type of interaction.

The highest upland rice yield was reached by the 50% : 50% population ratio under the planting mung bean 10 days ahead of upland rice. However, the highest relative yield total (RYT) and area time equivalent ratio (ATER) was reached by the population ratio of 25% upland rice and 75% mung bean in the same planting time (table 2).

3.1.3. Upland rice vs groundnut (Hotnida, 2004).

The experiment was intended to find out the suitable varieties combination of upland rice and groundnut under intercropping system. It was done during the wet season 2003/2004. The design of the field experiment was 4 x 4 factorial arranged in strip plot with 4 additional monoculture treatments arranged in randomized complete block. The first factor was upland rice varieties, i.e. (1) Towuti, (2) Danaugaung, (3) Batulegi, (4) Limboto; while the second factor was groundnut varieties, i.e. (1) Singa, (2) Panter, (3) Komodo and (4) Kelinci. Crops were planted under population ratio of 50% : 50%.

The results revealed that combination of upland rice and groundnut varieties in intercropping system led to an increase of upland rice yield but accompanied by the decrease of groundnut yield, which means a compensation type of interaction. The most suitable varieties combination of this intercropping system was Towuti (upland rice) and Komodo (groundnut) i.e. it gave the highest RYT value (1.47) (table 4).



a. Mung bean planted 10 days before upland rice

b. Mung bean planted in the same time with upland rice

Fig. 3. Replacement diagram of upland rice-mung bean intercropping.

Table 2. Upland rice and mung bean yields (ton/ha) in intercropping system and their RYT and ATER

Treatment	Yield (ton/ha)		RYT	ATER
	UR	MB		
K1P1	4.92	1.45	1.10	1.11
K1P2	5.43	1.44	1.08	1.10
K1P3	4.91	1.80	1.10	1.15
K2P1	4.95	1.29	1.08	1.10
K2P2	4.94	1.48	1.03	1.04
K2P3	4.76	1.77	1.08	1.09
K3P1	4.90	1.38	1.04	1.09
K3P2	4.68	1.48	1.00	1.03
K3P3	4.69	1.76	1.07	1.08
MC	4.16	1.65	-	-

Note :

- Mung bean planted 10 days before upland rice (K1), together (K2), 10 days after (K3).
- P1 : 75% upland rice, 25% mung bean ; P2 : 50%, 50% ; P3 : 25%, 75%

However, the highest upland rice yield was reached by Danaugaung partnering with Komodo (groundnut) (table 4).

3.2. Interaction between upland rice and Horticultural Crops.

3.2.1. Upland rice vs watermelon (Tjahjono, 1995).

The field experiment had been carried out in the agricultural experiment station, Gadjah Mada University, Kalitirto, Yogyakarta, in the late dry season (August-December) 1994. The design was RCBD with six replacement series treatments with four replications, i.e. (1) watermelon monoculture (1:0), (2) 75% watermelon, 25% upland rice (3:1), (3) 50% watermelon, 50% upland rice in 1:1 rows arrangement (1:1), (4) 50%watermelon: 50% upland rice in 2:2 rows arrangement (2:2), (5) 25% watermelon, 75% upland rice (1:3) and (6) monoculture of upland rice (0:1).

The results of the experiment showed that upland rice, when intercropped with watermelon, was able to increase the watermelon yield 27% compared to its monoculture

(if the number of population is equal). On the other hand, watermelon was able to increase upland rice yield up to 28% (table 5). This means that complementation or mutual cooperation occurred in the intercropping of the two species (figure 4). Based on RYT value, the 1:1 rows arrangement is better than 2:2 although both gave positive effects. (table 5.). Cropping pattern 1:3 gave the highest RYT value (1.7). Only cropping pattern 3:1 gave the negative ef-

Table 3. Upland rice yield (ton/ha) under intercropping with groundnut

Upland Rice Varieties	Groundnut Varieties				Monoculture
	Singa	Panter	Komodo	Kelinci	
Towuti	2.10	2.64	4.00	2.60	3.23
Danau Gaung	2.22	2.57	4.45	3.18	3.56
Batu legi	3.99	3.27	3.31	3.26	4.79
Limboto	1.76	2.79	3.03	3.18	3.32

Table 4. Relative Yield Total values of intercropping between upland rice and groundnut

Upland Rice Varieties	Groundnut Varieties			
	Singa	Panter	Komodo	Kelinci
Towuti	1.11	1.04	1.47	0.96
Danau Gaung	1.13	1.13	1.23	1.15
Batu legi	1.15	1.35	1.01	1.13
Limboto	1.33	0.91	1.26	1.53

Table 5. Means of upland rice, watermelon yields (ton/ha) and their RYT value in intercropping system.

Treatment	Yield (ton/ha)		RYT
	Watermelon	Upland rice	
Watermelon monoculture	2.59	-	1.00
3 W : 1 UR	1.89	1.05	0.97
1 W : 1 UR	1.41	2.01	1.12
2 W : 2 UR	1.63	1.94	1.06
1 W : 3 UR	0.82	2.92	1.17
Upland rice monoculture	-	3.26	1.00

fect.

3.2.2. Upland rice vs onion (Lapanjang, 1997).

The experiment was carried out at our experiment station, Kalitirto, Yogyakarta, in the dry season 1996. 3 x 5 factorial treatments arranged in split plot with main plot arranged in latin square, was used with three replications. The main plot treatment was a mixed organic fertilizer, i.e. rice straw + EM4 (“mixed micro-organism” fertilizer) in three levels, i.e. (1) no organic fertilizer (A0), (2) rice straw + EM4 (A1) and (3) only EM4 (A2). The sub-plot consisted of replacement series treatments, i.e. (1) Onion monoculture (B0), (2) 75% onion, 25% upland rice (B1), (3) 50% onion, 50% upland rice (B2), (4). 25% onion, 75% upland rice (B3) and (5) upland rice monoculture (B4).

The results of the experiment showed that upland rice had beneficial effect from intercropping condition under additional organic fertilizer. On the contrary, onion had the beneficial effect from intercropping treatments if there was no additional organic fertilizer (figure 5.). The interaction type is compensation. The highest yield of upland rice was reached by the combination of 50% upland rice and 50% onion, but the highest RYT was reached by intercropping of 25% onion and 75% upland rice (table 6.).

3.2.3. Upland Rice vs Pineapple (Rahayu, 2004).

The aim of the research was to study (1) the effect of some pineapple varieties on the growth and yield of upland rice, (2) the best pineapple proportion in intercropping system which gave the highest yield of upland rice. The research was conducted on farmer’s field during the wet season 2003/2004 at Logandeng village, Playen, Gunung Kidul district, Yogyakarta province. The design of the field experiment was 3 x 2 factorial + 3 additional treatments arranged in randomized complete block. The first factor was pineapple varieties i.e. Queen Blitar (Nb), Queen Hijau Bogor (Nq), and Cayenne Subang (Nc), while second factor was intercropping level i.e. pineapple monoculture (Po) and 50% proportion of intercropping system (P_{50}). The additional treatments consist of upland rice monoculture (P_{100}), intercropping with proportion Queen Blitar 25% : 75% upland rice (P_{75}) and intercropping with proportion Queen Blitar 75% : 25% upland rice (P_{25}). The rice variety used was IR-64.

The results of this research showed upland rice-some varieties of pineapple gave beneficial effect to upland rice (increased upland rice yield). Intercropping of 75% Queen Blitar, 25% upland rice gave the highest yield of grain per hill. The upland rice and Cayenne type of pineapple under 50% proportion gave higher yield per hectare compared to upland rice-Queen type of pineapple intercropping (table 7).

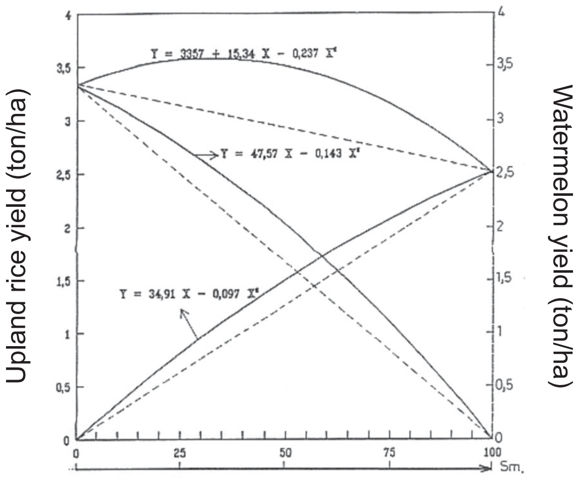
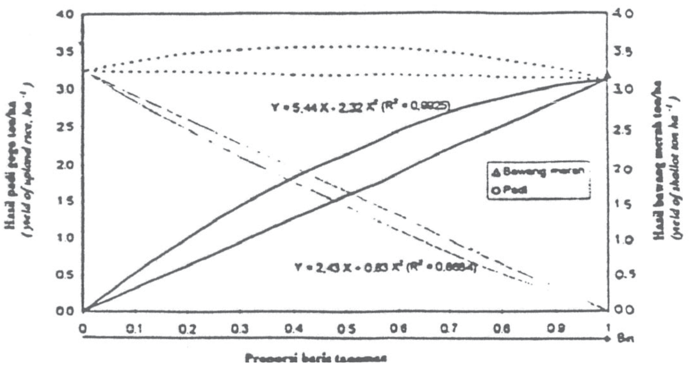


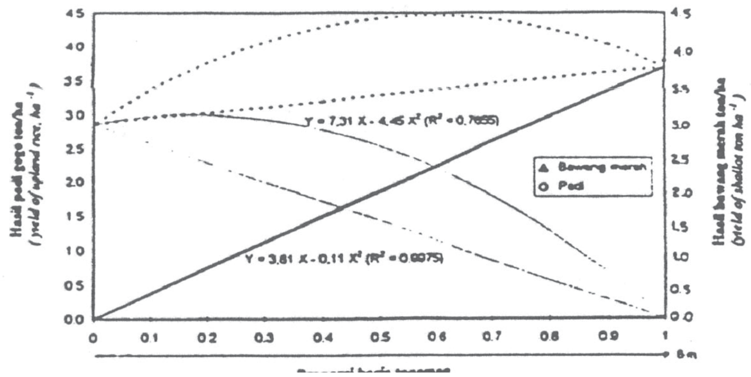
Fig. 4. Replacement series diagram of upland rice-watermelon intercropping system.

Table 6. Means of upland rice and onion yields (ton/ha) and their RYT in intercropping system.

Treatment	Yield (ton/ha)		RYT
	Onion	Upland rice	
Onion monoculture	3.56	-	1.00
75% O : 25% UR	2.57	1.01	1.04
50% O : 50% UR	1.91	2.01	1.12
25% O : 75% UR	1.19	2.87	1.17
Upland rice monoculture	-	3.70	1.00



(a)



(b)

Fig. 5. Replacement series diagram of upland rice-onion intercropping system. (a). no organic fertilizer. (b). with organic fertilizer.

Table 7. The effect of intercropping level on the yield of upland rice (ton/ha) and the weight of pineapple biomass (g. dry weight/plant).

Treatment	Upland rice	Pineapple
P100	4.24	-
NB25 P75	2.28	29.34
NB50 P50	2.18	50.47
NB25 P75	1.47	33.16
NQ50 P50	2.37	37.15
NC50 P50	2.45	49.69
NB100	-	24.97
NQ100	-	35.26
NC100	-	88.06

It should be noted here that the pineapple still under was vegetative phase when upland rice was harvested.

The descrease in soil characteristics (CEC and N total) under intercropping system was lower compared to upland rice monoculture. Upland rice-pineapple intercropping increased soil bulk density and pore volume. The highest soil nitrogen absorption was met in upland rice monoculture.

IV. Conclusions

One of the advantages of upland rice compared to lowland rice is that it can be grown with other crops in intercropping system. Unfortunately, in Indonesia, the production potential of upland rice is still lower compared to lowland rice, although area suitable for developing this crop is much more broader. Consequently, breeding programs for high yield varieties of upland rice is urgent and should be done continuously.

The types of interaction between upland rice and other crops are specific, depend on crop species grown side by side in intercropping system. From the compilation of six field experiments, the results showed that most legume crops stimulate upland rice yield. However, the effect of upland rice on legume crops is different, i.e. decreasing yield such as in mung bean and groundnut and no significant effect such as in velvet bean. Thus a compensation type of interaction is occurred.

There is no general rule for interaction with horticultural crops. Complementary type was shown in the interaction between upland rice and watermelon. However, compensation type of interaction occurred on the intercropping between upland rice and pineapple, where upland rice got the beneficial effect. Compensation type was also shown on the interaction between upland rice and onion, but the beneficial effect was received by onion. However, under the occurrence of organic fertilizer, upland rice got the beneficial effect.

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The impact of free-air CO_2 enrichment (FACE) and N supply on growth, yield and quality of rice crops with large panicle

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Keywords: Free-Air CO_2 Enrichment (FACE), Growth, Quality, Rice, Yield

Abstract

Because CO_2 is needed for plant photosynthesis, the increase in atmospheric [CO_2] has the potential to enhance the growth and development of plant. However, the resultant effects on growth, yield and quality of field-grown rice remain unclear, especially under differing nitrogen (N) availability and/or using cultivars with large panicles. To investigate these, a Free-Air CO_2 Enrichment (FACE) experiment was performed at Wuxi, Jiangsu, China, in 2001-03. A japonica cultivar with large panicle was exposed to two [CO_2] (ambient, ambient+200 μmol mol^{-1}) at three levels of N supply (15, 25, 35 g N m^{-2}). FACE accelerates phenology significantly, with 3-5 days earlier in heading and 6-9 days earlier in maturity across 3 years. FACE significantly increased the grain yield by 12.8%, which was mainly due to substantially increased panicle number per square meter (+19%) as result of significant increases in tillering occurrence speed. However the spikelet number per panicle was greatly reduced (-8%), which was due mainly to the significant increase in degenerated spikelets per panicle (+52%) while differentiated spikelets per panicle showed no change. Overall DM accumulation at harvest was stimulated somewhat more (+16%) by FACE, compared to grain yield, by an average of 13% by FACE, thus resulting in 3% reduction in harvest index. FACE caused significant reduction in shoot N concentration (-7%) and significant increase in P concentration (+14%) at grain maturity, resulting in significant increase in N use efficiency and significant reduction in P use efficiency. Both shoot N uptake (+9%) and P uptake (+33%) showed significant increase at harvest, which was mainly due to significant enhanced N and P uptake during early growth stage. On a per plant basis, FACE significantly increased cumulative root volume, root dry weight, adventitious root length and adventitious root number at heading, which was mainly associated with significant increases in root growth rate during early growth period, while total surface area, active adsorption area and root oxidation activity per unit root dry weight showed significant reduction. As for grain quality, FACE cause deterioration of processing suitability and appearance quality drastically, the nutritive value of grain was also negatively influenced by FACE due to a reduction in grain protein and Cu concentration. By contrast, FACE resulted in better eating/cooking quality. For most cases, no [CO_2]×N interaction was detected for the growth, yield and quality parameters. Data from this study has important implications for fertilizer (e.g. N, P) management and variety selection in rice production systems under future elevated [CO_2] conditions.

1. Introduction

Empirical records provide incontestable evidence of global changes; Foremost among these changes is the increasing atmospheric CO_2 concentration ([CO_2]), which, as is predicted, will double the concentration of the pre-industrial era around the mid 21st century (IPCC, 2001). Atmospheric carbon dioxide is the substrate for photosynthesis for all terrestrial higher plants, hence, its enrichment must have profound impact on plant growth and development. Rice (*Oryza sativa* L.) is one of the most leading crops in the world and the first staple food in Asia, providing nutrition to a large proportion of the world's population. The improvement of grain yield and quality are the two most important objectives in rice production in most of the rice-producing areas of the world. Hence, it is very important to determine how the predicted increase in the levels of atmospheric [CO_2] will affect growth, yield and quality of rice.

Over the last a decade, many studies have been carried out to determine the effects of elevated [CO_2] on growth, yield and quality of rice crops (Baker and Allen, 1993; Horie et al., 1995, 2000; Ziska et al., 1997; Seneweera et al., 1996, 1997; Kim et al., 1996, 2001, 2003a, b; Tomio et al., 2005). Studies with cereal crops other than rice suggest that nitrogen (N) availability can have a large effect on the responses of agricultural crops to elevated [CO_2] (Kimball et al., 1995, 2002). However, as for the interactive effects of elevated [CO_2] and N availability on the growth and yield of rice crops, we know only a single study conducted for three cropping seasons (1998-2000) using a japonica cultivar with small panicle (average ca. 80 spikelets per panicle) under differing low N levels (from 4 to 15 g N m^{-2}) (Kim et al., 2001, 2003a b; Lieffering et al., 2004; Tomio et al., 2005). To date, there is no information on the combined effect of these factors on growth, yield and quality of rice cultivar with large panicles or under differing high N supply. However, over the last several decades, the consumption of N fertilizer increased dramatically with the increase in rice yield in developing countries. For example, the average rate of N application for rice production in China is about 75% higher than the world average (FAO, 2001). At present, in Tai Lake region in China, N application has reached 27-30 g m^{-2} and even exceeded 35 g m^{-2}. On the other hand, the presence of large panicles of high-yielding rice cultivars ensures that a sufficient spikelet number per unit area can be obtained, leading to the increase of the grain yield potential (Ling et al., 1994; Peng et al., 1999). So there is a need to reveal out [CO_2]-response on the rice growth, yield and quality of large panicle cultivar under high N application.

The effects of elevated [CO_2] on rice growth and development were studied mostly based on the experiments conducted using chambers or enclosures with elevated [CO_2] (Baker and Allen, 1993; Horie et al., 1995, 2000; Ziska et al., 1997; Seneweera et al., 1996, 1997; Kim et al., 1996). In both situations, the environment experienced by the crops can be markedly different from that under field conditions, which have been shown to influence the response of plants to elevated [CO_2] (McLeod and Long, 1999). Also, because of their limited size, use of these facilities prevents intensive destructive sampling. However, the free-air CO_2 enrichment (FACE) technique can avoid these limitations of enclosure methods (McLeod and Long, 1999), as a result, it is presumed to be the most ideal method to study the response of crop ecosystem to elevated [CO_2]. The China Rice FACE platform, which is also the second Rice FACE system in the world, have been set up and operated in June 2001, with the objective of investigating the effects of elevated [CO_2] on rice growth, yield, quality, soil change in microbiology, nutrients supply, competition among crop and herbs, canopy micro-meteorology, trace gas emission and consumption under field conditions.

In the study reported here, as in the Japanese Rice FACE project (also first rice FACE facility in the world), rice crops were grown from seedling to grain maturity under two levels of [CO_2] (ambient and ambient plus 200 μmol mol^{-1}) (Kim et al., 2001, 2003a b). In contrast, however, according to the actual Chinese rice production, a cultivar with larger panicle (ca 155 spikelets per panicle) that has been used in large-scale production in China was tested and three higher N levels (15, 25, 35 g N m^{-2}) were supplied. The objective of the present work was to elucidate the effects of elevated [CO_2] in combination with differing high N availability on growth, yield and quality of rice with large panicle. The results obtained here should provide important implications with respect to adaptation strategies of rice under future elevated CO_2 conditions.

2.Materials and Methods

The rice FACE experimental system was located at Wuxi city, Jiangsu province, China (31°37'N, 120°28'E), which has eight rings located in different paddies having similar soils and agronomic histories. Three replicate plots were randomly allocated for the elevated CO_2 treatments (hereinafter called FACE plots) and five for the ambient treatments (hereinafter referred to as ambient plots). Each replicate plot was ca. 80 m^2. In the FACE plots, crops were grown within 12.5 m diameter 'rings' which sprayed pure CO_2 both day and night throughout the growing season except for a few days during transplantation towards the plot centre from eight peripheral emission tubes (5 m long) located about 50-60 cm above the canopy. In the ambient plots, plants were grown under ambient [CO_2] without ring structures. The target [CO_2] in the FACE plots throughout the season was controlled to 200 μmol mol^{-1} above that of ambient by computer system platform. Details of the design, rationale, operation, and performance of the CO_2 exposure system used in this study are provided by Okada et al. (2000) and Liu et al. (2002).

A japonica cv. Wuxiangging 14 tested in the experiment was a major local cultivar with large panicle (ca 155 spikelets per panicle) and a high-yielding potential. Standard cultivation practices as commonly performed in the area were followed in all experimental plots. Rice seeds were sown on 18 May. The seedlings for the ambient plots were grown under ambient [CO_2] conditions, while those for the FACE plots were grown under elevated [CO_2] conditions. On 13 June, the seedlings were manually transplanted at a density of 3 seedlings per hill into the FACE and ambient plots. Spacing of the hills was 16.7 by 25 cm (equivalent to 24 hills m^{-2}). Each of the eight circular rings (main plots) was further spit into three subplots to test the effect of three different N levels: low (LN, 15 g N m^{-2}), medium (MN, 25 g N m^{-2}) and high N (HN, 35 g N m^{-2}). The more detailed description of soil properties and cropping history was provided in the previously published reports (Yang et al., 2006a, b, 2007a, b, c, d).

Areas of the crop were destructively sampled at different times over the season. Sampling dates were fixed so as to coincide as much as possible with the early-tillering, mid-tillering, panicle initiation (PI), booting, heading (50% of plant headed) and grain maturity stages of the plants. In 2001, Plants were sampled at 28 and 51 days after transplanting (DAT), heading stage, and grain maturity. In 2002, plants were sampled at 16, 27, 47 and 58 DAT, heading stage and grain maturity. In 2003, sampled at 12, 28 and 45 DAT, heading stage and grain maturity. In order to ensure representativeness of the sampling, the number of stems in 100 hills was counted at different places in each subplot, and then five plants with the mean stem number were selected. To maintain canopy conditions, the vacant spaces left after sampling were replanted with hills taken from the borders and these replanted hills were not subject to sampling any more. The samples were separated into living and dead leaf tissues, stem (including leaf sheath), root, and panicle (when applicable). For two of the five hills green leaf areas were measured. All the plant parts were oven-dried at 80°C for 72 h or until dry weights were constant for subsequent measurements. Grain yield and quality was determined of all the plants from a 2 m^2 patch (excluding plants in the borders) in each subplot. The details of measurements for nutrient concentrations, root characteristics, yield formation, and grain quality properties as well as statistical analysis all can be found in previous reports (Yang et al., 2006a, b, 2007a, b, c, d).

3. Results

3.1. Effects of CO_2 and N on phenology

The duration from sowing to heading, from heading to maturity and the whole growth duration of rice shrank 3-5 (mean value 3.4, Fig. 1a), 1-5 (mean value 2.4, Fig. 2a), 4-9 (mean value 5.8) days, respectively, in the FACE vs ambient plots. Increment of N application rate could weaken the effect of FACE on growth duration. For the most part, the year effects were significant for the whole growth duration; however, interactions between all treatment variables (Year×CO_2, Year×N, CO_2×N, Year×CO_2×N) were hardly detected.

3.2. Effects of CO_2 and N on biomass, yield and yield components

On average, compared to ambient [CO_2], FACE significantly increased shoot biomass and grain yield

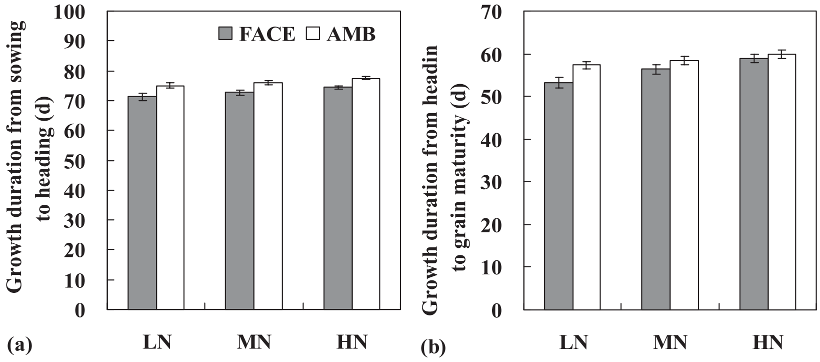

Fig. 1. Effect of elevated [CO_2] of growth duration from transplanting to heading (a) and from heading to grain maturity (b) of rice plants under three levels of N application (15, 25, 35 g m^{-2}) over three cropping seasons (2001-03). Data are average values across three years with ± one standard error (vertical bars).

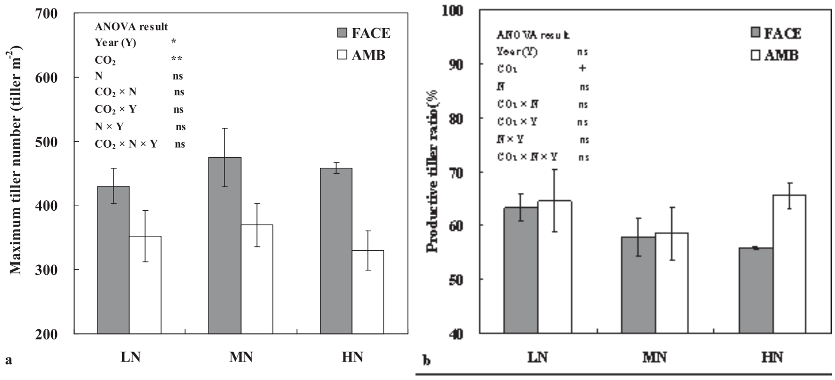

Fig. 2. Effect of elevated [CO_2] on maximum tiller number per square meter (m^2) (a) and productive tiller ratio (%) under three levels of N application (15, 25, 35 g m^{-2}). Data averaged aross 2001 and 2002. Vertical bars indicated one standard error. ANOVA results are shown with ns, +, * and ** indicating no significance, $P < 0.1$, $P < 0.05$ and $P < 0.01$, respectively.

of rice crops at maturity, with an average increase of 16% (data not shown) and 12.8% (Table 1) across the three years, respectively. Across [CO_2] levels, biomass and grain yield increased significantly with N supply from 15 to 25 g N m^2, but further increases in N supply to 35 g m^{-2} resulted in significant decline.

FACE significantly increased panicle number per square meter, showing an average increase of 18.8% across three years (Table 1). Across [CO_2] levels, the panicle number per square meter increased significantly with increasing N level from 15 to 25 g N m^2, but higher N (e.g. 35 g N m^{-2}) levels showed the reverse. Panicle number per square meter is determined by maximum tiller number (MTN) per square meter and productive tiller ratio (PTR). FACE significantly increased MTN per square meter (+30.0%, Fig. 2a), while PTR was reduced with FACE (-7.7%, Fig. 2b), indicating greater panicle number per square meter was mainly due to the substantial increases in tiller occurrence with FACE.

FACE significantly reduced spikelet number per panicle (SNPP), averaging 7.6% across the three seasons (Table 2). N had no significant effect on SNPP. SNPP is represented by the difference in the number of differentiated and degenerated spikelets. Our results indicated that FACE had no effect on the number of differentiated spikelets per panicle (Fig. 3a), while it significantly increased the number of degenerated spikelets per panicle, averaging 97.3% and 38.6% in 2001 and 2002, respectively (Fig. 3b).

Filled spikelet percentage and grain weight all responded positively to FACE but negatively to N (Table 1). Though the degree of stimulation due to FACE was less overall, averaging 4.9% for filled spikelet percentage and 1.3% (0.4 mg) for grain weight across three years, both of them reached significant level ($P < 0.01$).

For the most part, the year effects were all significant for final biomass, grain yield and yield components (Table 1); however, interactions between all treatment variables were hardly detected.

3.3. Effects of CO_2 and N on N uptake and utilization

Averaged across all N levels and years, FACE significantly increased shoot N uptake by 9% at grain maturity (Fig. 4a). The whole growth season of rice plants is consisted of different growth periods. On average, shoot N uptake in FACE plots was increased significantly by 46, 38, 6 and 16% during the growth periods from transplanting to early-tillering (Period 1), early-tillering to mid-tillering (Period 2), mid-tillering to panicle initiation (PI) (Period 3) and heading to grain maturity (Period 5), respectively, while it was reduced by 2% in the period from PI to heading (Period 4), the responses showing a progressive decrease with time during the season up to heading and then a slightly increase at grain maturity (Fig. 5a). The similar trend applied to shoot N uptake ratio (the ratio of shoot N uptake during a given growth period to final shoot N acquisition at maturity): on average, the response of shoot N uptake ratio to FACE was 33, 26, -3, -11 and 10% in Periods 1, 2, 3, 4 and 5 of the growth period, respectively (figure not shown).

As a result of the greater increase in shoot DM production at maturity, relative to the increase in N up-

Table 1. Effect of elevated [CO_2] on yield and its components of rice crops under three levels of N application (15, 25, 35 g m^{-2}) over three cropping seasons (2001-03)

Year	N	CO_2	Panicle number (m^{-2})	Spikelet number ($panicle^{-1}$)	Total spikelets (m^{-2})	Spikelet fertility (%)	Grain weight (mg)	Yield (g m^{-2})
2001	LN	FACE	347.2	128.8	44719	76.3	30.0	1149
		AMB	284.8	144.7	41211	67.1	30.5	1040
	MN	FACE	364.8	143.7	52422	68.5	30.3	1217
		AMB	315.2	153.0	48226	63.0	30.0	1095
2002	LN	FACE	324.0	137.5	44550	72.0	28.5	1064
		AMB	284.4	149.6	42546	62.9	27.9	980
	MN	FACE	346.0	136.5	47229	63.5	27.6	1167
		AMB	291.6	151.2	44090	63.2	27.9	992
	HN	FACE	328.0	147.2	48282	61.7	27.9	1081
		AMB	288.0	152.8	44006	61.0	27.7	932
2003	LN	FACE	303.6	148.8	45176	73.2	28.2	1003
		AMB	253.0	154.0	38962	74.6	27.1	880
	MN	FACE	318.1	145.0	46125	71.3	27.3	976
		AMB	269.6	159.4	42974	71.8	26.3	903
	HN	FACE	330.7	141.5	46794	66.9	26.8	936
		AMB	257.1	156.3	40185	70.0	26.2	783
				ANOVA results				
Year (Y)			**	*	**	**	**	**
CO_2			**	**	**	*	*	**
N			**	ns	**	**	**	**
CO_2×N			ns	ns	ns	ns	ns	ns
CO_2×Y			ns	ns	ns	*	**	ns
N×Y			ns	ns	ns	ns	ns	ns
CO_2×N×Y			ns	ns	ns	ns	ns	ns

ns, * and ** indicating no significance, $P < 0.05$ and $P < 0.01$, respectively.

Table 2. Effect of elevated [CO_2] on total surface area (TSA), active adsorption area (AAA) and amount of α-NA oxidation per unit root dry weight (RDW) under three levels of N application [15, 25, 35 g m^{-2}] in 2003 rice season

N	CO_2	TSA per unit RDW (m^2 g^{-1})	AAA per unit RDW (m^2 g^{-1})	Amount of α-NA oxidation per unit RDW (μg g^{-1} h^{-1})
	FACE	8.12	2.32	120.88
	AMB	10.74	2.89	147.89
MN	FACE	7.06	2.35	137.45
	AMB	9.16	3.18	170.03
LN	FACE	6.87	2.32	134.03
	AMB	9.99	3.07	245.13
CO_2		**	*	**
N		*	n.s.	**
CO_2×N		n.s.	n.s.	**

ns, * and ** indicating no significance, $P < 0.05$ and $P < 0.01$, respectively.

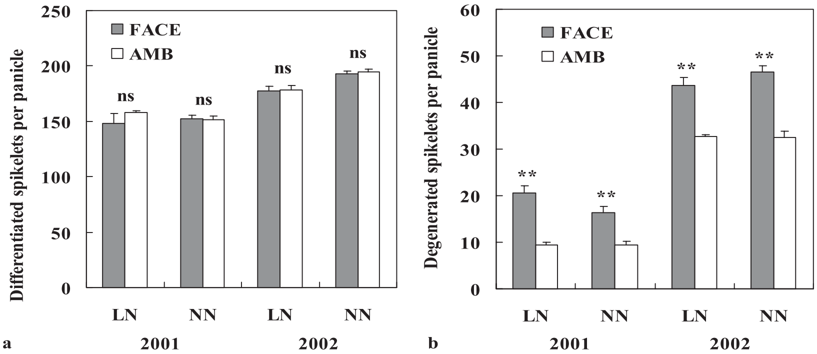

Fig. 3. Effect of elevated [CO_2] on number of differentiated spikelets (a) and degenerated spikelets (b) per panicle under three levels of N application (15, 25, 35 g m^{-2}) over two cropping seasons (2001-02). Vertical bars indicated one standard error. ANOVA results are shown with ns, ** indicating no significance, $P < 0.01$, respectively.

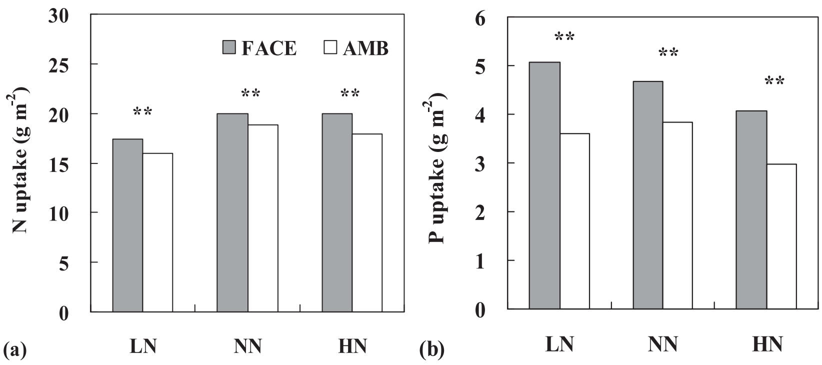

Fig. 4. Effects of elevated [CO_2] on shoot N (a) and P (b) uptake at maturity under three different levels of N application (15, 25, 35 g m^{-2}) over three cropping seasons (2001-03). Bars represent ± stardard error (n = 3 or 5) when it exceeds the size of the symbol.

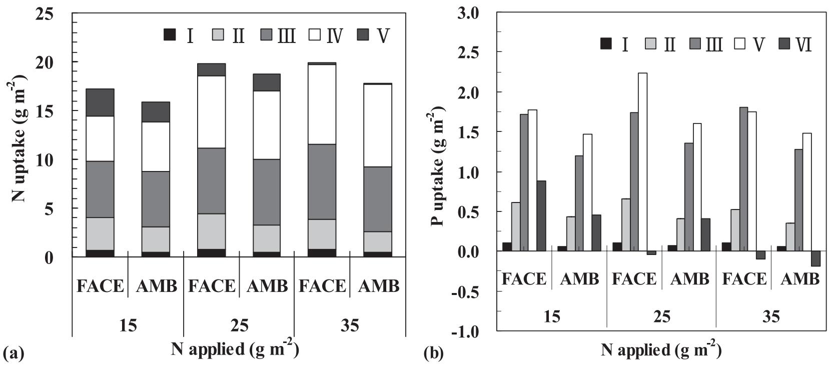

Fig. 5. Effect of elevated [CO_2] on shoot N (a) and P (b) uptake during five successive growth periods of rice under three different levels of N application (15, 25, 35 g m^{-2}) over three cropping seasons (2001-03). A, B, C, D and E indicate different growth periods: from transplanting to early-tillering, early-tillering to mid-tillering, mid-tillering to panicle initiation (PI), PI to heading, heading to grain maturity, respectively. For each N level, data are average values across three years (2001-03).

take, N use efficiency (NUE) increased significantly, whereas the reverse was true for shoot N concentration at maturity. Averaged across all N levels and years, shoot N concentration was lower under FACE by 7% at maturity. As for NUE at maturity, N use efficiency for biomass (NUEp), N use efficiency for grain (NUEg) and N harvest index (NHI) increased by an average of 7 (P <0.05), 5.7 (P <0.05) and 2.0% (P >0.05) with FACE, respectively.

Across [CO_2] levels, shoot N concentration and uptake increased apparently with increasing N supply, while NUE showed an opposite trend. For the most part, interactions between all treatments variables were not detected although there was obvious variation between different years with regards to N nutrient parameters.

3.4. Effects of CO_2 and N on P uptake and utilization

Shoot P accumulation showed significant and substantial increase under FACE irrespective of N application (Fig. 4b). Averaged across all N levels and years, the shoot P uptake was greater under FACE by 33% at maturity. The whole growth season of rice plants is consisted of different growth periods. Averaged over all N levels and seasons, shoot P uptake in the FACE plots was increased significantly by 57, 51, 37, 26 and 11%, in Periods 1, 2, 3, 4 and 5 of the growth periods, respectively, showing a progressive decrease with time across the season (Fig. 5b). The similar trend applied to shoot P uptake ratio (i.e., the ratio of P uptake during a given growth period to final P acquisition at maturity): on average, the response of shoot P uptake ratio to FACE was 19, 14, 3, -5 and -16% in Periods 1, 2, 3, 4 and 5 of the growth period, respectively (figure not shown).

As a result of the greater increase in P uptake, relative to the increase in DM production at maturity, P use efficiency (PUE) decreased significantly, whereas the reverse was true for shoot P concentration. Averaged across all N levels and years, shoot P concentration increased by 14% in FACE vs. ambient plants at maturity. As for PUE, P use efficiency for biomass (PUEp), P use efficiency for grain (PUEg) and P harvest index (PHI) were all decreased significantly with FACE by an average of 12, 13 and 7%, respectively.

N fertilization had little effect on all the observed P nutrient parameters. For the most part, interactions between all treatments variables were not detected although there was obvious variation between different years with regards to P nutrient parameters mentioned above.

3.5. Effects of CO_2 and N on root growth and development

On a per hill basis, cumulative adventitious root number (ARN), adventitious root length (ARL), root volume (RV) and root dry weight (RDW) per hill were consistently high at elevated relative to ambient [CO_2] (P <0.01) (Fig. 6): Averaged across all N levels and two years, cumulative ARN, ARL, RV and RDW per hill was greater under FACE by 29.0, 24.6, 34.7 and 35.5% at heading stage, respectively. N treatment had no effect on these parameters except for ARL per hill. The year effects were all significant (P <0.01 or P <0.05) for the four parameters, with the absolute values being markedly higher in 2003 than in 2002 growth season; however, interactions between all treatments variables were generally, but not always, nonsignificant for these parameters.

In contrast to root accumulation, FACE treatments exerted negative effects on total surface area (TSA), active adsorption area (AAA) and root oxidation activity (as measured by amount of α-NA oxidation) per unit root dry weight (RDW) at heading independently of N fertilization (Table 2): Averaged over three N levels, TSA, AAA and root oxidation activity per unit RDW were reduced by 26.3%, 23.6% and 30.3%, respectively. ANOVA showed that the differences between two [CO_2] levels were significant for the three parameters (P <0.01). N treatments had no influence on AAA per unit RDW but significant impacts on the other two parameters. And no interactions between [CO_2] and N supply were observed except for amount of α-NA per unit RDW.

3.6. Effects of CO_2 and N on grain quality

In general, the processing quality are evaluated by three milling traits, namely, brown rice percentage (BRP), milled rice percentage (MRP), head rice percentage (HRP). BRP showed small but significant increase (0.3%, Fig. 7a) with FACE, while, FACE significantly reduced MRP, HRP by 2.0 and 23.4% across the three seasons (Fig. 7b, c), respectively. Across both [CO_2] levels, BRP, MRP and HRP all increased apparently with increasing N supply.

Figs 7c, d, e summarizes three main appearance quality traits, including of chalky grain percentage

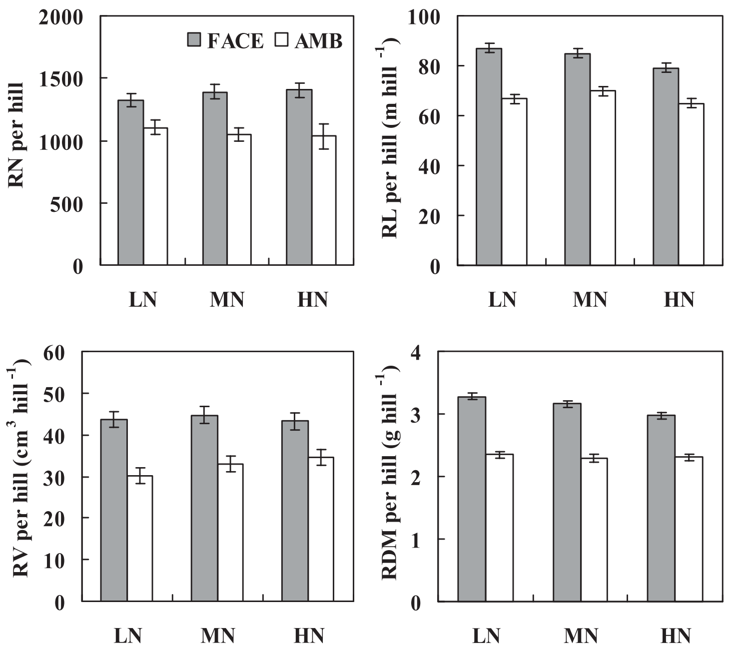

Fig. 6. Effect of elevated [CO_2] on adventitious root number (ARN, a), adventitious root length (ARL, b), root volume (RV, c), root dry weight (RDW, d) per hole under three different levels of N application (15, 25, 35 g m^{-2}) over two cropping seasons (2002-03). Data averaged for 2002 and 2003. Bars represent ± stardard error when it exceeds the size of the symbol.

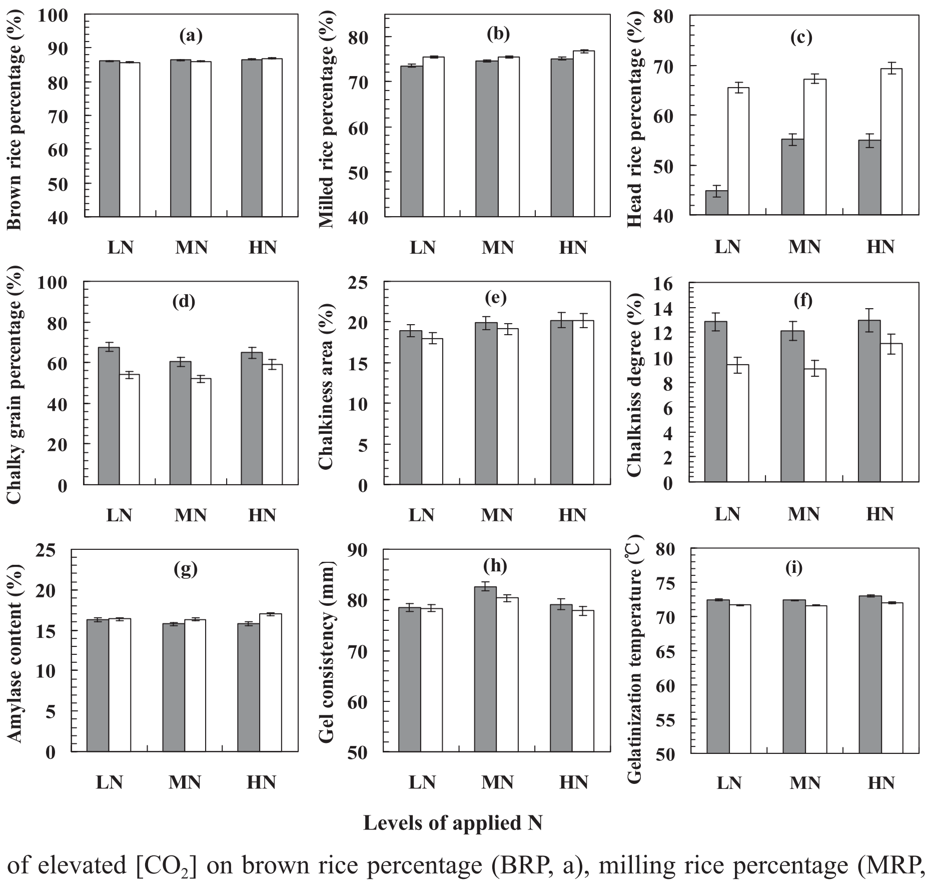

Fig. 7. Effect of elevated [CO_2] on brown rice percentage (BRP, a), milling rice percentage (MRP, b) and head rice percentage (HRP, c), chalky grain percentage (CGP, d), chalkiness area (CA, e), chalkiness degree (CD, f), amylose content (AC, g), gel consistency (GC, h) and gelatinization temperature (GT, i) of rice plants under three different levels of N application (15, 25, 35 g m^{-2}). Data are average values across three years with ± one stardard error (vertical bars).

(CGP), chalkiness area (CA), chalkiness degree (CD) of brown rice. CGP, CA and CD were consistently higher at the elevated relative to the ambient [CO_2] regardless of the N treatment (P <0.01), showing an average increase of 16.9, 3.1 and 28.3% across three years, respectively. By contrast to [CO_2], N had relatively minor effects on appearance quality properties.

The cooking/eating quality of rice is largely determined by three primary physical and chemical characteristics of the starch in the endosperm: amylose content (AC), gel consistency (GC) and gelatinization temperature (GT). When averaged over all N levels and years, FACE significantly decreased AC in milled rice by 3.8% (Fig. 7g). Although not statistically, the trend was for lower N application to decrease AC in milled rice. As for GC, it showed only a weak increase in FACE grains compared to ambient ones (Fig. 7h). Across [CO_2] levels, varying the supply of N significantly influenced GC with greatest GC occurring at MN rather than LN or HN. With respect to GT, FACE grains showed an average increase of 0.8°C (relative increases 1.2%) across three years (Fig. 7i), while no influence of N fertilization was observed.

Regardless of N application rate, FACE significantly reduced protein concentration (PC) in milled rice, while protein yield per square meter exhibited opposite trend (Figs 8a, b): averaged across two [CO_2] levels and three years, PC in milled rice was lower under FACE by 6.2%, while significant 6.0% increase was found for protein yield. Across [CO_2] levels, PC increased apparently with increasing N supply. Unlike PC, the yield of protein increased with increasing N supply, but luxury N application (35 g m^{-2}) resulted in significant reduction.

The ANOVA results consistently showed that the year effects were all significant for all the grain quality properties; however, for the most part, interactions between all treatments variables were not detected.

4. Discussion

4.1. Phenology

Concerning effects of FACE on phenology, there is only one report to date by Kobayashi et al. (2000), finding that the FACE grown plants exhibited ca 2 days earlier in heading compared with the ambient grown plants. Our trial indicated that FACE accelerates phenology significantly, with 3-5 days earlier in heading and 6-9 days earlier in grain maturity. In addition to the increased daytime canopy temperature and inside canopy air temperature due to FACE (Luo et al., 2002), we speculate that a significant decrease in N concentration and significant increases in concentrations of both P and soluble carbohydrate of plants contributed to the accelerated phenology.

4.2. Grain yield formation

As for the interactive effects of elevated [CO_2] and N supply on grain yield of rice, there is only one study to date conducted using Japanese Rice FACE facility (Kim et al., 2003a). In our present experiment, the low nitrogen (LN, 15 g N m^2) was actually higher or equal to the high nitrogen (HN, 12 or 15 g N m^2) in Japanese Rice FACE experiment (Kim et al., 2003a). We detected an average response of 13% to FACE in rice yields which is similar to the result by Kim et al. (2003a). However, unlike their results, we found no significant [CO_2]×N interaction with respect to grain yield, suggesting that the positive effects of

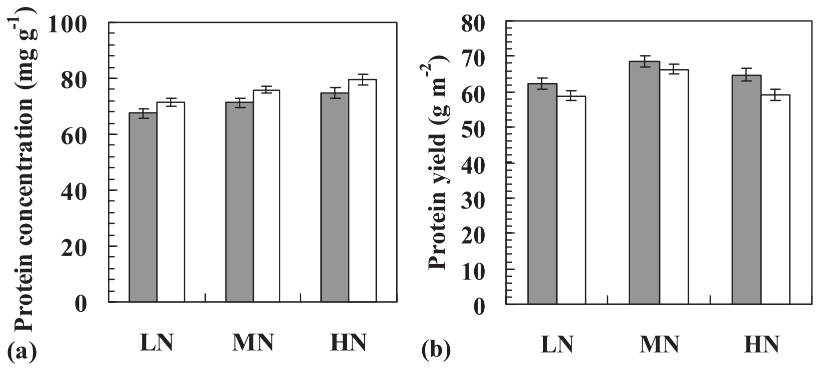

Fig. 8. Effect of elevated [CO_2] on protein concentration (a) and protein yield (b) in milled rice under three different levels of N application (15, 25, 35 g m^{-2}). Data are average values across three years with ± one standard error (vertical bars).

N availability on the responses of rice yield to elevated [CO_2] would reduce or even disappear under higher levels of fertilizer N (as in this trial). Regardless of CO_2 treatment, the absolute values of yield increased significantly with N supply from 15 to 25 g N m^2, but further increases in N supply to 35 g m^{-2} resulted in significant reduction, which were also different from the result by Kim et al. (2003a), suggesting that, as under ambient condition, the absolute grain yield under elevated [CO_2] will also approach a ceiling at a given N level.

The grain yield of rice is a function of panicle number per square meter, SNPP, filled grain percentage and grain mass. Our results indicated that the main reason for the increases in yield with FACE were due mainly to the increased panicle number per square meter (+19%), while SNPP showed significant reduction due to FACE.

Panicle number per square meter is determined by MTN per square meter and PTR. Our results indicated that greater panicle number per square meter was clearly due to the increases in maximum tiller number (+30%) with FACE being substantially more than the decreases in PTR (-8%). As the ratio of the number of panicle-bearing tillers to that of total tillers was lower with FACE across all N levels, so in this study we also found a small but significant 3% reduction in harvest index (HI, data not shown). Similar trends in MTN, PTR and HI with FACE have also been reported by Kim et al. (2003a, b). The variations of MTN and PTR are determined by the changes of tillering speed during different growth stages. Further analysis indicated that FACE-induced increase in MTN was related to significant increases in tillering occurrence speed at early growth stage (ca. from 10 to 30 DAT), while FACE-induced reduction in PTR was linked with increased tillering extinction speed at middle growth stage (ca. from 45 DAT to heading) (data not shown).

With respect to SNPP, some researchers reported significant increases due to elevated [CO_2] (Kim et al., 1996, 2003a), while others reported no change (Baker and Allen, 1993). In this study, FACE significantly reduced SNPP by 8%. The above results indicated that the responses of SNPP to elevated [CO_2] depended on the cultivars grown or experimental conditions. SNPP is represented by the difference in the number of differentiated and degenerated spikelets. Our results for the first time indicated the negative effect of CO_2-enrichmant on SNPP was not due to spikelet differentiation per panicle but mainly due to the enhancement of spikelet degeneration per panicle. Based on other parameter responses, we hypothesized that greater degenerated spikelets per panicle due to FACE may be mainly attributed to dissonance between carbon and nitrogen metabolisms during the phases of spikelet formation.

4.3. N uptake and utilization

The present study showed the final shoot N uptake at maturity was increased significantly by 9% due to FACE, and this is in contrast to those with rice from a OTC study (Ziska et al., 1996) and a FACE study (Kim et al., 2001, 2003b) which demonstrated that the total amount of N taken up was similar for both elevated and ambient [CO_2] crops by the end of the experiments. In addition to the difference in test cultivar and environmental conditions, one possibility for this contrast may be due to the different levels of N supplied. The N application rate in this trial was 15-35 g N m^{-2}, while it was 0-20 g N m^{-2} in the two experiments cited above (Ziska et al., 1996; Kim et al., 2001, 2003a). A result with cotton by Rogers et al. (1996) indicated that there was no CO_2 effects on N accumulation at low level to moderate level of N supply, while apparent [CO_2]-induced increases in N accumulation were observed at high level of N supply. Thus, there appears to be a fairly wide range in the effects of elevated [CO_2] on N yield depending on soil N availability.

The final shoot N acquisition of rice at maturity is related to dynamics of shoot N uptake during various growth periods. To date, there is no information on effects of elevated [CO_2] on seasonal changes in shoot N uptake of rice. Our study indicated that the response in shoot N uptake declined gradually with crop development before heading, while it showed a slight increasing trend again after heading, with average responses of 46, 38, 6, -2 and 16% during the Period 1, 2, 3, 4 and 5. With respect to shoot N uptake ratio, the average responses to FACE were 33, 26, -3, -11 and 10%, respectively, during the respective growth periods, similar to what occurred with shoot N uptake. Such seasonal responses in shoot N uptake (ratio) are mainly regulated by soil N availaility, plant N uptake ability and also related to plant phenology: Overall, because of plentiful N supply in the soil together with a greater relative N uptake capacity during early development, FACE plants showed the largest N uptake increase over the season as compared with ambient plants. As soil N availability and plant N uptake ability decreased during MGP, together with accelerated crop phenology, relative stimulation of N uptake by FACE either disappeared or even slightly reversed. Contrary to seasonal trend in N uptake response to elevated [CO_2] before heading, FACE crops showed again enhanced N uptake during LGP. Such a phenomenon could primarily be attributed to N fertilization in this trial (40% of the total N was applied at about 20 days before heading) which induced higher soil N availability again during LGP, though mean duration from heading to grain maturity shrank 2.4 days on average in FACE crops.

4.4. P uptake and utilization

The present study indicated that the total shoot P uptake over the whole season was increased substantially by 33% under FACE, which is similar to most of previous reports (Fangmeier et al., 1997; Barrett and Gifford, 1999). The final P accumulation of plant is related to dynamics of P uptake during various growth periods. Our results indicated that there were clear seasonal trends in shoot P uptake response: the relative stimulation due to FACE declined gradually with crop development, with average responses of 57, 51, 37, 26 and 11% during the Period 1, 2, 3, 4 and 5. With respect to shoot P uptake ratio, the average responses to FACE were 19, 14, 3, -5 and -16%, respectively, during the respective growth periods, similar to what occurred with shoot P uptake. Considering the seasonal changes in other parameters, we conclude that P uptake of rice before PI appeared to be mainly determined by P uptake ability (or P demand) as showed by stronger rice root system and relatively lower soil P availability under FACE condition, while shoot P uptake after PI seemed to be mainly regulated by soil P availability, which was reflected in the inability of rice root systems and increased soil extractable P in the FACE plots.

As for CO_2 response of P concentration in plants or leaves, a variety of observations have been made under different experimental conditions, most of which have shown negative response (Manderscheid et al., 1995) or zero response (Manderscheid et al., 1995; Seneweera and Conroy, 1997; Fangmeier et al., 1999), less of which have showed positive response (Rouhier and Read, 1998). In this experiment, because there was an increase in the amount of P taken up relative to the biomass across the season, the significant and sustained increase in P concentration was observed due to elevated [CO_2]. These inconsistencies showed the potentially complex nature of the CO_2 effect on P concentration, which could be attributed to complex interactions between the uptake of P and other elements at different availability and mobility under varied experimental conditions (include soil type, weather and species).

4.5. Root growth and development

Because of the greater inaccessibility of belowground system, only a fraction of rice studies have examined root responses to elevated [CO_2], of such limited studies, almost all of them just focused on root biomass (Baker *et al*., 1990; Ziska *et al*., 1996; Moya *et al*., 1998; Weerakoon *et al*., 1999; Kim *et al*., 2001, 2003 b). In this FACE trial, four root parameters on a per hill basis were examined at heading: RV, RDW, ARL and ARN. These parameters all showed prominent increases (25-33%) under FACE. The root accumulation at heading is related to root growth rate during different growth periods. Further study indicated that larger root standing crop at heading stage was mainly associated with significant increases in root growth rate during early growth period, while a slight inhibition of root growth rate (except ARN-growth rate) occurred during middle growth period.

The root physiological response is an important component of the root response to rising CO_2. For rice, there is no relevant information on root activity responses. Our data indicated that specific root activity of rice (i.e., TAA, AAA and amount of α-NA oxidation per unit RDW) all dropped sharply with FACE. We concluded that the CO_2-induced decreases in specific root activities were associated with a larger amount of root accumulation during early growth period and lower N concentration and higher C/N ratio in roots in FACE vs. ambient plants.

4.6. Grain quality

Milling quality of rice is one of the most important traits in rice as it is directly related to market value and thus influences income of both rice producers and processor. To date, however, little is known regarding the impact of elevated [CO_2] on processing quality of rice. One of the prominent phenomenons observed in this study was the significant decreases in milling traits (i.e., MRR and HRP), indicating a higher fraction of removed outer layer (i.e., pericarp and aleurone) and broken (or damaged) rice during milling (i.e., higher degree of milling). Because the milling conditions were identical for FACE and ambient plants, the grains in the FACE plots were supposed to be lower hardness or more easily ground than those in the ambient plots. The dramatic 24% reduction in MHP needs requisite attention in future research because most rice is consumed in the whole grain form.

Appearance is influenced by grain size and shape. The latter is mainly composed of CGP, CA and CD. Our results indicated that FACE significantly increased CGP (+16%) and CD (+28%). The higher extent of chalkiness implies that rice grains grown under higher [CO_2] condition have a lower density of starch granules and are therefore more prone to breakage during milling, as indicated by a close negative correlation in this study between CGP (r = -0.757**), CA (r = -0.393**), CD (r = -0.544**) and HRP when plotted for each combination of years, CO_2, N and blocks. Similar relationship between appearance and milling quality has also been reported in the literatures (Nakatat and Jackson, 1973). These are two possible reasons for the observed deleterious effects of elevated [CO_2] in chalkiness and milling quality. First, from the point of view of internal causes, such results appeared to be associated with the changes in grain-filling characteristics (include rate and duration of grain filling) due to FACE. As for grain-filling rate, our results indicated that the FACE plants showed a significant increase during the early grain-filling stage, whereas an adverse trend was displayed during the late grain-filling stage (data not shown). Additionally, our data of this study also demonstrated that, the FACE plants matured and senesced about 6 to 9 days earlier than the ambient plants. Because of the acceleration of senescence, there was a shortening of grain-filling duration, and consequently influencing final physical qualities of grains. Second, in term of external causes, it is well documented that temperature during grain-filling is one of the most important environmental factors that significantly affects the rice quality (Resurreccion et al., 1977). Using the same FACE platform, Ruo et al. (2002) reported FACE significantly increased daytime canopy temperature and inside canopy air temperature during the filling stage. We speculate that this temperature rise also contributed to the increased grain-filling rate at early ripening stage and the earlier maturity, which resulted in incomplete filling of the grain thereby leading to an increase in chalky appearance but a decrease in milling rate.

The cooking/eating quality is a very important aspect of the grain quality. AC is considered to be the most important trait closely related to the eating/cooking quality of rice. In general, higher contents of amylose relative to amylopectin increase the hardness of the cooked grain (Mohapatra and Bal, 2006). In this study, AC in starch was significantly reduced by FACE, suggesting that [CO_2] enrichment is likely to reduce the hardness of the cooked grain. Our observation is in contrast to the results of Seneweera et al. (1996) and Terao et al. (2005). From a growth chamber experiment with rice, Seneweera et al. (1996) reported significant increase in AC with elevated [CO_2], while in Japanese rice FACE experiment no change in AC was detected (Terao et al., 2005). The explanation for this inconsistency probably resides in varietal differences.

Rice is a major source of dietary protein for most of the Asian rice-growing countries. Our results indicated that, although the FACE treatment caused decreases (-6%) in grain PC, the significant increase in grain yield due to FACE resulted in greater harvests of protein (+6%). This result is basically in agreement with previous results reported in the literature (Seneweera et al., 1996, 1997; Terao et al., 2005). The observed decrease in PC under FACE directly reduced the nutritional value of rice, but at the same time, increased the palatability of cooked rice: generally, low PC in the grains is closely associated with the improvement of taste properties (Ishima et al., 1974; Matsue et al., 1997). Our measurements of viscosity properties indicated that, corresponding to the change in AC, FACE grown plants showed a significant increase in peak viscosity (+5%) and breakdown (+3%), but a 28% significant decrease was recorded in setback (data not shown), all these effects on the three RVA pasting properties being considered to be a favorable changes for enhancing the sensory acceptability of cooked rice (Allahgholipour et al., 2006). Based on PC response to FACE, together with responses of AC and three RVA pasting properties (i.e. PV, MV and BD) mentioned above which are also involved in the sensory acceptability of cooked rice, we could therefore assume that the palatability should be improved in rice grown under elevated [CO_2]. Such a hypothesis needs to be confirmed by sensory evaluation.

4.7. Implications

The results of this study have important implications for formulating adaptation strategies of rice to achieve maximum productivity while maintaining desirable quality characteristics in a future high CO_2 word, at least for the similar conditions of this experiment. First, the current recommended rates of N fertilization (ca. 25 g N m^2 in China) for rice production systems should not be modified as the [CO_2] rises. Excessive N supply would not only reduce the rice yield and quality (Matsue *et al*., 1997), but also induce bad environmental pollution (Ling et al., 1994). Secondly, it is likely that the rice cultivation technologies may need to be focused on regulations during the middle and late growth stages (e.g. increase N fertilizer proportion after PI, enhance irrigation management during MGS and use relevant plant growth regulator) in order to (1) enhance root growth and activities during middle growth stage, (2) facilitate nutrient (i.e., N, P) uptake after PI, and (3) increase the PTR and HI, but reduce the number of degenerated spikelets per panicle. However, additional experiments with different cultivars would be needed to develop N fertilizer strategies for high-yield cultivation under future elevated [CO_2] conditions.

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Cultural Practices to Reduce Cd Content in Edible Parts of Staple Crops in Korea

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Abstract

Objectives of this study were to determine the uptake and translocation of Cd in rice plant from soil with applying the water management and soil ameliorators and to investigate the correlations among heavy metal contents in the brown rice, soil pH and chemical species of Cd existing in soil by sequential extracting method with paddy soil contaminated with Cd near abandoned mine.

To identify the effect of soil ameliorators on Cd uptake in rice plants, compost and lime were treated. Plants were grown with irrigation water concentrated by 0.01 mg kg^{-1} of cadmium in two soil types (sandy loam and clay loam) with treatments of intermittent irrigation and continuous submersion conditions. Compared to intermittent irrigation plots, average Eh value in the continuous submersion plots was low at 136.7 mV whereas pH value was high at 0.3. Eh value was decreased in the treatment of soil ameliorator while pH value was increased by 0.2~0.3. Cd content of leaves and brown rice had significantly positive correlation with Eh value in soils while was negatively correlated with soil pH. At the harvest stage, Cd content in the leaves and brown rice was decreased in the continuous submersion plots by 30% relative to the intermittent irrigation plots. In case of soil ameliorator applied plots, Cd content of leaves and brown rice was lower by 35% than that of N, P, K fertilizer plots, respectively. Compared to the soil types, Cd content of leaves and brown rice in sandy loam soil was lower by 64 and 37% than that in clay loam soil, respectively. Order of reduction to Cd uptake was the compost and lime mixture plot>silicate plot>lime plot. However, the effect of Cd uptake reduction by soil ameliorator was decreased in the N, P, K+compost and N, P, K+phosphate plots. Cd uptake reduction by water management and soil ameliorator was more effective in the sandy loam soil than that in the clay loam soil.

1. Introduction

Increase of contaminants in agricultural ecosystem has become a social issue worldwide as it related with public health. International agencies, such as the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), are currently advocating compliance to permission criteria of pollutants in agricultural products. In Korea, heavy metal contamination in agricultural fields may have been caused by wastewater, dust and sewage sludge originating from industries, mines, smelters and metal processing industries (Jung *et al*., 2002; Lee *et al*., 2001; Oh, 1997). Generally, heavy metals accumulated slowly but continuously in paddy fields may damage crops by Cu, Pb, Zn and As directly and livestock and humans by Cd and Hg indirectly through food chain (Soil-Plant Barrier). One causes more serious toxicity than the other (Adriano, 1992; Fergusson, 1990; Kitagishi and Yamane, 1981). Several soil factors, such as soil pH, Eh, clay contents, Mn oxide and oxidized Fe, organic matter as well as cation exchange capacity, were involved with distribution of cadmium and their availability to plant in soils (de Matos *et al*., 2000; Martinez and Motto, 2000; Mench *et al*., 1997; Sterckeman *et al*., 2000).

On the other hand, it was reported that translocation of Cd in the plant from rice paddy could be controlled by applying water management and soil ameliorators such as organic matter, lime, phosphorous and silicate fertilizer (Kim, 1987; McBride, 1995; Charlatchka and Cambier, 1997; Reddy and Patrick, 1971). Therefore, it was considered to be necessary to apply the water management and soil ameliorators for controlling the uptake and translocation of Cd in the plant from rice paddy in Korea. Objectives of this study were to study on uptake and translocation of Cd in rice plant from soil with applying the water management and soil ameliorators.

2. Materials and Methods

Studies on reduction of cadmium uptake in paddy rice by the irrigation of cadmium-enriched water (Pot experiment)

Two-year pot experiment was done to investigate the effect of Cd uptake on the various agricultural managements. The variety used in the experiment was Ill-Pumbyeo, and the selected soils were sandy loam and clay loam soils that are originally representative soils at rice paddy in Korea. The rice was transplanted with three plants at each Wagner pot (1/2,000a), and amount of irrigated water with an intermittent irrigation and continuous submersion conditions were 100 ℓ and 120 ℓ per pot, respectively, during the whole cultivation period. Cadmium concentration of irrigation water was adjusted at 0.01 mg L^{-1} with cadmium chloride ($CdCl_2{\cdot}H_2O$) as agricultural water standard (Ministry of Environment. 1999). For the soil ameliorators, increment of phosphorous was applied with 50 kg ha^{-1} of magnesium phosphate, 10 ton ha^{-1} of compost, lime with adjusted amount of pH 6.5, and silicate with 2 ton ha^{-1} of silicate fertilizer based on application of urea, magnesium phosphate and potassium chloride (110-70-80 kg ha^{-1}). The experimental design was split-split plot that consisted of main plot as management of irrigation water and sub-plot as soil ameliorators. Management of irrigation water consisted of an intermittent irrigation and continuous submersion conditions. Soil ameliorators were 7 plots applied with phosphorous, compost, lime, silicate, compost+lime, compost+silicate, compost+lime+silicate as relatives to the control (N.P.K). Cation exchange capacities and clay contents of sandy loam and clay loam soils were 9.1 and 20 $cmol^{+}$ kg^{-1}, and 104 and 345 g kg^{-1}, respectively (Table 1).

Soluble and total contents of Cd extracted with 0.1N-HCl in sandy loam and clay loam soils were 0.083 and 0.090 mg kg^{-1}, and 0.43, 0.57 mg kg^{-1}, respectively. It was observed that soluble Cd contents were lower than the average, and total contents of Cd were higher at five fold than the soluble Cd content of rice paddy in Korea.

pH and Eh of soil were measured with different growing stage, and Cd contents of stem and leaf, brown rice and soil after harvesting were analyzed. The relationship between the change of Eh and soil pH was affected by irrigation methods and soil ameliorators and the partial Cd content in rice plant were analyzed.

Soil chemical analysis

Soil samples were prepared and analyzed by Korean Soil Standard Method (NIAST, 2000) and by Ministry of Environment (2001). Soils were air-dried and crushed to pass through a 20-mesh sieve. Soil pH was measured in distilled water at 1:5 ratio of soil to water. The fraction of organic carbon was determined by the wet oxidation method (Tyurin). Available phosphate was calibrated by Lancaster method. Cation-exchange capacities were measured by 1N-ammonium acetate (pH 7.0) solution extraction. An experiment of available heavy metals in soil was conducted that 10 g of soil in 100 ml triangular-flask was shaken steadily in 0.1N-HCl 50 ml at 30°C for 1 hour and filtered by No. 5B filter paper (Ministry of Environment, 1999). Cadmium content in brown rice was assayed by dry-acid digestion, and cadmium content in stem and leaf was decomposed in ternary solution (HNO_3 : $HClO_4$: H_2SO_4= 10:4:1) using a hot plate (NIAST, 2000; Kim and Lee, 1995).

Table 1. Physico-chemical properties of the soils used

Soil texture	pH (1:5)	OM (g kg^{-1})	$Av.P_2O_5$	$Av.SiO_2$	CEC ($Cmol^{+}$ kg^{-1})	Clay (g kg^{-1})	Cd*	T-Cd
			---(mg kg^{-1})---				--(mg kg^{-1})--	
SL	5.0	9	110	103	9.1	104	0.083	0.43
CL	5.2	19	24	240	20.4	345	0.090	0.57

* Extracted with 0.1N-HCl solution

3. Results and Discussion

Changes of Eh and pH values in sandy loam soil at the different sampling date with different water management and amelioration were described in table 2. The value of soil pH was highest at 60 days after rice transplanting in all treatments over rice cultivation period. It was observed that the average of Eh at the continuous submersion plot was low at 136.7 mV, but soil pH was high at 0.3 as compared to the intermittent irrigation. Therefore, the more reduction process and the higher soil pH by a continuous submersion were observed.

The values of Eh were not significantly different among the treatments of soil ameliorators, but generally low relative to the control. The values of soil pH were hardly different between the increment of phosphorous and the control. However, those were increased at 0.2-0.3 of soil pH by applying the lime, compost and silicate. Also, it was observed that the value of Eh was decreased and pH was increased with applying the combinations of compost with lime and compost with silicate.

Cadmium concentrations of stem with leaf, and root at 45 days after transplanting in sandy loam soil with different water management and amelioration were demonstrated in table 3. It was observed that cadmium concentrations of stem and leaf with continuous submersion were lower than that of the intermittent irrigation. The average concentrations of Cd in the stem with leaf and roots were 0.658 mg kg^{-1} and 2.51 mg kg^{-1} for the continuous submersion and 0.680 mg kg^{-1} and 2.81 mg kg^{-1} for the intermittent irrigation, respectively. On the other hand, those were significantly decreased with applying the soil amelioration. For the application of soil amelioration, the decreasing rates of Cd in stem with leaf and roots were 29.8% and 25.6% for the continuous submersion and 31.2% and 18.1% for the intermittent irrigation.

The decreasing efficiencies of Cd uptake were appeared in the stem with leaf among the soil ameliorators, but greatly observed in root with applying the compost and silicate. Therefore, it was demonstrated that the Cd uptake of rice with decreasing the solubility of Cd in soil by increasing pH and stimulating the reduction with applying the lime, compost and sili-

Table 2. Changes in soil Eh and pH values at the different sampling date with different water management and amelioration

Treatment		Days after transplanting							
Irrigation methods	Amelioration	44	60	74	93	44	60	74	93
		Eh (mV)				pH			
Intermittent irrigation	Control (NPK)	243	270	178	107	5.8	7.0	6.2	6.3
	NPK+Phosphate	252	239	170	74	5.9	6.9	6.2	6.3
	NPK+Lime (L.)	189	95	92	22	6.5	7.3	6.4	6.4
	NPK+Compost (C.)	240	230	111	76	6.0	7.2	6.5	6.5
	NPK+Silicate (S.)	223	206	98	46	6.4	7.1	6.5	6.5
	NPK+C.+L.	160	79	62	76	6.8	7.0	6.7	6.9
	NPK+C.+S.	187	231	60	64	6.5	7.0	6.7	7.0
Continuous submersion	Control (NPK)	154	28	53	9	6.4	7.4	6.5	6.5
	NPK+Phosphate	125	-39	12	-11	6.5	7.4	6.5	6.7
	NPK+Lime (L.)	97	-55	11	-31	6.7	7.9	6.5	6.8
	NPK+Compost (C.)	94	-43	17	-41	6.5	7.6	6.7	6.8
	NPK+Silicate (S.)	97	-48	6	-65	7.0	7.8	6.6	6.8
	NPK+C.+L.	90	-48	-36	-61	6.8	7.6	6.9	7.2
	NPK+C.+S.	90	-65	-11	-76	6.6	7.7	6.9	7.1

Table 3. Cadmium content in stem with leaf and root at 45 days after transplanting with different water management and amelioration (Unit : mg kg^{-1})

Treatments	Stem & leaf		Root	
	Intermittent irrigation	Continuous submersion	Intermittent irrigation	Continuous submersion
Control (NPK)	0.928 a[1)]	0.884 a	3.33 a	3.23 a
NPK+Phosphate	0.625 b	0.629 c	3.13 ab	3.03 ab
NPK+Lime	0.613 b	0.595 c	2.73 c	2.52 c
NPK+Compost	0.656 b	0.572 c	2.22 d	2.12 d
NPK+Silicate	0.663 b	0.605 c	2.32 d	1.92 d
NPK+Compost+Lime	0.568 b	0.621 c	2.73 c	2.63 c
NPK+Compost+Silicate	0.707 b	0.703 b	3.24 a	2.12 d

[1)] Column values followed by the same letter are not significantly different. (DMRT, 0.05 Significant level).

Table 4. Cadmium content in the stem with leaf and brown rice in sandy loam soil with different water management and amelioration at the harvest stage (Unit : mg kg^{-1})

Treatment		1st year		2nd year	
Irrigation methods	Amelioration	Stem & leaf	Brown rice	Stem & leaf	Brown rice
Intermittent irrigation	Control (NPK)	2.07 a[1)]	0.198 a	2.29 a	0.241 a
	NPK+Phosphate	1.90 a	0.185 b	1.76 b	0.149 c
	NPK+Lime (L.)	1.32 c	0.091 e	1.37 c	0.134 cd
	NPK+Compost (C.)	1.68 b	0.191 ab	1.65 b	0.177 b
	NPK+Silicate (S.)	1.30 c	0.115 d	0.91 d	0.100 d
	NPK+C.+L.	0.89 d	0.069 f	0.60 e	0.082 e
	NPK+C.+S.	1.30 c	0.127 c	0.84 de	0.105 d
Continuous submersion	Control (NPK)	1.36 a	0.125 a	1.40 a	0.141 a
	NPK+Phosphate	1.04 b	0.095 c	1.21 b	0.112 b
	NPK+Lime (L.)	0.82 c	0.076 d	0.82 c	0.079 c
	NPK+Compost (C.)	0.95 bc	0.105 b	1.26 ab	0.125 ab
	NPK+Silicate (S.)	0.81 c	0.074 d	0.80 c	0.082 c
	NPK+C.+L.	0.69 d	0.066 d	0.51 d	0.072 c
	NPK+C.+S.	0.92 bc	0.071 d	0.63 cd	0.077 c

[1)] Column values followed by the same letter are not significantly different (DMRT, 0.05 Significant level).

cate under the continuous submersion was decreased.

It was reported that uptake and translocation of heavy metals in plant, and their adsorption in soil were affected by change of Eh in rice paddy (Kitagishi & Yamane, 1981; Charlatchka & Cambier, 1997). Also, Choi *et al*. (1991) and de Matos *et al*. (2000) described that an exchangeable Cd concentration was decreased by applying the soil amelioration as lime and reductant under the continuous submersion in the contaminated soil.

Over the review of comprehensive results to the experiment, decreasing rates of Cd uptake were 29.6% in the stem with leaf and 30.5% in the brown rice at a continuous submersion as compared to the intermittent irrigation (Table 4). For relatives to the control, those were 48.1% and 37.7% in the stem with leaf and 48.3% and 35.3% in the brown rice at the intermittent irrigation and a continuous submersion, respectively. Order of decreasing rate of Cd uptake was the combination of compost and lime>silicate or lime>the increment of phosphorous and only compost.

As a result, the concentration of Cd in a plant at the intermittent irrigation was lower than that of the continuous submersion in respect of irrigation methods with applying the soil amelioration. This result was agreement with Pb uptake (Kim *et al*., 1986), but opposite to Cu and As uptake (Kim *et al*., 1985; Lee and Lim, 1987) in the plant.

Correlation coefficients among soil Eh, pH and cadmium concentration of stem with leaf and brown rice in sandy loam soil during the cultivation period were presented in table 5. It was shown that concentrations of Cd in stem with leaf and brown rice had significantly a positive correlation with soil Eh, but a negative correlation with soil pH. Degree of correlation was highest at 74 days after transplanting for Eh and 44 days after transplanting for pH. However, degree of correlation among soil Eh, pH and cadmium concentration of brown rice was generally highest at 74 days, but lowest at 60 days after transplanting.

Soil pH was increased with applying the soil amelioration relative to the control (Table 6). Especially, it was more affected by the application of lime and silicate than the phosphorous and compost. However, there were not differences between a continuous submersion and the intermittent irrigation.

The decreasing rate of Cd uptake in sandy loam soil was 63.9% in the stem with leaf and 36.9% in the brown rice as compared to clay loam soil, but 31.7% in the stem with leaf and 31.2% in the brown rice at continuous submersion relatives to the intermittent irrigation (Fig. 1). As compared to the control, order of decreasing rate of Cd uptake with applying soil ameliorators was the combination of compost and lime>lime>the only compost. Overall, it was observed that the decreasing efficiency of Cd uptake in rice was great at sandy loam for soil textures, a

Table 5. Correlation coefficients among soil Eh, pH and cadmium content in stem with leaf and brown rice (n=28) at different sampling date

	Days after transplanting			
	44	60	74	93
	Stem & leaf			
Eh	0.652**	0.751**	0.773**	0.664**
pH	-0.846**	-0.585**	-0.814**	-0.694**
	Brown rice			
Eh	0.536**	0.728**	0.739**	0.630**
pH	-0.814**	-0.541**	-0.762**	-0.716**

** Significant at 1%.

Table 6. pH value and cadmium content (0.1N-HCl extractable) in soil after harvest with different water management and amelioration

Treatments	pH (1:5)		0.1N-HCl extractable Cd (mg kg^{-1})	
	Intermittent irrigation	Continuous submersion	Intermittent irrigation	Continuous submersion
Control (NPK)	5.3	5.0	0.312	0.304
NPK+Phosphate	5.4	5.3	0.324	0.312
NPK+Lime	6.5	6.4	0.252	0.228
NPK+Compost	6.0	5.8	0.235	0.224
NPK+Silicate	6.9	6.9	0.246	0.222
NPK+Compost+Lime	7.3	7.2	0.250	0.230
NPK+Compost+Silicate	7.3	7.2	0.238	0.228

continuous submersion for irrigation methods and the combination of compost and lime for soil ameliorators. It was reported that it was great at a continuous submersion for the decreasing efficiency of Cd uptake in rice (Choi *et al*., 1991; Naidu *et al*., 1997). Therefore, it might be considered that soil addition was important to restore the contamination site with heavy metals.

Concentration of Cd had a positive correlation with Eh, but the negative correlation with pH in both sandy loam and clay loam soils (Table 7). Degree of correlation was highest at 74 days after transplanting in both soils. Overall, it was considered that soil textures, irrigation methods, organic matter content and soil pH is very important to uptake and translocation of Cd. Therefore, the uptake of Cd could be decreased in case of considering the above factors for rice cultivation in the contaminated field with Cd.

Fig. 1. Cadmium content in the stem with leaf and brown rice grown in paddy soils treated with different soil textures, water management and amelioration (adopted from Jung, 2001).

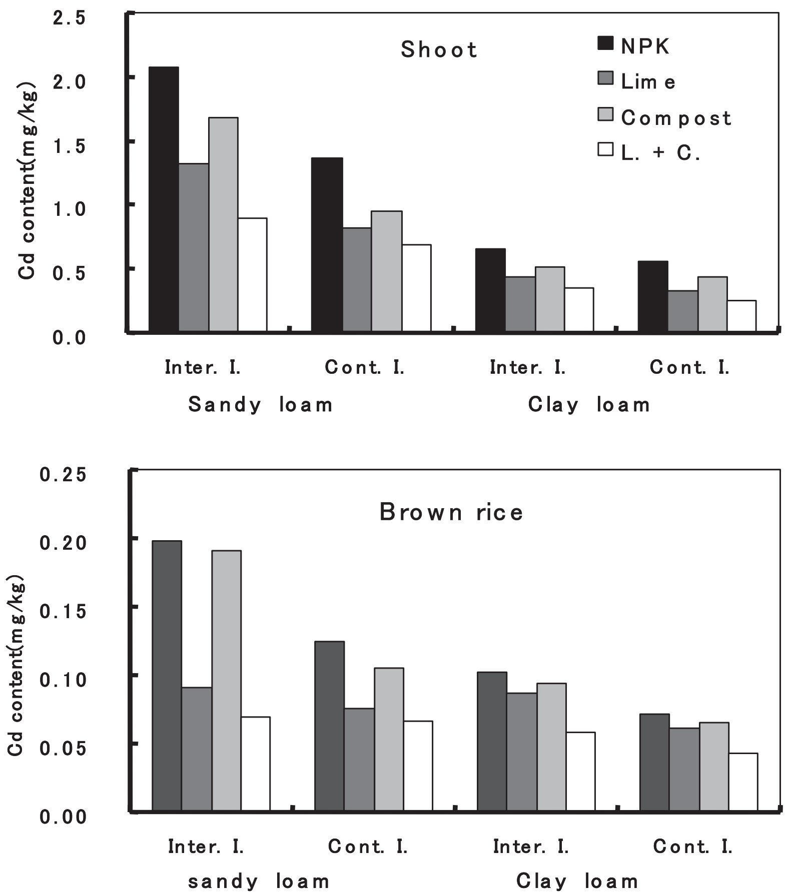

Table 7. Correlation coefficients between soil Eh, pH at different sampling date and cadmium content in stem and leaf, brown rice (n=8) at the harvest stage

Soil Textures		Days after transplanting			
		74	93	74	93
		Stem & leaf		Brown rice	
Sandy loam	Eh	0.936^{**}	0.853^{**}	0.914^{**}	0.784^{*}
	pH	-0.723^{*}	-0.679^{NS}	-0.816^{*}	-0.624^{NS}
Clay loam	Eh	0.806^{*}	0.522^{NS}	0.907^{**}	0.735^{*}
	pH	-0.933^{**}	-0.812^{*}	-0.871^{**}	-0.752^{*}

*, ** Significant at 5%, 1%. NS : not significant.

4. Conclusion

The community problem, which is related with safety of crop production and crop injury by contamination of heavy metals from an industrial complex and metal mine, occurs. Recently, it is described that threshold and intervention values of soils are 1.5, 4.0 mg kg^{-1} for Cd on Soil Environmental Conservation Act in Korea (1996). The threshold levels of soil contamination are criteria to require the regulation of land use and facility installation because the soil contamination causes the serious damage of plant, animal and human health. Its intervention levels are the criteria to prevent the soil contamination with concentration at more 40% of soil contamination concentration than its threshold levels. In Korea, for polluted soils over the threshold values of heavy metals, the fine red soil dressing, land reconsolidation, and soil amelioration such as lime, phosphate, organic matter, and submerging are recommended. For the corrective action area, cultivation of non-edible crops such as garden trees, flowers, and fiber crops, land reformation and fine red soil dressing (up to 30 cm) were strongly recommended. Also, the level of cadmium concentration in the brown rice was restricted at 0.2 mg kg^{-1}. Therefore, agricultural management as the irrigation methods and application of soil ameliorators is interesting subject in order to decrease the Cd uptake in rice as main cereal crop in Korea.

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Pedological Characteristics and Heavy Metals Contamination of the Paddy Soils in Taiwan

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Abstract

Extensive rice production on numerous alluviums and terraces in Taiwan has been done by the complete irrigation systems since the early and mid stages of the 20th century. Irrigation water and the fluctuation of groundwater play important roles in controlling the soil hydrology and redoximorphology. Redoximorphic features are consequently formed by the alternative wet and dry cycles, such as Fe soft masses, Fe and clay depletions and Fe-Mn nodules through the profiles of paddy soils. The saturated and reducing durations were specified associated with the definite redoximorphic features in the soils under a landscape unit. In the case studies of rice-growing Ultisols on red earth terrace in northwestern Taiwan, the optimum durations of saturation and reduction were about 50% of the year in the formation of redoximorphic features. This anthraquic condition could promote the formation of diverse redoximorphic features associated with plinthites. In the paddy soils of Taiwan, Entisols, Inceptisols, Alfisols, Ultisols, Mollisols and Oxisols are main Soil Orders based on *Soil Taxonomy*. On one hand considering by soil quality and food security of rice, heavy metal contamination is the main issue in rice production of Taiwan. On the other hand by rice market liberalization, changing the land use from paddy soils into non-waterlogged cropping has some problems in initial soil properties such as poor drainage and impeded root growth by the subsurface compacted layers for upland crops. Irrigation water for rice production in Taiwan has been contaminated by illegal discharges of industrial and livestock wastewater affecting the paddy soil qualities by heavy metals. According to the regulation for pollutants in Soil and Groundwater Pollution Remediation Act of Taiwan, the total seriously contaminated area by heavy metals is more than 300 ha, especially by Cd, Cr, Cu, Ni and Pb contamination of rice in Taiwan. Due to the special profile morphology and hydrology of paddy soils, dilution by deep plowing and mixing, acid washing, chemical stabilization, and phytoremediation are major remediation technologies applied on the contaminated sites with pilot or field scales. However, the recovery of soil fertilities and ecological functions is needed to be evaluated after remediation.

1. Introduction

1.1. Soil Survey of Paddy Soils in Taiwan

Detailed soil surveys of rural soils in the western, northern and eastern plains of Taiwan were conducted by National Chung-Hsing University and Taiwan Agricultural Research Institute, from 1962 to 1973, and from 1974 to 1976, respectively. Total 178 field sheets of the soil survey on a scale of 1:25,000 have been published. From 1979 to 1987, the detailed soil surveys of the slope lands with elevation lower than 1,000 m above sea level were also conducted by the former Taiwan Provincial Mountain Agriculture and Pasture Development Bureau which has been reformed as Taiwan Soil and Water Conservation Bureau, Council of Agriculture, Taiwan. However, 215 field sheets of the soil maps were consequently published on a scale of 1:25,000. The mapping units were soil types in the rural regions and soil phases in the slope regions. Additionally, 106 map units were republished on the same scale in 1988. Paddy fields occupied approximately 50% (450,000 ha) of the agricultural lands in Taiwan in last decade, and the history of planting lowland rice ranged from 50 to 350 years, particularly on the numerous alluviums and terraces followed by the complete irrigation systems since the early and mid stages of the 20th century. Because of the worldwide liberalization of rice marketing, the government of Taiwan therefore changed the policy of land use in decreasing the production of rice and into increasing upland crop production in original paddy fields.

There are nearly 1,000 soil series in Taiwan. According to the land use and different parent materials, these soils were classified as 34 major soil groups based on the classification system of Taiwan, and 106 soil units in the soil map of Taiwan on a scale of 1:250,000 (Sheh and Wang, 1989). The properties of paddy soils in Taiwan can be approximately divided into five alluvial soil groups: (1) slate alluvial soils, (2) sandstone and shale alluvial soils, (3) schist alluvial soils, (4) slate, sandstone and shale mixed alluvial soils, and (5) Quaternary aged alluvial soils. However, most of them are on the western part of Taiwan and on the alluvial fans of some main rivers.

1.2. Soil Hydrology of the Paddy Soils

Seasonal flooding and drainage cycles control the durations of saturation and reduction of paddy soils. Saturation and reduction are the common characteristics of paddy soils in Taiwan, and various redoximorphic features occur with anthraquic or oxyaquic conditions (Hseu and Chen, 1995, 1996, 1999, and 2001; Jien et al., 2004). The concept of aquic conditions was introduced in the *Keys to Soil Taxonomy* to assess seasonal wetness throughout the soil profile rather than just using indicators within the upper 50 cm of the pedon for moisture category (Soil Survey Staff, 2006). Alternating cycles of reduction and oxidation in soils over prolonged periods, and the consequent mobility and accumulation or depletion of Fe and Mn, result in the formation of redoximorphic features (Fanning and Fanning, 1989; Vepraskas, 1992). Past studies have tested the application of redoximorphic features as saturation indicators in various pedogenic environments of paddy soils (Hseu and Chen, 1995, 1996, 1999, and 2001; Jien et al., 2004).

1.3. The Objectives of the Present Review

In this article, we will review the general morphology, pedological characteristics and processes, classification, contamination, and remediation of rice production of paddy soils in Taiwan, particularly in the contribution of soil hydrology on the formation of redoximorphic features in Quaternary red earth and in the remediation strategies of heavy metal contamination.

2. Pedological Characteristics of Paddy Soils in Taiwan

2.1. Field morphology

Paddy soils of Taiwan were used in planting lowland rice on the western and eastern alluvial plains and on Quaternary terraces with different histories of paddification, parent materials and topography. Therefore, the above biotic and abiotic factors significantly affect the morphology and soil properties of the paddy soils. The soil series were diversely developed based on the source of parent material, the texture sequence in the profile, the degree of drainage and calcareousness. The main diagnostic epipedons of paddy soils in Taiwan are ochric, umbric and mollic epipedons. Additionally, the diagnostic subsurface horizons are predominantly cambic horizons (Bw or Bg) on the alluvial plains, argillic horizons (Bt, Btg or Btv) on the Quaternary terraces or aged alluvial plains. However, no clearly diagnostic B horizons of the paddy soils have been found in the young alluvial plains. Based on the processes of paddification and on the degrees of drainage, the main morphological characteristics of the epipedons or subsurface horizons in the paddy soils are divided into five sequence groups of profile: Ap-R, Ap-Bg-2Bg-2Cg, Ap-Bw (Bg)-C, Ap-Btv (Btg)-Bt-C, and Ap-Bo-C, respectively. The representative morphology of these groups is listed in Table 1. These morphological attributes are characterized by solum depth, color, texture and structure of plowed layer (Ap). The Ap horizons in the five groups were further characterized by (1) hues of 2.5Y or 5Y and chroma of 2 or less, (2) massive structures, and (3) depth of 15 cm or deeper. The following approach was produced by the pedogenic processes of paddy soils of Taiwan which were mainly affected by irrigation water, groundwater table and dissolved oxygen concentration in water. They are gleyzation of surface soil, formation of compact subsurface layer (plow pan), accumulation of organic matter on the surface soil, formation of redoximorphic features such as Fe/Mn nodules and clay/Fe depletions, chloritization of clay minerals in the surface soils by submergence, redistribution of base cations by irrigation water (Chen, 1984 and 1992).

Table 1. Soil morphological characteristics of five typical groups of paddy soils in Taiwan based on the most frequently occurring attributes (Chen, 1992)

Horizon	Depth (cm)	Color (moist)	Texture*	Structure**	Mottle
Ap-R (6 soil pedons)					
Ap	0-14	5Y 4/1	L	massive	2.5Y 3/1
R					
Ap-Bg-2Bg-2C (41 soil pedons)					
Ap	0-21	5Y 4/1	L	massive	2.5Y 4/6
Bg	21-53	2.5Y 4/1	SiL	massive	10Y 6/6
B	53-116	2.5Y 5/4	SiL	massive	5Y 4/3
C	>116				
Ap-Bg (Bw)-C					
Ap	0-20	2.5Y 5/2	SiL	massive, 2 sbk	10YR 5/3
Bg1	20-57	2.5Y 5/1	SiL	3 sbk	10YR 7/2
Bg2	57-74	2.5Y 5/3	SiL	2 sbk, massive	10YR 6/4
Bw	74-137	2.5 Y 6/2	SiL	massive	5Y 5/1
C	>137				
Ap-Btg-Bt-C					
Ap	0-28	10YR 5/2	SiCL	massive, 2 sbk	10YR 4/6
Btg/v	40-68	7.5YR 5/2	SiCL	3 sbk	7.5YR 6/6
Bt	68-130	10YR 4/8	SiC	2 sbk	10YR 6/6
C	>130				
Ap-Bo-C					
Ap	0-26	10YR 4/3	SiC	3 sbk	5YR 6/6
Bo	26-148	7.5YR 5/8	SiC	1 sbk	5YR 5/8
C	>148				

*: L=loam, SiC=Silt loam, SiCL=silty clay loam, SiC=silty clay.
**: 3=strong, 2=moderate, 1=weak; sbk=subangular blocky.

2.2. Case Studies in Redoximorphic features implication on Soil Hydrology

Hseu and Chen (2001) have selected three paddy soils from Quaternary terrace along a toposequence of the Chungli Terrace in northern Taiwan for monitoring of water table, matric potential, and redox potential (Eh) at various soil depths in 1996 and 1997. The three soils are Houhu (Typic Plinthaquult) in the toeslope, Hsinwu (Typic Plinthaquult) in the footslope, and Lungchung (Plinthaquic Paleudult) in the lower backslope. Redox concentrations originally occurred as soft masses and concrete nodules associated with seasonally high water levels, but irrigation and drainage processes also influenced the development of redoximorphic features. The studied Fe-Mn concretions and Fe depletions increased with increasing the cycling of oxidation and reduction in rice production (Fig. 1). The durations of saturation and reduction in the Btv horizons (argillic horizons with plinthites) of the Houhu soil in the toeslope position were more than 80% of the year and the soil had about 10% of Fe-Mn concretions. The Btv horizons of the Hsinwu soil in the footslope position were saturated for 50% of the year and reduced for 25% of the year, and the soil had about 20% of Fe-Mn concretions. The Btv horizons of the Lungchung soil in the lower backslope position were saturated for 40% of the year and reduced for only about 10% of the year, and the soil had 15% of Fe-Mn concretions. The Houhu and Hsinwu soils were belonging to the anthraquic condition and the Lungchung soil with less reduction was proposed as having oxyaquic conditions as defined in U.S. soil taxonomy. However, the optimum durations of saturation and reduction were about 50% of the year in the formation of redoximorphic features within the landscape unit, and thus indicating that semi-quantative soil hydrology can be estimated by the above redoximorphic features for the paddy soils.

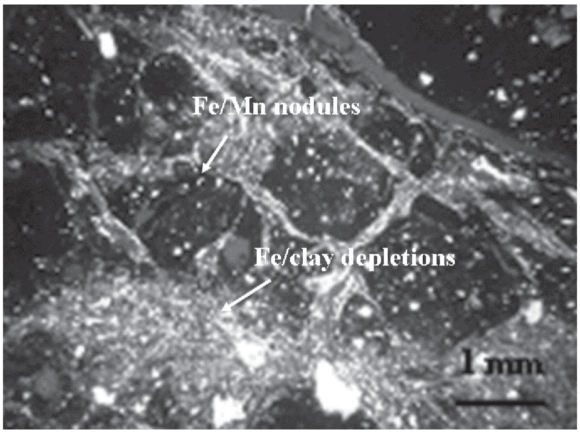

Fig. 1. Photomicrographs of redoximorphic features in the Btv horizons from a paddy soil pedon (Plinthaquults) on Chungli terrace in northwestern Taiwan by plane polarized light, such Fe/Mn nodules and Fe/clay depletions.

Jien et al. (2004) further attempted to establish the relationships between soil morphology-based soil chroma index and soil wetness conditions in the paddy fields, including annual duration of both saturation and reduction along hydrosequences around the Chungli Quaternary terraces in northern Taiwan (Fig. 2). They selected three transects of a toposequence ranging from 20 to 40 m above the sea level. Four soils (Plinthaqualfs and Plinthaquults) were located in the toeslope position (20 m), four soils (Plinthudults and Paleudalfs) in the footslope position (30 m), and three soils (Paleudults and Paleudalfs) in the backslope position (40 m) with different redoximorphic features under a landscape unit (Tables 2 and 3). All

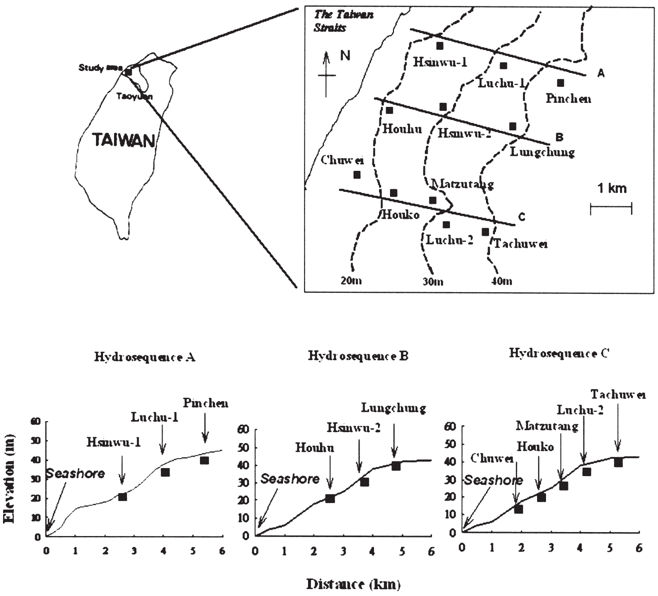

Fig. 2. Sites location and landscapes position of the eleven soils reported by Jien et al. (2004). Dotted line indicates the elevation above the sea level.

these soils are considered anthraquic, since they are seasonally flooded for lowland rice production and have perched water tables from February to October of the year. Seasonally high groundwater levels also occur during the growing season. Hydric soils are defined as soils formed under conditions of sufficient saturation or flooding during the growing season to develop an anaerobic condition in the upper part of the soil (USDA-NRCS, 2003). Ideally, hydric soil states should be confirmed with hydrological and redox potential monitoring data. Because these data are difficult to obtain in paddy soils, the investigation of the relationships between soil chroma and soil wetness were conducted in these soil layers <50 cm, 50-100 cm, and >100 cm.

The chroma index (CI) was used herein from Megonigal et al. (1996) for soil color notations converted into color indices with a single numerical value, respectively. As a result, regression analysis between the CI and soil wetness on Chungli Quaternary terraces in northern Taiwan, including the saturated time (%) and reduced time (%) of the year, demonstrated that the saturation duration of the horizon above 50 cm did not markedly correlate with

Table 2. Identification of hydric soils based on the accumulation days of redox potential, saturation condition of studied soils selected from Chungli Terrace (Jien et al., 2004)

Soil soils#	Classification†	Accumulation days‡ 1996 Eh	 SAT	 1997 Eh	 SAT	Munsell A horizon	Hydric color of
		------------- days -------------					
<u>Toeslope</u>							
Hsinwu-1	Typic Plinthaquults	229	183	244	197	10YR 5/3	Y
Chuwei	Typic Plinthaqualfs	229	183	244	197	7.5YR 4/6	Y
Houhu	Typic Plinthaquults	229	183	244	197	2.5Y 4/2	Y
Houko	Typic Plinthaqualfs	229	183	244	197	10YR 6/2	Y
<u>Footslope</u>							
Luchu-1	Oxyaquic Paleudults	116	79	60	125	2.5Y 7/3	Y
Hsinwu-2	Typic Plinthudults	116	79	60	125	2.5Y 4/3	Y
Matzutang	Plinthaquic Paleudalfs	116	79	60	125	10YR 4/1	Y
Luchu-2	Plinthaquic Paleudalfs	116	79	60	125	10YR 5/8	Y
<u>Backslope</u>							
Pinchen	Oxyaquic Paleudults	216	228	244	216	10YR 4/4	Y
Tachuwei	Plinthitic Paleudalfs	216	228	244	216	10YR 5/6	Y
Lungchung	Plinthaquic Paleudults	216	228	244	216	2.5Y 4/2	Y

† Based on Soil Taxonomy (Soil Survey Staff, 2006)
‡ Accumulation days of rice-growing season (Feb. 1 to Oct. 31) at 25 cm depth which the redox potential (Eh) is ≦ 200mV when soil pH was calibrated to 7, and accumulation days at 25 cm depth which the matrix potential is 0 bar or in saturation condition (SAT) (Hseu and Chen, 2001).
#: Y: meet the definition of hydric soil

Table 3. Morphological features and semi-quantitative of redoximorphic features of paddy soil on Chungli terrace (Jien et al., 2004)

Horizon	Depth	Matrix color	Redoximorphic features Mottles color	Texture	Saturated time	Reduced time
					-----------%-----------	
			Chuwei (Typic Plinthaqualfs)			
Ap	0-35	7.5 YR 4/6	Cp7.5YR 5/8 (10%)† Fp2.5YR 5/8 (<2%)	SiL	55	95
AB	35-65	10 YR 5/4	Cp7.5YR 6/8 (15%)	SiL	60	100
Bt1	65-90	5 G 5/1	Mp10 YR 7/8 (30%)	SiCL	65	100
Bt2	90-105	5 PB 6/1	Cp10 YR 7/8 (10%)	SiCL	70	100
Bt3	105-120	5PB 6/1	Cp2.5Y 7/6 (4%)	SiC	80	100
			Houhu (Typic Plinthaquults)			
Ap	0-34	2.5Y 4/2	Mp 5YR 4/4 (30%)	CL	55	90
AB	34-47	2.5Y 4/1	Cp 7.5YR 5/8 (10%)	SiCL	55	90
Bt1	47-66	10YR 4/3	CP 7.5YR 5/8 (10%)	SiCL	60	100
Btv1	66-82	10YR 5/3	CP7.5YR 5/8 (10%) Cd 10YR 6/1 (10%)	SiC	65	100
Btv2	82-102	10YR 6/1	Mp2.5YR 5/8 (25%)	SiC	70	100
Btv3	102-122	7.5YR 6/1	Mp2.5YR 5/8 (25%) Md10YR 7/1 (10%)	SiC	70	100
Btv4	>122	7.5YR 6/1	Mp5YR 5/8 (30%) Mp 7.5YR 5/6 (20%)	C	80	100
			Houko (Typic Plinthaqualfs)			
Ap	0-25	10YR 6/2	Cp 5YR 5/8 (10%)	SiCL	50	95
Bt1	25-45	2.5Y 4/4	Cp 5YR 5/8 (10%)	SiC	60	90
Bt2	45-70	2.5Y 6/2	Mp 5YR 5/8 (40%)	SiC	65	100
Bt3	70-110	10YR 6/1	Mp 2.5YR 5/8 (40%)	SiC	70	100
Bt4	110-140	5PB 6/1	Mp10YR 5/8 (20%) Mp 2.5YR 5/8 (20%)	SiC	80	100
			Hsinwu-1 (Typic Plinthaquults)			
Ap	0-15	10YR 5/3	Cp7.5YR 5/8 (5%)	SiL	55	95
AB	15-30	2.5Y 5/3	Cp7.5YR 5/8 (5%)	SiL	55	90
Bt1	30-40	10YR 5/6	Cp2.5YR 5/8 (5%)	SiC	55	90
Btv1	40-80	2.5YR 6/4	Cp2.5YR 4/8 (15%)	CL	65	100
Btv2	80-100	2.5YR 5/8	Cp2.5Y 6/8 (15%) Mp2.5YR 7/2 (30%)	C	60	100
Btv3	100-130	5YR 5/8	Cp10YR 4/6 (20%) MP2.5YR 7/2 (30%)	C	65	100
Btv4	130-160	2.5YR 5/8	Cp10YR 6/6 (20%) Mp2.5YR 7/1 (40%)	C	70	100
			Hsinwu-2 (Typic Plinthudults)			
Ap	0-15	2.5Y 4/3	--	SiL	40	10
AB	15-26	2.5Y 4/1	Cf 2.5YR 4/2 (10%)	SiL	40	10
Bt1	26-45	10YR 5/4	Cd 7.5YR 4/4 (10%)	SiC	45	30
Bt2	45-75	10YR 5/6	Cp 5YR 5/8 (15%)	SiC	45	30
Btv1	75-107	10YR 5/2	Mp 2.5YR 4/4 (25%) Cp 10YR 6/1 (5%)	CL	50	25
Btv2	107-133	2.5YR 4/8	Cp10YR 6/3 (5%) Cp10YR 6/2 (5%)	C	50	30
Btv3	>133	2.5YR 4/8	Cp 10YR 6/2 (10%)	C	55	10

§ F= fine, C= coarse, M= medium, p= prominent, d= distinct, f= faint
†: The value in parentheses is amount of redoximorphic features
(continued to next page)

Table 3. (Continued)

Horizon	Depth	Matrix color	Redoximorphic features Mottles color	Texture	Saturated time	Reduced time
					-----------%-----------	
			Matzutang (Plinthaquic Paleudalfs)			
Ap	0-10	10YR 4/1	Fp 7.5YR 4/4 (<2%)	SiCL	40	10
AB	10-40	7.5YR 3/2	Fp 10YR 3/6 (<2%)	SiCL	40	30
Bt1	40-60	7.5YR 5/6	Cp5YR 4/6 (5%)	SiC	45	30
			Cp 2.5Y 5/1 (5%)			
			CpP2.5Y 5/3 (10%)			
Bt2	60-100	7.5YR 4/6	Cp 2.5Y 6/1 (20%)	SiC	50	25
			Cp2.5Y 6/4 (10%)			
Bt3	100-135	5YR 4/6	Cp 2.5Y 6/1 (20%)	SiC	50	30
			Luchu-1 (Oxyaquic Paleudults)			
Ap	0-30	2.5Y 7/3	Cp10R 4/6 (15%)	SiL	40	30
AB	30-55	2.5Y 5/4	Cp2.5YR 5/8 (15%)	SiL	45	30
Bt1	55-90	2.5YR 4/6	Mp10YR 5/3 (20%)	SiCL	45	25
Bt2	90-140	10R 4/6	Mp10YR 5/3 (20%)	SiCL	50	30
Bt3	140-180	10R4/6	Mp10YR 5/8 (35%)	SiC	55	30
			Cp2.5Y 7/6 (5%)			
Bt4	>180	2.5YR 4/8	Mp10YR 6/8 (30%)	SiC	65	30
			MP10R 3/6 (20%)			
			Cp10YR 7/2 (20%)			
			Luchu-2 (Plinthaquic Paleudalfs)			
Ap	0-20	10YR 5/8	Cp2.5YR 4/6 (5%)	SiCL	40	10
AB	20-40	10YR 5/3	Mp2.5YR 5/8 (30%)	SiCL	40	30
Bt1	40-65	10YR 3/2	Cp10YR 6/8 (5%)	SiCL	35	30
			Mp 5YR 6/8 (25%)			
Bt2	65-85	10YR 7/6	Mp2.5YR 4/6 (20%)	SiC	50	25
			Cp10YR 6/1 (20%)			
Bt3	85-105	2.5YR 5/8	Cp10YR 7/1 (30%)	SiC	50	25
Bt4	>105	10R 4/6	Mp10YR 7/2 (40%)	SiC	55	30
			Tachuwei (Plinthitic Paleudalfs)			
Ap	0-35	10YR 5/6	Fp10R 4/6 (2%)	L	75	70
AB	35-60	2.5Y 6/6	Mp 10R 4/8 (40%)	L	60	70
Bt1	60-80	2.5YR 4/8	Mp7.5YR 6/8 (25%)	SiL	55	10
Bt2	80-120	10YR 7/8	Mp2.5YR 4/8 (30%)	SiL	40	15
Bt3	120-150	2.5YR 3/6	Mp7.5YR 5/8 (20%)	SiL	35	5
			Mp 5YR 7/2 (30%)			
			Lungchung (Plinthaquic Paleudults)			
Ap	0-20	2.5Y 4/2	--	SiCL	75	70
Bw	20-41	10YR 5/2	Cd5YR 5/8 (5%)	SiC	75	70
2A	41-56	10YR 4/2	Cp2.5YR 3/4 (5%)	SiCL	60	70
2Bt	56-85	10YR 4/4	Cd7YR 5/6 (10%)	SiC	55	10
2Btv1	85-100	10YR 5/3	Cd2.5YR 5/8 (30%)	SiC	40	15
2Btv2	100-140	10YR 6/2	Mp2.5YR 5/6 (20%)	SiC	35	5
			Pinchen (Oxyaquic Paleudults)			
Ap	0-20	10YR 4/4	Fp5YR 5/8 (15%)	SiCL	75	70
AB	20-40	10YR 4/4	Fp5YR 5/8 (15%)	SiCL	75	70
Bt1	40-60	7.5YR 5/8	Mp5Y 5/3 (15%)	SiC	60	70
Bt2	60-100	10R 3/6	M&Fp5Y 5/3 (<2%)	SiC	55	15
			Mp10YR 5/6 (40%)			
Bt3	100-130	10R 3/6	M&Cp10YR 7/4 (30%)	C	40	5
Bt4	130-160	2.5YR 4/8	M&Cp10YR 7/4 (30%)	C	35	5
Bt5	160-200	2.5YR 4/8	M&Cp10YR 7/4 (30%)	C	35	5
			Mp 2.5Y 8/2 (20%)			

§ F= fine, C= coarse, M= medium, p= prominent, d= distinct, f= faint
†: The value in parentheses is amount of redoximorphic features

the CI values, and soil reduced duration displayed the same pattern (Fig. 3). These results may indicate the disturbance of the surface 50cm soil by rice cultivation during the growing season. The Fe depletions in the Ap horizon were very difficult to see, possibly owing to masking by organic matter, which controls the matrix color. The soil CI values above a depth of 50 cm thus did not predict the soil wetness condition. However, negative significant correlations were found between the CI values and soil saturation duration (r = -0.43, $p < 0.01$), and the reduced duration (r = -0.52, $p < 0.01$) for the soils at a depth of 50 to 100 cm (Fig. 4). The redoximorphic features at this depth probably were affected more by groundwater table than perched water. The reduction and saturated times at this depth were >25% and >35% of the year, respectively, and the contents of the Fe depletions ranged from 5% to 40%. Some pedons dropped out of the standard deviation at the 95% confidence level, such as Bt1 of Luchu-2, Btv1 of Hsinwu-2, Bt1 and Bt2 of Tachuwei, and Bt1 of Pinchen soils. This study assumed that the main reasons for the saturation condition were abrupt soil texture change, such as Btv1 of the Hsinwu-2 soil, or upper soils being disturbed by plowing and leading to pores being discontinued, resulting in a perched water table, such as Bt1 of the Luchu-2 soil. The perched water was always present, and then leads to the formation of more reduced Fe depletions more quickly than for other horizons with a clayey texture. For the paddy soils below 100 cm depth, the redoximorphic features were affected by groundwater fluctuation. The soil chroma index was significantly correlated with annual soil saturation time (r = -0.47, $p < 0.01$) or annual soil reduction time (r = -0.59, $p < 0.01$) (Fig. 5). The Bt2 horizon (80-120 cm) of the Tachuwei soil and the 2Btv2 horizon (>140 cm) of Lungchung soil had >30% Fe concentrations and 10-30% reduction time each year. This investigation assumed the Fe concentrations to be a relict during the initial deposition of Quaternary-aged

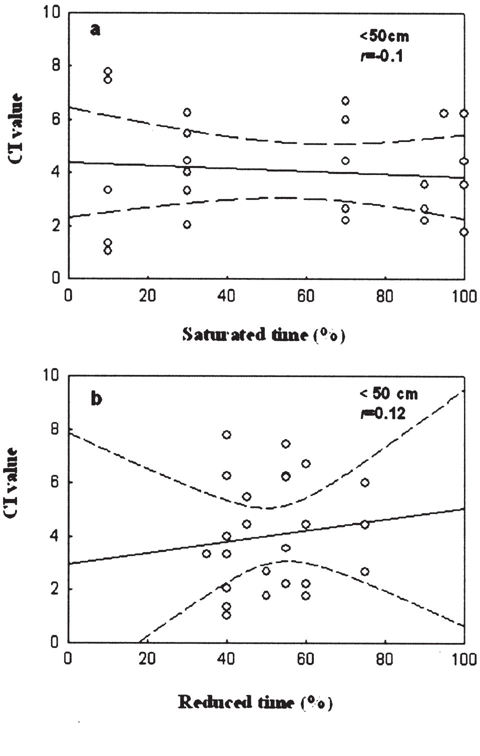

Fig. 3. Relationships between chroma index and (a) soil saturated time (% of a year) (<250 mV, pH 5.5) and (b) reduced time (% of a year) above 50 cm of soil pedon reported by Jien et al. (2004). Solid line is regression line and dash line is the range of 99% confidence level.

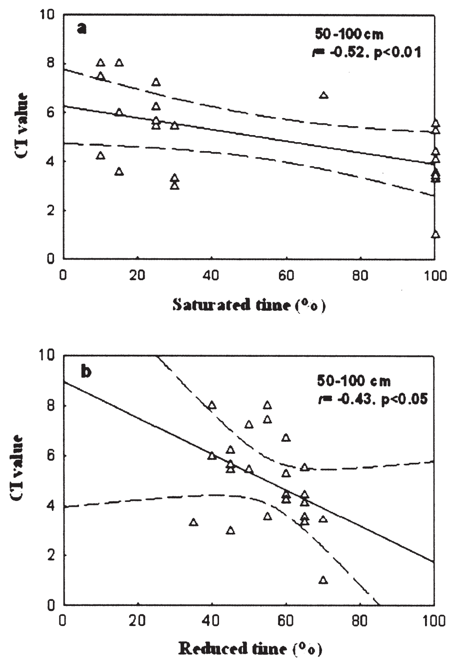

Fig. 4. Relationships between chroma index and (a) soil saturated time (% of a year) (<250 mV, pH 5.5) and (b) reduced time (% of a year) between 50-100 cm of soil pedon reported by Jien et al. (2004). Solid line is regression line and dash line is the range of 99% confidence level.

alluvial red earth, and furthermore assumed it would produce an error in the calculated CI value. On the other hand, soils below the 100 cm depth of Btv3 and Btv4 of Hsinwu-2 soil and the Bt4 of the Luchu-1 soil were saturated with water for 50-65% of the year, with the reduction time comprising just 10-30% of the year.

3. Classification of Paddy soils in Taiwan

Paddy soils in Taiwan are mainly classified into Entisols, Inceptisols, Alfisols and Ultisols, and with minor into Mollisols and Oxisols based on Soil Taxonomy (Soil Survey Staff, 2006). Chen (1984) and Sheh and Wang (1989) have proposed and established the classification system of the cultivated soils in Taiwan, including paddy soils. From the above description in the diagnostic subsurface horizons, typical horizons in the paddy soils of Taiwan included (1) Ap horizon (with ochric, mollic or umbric epipedon), (2) plow-sole (or plow pan Bt or Bg) horizon with relatively high bulk density, (3) argillic horizon (Bt, Btg or Btv) or cambic horizon (Bw or Bg) with various redoximorphic features and with significant translocation of Fe, Al and Mn below the plow-sole horizon, and (4) gleyed horizon with seasonal high water table. The main soil taxa are listed in Table 4 and explained as followings.

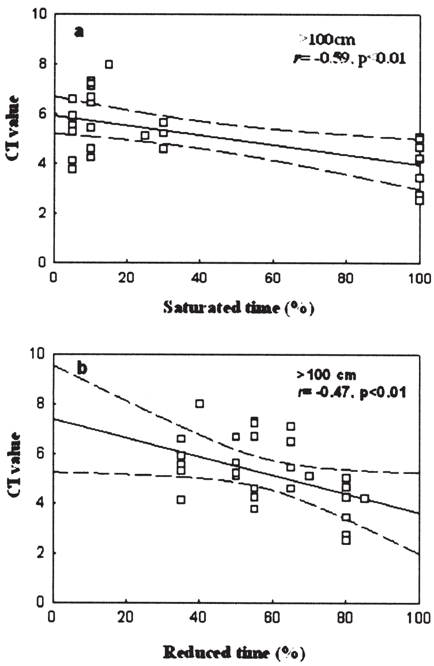

Fig. 5. Relationships between chroma index and (a) soil saturated time (% of a year) (<250 mV, pH 5.5) and (b) reduced time (% of a year) below 100 cm of soil pedon reported by Jien et al. (2004). Solid line is regression line and dash line is the range of 99% confidence level.

3.1. Entisols

Aquents, Fluvents and Psamments are major Soil Suborders in Entisols which were mostly on the young alluvial fans near the coast areas in the western and eastern plains. Additionally, they have no clearly pedogenic features, except for the Ap horizon. The above Soil Suborders are different in moistures, amount and vertical distribution of organic carbon and textures. The total area with Entisols of the paddy soils is roughly 700 km^2 (about 5% of total survey area). Generally, Aquents is much more waterlogged through the profile than Fluvents and Psamments, and thus they are different in soil hydrological conditions such as saturation and reduced durations of the year.

3.2. Inceptisols

Inceptisols are generally on the soils derived from recent alluvium of sandstone, shale and slate in western Taiwan. The Soil Suborders are Aquepts, Ochrepts and Umbrepts with Bwg or Bw horizons. Furthermore, Haplaquepts, Dystrochrepts, Eutrochrepts and Haplumbrepts are the main Great Groups in the alluvial soils of Taiwan. However, the total area of Inceptisols is about 4,400 km^2.

3.3. Alfisols

Alfisols are mainly on the older alluvium from sandstone, shale, and slate in the western part of Taiwan. Argillic horizons (Bt or Btg) are in the lower parts of the pedons. Aqualfs, Udalfs and Ustalfs are the most important Soil Suborders and have different moisture regimes. Ustalfs are locally on the southern part of Taiwan with higher evaporation. Ochraqualfs, Hapludalfs and Haplustalfs are the main Great Groups in such alluvial soils which carbonates are sometimes found herein.

3.4. Ultisols

Ultisols are mainly found in the paddy soils of red earth and aged alluvium from the red earth on Quaternary terraces of northwestern part of Taiwan. These

Table 4. Approximate area of major soil classes in paddy soils of Taiwan (Chen, 1992)

Soil Order	Suborder	Great Group	Area (km^2)	Percentage of total surveyed area
Entisols	Aquents	Haplaquents	20	
		Fluvaquents	150	
	Fluvents	Udifluvents	530	
			(700)	5%
Inceptisols	Aquepts	Haplaquepts	1500	
	Ochrepts	Dystrochrepts	1500	
		Eutrochrepts	1100	
	Umbrepts	Haplumbrepts	300	
			(4400)	30%
Alfisols	Aqualfs	Ochraqualfs	1000	
	Udalfs	Hapludalfs	1600	
	Ustalfs	Haplustalfs	1000	
			(3066)	25%
Ultisols	Aquults	Paleaquults	100	
		Plinthaquults	100	
	Udults	Hapludults	500	
	Humults	Haplhumults	30	
			(730)	5%
Mollisols	Udolls	Hapludolls	110	
	Ustolls	Haplustolls	15	
			(125)	1%
Oxisols	Peroxes	Kandiperoxes	50	
	Udoxes	Hapludoxes	50	
			(100)	<1%
Other soils and upland soils			(5000)	35%
Total surveyed area in Taiwan		14,600	100%	

soils have been used for lowland rice production for over 50 years, and the significant morphological characteristics of the surface epipedon were the color change owing to flooding by irrigation water. The diagnostic subsurface horizon is argillic horizon with plinthites that are iron-rich, humus poor mixtures of clay with quartz and other minerals (Soil Survey Staff, 2006). It commonly occurs as dark red redox concentrations that usually form platy, polygonal or reticulate patterns (Fig. 6). It changes irreversibly to an ironstone hardpan or to irregular aggregates on exposure to repeated wetting and drying, especially if it is also exposed to heat from the sun. Therefore, the Great Groups of Aquults are Paleudults and Plinthaquults, respectively. On the other hand, Udults are the dominant Soil Suborders in the paddy

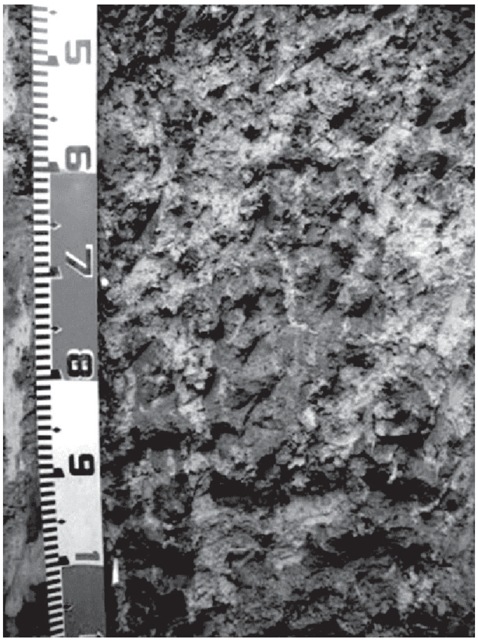

Fig. 6. Plinthites through the Btv horizons from a paddy soil profile (Plinthaquults) on Chungli terrace in northwestern Taiwan. The dark colored zones indicate Fe-rich masses and the light gray zones are redox depletions. The scale unit is 1 cm.

soils of red earth. Hapludults and Paleudults are the main Great Groups. A small area with about 30 km^2 of Haplhumults was only found in local depression farms.

3.5. Mollisols

Mollisols for lowland rice production can be only found in the eastern part of Taiwan, particularly on igneous rock and mudstone alluvial soils or andesite derived soils. The diagnostic horizon is mollic epipedon, but there is no diagnostic subsurface horizon in the Mollisols. The soil depth is generally shallow (<60 cm). However, high organic matter and low color value and chroma in the surface soil are the dominant characteristics in these paddy soils. Udolls are the main soil Suborder, and Hapludolls are the main Great Group.

3.6. Oxisols

Oxisols are mainly on the aged terrace land and have an oxic horizon. They have undergone paddification for about 50 years. Kandiperoxes and Hapludoxes are the main Great Groups in Taiwan.

4. Contamination of Heavy Metals in Paddy Soils of Taiwan

4.1. Soil Pollution Status

Heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) contamination have been found in the paddy soils due to illegal waste water discharged from industrial plants (i.e., chemical, electroplate, pigment) and livestock (i.e., swine). As a result, four stages of soil survey project of the contamination soils in Taiwan were conducted by the Environmental Protection Administration of Taiwan (Taiwan EPA) since 1982. The objectives of the survey are to understand the heavy metal levels in the rural soils of Taiwan. The major results of these stages are illustrated as follows (Taiwan EPA, 2003).

- Stage 1 (1983-1987): The total survey areas were about 1,160,000 ha and each representative survey unit is 1,600 ha. The final report was published by Taiwan EPA in 1987 (Taiwan EPA, 1987).
- Stage 2 (1987-1991): Stage 2 was conducted for 300,000 ha of rural soils selected from stage 1 which have relatively high concentrations of metals and each representative survey unit was 100 or 25 ha. The results showed that about 790 ha of rural soils have higher concentrations of the metals than the regulations of heavy metals announced by Taiwan EPA in 1991 (As 60, Cr 16, Cd 10, Cu 100, Pb 120, Hg 20, Ni 100, Zn 80 mg kg^{-1}) (Taiwan EPA, 1991). However, the soils were extracted by 0.1 M HCl for the measurement of metals, except As and Hg which were extracted by aqua regia.
- Stage 3 (1992-2000): The survey lands were selected according to the results of stage 2 which have relatively high concentration of metals in soil. The total survey area is about 50,000 ha in this stage and each representative survey unit was 1 ha.
- Stage 4 (2000 to now): This stage was conducted following the Soil and Groundwater Pollution Remediation Act (SGWPR Act) announced in 2000. The contaminated control or remedial sites were announced based on the criteria of pollutant levels listed in the SGWPR Act (Taiwan EPA, 2003).

According to the survey of rural soils with potential contamination conducted by Taiwan EPA in 2002, more than 300 ha of rural soils were contaminated by heavy metals. The regulations of heavy metals (mg/kg) in the SGWPR Act are as follows: Cd 5.0, Cr

250, Cu 200, Ni 200, Pb 500, and Zn 600, based on aqua regia and total digestion methods. The contaminated area by different metals which was higher than the regulation of pollutants in SGWPR Act of paddy soils were about 159 ha for Ni, 148 ha for Cu, 127 ha for Cr, 113 ha for Zn, 17 ha for Cd, 4 ha for Pb, and 0.3 ha for Hg, respectively. Most of them (184 ha) were located in Changhua prefecture, central Taiwan which were mainly contaminated by Cu, Zn, Ni, and Cr (Taiwan EPA, 2003). The other serious contaminated prefectures are Hsinchu (27.54 ha), Taoyuan (11.46 ha), Pingtung (6.9 ha), Taipei (1.62 ha), Miaoli (0.55 ha), Nantou (0.39 ha), and Taichung (0.3 ha), respectively. According to the AGWPR Act, the crops grown in the contaminated soils should be collected and destroyed by the governmental agency to avoid the human health risk through food chain. Although the heavy metal contents of the contaminated paddy soils were higher than those in the regulation, the effects of these total concentrations of the metals on the crop quality and human health were needed further examinations.

4.2. The suitability of total metal concentration of pollutants as regulation

4.2.1. Arsenic

The regulation of As total contents in soils were ranged from 20 mg/kg to 75 mg/kg in the world. The upper limit of background As contents of representative rural soil was 18 mg/kg in Taiwan (Table 5). If the total As in the soil was lower than 20 mg/kg, the As content of the brown rice (fresh weight) was 0.15 mg/kg (in average) and the As content of other crops was 0.01 mg/kg (in average). However, if the total As contents of the rural soils reached up 60 mg/kg, the rice production clearly decreased. Therefore, the regulation of As in soils of Taiwan is proposed to keep in the present level (60 mg As/kg).

4.2.2. Cadmium

The regulation levels of soil Cd total contents were ranged from 1 mg/kg to 5 mg/kg in the world. The relative studies in Taiwan and Japan have suggested that the Cd content in brown rice and in soil was not significantly correlated. The upper limit of back-

Table 5. The upper limit of background content, the EPA regulation, and the proposed regulation of soil heavy metals in Taiwan.

	As*	Cd	Cr	Hg	Cu	Ni	Pb	Zn
Background content of soil heavy metal in Taiwan§								
Mean	7.8	0.23	1.51	0.26	17	7.7	11.6	23.4
Middle value	7.3	0.16	0.53	0.13	7.6	2.3	9.2	12.7
Proposed regulation	25	1	30	1	100	40	120	100
Upper limit of background content (total content)	18	3	100	35	0.5	60	120	120
Taiwan EPA regulation (2000)								
Total content (rural soil)	60	5	250	5	200	200	500	600
Total content (general land)	60	20	250	20	400	200	2000	2000
Proposed regulation								
Total content (rural soil)	60	4	250	5	600	200	1000	800
Total content (general land)	60	20	250	20	1000	200	2000	2000

*: As and Hg: total content; Cd, Cr, Cu, Ni, Pb, Zn : 0.1M HCl extraction (n = 9000).

ground Cd contents of representative rural soil was 3 mg/kg in Taiwan (Table 5). The most brown rice and the polished rice were regarded as Cd-contaminated rice when the total soil Cd content is > 5 mg/kg (Chen, 1991). Liu et al. (1998) suggested that the brown and polished rice were Cd-contaminated rice when the soil Cd concentration was higher than 2 mg/kg extracted by 0.1 M HCl in the potentially contaminated areas of Taiwan (Fig. 7). The estimated total content of Cd in the rural soils was about 5 mg/kg based on the above 0.1M HCl extractable Cd levels. The regulation of Cd in brown rice is 0.5 mg/kg in Taiwan. The database in Taiwan and Japan indicated that the Cd-contaminated rice could be found in areas with different soil properties and soil management, even though the total content of Cd in soil was less than 5 mg/kg. We recommend that the regulation of total contents of Cd in Taiwan rural soils should be reduced to 4 mg Cd/kg from 5 mg/kg.

4.2.3. Chromium

The regulation levels of soil Cr total contents were ranged from 100 mg/kg to 1,500 mg/kg in the world. The upper limit of background Cr contents of representative rural soil was 100 mg/kg in Taiwan (Table 5). The mean content of Cr is 0.14 mg/kg in brown rice, <0.01 mg Cr/kg in the shoot and root vegetables. The rice production will be reduced when the total Cr content of rural soil reached to 250 mg/kg, but the rice should be edible because the Cr level of polished rice was <4 mg/kg (Liu et al., 1998) (Fig. 8). The regulation of Cr in soil of Taiwan is proposed to keep in the present level (250 mg/kg).

4.2.4. Copper

The regulation levels of soil Cu total contents were ranged from 100 mg/kg to 1,500 mg/kg in the world. The upper limit of background Cu contents of representative rural soil was 35 mg/kg in Taiwan (Table 5). The soil total concentration of Cu ranged from 20 to 320 mg/kg. The Cu content of polished rice ranged from 4 to 8 mg/kg, and it is not increased with increasing soil Cu content (Liu et al., 1998) (Fig. 9). When the soil total Cu level reached to 320 mg/kg, the rice production will be significantly reduced by 30%. The rice production will reduce 50% when the total Cu content of rural soil reached 600 mg/kg, but the brown rice would be edible because the Cu content of polished rice was <17 mg/kg (Liu et al., 1998). We proposed the regulation of total contents of Cu in Taiwan rural soils should be revised as 600 mg/kg.

4.2.5. Mercury

The regulation levels of soil Hg total contents were ranged from 1 mg/kg to 10 mg/kg in the world. The upper limit of background Hg contents of representative rural soil was 0.5 mg/kg in Taiwan (Table 5). The mean concentration of Hg in brown rice of Taiwan was 0.0014 mg/kg, and that of leaf vegetables was 0.04 mg/kg (Liu et al., 1998). Because all the total Hg

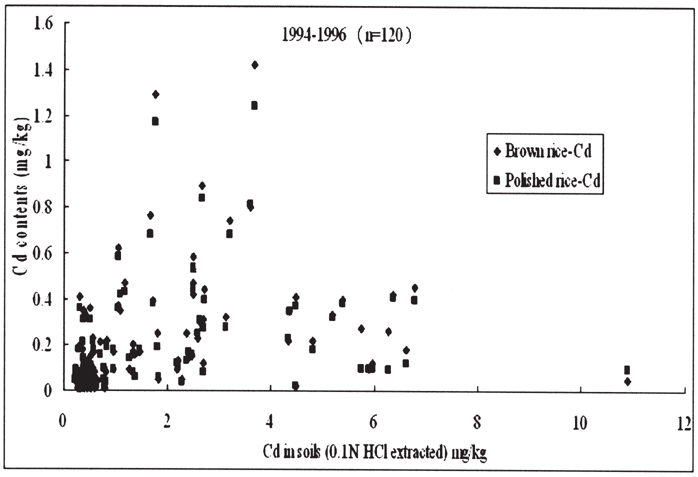

Fig. 7. The relations of Cd content in brown rice and in soil (0.1 N HCl extractable) for database of six cropping system of rice from 1994 to 1996 in central Taiwan Plotted from database of Liu et al (1998).

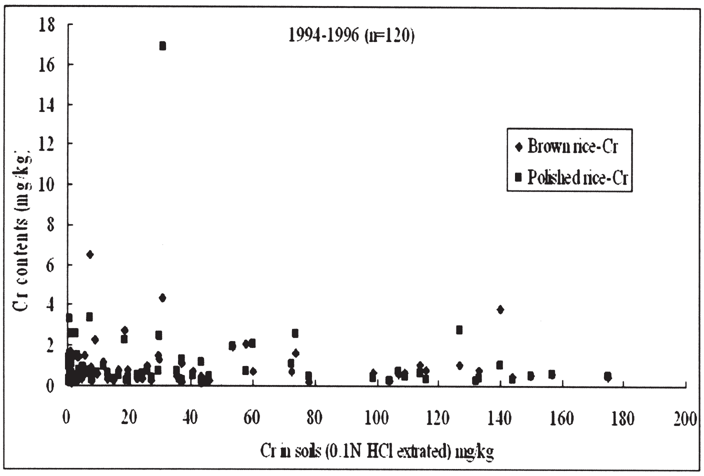

Fig. 8. The relations of Cr content in brown rice and in soil (0.1 N HCl extractable) for database of six cropping system of rice from 1994 to 1996 in central Taiwan Plotted from database of Liu et al (1998).

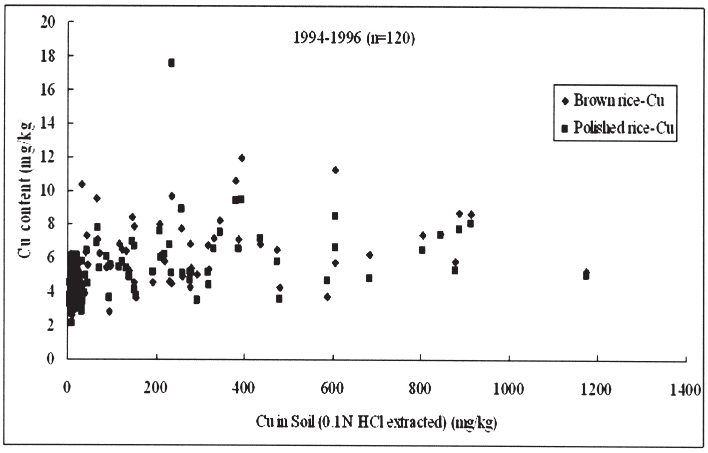

Fig. 9. The relations of Cu content in brown rice and in soil (0.1 N HCl extractable) for database of six cropping system of rice from 1994 to 1996 in central Taiwan Plotted from database of Liu et al (1998).

contents of the rural soils were lower than 5 mg/kg, the regulation of Hg in soil of Taiwan is proposed not to be changed (5 mg Hg/kg).

4.2.6. Nickel

The regulation levels of soil Ni total contents were ranged from 20 mg/kg to 400 mg/kg in the world. The upper limit of background Ni contents of representative rural soil was 60 mg/kg in Taiwan (Table 5). The Ni content of the brown rice ranged from 4 to 30 mg/kg when the total Ni of rural soil ranged from 40 to 320 mg/kg in Taiwan. When the total Ni content of rural soils reached 600 mg/kg, the Ni content of polished rice was still <14 mg/kg (Liu et al., 1998) (Fig. 10). Because only a few data suggested that the total content of Ni was higher than 200 mg/kg in the rural soils, the regulation of Ni in soil of Taiwan is proposed not to be changed (200 mg Ni/kg).

4.2.7. Lead

The regulation levels of soil Pb total contents were ranged from 100 mg/kg to 1,000 mg/kg in the world. The upper limit of background Pb contents of representative rural soil was 120 mg/kg in Taiwan (Table 5). The Pb content of the brown rice and polished rice was almost <1 mg/kg when the total soil Pb ranged from 50 to 1350 mg/kg in Taiwan (Liu et al., 1998) (Fig. 11). We estimated that the rice production will be reduced by 20% if the total content of Pb reached 2,000 mg/kg. We recommend that the regulation of

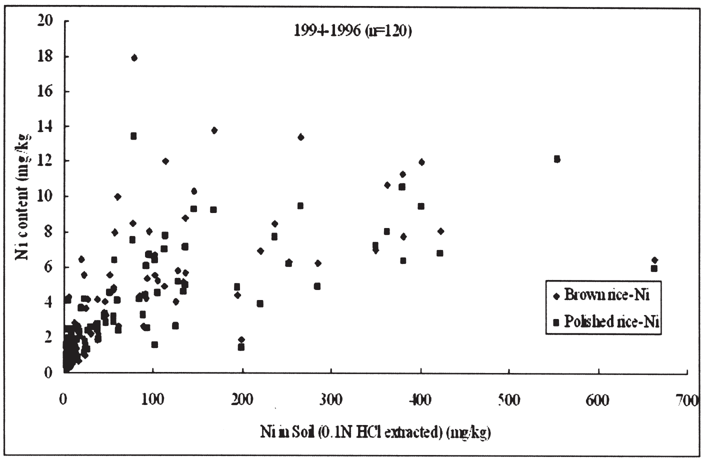

Fig. 10. The relations of Ni content in brown rice and in soil (0.1 N HCl extractable) for database of six cropping system of rice from 1994 to 1996 in central Taiwan Plotted from database of Liu et al (1998).

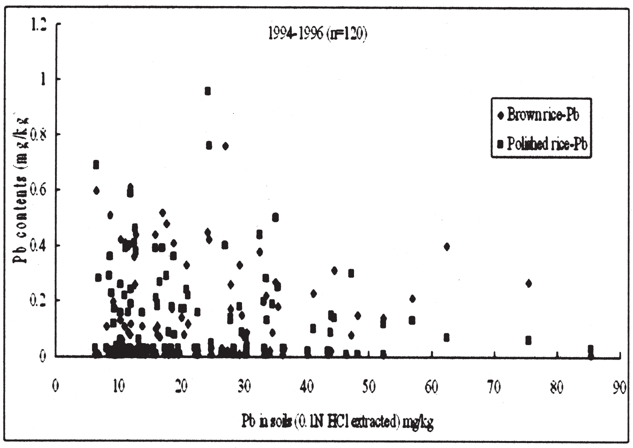

Fig. 11. The relations of Pb content in brown rice and in soil (0.1 N HCl extractable) for database of six cropping system of rice from 1994 to 1996 in central Taiwan Plotted from database of Liu et al (1998).

total contents of Pb in Taiwan rural soils should be revised as 1,000 mg/kg.

4.2.8. Zinc

The regulation levels of soil Zn total contents were ranged from 200 mg/kg to 3,000 mg/kg in the world. The upper limit of background Zn contents of representative rural soil was 120 mg/kg in Taiwan (Table 5). The Zn content of the polished rice ranged from 20 to 80 mg/kg when the soil total Zn ranged from 60 to 960 mg/kg. If the total soil Zn content reached to 500 mg/kg, the rice production will be significantly reduced by 30% and the Zn level of polished rice ranged from 50 to 80 mg/kg (or the Zn level of brown rice ranged from 30 to 90 mg/kg). The rice production will be reduced by 50% when the total Zn content of soil reached to 800 mg/kg, but the rice should be edible because the polished rice Zn content was <30 mg/kg (Liu et al., 1998) (Fig. 12). The regulation of Zn in soil of Taiwan is proposed not to be changed (2,000 mg Zn/kg).

5. Remediation Techniques Used in Taiwan

5.1. Soil Turnover and Dilution Method

If the heavy metal concentration is lower in the subsurface soil than that in the surface soil, deep plow and consequently mixing the two layers can significantly decrease the metal levels to meet the regulation of pollutants in the SGWPR Act of Taiwan. The depth of subsoil should be enough to di-

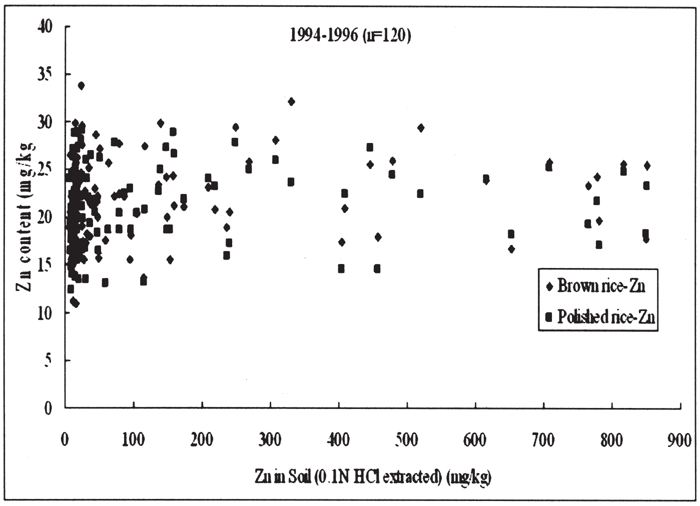

Fig. 12. The relations of Zn content in brown rice and in soil (0.1 N HCl extractable) for database of six cropping system of rice from 1994 to 1996 in central Taiwan Plotted from database of Liu et al (1998).

lute the total metal concentration of the surface soil (0-20 cm). This turnover and dilution method is thus suitable for contaminated paddy soil, especially for relatively low metal concentrations in Taiwan (Huang et al., 1995; Taoyuan Prefecture Government, 1999). The turnover and dilution method significantly improved in the decrease of the soil Cd concentration in Chungfu soil in northern Taiwan, which have 1-5 mg Cd kg^{-1} (extracted by 0.1M HCl) and are suitable for the contaminated soils more than 2 m soil depth. This method can decrease the concentration of metals in the surface soil (0-20cm) of the contaminated soil. However, the total amount of metals is still not reduced through the soil pedon.

For most of the metals-contaminated paddy soils in Taiwan since 2000, soil turnover and dilution method was the most popular remediation method because it has the advantages of low time economic costs compared with other soil remediation techniques such as acid washing and chelating agent extraction techniques. However, the subsoil has lower organic carbon content and the concentrations of metals are also lower compared with the surface soil. The soil turnover and dilution method produce the lower levels in organic carbon and nutrient after the above dilution. Fertilization by composts and chemical fertilizers should be added to the remediated soils to increase the soil fertility and to promote crop growth. For paddy soils in Taiwan, plowing layer was also disturbed by the diluting practices and their rebuilding is also requested if household farmers need to continue cultivation for lowland rice.

Chen and Lee (1997) used soil turnover and dilution method to decrease the Cd and Pb concentrations in the contaminated soils. The soils in the surface layer (0-20 cm) were mixed with the subsoil (20-40 cm) and then were planted by lettuce, water celery, and Chinese cabbage, respectively. These plants were harvested after planting in the treated soils for 4 weeks. Even the mixture of surface and subsurface soils decreased the soil Cd and Pb concentrations, but the mixed soils were still higher than 2.10 mg Cd/kg and 9.07 mg Pb/kg (0.1 M HCl) because the original metal concentrations were not significantly different in the upper 0-60 cm (data not shown). Soil turnover and dilution method can decrease the Cd and Pb concentrations of the crops (Table 6), but their concentrations were still too high and the treated soils were not suitable for rice planting (Chen, 1991).

5.2. Chemical Stabilization Techniques

This method is the application of chemical amendments to decrease the mobility and solubility of metals in the contaminated paddy soil and thus to decrease the metal uptake of plants. The reliable reclamation materials were successfully used in many contaminated cases of the world including lime materials, organic materials, compost, hydrous Fe oxides, hydrous Mn oxides, zeolites, etc. (Chen et al., 1992; Chen, 1994; Lin, 1998; Kuo and McNeal, 1984; Kuo et al., 1985; Chen, 1999a & b; 2000a & b; Yang et al., 2001; Basta et al., 2001; Hettiarachchi et al., 2001; Cheng and Hseu, 2002).

5.2.1. Case study 1

The studied soils for pot experiment were sampled from Chungfu village (Chungfu soil: CF-soil 1, CF-soil 2, CF-soil 3, and CF-soil 4) and Tatan village (Tatan soil: TT-soil 1, TT-soil 2, TT-soil 3, and TT-soil 4) Cd and Pb-contaminated sites, respectively. Table 7 shows the basic characteristics of the two studied soils (Chen et al., 2000 a and b). Those treatments used in this study include (1) control (CK), (2) Fe oxide (FO) (20 tons ha^{-1}) -Fe_2O_3, (3) Mn oxide (MO) (20 tons ha^{-1}) -(NaK) Mn_8O_{16}. X H_2O, (4) $CaCO_3$ (CA) (20 tons ha^{-1}), (5) Calcium phosphate (PP) (0.1 tons ha^{-1}) -10CaO. $3P_2O_5.H_2O$, (6) Compost (CO) (40 tons ha^{-1}), and (7) Zeolites (ZL) (20 tons ha^{-1}) (Na_3K_3) ($Al_6Si_{30}O_{72}$. 24 H_2O). The chemical treated soils (500 g, DW) were added in each pot and control the water content by weighing. Soil extractable Cd and Pb concentrations were analyzed at 1st and 2nd month after different chemical treatments by using 0.1M Ca $(NO_3)_2$, 0.05M EDTA (pH 7.0), 0.43M HOAc, and 0.1M HCl, respectively. Seeds of wheat (*Triticum vulgare*) were sowed in the different chemical amendments treated soils, harvested at 1st month after planting, and analyzed the Cd and Pb concentration by using $H_2SO_4/HClO_4$ method.

Except for PP treatment, other chemical amendments were significant to decrease the Ca $(NO_3)_2$ extractable Cd concentration of CF-soil 1 (p <0.1). Application of treatments of CA, CO, and ZL were significant to decrease the EDTA extractable Cd concentration of TT-soil 1 and TT-soil 2 (p <0.1) (data not shown). Different chemical amendments were significant to decrease the HOAc extractable Cd concentration of TT-soil 1 and TT-soil 2 (p <0.1). For Chungfu clayey soils, the extractable Cd concentrations were only significantly decreased in some chemical amendments. The HCl extractable also significantly decreased in different chemical amendments except for TT-soil 2 (p <0.1). Except for PP and CO treatments, different chemical amendments was significant to decease the Ca $(NO_3)_2$ extractable Pb concentration of CF-soil 1 and CF-soil 2 (p <0.1). Different chemical amendments significantly decrease the EDTA extractable Pb concentration of TT-soil 1 and TT-soil 2 except for PP (p <0.1). The treatments of MO, PP, CO, and ZL can significantly decrease the

Table 6. The accumulated Cd and Pb concentration of different crops after planting in the turnover and dilution method treated soil for 4 weeks

Treatment	Water celery		lettuce		Chinese cabbage	
	Cd	Pb	Cd	Pb	Cd	Pb
	-------------------------------- mg kg^{-1} --------------------------------					
Control	23.2	4.11	70.4	4.79	49	2.76
After dilution	18.4	2.77	39.6	3.44	34	6.94

Chen and Lee (1997)

Table 7. The basic soil characteristics of contaminated Chungfu and Tatan soils in Taiwan (Chen et al., 2000a and b).

Soils	pH (H_2O)	O.C.#	CEC†	Extractable concentration¶ Cd	Pb
		g kg^{-1}	$cmol_{(+)}$ kg^{-1}	------mg kg^{-1}-----	
TT-soil 1 & 2	5.4-5.5	12.1-12.9	4.5	5.02-17.6	25.1-377
TT-soil 3 & 4	5.9-6.0	12.1-12.9	4.5	9.96-32.0	121-158
CF-soil 1 & 2	5.0-5.5	15.2-23.5	9.90-12.4	1.36-5.04	8.80-13.2
CF-soil 3 & 4	5.1-5.4	15.2-23.5	9.90-12.4	1.40-2.17	9.93-13.8

#: O. C.: organic carbon content
†: CEC: cation exchange capacity
¶: 0.1M HCl extractable concentration

HOAc extractable Pb concentration only in TT-soil 2 (p <0.1).

The treatments of MO, CA, CO, and ZL significantly decrease the total uptake of Cd by wheat grown in the TT-soil 1 and CF-soil 1 (p <0.1) (Table 8). In the Chungfu soils (CF-soil 1 and CF-soil 2), the applying of CA, PP, CO, and ZL also significantly decrease the total removal of Pb by wheat (p <0.1) (Table 8). The experimental result shows that the chemical treatments of CA and ZL were efficient to decrease the total uptake of Cd and Pb among those treatments.

5.2.2. Case study 2

The used soils for pot experiments were sampled from Tatan village (TT-soil 3 & soil 4) and Chungfu village (CF-soil 3 & soil 4), respectively. Those treatments include (1) control (CK), (2) compost (CO) (40 tons ha^{-1}), (3) $CaCO_3$ (CA) -to rise soil pH to 7.5, (4) Zn oxide (ZN) (50 kg ZnO ha^{-1}), (5) mixture of $CaCO_3$ and Zn oxide (CA+ZN), and (6) mixture of $CaCO_3$ and compost (40 tons ha^{-1}) (CA+CO) (Lee et al., 2004). The treated soils were incubated for 6 months and then planted the seeds of wheat (*Triticum vulgare*). Soil solution was sampled by using Rhizon Soil Moisture Sampler (RSMS) and the metal concentration in soil was extracted by 0.005M DTPA (pH 5.3) and 0.05M EDTA (pH 7.0), respectively. The metal concentration in wheat was digested by H_2SO_4/ $HClO_4$ method and determined by ICP.

The treatments of CA, CA+ZO (or CA+CO) were significantly to decrease the EDTA extractable Cd concentration in TT-soil 3 and CF-soil 4 (p <0.01). The DTPA extractable Cd concentration in TT-soil 3 also decreased after applying these chemical amendments. Because of the formation of insoluble cadmium carbonate after applying $CaCO_3$ (Holm et al., 1996), the extractable Cd and Pb concentration and their solubility was thus decreased (Chlopecka et al., 1996; Krebs et al., 1998). Different chemical amendments were not significantly to affect the EDTA extractable Pb concentration. However, the treatments of CA, CA+ZN (or CA+CO) were significantly to decrease the DTPA extractable Pb concentration in TT-soil 3, TT-soil 4, and CF-soil 3, respectively

Table 8. Effect of applying different chemical amendments on total uptake of Cd and Pb by wheat (Chen et al., 2000a and b)

Treatment#	Total uptake of Cd and Pb by wheat			
	CF-soil 1	CF-soil 2	TT-soil 1	TT-soil 2
	-------------------------- mg 20 $plants^{-1}$ pot^{-1} --------------------------			
	Cd			
CK	0.05 a	0.03 ab	0.09 a	0.13 a
FO	0.02 bcd	0.03 a	0.10 a	0.13 ab
MO	0.02 bcd	0.01 b	0.06 b	0.10 b
CA	0.01 d	ND b	0.03 c	0.10 ab
PP	0.04 ab	0.02 b	0.09 a	0.12 ab
CO	0.03 abc	0.01 b	0.06 b	0.12 ab
ZL	0.02 cd	0.01 b	0.02 c	0.06 ab
	Pb			
CK	0.14 a	0.10 a	0.08 a	0.31 a
FO	0.02 b	0.05 ab	0.05 ab	0.25 ab
MO	0.05 b	0.07 ab	0.02 b	0.21 b
CA	0.05 b	0.03 b	0.03 ab	0.15 ab
PP	0.02 b	0.03 b	0.07 ab	0.23 ab
CO	0.02 b	0.03 b	0.03 ab	0.18 ab
ZL	0.02 b	0.03 b	0.05 ab	0.14 ab

: CK-control; FO- Fe oxide (20 tons ha^{-1}); MO-Mn oxide (20 kg ha^{-1}); CA-$CaCO_3$(20 tons ha^{-1}); PP-Calcium phosphate (0.1 tons ha^{-1}); CO-compost (40 tons ha^{-1}); ZL-zeolite (20 tons ha^{-1})
The probability level of significant difference is at p = 0.1. Replicates (n) = 2

(p <0.01). There was no effect of different chemical amendments on the Pb concentration in soil solution because the initial Pb concentration is very low.

The yield of wheat grain significantly increased in the treatments of CA, CA+ZN (or CA+CO) in TT-soil 3, TT-soil 4, and CF-soil 4 (p <0.01) (Table 9). In Chungfu and Tatan soils, the Cd concentration in the grain, stem, and husk of wheat also significantly decreased after applying these treatments (p <0.01) (Table 14). However, there is no effect of different chemical amendments on Pb concentration in the grain, stem, and husk of wheat (data not shown). The application of $CaCO_3$ significantly decrease the Cd concentration in the grain, stem, and husk of wheat and some of them were less than the Cd standard of rice (0.5 mg kg^{-1}) (p <0.01). Except for TT-soil 3, the application of CA and CA+ZN (or CA+CO) significantly decreased the total uptake of Cd by wheat grown in the TT-soil 4, CF-soil 3, and CF-soil 4 (p <0.01) (data not shown). The experimental re-

Table 9. Effect of applying soil amendments on grain yield and Cd concentration in grain, stem, and husk of wheat (Lee et al., 2004).

Treatmwnt#	Grain yield	Cd concentration		
		Grain	Stem	Husk
	----g pot^{-1}----	--------------------mg kg^{-1}-----------------------		
		TT-soil 3		
CK	0.09 b	11.0 a	136 a	27.2 b
CO	0.59 b	7.14 ab	56.0 b	16.1 c
ZN	0.08 b	10.3 ab	125 a	37.6 a
CA	3.04 a	4.63 b	28.4 c	10.2 d
CA+ZN	3.15 a	4.43 b	27.2 c	11.3 d
CA+CO	3.64 a	5.58 ab	38.8 bc	12.0 d
		TT-soil 4		
CK	0.49 bc	10.1 a	62.0 a	19.5 a
CO	1.31 bc	6.79 b	34.8 bc	13.0 b
ZN	0.11 c	8.10 ab	49.4 ab	16.6 b
CA	2.57 a	4.32 c	18.1 c	8.13 c
CA+ZN	1.50 ab	3.74 c	16.0 c	7.46 c
CA+CO	2.64 a	3.53 c	20.4 c	7.19 c
		CF-soil 3		
CK	3.84 a	1.49 b	8.09 a	6.50 a
CO	2.06 a	1.75 a	9.62 a	6.98 a
ZN	3.55 a	1.53 b	7.47 a	6.78 a
CA	4.47 a	0.52 c	1.79 b	1.32 b
CA+ZN	4.57 a	0.36 c	1.25 b	1.00 b
CA+CO	4.05 a	0.47 c	1.73 b	1.40 b
		CF-soil 4		
CK	2.08 b	1.46 b	7.56 b	5.97 b
CO	1.58 b	1.87 a	9.82 a	8.64 a
ZN	2.15 b	1.76 a	8.04 b	7.07 b
CA	4.79 a	0.16 c	0.72 c	0.41 c
CA+ZN	4.52 a	0.13 c	0.71 c	0.32 c
CA+CO	3.20 ab	0.23 c	1.41 c	0.66 c

; CK-control; CO-compost (40 tons ha^{-1}); ZN-ZnO (50 kg ha^{-1}); CA-$CaCO_3$ (rise soil pH to 7.5); CA+ZN-$CaCO_3$+ZnO; CA+CO-$CaCO_3$+compost

The probability level of significant difference is at p = 0.01. Replicates (n) = 4 sult shows that the use of $CaCO_3$ to increase the soil pH value can decrease the bioavailability of Cd in contaminated soil and thus to decrease the uptake by wheat.

5.3. Soil Washing Techniques

The suitable extracting agents which can be applied to the different heavy metals-contaminated soils include water, synthetic chelating agents and acid. Water can be used in the contaminated soils when the most of the metals in the contaminated soils were in the water soluble fractions. The other potential agents for soil washing include diluted acids or synthetic chelating agents. Compared with other remediation methods, soil washing method using diluted acids is highly destructive. This method can decrease the soil pH value, nutrient content, and some exchangeable bases. The population of soil microorganism will disappear after soil acid washing processes. Lime materials, organic materials, and chemical fertilizers are needed to apply and restore the soil characteristics after soil washing.

An off-site study was conducted to assess the effect of applying soil washing method for metals-contaminated soils remediation (Chang et al., 1991). Their experimental results indicated that application of EDTA or citric acid on contaminated paddy soils is efficient to remove Pb and Cd, respectively. Water celery was grown in the initial and treated soils and was harvested at 45th day after first planting. The accumulated Cd and Pb concentration increased from 35-80 and 80-125 (before soil washing) to 68 and 71 mg kg^{-1} (after soil washing), respectively. The experimental results also showed that soil washing had risk potential in increasing the availability of metals in the contaminated soils which was not suitable for crops planting. Further treatments are needed to decrease the high availability of metals after the treatment with soil washing method.

Apollo Technology Co., Ltd. in Taiwan applied acid washing method to remediate a Cd-contaminated site (0.98 ha) of Hsinchu city in the northern Taiwan (Apollo Technology Co., 2000). A pilot study is necessary to obtain the optimum condition before using soil acid washing method to remediate metal-contaminated soils in Hsinchu city, including metal concentration distribution in different sized soil particles and ideal agent for soil acid washing, etc. In this study, the contaminated soils were all soaked in the treatment system by 0.2 M HCl and the maximum operation rate was about 1.8 m^3 soils/day. The used waste liquids (HCl) were drained into the wastewater treating system at the end of the day, recycled as the diluting water after treated and the sludge was packed and treated legally. Soil acid washing method can decrease the soil Cd concentration from 9.58 ± 1.39 to 5.02 ± 0.35 mg/kg and the treating efficiency is about 33-72%. The experimental result shown in the addition of lime materials into the acid washing-treated soils can increase the germination percentage of Chinese kitam. It is necessary for further experiment to assess the effects of applying different soil amendments on the soil fertility of acid washing-treated soils considered by the soil properties and crop metal concentrations.

5.4. Phytoremediation Techniques

Phytoremediation of heavy metals that are usually persistent in the environment is a low-cost and environmentally compatible alternative to the chemical methods and therefore has attracted growing interest since last decade (Blaylock et al. 1997; Baker et al. 1998; Lasat, 2002). Moreover, phytoremediation offers the great advantage of causing only minimal environmental disturbance, since it does not adversely alter the soil matrix. Thus after successful phytoremediation, the soil can be directly used for agricultural purposes. All plants have the potential to extract metals from soil, but some of them have shown the ability to extract, accumulate and tolerate high levels of heavy metals, which would be toxic to other organisms. Such plants are so called hyperaccumulators and also provide the vegetation to control soil erosion on contaminated sites (Brooks et al., 1977; Cunningham and Ow, 1996; Evangelou et al., 2004). For phytoremediation to be successful, plants with high metal uptake capacity and high biomass production are needed. Since most of the known hyperaccumulators have a low annual biomass, much research is being done to enhance the availability of heavy metals in soils and increase phytoextraction efficiency of the potential accumulators (Baker et al., 1998). Another drawback of hyperaccumulator in phytoextraction is not able to accumulate various metals in multi-metal contaminated soils (Lombi et al., 2001; do Nascimento et al., 2006).

Chen and Lee (1997) planted 42 species of garden flowers in the Cd- and Pb-contaminated sites to study the possibility of using these flowers for phytoextraction of metals-contaminated soils. These potential phytoremediation plants include Rainbow pink (*Dianthus chinensis*), Star cluster (*Pantas lanceolata*), Cock-comb (*Celosia cristata*), Impatiens (*Impatiens wallerana*), and French marigold (*Tagetes patula*). After growing in the metals-contaminated sites for 5 weeks, the shoot Cd concentration of rainbow pink increased from 1.56 to 115 mg kg^{-1} (Table 10). The accumulated Cd concentration in their shoot was beyond the threshold of a Cd hyperaccumulator (100 mg kg^{-1}) (Baker et al., 2000). Because of the low availability and mobility of some metals, available synthetic chelating agents were applied to the metals-contaminated soils to increase their uptake by plants and thus to decrease the remediation period (Huang et al., 1997).

The experimental result showed that the application of 5 or 10 mmol 2Na-EDTA kg^{-1} on the soils significantly increased the Cd, Zn, and Pb concentration in soil solution when rainbow pink (*Dianthus chinensis*) was planted in an artificially Cd-, Zn-, and Pb-contaminated soil of Taiwan (p <0.05). The total removal of Pb by rainbow pink was significantly increased after applying these two concentrations of 2Na-EDTA (p <0.05). High metal concentration in soil solution after applying different chelating agents has high risk of groundwater contamination especially in the sandy soil. Lai and Chen (2005) applied 2 or 5 mmol 2Na-EDTA kg^{-1} soil to the single or combined metals-contaminated soils to study the effect of EDTA-enhanced phytoextraction using rainbow pink. The experimental result showed that 5 mmol 2Na-EDTA kg^{-1} soil was significantly to increase the metal concentration in soil solution (Fig. 13) or extracted by deionized water and thus to increase their concentration in the shoots of plants. Results of this studies indicated that rainbow pink is a potential hyperaccumulator for phytoextraction of metals-contaminated

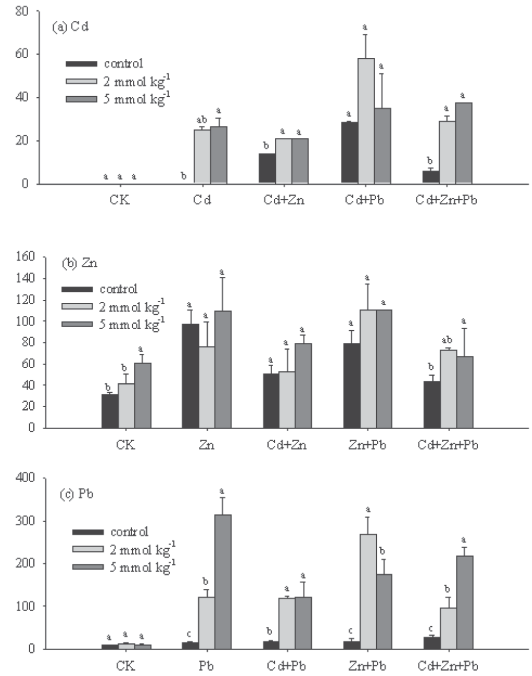

Fig. 13. The (a) Cd, (b) Zn, and (c) Pb concentrations (mg/kg) in rainbow pink shoots harvested at the 7th day after applying 2 and 5 mmol kg^{-1} EDTA solutions. Rainbow pink was grown for 21 days before applying the EDTA solutions. The probability level of significant difference is at p = 0.05. Replicates (n) = 3. (Lai and Chen, 2005)

Table 10. The concentration and total uptake of Cd in the leaves of plants after growing in the contaminated site for 5 weeks (Chen and Lee, 1997)

Plant	Site	Cd concentration in leaves* -------------mg kg^{-1}-------------		Total uptake# g ha^{-1}yr^{-1}
		Before	5 weeks	
Star cluster	Tatan	1.44	43.6	50
Cock-comb	Tatan	2.3	86.7	56
Impatiens	Tatan	1.82	41.5	50
Rainbow pink	Tatan	1.56	115	90
	Chungfu	0.39	11.1	50
French marigold	Tatan	1.15	27.5	70
	Chung-Fu	1.26	11.1	50

*: Replicates (n) = 4; #: 70,000 plants ha^{-1} and 3 times y^{-1}

soils in Taiwan. The phytoextraction effect increased after applying 2Na-EDTA, but the risk of groundwater contamination also increased because of the high metal concentration in soil solution.

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Recent trends in the nutrient status of the paddy field soil in Japan and related topics

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Introduction

Paddy rice production is important for Asian people because rice is their traditional staple diet and it is a reliable crop for them. Rice shows second highest yield per ha next to maize (Kyuma, 2004) and sustainability of paddy rice production is excellent. In general, advantages and sustainability of paddy rice production are at least partly due to flooding and nutrient supply through irrigation water. Yield and quality of paddy rice are better than those of upland rice. In this paper, we review characteristics of the paddy field soils and recent trends in the nutrient status of Japanese paddy field soils, and then we discuss our recent research topics on N, P, S and Cd in the paddy field soil.

1. Characteristics of the paddy field soils

The conventionally tilled Ap horizon, 10-15 cm thick, of paddy field soils in Japan has many similarities even though soil classification names are different (Fig. 1). Soil classification names are determined using properties of soil horizons underlying the Ap horizon.

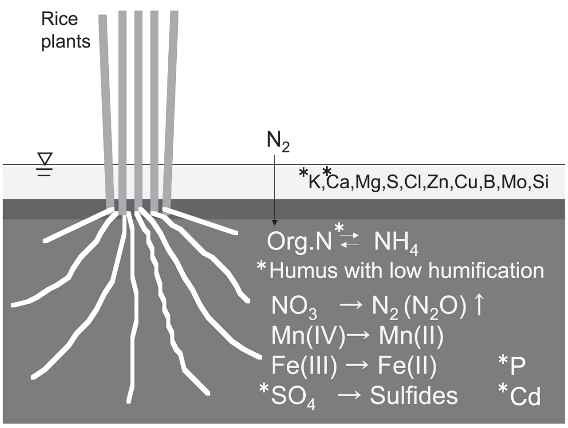

Fig. 1. Characteristics of the paddy field soil.

The Ap horizon is differentiated into two layers under flooded water during the rice-growing season. Upper 1 or 2 centimeters of the Ap horizon is kept oxidative due to O_2 diffusion through flooded water. Two thin layers, in millimeter scale, are often found at the very surface of the oxidative layer. The upper one is fine and the underlying one is relatively coarse due to sedimentation process of suspended soil particles after paddling (Saito and Kawaguchi, 1971). The Ap horizon below the oxidative layer is reduced during the rice-growing season. Manganese oxides, nitrate, iron oxides, sulfate, etc. are reduced, soil pH rises, organic N is partly mineralized, availability of P increases, and sulfides and carbonates of heavy metals may precipitate (Kyuma, 2004). Organic matter with low humification tends to accumulate in comparison with upland soils (Mitsuchi, 1974) due to restriction of O_2 supply.

On the other hand, morphological properties of subsoils are different due to many factors such as topography, groundwater level, drainage, soil texture, and so on. Paddy field soils are largely divided into two types that are endoaquic and anthraquic. The endoaquic type is found in the soil with high water table level. In this type, water percolation is slow and reductive elluviation of Fe from the Ap horizon and accumulation at the underlying horizon are relatively weak. Artificial drainage often improves rice production and harvest operations in the endoaquic paddy fields. Morphological properties of the Anthraquic type are formed due to artificial irrigation to the soils lacking inherited aquic conditions. In this type, subsoil is more or less kept oxidative, water percolation is relatively rapid, and reductive eluviation of Fe from Ap horizon and precipitation of Fe in the subsoil are intensive. Formation of iron mottles and soft Mn oxide masses is conspicuous.

2. Recent trends in nutrient status of Japanese paddy field soils

According to recent statistics (IRRI, 2006), rough rice production in Asia and in the world steeply increased during these 40 years (Fig. 2a). As the increases in the harvested area of the world have been quite gentle (Fig. 2b), it is due to the increase in yield (Fig. 2c) that the rough rice production increased. Regarding Japan, the rice production gradually decreased (Fig. 2a) and the harvested area has also been gradually decreased (Fig. 2b) due to production control that stated in 1970. Although rice yield often declined due to cold summer especially in the northern part of Japan, rice yield still tends to increase gently. These statistics suggest that the nutrient status in the paddy field soils is not deteriorating in Japan and also in the world. Thus, the rice production in the world appears highly sustainable.

Nation-wide soil test data of agricultural lands have been collected in Japan since 1960's (Oda et al., 1987; Obara, 2000; Nakai and Obara, 2003; Obara and Nakai, 2003). As a general view, little deterioration has been found in the paddy field soil during these 3 or 4 decades. Soil pH slightly rose (Fig. 3a), exchangeable Ca content (Fig. 3b), cation exchange capacity (Fig. 4a) and organic C content (Fig. 4b) were almost constant, exchangeable K content (Fig. 3c) and available N content (Fig. 4c) showed a slight increase, and available P content increased (Fig. 4d).

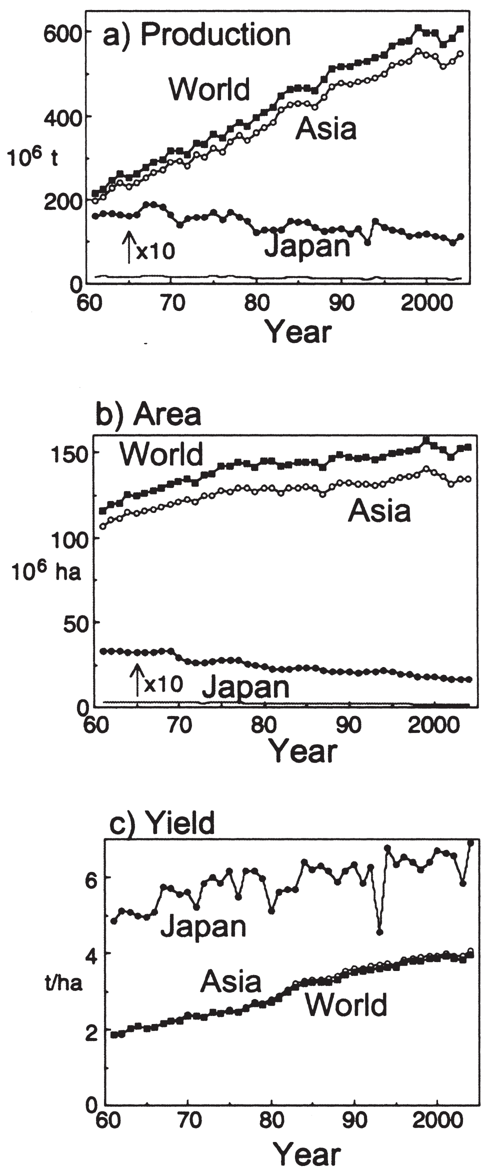

Fig. 2. Rough rice production (a), area (b) and yield (c). (IRRI, World rice statistics)

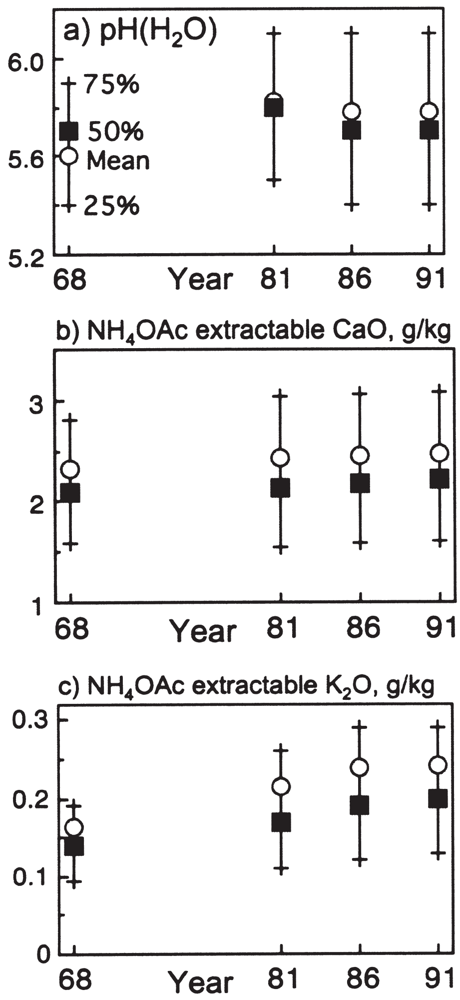

Fig. 3. Changes in pH (H_2O), exchangeable Ca and K.

The increase in exchangeable K content is probably due to recent changes in the method to harvest rice in Japan. Unlike N and P, a major part of K does not translocate to ear and remains in the straw. After widespread of combine harvester, straw is cut and returned to the paddy field soil. Thus, the present K input to the paddy field soil is more than before if the amount of K fertilizer application is the same as before. Slight increase in available N content may be due to application of rice straw and animal wastes.

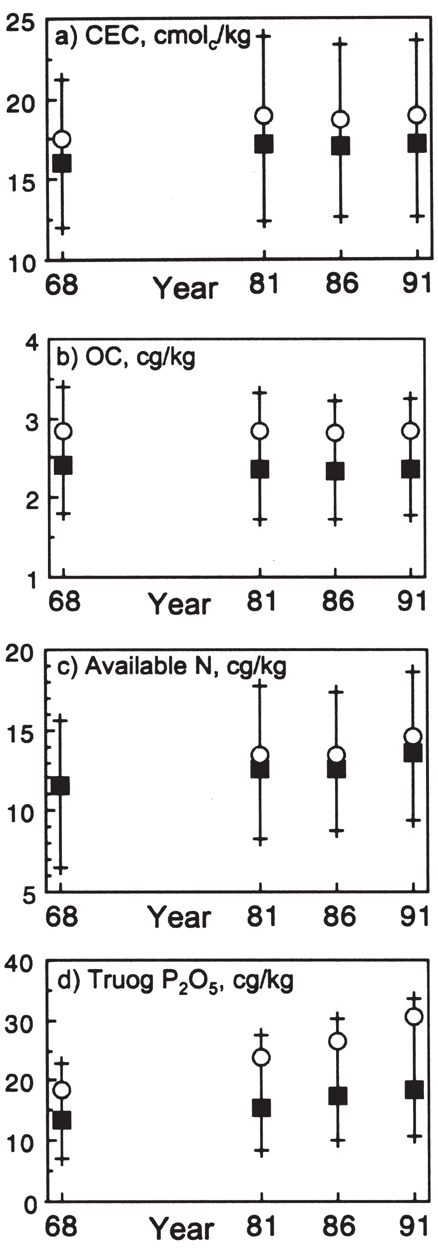

Fig. 4. Changes in CEC (a), Organic C content (b), available N content (c) and Truog P content (d).

The increase in available P is due to fixation of applied P in the soil although the rate of the increase is lower than those in upland and orchard soils.

Supply of nutrients such as Ca, Mg, K, S and micronutrients by irrigation water, increases in availability of Fe, Mn and P for rice plants under reducing conditions and microbial N fixation estimated as 20 to 40 kg ha^{-1} are the reasons for high sustainability of paddy rice production as well as lack of sick soil.

These statistics suggest our paddy rice fields are mostly in ordinary conditions. However, according to regional reports, organic C content is slightly decreasing in Hokkaido (Hashimoto, 2000; Goto et al., 2003) and Ishikawa prefecture (Kitada et al., 1999) due to reduction of organic matter application. Thus, careful management is indispensable to maintain soil fertility in adequate conditions.

Concentration of Si in the irrigation water is decreasing (Kumagai et al., 1998) and the factors involved may be an increase in irrigation canals made of concrete, absorption by diatom in the dam lakes and so on. This is an adverse trend for the recent paddy field soils as Si is beneficial for rice plants.

3. Increase in available N for rice after soy been cultivation

Due to overproduction of rice, shifting from rice to cultivation of other crops in the paddy fields started in 1970 in Japan. Soybean was one of the major crops shifted from rice. It is well known that available N content increases after soybean cultivation (Sumida and Kato, 2001; Sumida et al., 2005, Fig. 5) although the reason is not yet completely understood.

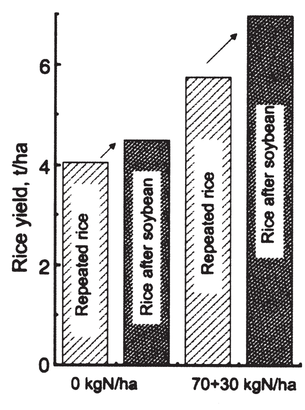

Fig. 5. Rice yield increases after soybean cultivation. Prepared after Sumida et al., (2005)

We determined available N content of the soil under soybean cultivation in pots every month using an incubation method and we found that the available N content of the soil increased during August (Maekawa et al., 2005). The increase in the available N content was confirmed also with rice plant cultivation. However, total N content did not significantly change. Other changes in soil properties were decreases in exchangeable K, Ca and Mg and available P contents.

4. Mobility of P and K applied to the row side of rice seedlings

Machinery transplanting of rice seedling is now common in Japan and fertilizers (P, K and N) are automatically applied to the row side of the rice seedling using nozzles equipped with the rice transplanter. We determined vertical distribution of available P using the modified Bray P (II) method and exchangeable K content of the soils around the site of fertilizer application. High available P content was found at the site of the fertilizers application whereas distribution of the exchangeable K content was almost the same between the sites with and without K fertilizer application (Fig. 6, Akahane et al., 2006a). Thus, P moved little from the site of application. Although P availability in the paddy field soil increases under reducing conditions, the amount of P applied was still less than the P sorption capacity of the soils under reducing conditions (Nanzyo et al., 2004; Akahane et al., 2004). Localized P distribution in the Ap horizon soil was also confirmed by sampling horizontal soil sections after harvest (Fig. 7, Akahane et al., 2006a).

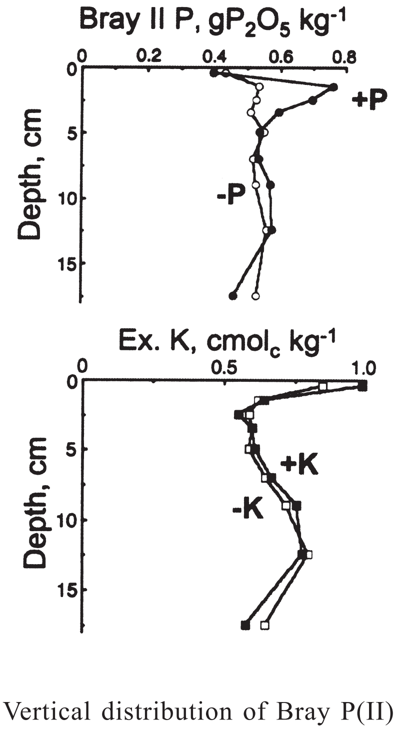

Fig. 6. Vertical distribution of Bray P(II) and exchangeable K at the sites with and without fertilizer application by a transplanting machine.

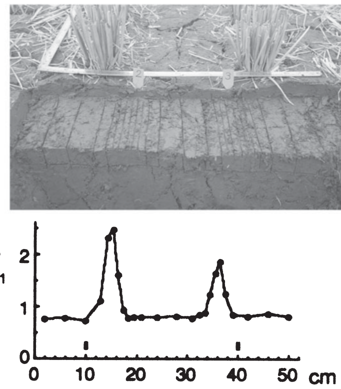

Fig. 7. Horizontal distribution of P applied to row side of rice seedlings.

Vertical distribution of P in the Ap horizon of the paddy field soil is also affected by biological activities. Labile inorganic P was partially converted to organic forms at the very surface of the soil and it was conspicuous in the no-till paddy rice field (Akanahe et al., 2006b).

5. S deficiency symptom of rice observed in the middle course plane of the Nihasama river

As sulfur is generally supplied as a solute in irrigation water and an accessory ingredient of N or P fertilizers, S deficiency was little observed so far. However, after Tsuji (2000) reported S deficiency of rice in Shiga prefecture, similar symptom was also recognized in the middle course plane of the Nihasama river, Miyagi prefecture. Lower leaves of rice plant started to show yellowish color at the growth stage of 5 leaves. Although the symptom resembles N deficiency, it was not ameliorated by an additional N application. It was with an enough application of $CaSO_4 \cdot 2H_2O$ that the symptom was ameliorated almost completely (Sasaki et al., 2006).

6. Partial removal of Cd from a contaminated soil by $CaCl_2$ washing

To ameliorate heavy metal contamination of paddy field soils, countermeasures such as removal of the contaminated soil and piling uncontaminated soil, simple piling of uncontaminated soil on the contaminated soil, removal of heavy metals using hyper-accumulator plants, washing the contaminated soils and so on were examined. Among these countermeasures, soil washing is one of the choices if the contaminated soil is washed and used on site. Washing does not take so long time as remediation by the hyper-accumulator plants. Mild washing procedure is desirable in order to keep the original soil properties and soil fertility as much as possible.

A Cd-contaminated soil was washed with 0.1 M $CaCl_2$ at pH 4. Content of Cd extractable in 0.1 M HCl reduced to almost a third. After thorough washing with water to remove excessive $CaCl_2$, pH was adjusted to about 7 using dolomite powder and rice plants were grown for 3 years using pots. Although removal of Cd is only two thirds, Cd content of the polished rice was kept below 0.2 mg kg^{-1} for at least 3 years whereas it was more than 0.5 mg kg^{-1} in the polished rice grown in the unwashed soil (Hayashi et al., 2006).

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Solophos fertilizer improved rice plant growth in aerobic soil

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Abstract

Yield decline of continuous monocropping of aerobic rice is the major constraint to the wide adoption of aerobic rice technology. This study was conducted to determine if solophos fertilizer could be used to reverse the yield decline of this cropping system using pot and micro-plot experiments. The soil for the pot experiment was collected from a field where aerobic rice has been grown continuously for 11 seasons at the IRRI farm. Four rates (4, 6, 8, and 10 g pot^{-1}) of solophos application were used in the pot experiment. Micro-plots (1 × 1 m) were installed in the field experiment where the 12th-season aerobic rice was grown. Treatments in the micro-plots were with and without additional solophos application. Solophos rate was 4,407.5 kg ha^{-1} which was equivalent to 10 g solophos pot^{-1} used in the pot experiment. An improved upland variety, Apo, was used for both pot and micro-plot experiments. Application of solophos significantly increased plant height, stem number, leaf area, chlorophyll meter reading, root dry weight, and total biomass in the pot experiment. The growth enhancement by solophos application was also observed in the micro-plot experiment under the field conditions. Photosynthetic rate and spikelet number per m^2 were increased by solophos application in the micro-plot experiment. Although the mechanism of growth promotion by solophos application is not clear, this study suggested that solophos application could be used as one of crop management options that could minimize the yield decline of continuous monocropping of aerobic rice.

Introduction

Aerobic rice is defined as high yielding rice grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil. It is responsive to high inputs, can be rainfed or irrigated, and tolerates (occasional) flooding (Bouman and Tuong 2001). Total water use and water productivity of aerobic rice was 27-51% lower and 32-88% higher than that of flooded rice, respectively (Bouman et al. 2005). Grain yield of 5-6 t ha^{-1} can be achieved in aerobic rice using currently available rice germplasm (George et al. 2002). However, yield decline under continuous monocropping of aerobic rice has been reported in Japan by Nishizawa et al. (1971), in Brazil by Guimaraes and Stone (2000), and in the Philippines by Ventura and Watanabe (1978), George et al. (2002), and Peng et al. (2006). Reduction in growth and yield caused by continuous monocropping of the same land is called soil “sickness”, which may involve the build up of soil-borne pathogens and nematodes, depletion of mineral nutrients, moisture stress and adverse effect on soil structure, and accumulation of toxic substances (Ventura, 1984). The causes of yield decline in the continuous aerobic rice system are still unknown. Understanding the causes of yield decline and developing proper management strategies will be very useful for sustaining the yield stability of aerobic rice under continuous cropping.

Zhou et al. (2002) reported that P fertilizer application increased plant height, tiller number, and root volume of rice grown in aerobic soil. Solophos is a commercial P fertilizer with 18.0% of available P_2O_5, 10.0% of S, and 18.0% of CaO. In this study, a pot experiment was conducted to determine the effect of solophos fertilizer on plant growth of aerobic rice grown under "sick" aerobic soil. The "sick" soil was from K6-7 field at the International Rice Research Institute (IRRI) farm where aerobic rice has been grown continuously for 11 seasons. About 40% yield reduction was reported after aerobic rice has been grown continuously for seven seasons in this field (Peng et al., 2006). The effect of solophos fertilizer was also determined in the K6-7 field using 1 × 1 m micro-plots during the wet season of 2006 when the 12^{th}-season aerobic rice was grown. The objective of this study was to determine if solophos fertilizer could be used to reverse the yield decline of continuous aerobic rice cropping system.

Materials and Methods

Pot experiment

A pot experiment was conducted at IRRI using soil collected from the K6-7 field where aerobic rice has been grown continuously for 11 seasons. The soil was Aquandic Epiaquoll with soil chemical and physical properties listed in Table 1. The soil was air-dried, chopped into small pieces, and mixed well for the pot experiment. Four-L porcelain pot filled with 3.0 kg air-dried soil was used in this experiment. Treatments were: four different solophos application rates, oven heating and untreated control. Because biotic and abiotic factors may contribute to "sickness" of aerobic soil under the continuous monocropping of aerobic rice, oven heating of the aerobic soil could alleviate the soil "sickness". Autoclave at 121°C has commonly been used to sterilize soils (Anderson and Magdoff 2005). In this study, pots with aerobic soil were placed inside an oven and treated at 120°C for 12 hours. Solophos rates were: S1 (4.0 g solophos pot^{-1}), S2 (6.0 g solophos pot^{-1}), S3 (8.0 g solophos pot^{-1}), and S4 (10.0 g solophos pot^{-1}). An improved upland variety, Apo, was used because of its good performance under aerobic conditions (George et al. 2002; Lafitte et al. 2002). Pots were placed in a greenhouse using a completely randomized design. Each treatment was replicated six times with six pots.

One day before sowing, different rates of solophos were applied to the pot and then the soil was soaked with tap water and kept saturated for about 1 week to promote good crop establishment after which the pots were kept under aerobic condition. Six pre-germinated seeds were sown in each pot on 5 May 2006 and thinning was done one week after sowing to maintain three uniform seedlings per pot. All pots were watered once every 1-3 days to keep soil moisture near saturation so that aerobic condition was maintained in the pots throughout the experiment. Pesticides were sprayed 3-4 times to control insect damage. Weeds were removed manually.

Plants were sampled on 13 June 2006. Before plant sampling, stem number per pot was counted and plant height from plant base to the tallest tip of leaf in each pot was measured. Three chlorophyll meter (SPAD)

Table 1. Chemical and physical properties of aerobic soil collected from K6-7 field at IRRI farm where aerobic rice has been grown continuously for 11 seasons.

Parameters	Unit	Value	SE
pH	-	7.1	0
Organic C	$g\ kg^{-1}$	16.4	0.03
Total N	$g\ kg^{-1}$	1.74	0.002
Olsen P	$mg\ kg^{-1}$	29.7	0.88
Available K	$mg\ kg^{-1}$	393	1.5
CEC	$cmol_c\ kg^{-1}$	40.5	0.67
Clay	%	58	0.33
Silt	%	33	0.33
Sand	%	9	0

SE represents standard error of mean.

readings were taken on one top-most fully expanded leaf per pot. Plants were separated into leaves, stems including sheath, and roots. Roots were then washed in a sieve with tap water to remove soil particles. Leaf area was measured with a leaf area meter (LI-3000, LI-COR, Lincoln, Nebraska, USA). Dry weights of leaves, stems and roots were determined after oven drying at 70°C to constant weight. Total biomass was the summation of leaf, stem and root dry weights.

Micro-plot experiment

Eight micro-plots of 1 × 1 m were established at 14 days after transplanting (DAT) into the K6-7 field where the 12th-season aerobic rice was grown in the wet season of 2006. In the K6-7 field experiment, twenty-one-day-old seedlings of Apo from wet bed nurseries were transplanted on 28 June 2006 at the rate of 3 seedlings per hill and at a spacing of 25 x 10 cm. Phosphorus (30 kg P ha^{-1} as solophos), potassium (20 kg K ha^{-1} as KCl), and zinc (5 kg Zn ha^{-1} as zinc sulfate heptahydrate) were applied and incorporated in all plots one day before transplanting. Fertilizer N was applied in three splits (20 kg ha^{-1} as basal, 20 kg ha^{-1} at 20 DAT, and 30 kg ha^{-1} at 40 DAT).

Micro-plot treatments were with and without additional solophos application. The treatments were replicated four times. Solophos rate was 4,407.5 kg ha^{-1} which was equivalent to S4 used in the pot experiment. Each micro-plot was surrounded by 30-cm metal plates inserted 15 cm deep in the soil. Plant height, tiller number, chlorophyll meter (SPAD) reading, and photosynthetic rate were recorded on 22 August 2006 at panicle initiation stage. At 14 days after flowering, all plants inside the micro-plot were sampled for growth analysis.

Data were analyzed following analysis of variance (SAS, 1982) and mean comparison between soil treatments was performed based on the Least Significant Difference (LSD) test at the 0.05 probability level for both pot and micro-plot experiments.

Results and discussion

Application of solophos had a significant effect on plant growth and leaf chlorophyll content compared with untreated control in the pot experiment (Figs. 1 and 2). On average, solophos application increased plant height by 46% over the control (Fig. 1a). Solophos input significantly promoted tiller and leaf area production compared with the control (Fig. 1b and

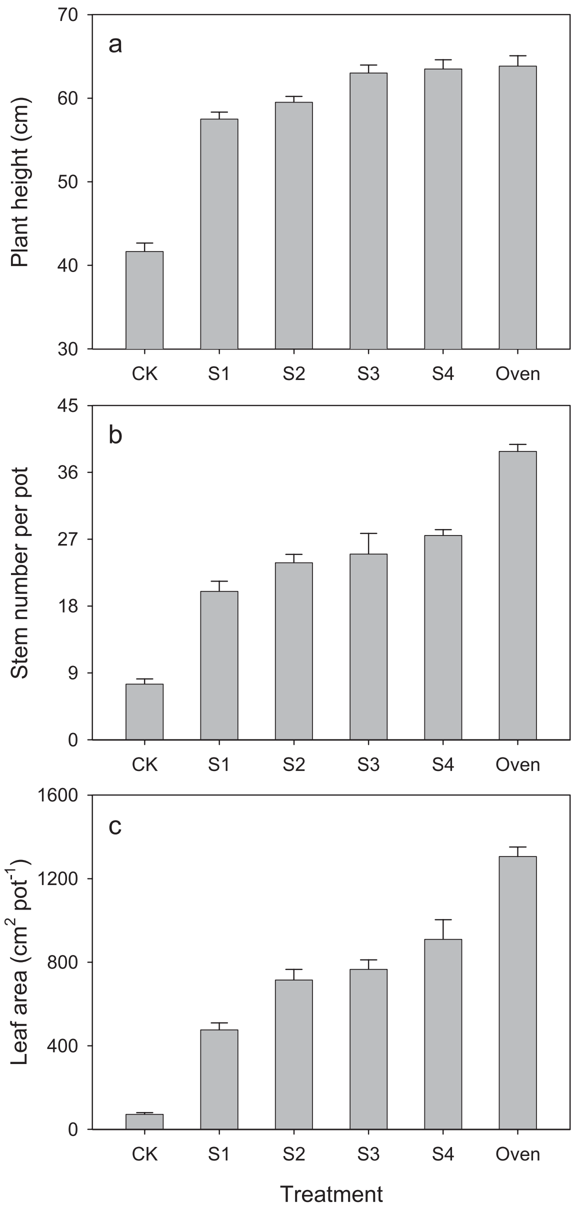

Figure 1. Plant height, stem number per pot, and leaf area per pot of aerobic rice grown under different rates of solophos application (S1 to S4 = 4, 6, 8, 10 g solophos pot^{-1}, respectively), oven-treated, and untreated control in a pot experiment. Soil was from K6-7 field where aerobic rice had been grown continuously for 11 seasons. Soil oven treatment was done at 120°C for 12 hours. Error bars represent standard error of mean (SE).

c). Stem number and leaf area per pot increased with increasing solophos rates. Solophos treated plants also had higher SPAD value, root dry weight, and total biomass than the control (Fig. 2). SPAD value increased as solophos rates increased (Fig. 2a). Plant response in root dry weight and total biomass to solophos application leveled off at 6.0 g solophos pot^{-1} (Fig. 2b and c). Among the plant growth parameters and leaf chlorophyll content, leaf area had the largest response to solophos, followed by total biomass, root dry weight, stem number, plant height, and SPAD value.

Oven heating increased plant growth and leaf chlorophyll content compared with untreated control in the pot experiment (Figs. 1 and 2). Oven heating had larger effects on stem number, leaf area, SPAD value, root dry weight, and total biomass than solophos application. The difference in plant height between solophos and oven treated plants was relatively small (Fig. 1a). The beneficial effect of oven heating of aerobic soil on plant growth suggested that the soil treatment removed some or all factors that had caused soil "sickness". Oven heating might have killed nematodes, fungi, and bacteria in the "sick" aerobic soil. At the same time, heating treatment could facilitate the availability of nutrients due to the changes of soil chemical and physical properties.

High level of solophos application in micro-plots increased crop growth significantly in the 12th-season continuous aerobic rice under the field conditions (Table 2). Solophos increased plant height by 60%, stem number by 79%, SPAD value by 45%, and single-leaf photosynthetic rate by 26% at panicle initiation stage compared with the control. There was a strong typhoon on 28 September 2006 and the plants were totally lodged. All lodged plants inside the micro-plots were harvested the next day after the typhoon to determine aboveground total biomass and spikelets m^{-2}. The micro-plots with high level of solophos application had 65% higher aboveground total biomass and 85% more spikelets m^{-2} than the control at 14 days after flowering (Table 3). These data in the micro-plot experiment confirmed the results of the pot experiment. Grain yield and yield components were not available due to the typhoon damage.

Solophos fertilizer was effective in enhancing plant growth of aerobic rice grown in the "sick" soil both in pot and micro-plot experiments. Although solophos is a commercial P fertilizer, we can not conclude

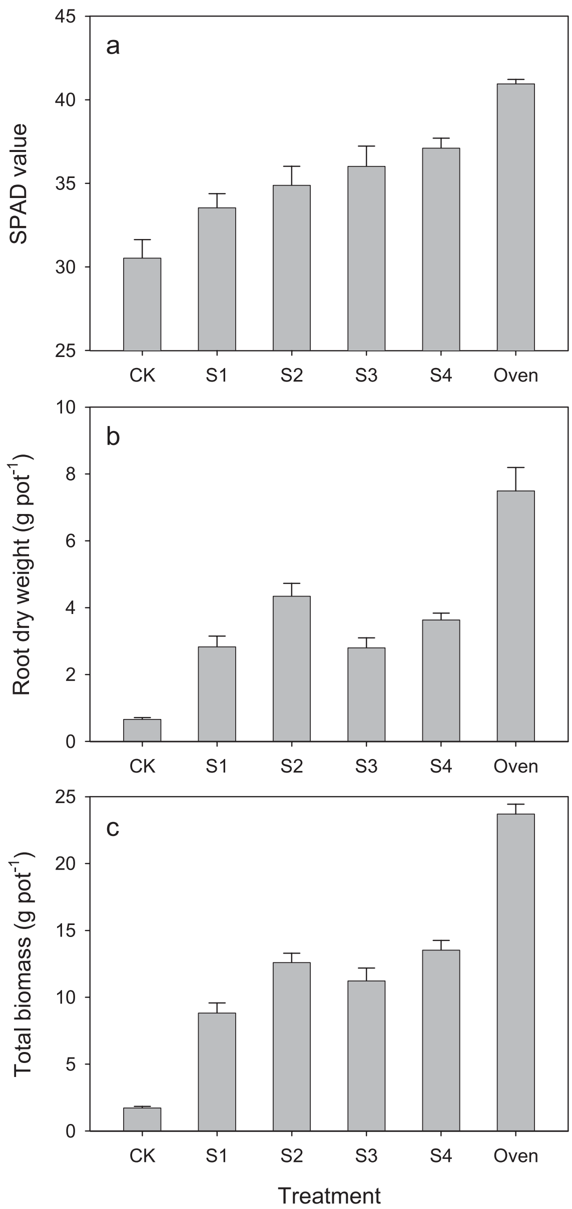

Figure 2. Chlorophyll meter (SPAD) reading, root dry weight per pot, and total biomass per pot of aerobic rice grown under different rates of solophos application (S1 to S4 = 4, 6, 8, 10 g solophos pot^{-1}, respectively), oven-treated, and untreated control in a pot experiment. Soil was from K6-7 field where aerobic rice had been grown continuously for 11 seasons. Soil oven treatment was done at 120°C for 12 hours. Error bars represent standard error of mean (SE).

Table 2. The responses of plant height, stem number, chlorophyll meter (SPAD) reading, and photosynthetic rate to solophos application at panicle initiation stage in the 12th-season aerobic rice grown at IRRI farm in the wet season of 2006.

Parameter	Control	With solophos
Plant height (cm)	62.3 b	99.7 a
Stem number per hill	7.2 b	12.9 a
SPAD value	29.6 b	43.0 a
Photosynthetic rate (μmol m^{-2} s^{-1})	21.6 b	27.3 a

Within a row, mean followed by different letters are significantly different at 0.05 probability level according to Least Significant Difference (LSD) test.

Table 3. The responses of aboveground total biomass and spikelet number per m^2 to solophos application at 14 days after flowering in the 12th-season aerobic rice grown at IRRI farm in the wet season of 2006.

Parameter	Control	With solophos
Biomass (g m^{-2})	842.6 b	1391.3 a
Spikelets m^{-2} (x1000)	25.9 b	48.1 a

Within a row, mean followed by different letters are significantly different at 0.05 probability level according to Least Significant Difference (LSD) test.

that the enhancement in plant growth was due to the improvement of P nutrition. First of all, 60 kg P ha^{-1} and 30 kg P ha^{-1} as solophos were applied in the dry and wet seasons respectively, every year since 2001 in the K6-7 field. Secondly, the "sick" soil contained 29.7 mg Olsen-P kg^{-1}, which was higher than the critical level for normal plant growth. We observed that Olsen-P content of the continuous aerobic rice soil has increased as the season progressed (data not shown). Thirdly, oven heating treatment on the "sick" soil did not alter Olsen-P or Bray-P contents. Therefore, it is unlikely that P deficiency is the cause of the soil "sickness" that was responsible for the yield decline of continuous monocropping of aerobic rice. In the subsequent experiments, the effects of solophos application and oven heating on soil physical and chemical properties, soil pathogens, and nematodes will be studied. Although the mechanism of growth promotion by solophos application is not clear, this study suggested that solophos application could be used as one of crop management options that could minimize the yield decline of continuous monocropping of aerobic rice.

Acknowledgement

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Introduction to Studies on Volcanic Ash Soils in Japan and International Collaboration

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1. Outlining properties of volcanic ash soils

The Japanese Islands are the places where 4 tectonic plates, that are Pacific, North American, Eurasia and Philippine Sea plates, meet. There are active volcanoes more than 80, and medium and small-scale eruptions frequently occur somewhere in Japan. Volcanic ash soils cover approximately one-sixth of the Japanese land surface. Volcanic ash soils are mainly distributed in southern and eastern parts of Hokkaido, eastern part of Tohoku, Kanto, Chubu, around the Mt. Daisen in Chugoku, and central and south Kyushu districts (Saigusa and Matsuyama, 1998). The word "volcanic ash soil" is used for any soil derived from volcanic ash. Kurobokudo is a name used more specifically for a black and fluffy soil, and is the major soil derived from volcanic ash on the uplands in Japan. Kurobokudo, Andisols, Andosols and Ando soils are the names used for the volcanic ash soils rich in active Al and Fe, and the definitions of these words are similar in many respects. In this paper, "Ando soils" is used as a common name.

a. Morphological properties

The matured Ando soils show a unique set of morphological, mineralogical, chemical and physical properties. A thick, humus-rich, dark-colored A horizon underlain by a brown Bw horizon is a typical profile of these soils. The black A horizon is formed under grass vegetation dominated by C4 plants (Yoneyama et al., 2001) and the grass vegetation was maintained by intensive human activities like setting fire to the fields. On the other hand, the dark brown A horizon is formed under forest vegetation. Thick multi-sequum soils locate near large volcanoes as a result of repeated huge eruptions with long dormant periods. Fresh deposits of air-borne ash and lahar are sandy layers, and they are vitrandic Entisols or volcanogenous regosols.

b. Mineralogical properties

Volcanic glass is the major component of the fresh volcanic ash and it is the major parent material of the Ando soils. Non-crystalline or poorly crystalline minerals such as allophane, imogolite, ferrihydrite and opalline silica are the characteristic secondary minerals in the Ando soils. Allophane has a very small hollow spherical structure 3 to 5 nm in diameter (Wada, 1989). Imogolite has very thin tubular structure 1 and 2 nm in inner and outer diameters, respectively. The typical allophane shows elemental composition close to $SiO_2 \cdot Al_2O_3 \cdot nH_2O$ similar to that of imogolite (Wada, 1989). Opalline silica shows thin ellipsoidal shape, consists mostly of silica, and is often found in the A horizon of young Ando soils (Shoji and Masui, 1971).

c. Chemical properties

Ando soils show unique chemical properties such as high phosphate sorption capacity, variable charge, etc. due to abundant non-crystalline secondary minerals and highly humified humus complexed with Al (Shoji et al., 1993). Phosphate is sorbed by the active Al contained in allophane, imogolite and Al complexed with humus and by the active Fe in ferrihydrite. A series of reactions are accompanied by the phosphate sorption such as a decrease in the amount of positive charge of the soil, release of hydroxide ion, silicate ion and soluble organic matter from the soil, and an increase in negative charge of the soil (Nanzyo and Watabanbe, 1981; Nanzyo, 1988). The variable charge means the amount of positive and negative charges dependent on pH and concentration of an indifferent electrolyte. The positively charged site is formulated as a protonated hydroxo-ligand bound to active Al and Fe. The negative charge arises from dissociation of hydroxyl group bound to the active Al and Fe and dissociation of carboxyl groups. The negative variable charges show high preference to multivalent cations, including heavy metals (Wada, 1989).

d. Physical properties

The noncrystalline and poorly crystalline secondary minerals and humus also affect the physical properties of Ando soils (Shoji et al., 1993). Allophane, imogolite, ferriydrite and humus form stable and highly aggregated structures that have abundant micro, meso and macro pores. These highly porous structures hold a large amount of hygroscopic and plant-available water. The porous structure also leads to high hydraulic conductivity of these soils. The highly porous structure is the reason for the low bulk density of these soils. Due to the high stability of porous micro aggregates that accommodate water inside, these soils show high liquid and plastic limits. Allophane and imogolite hardly disperse at neutral pH range because they have the zero point of charge in this pH range. Abundant humus further stabilizes the aggregated structure. Water holding capacity, dispersibility of noncrystalline clays, liquid and plastic limits of these soils irreversibly decrease with drying.

e. Classification

Some of the properties mentioned above are used in the criteria of soil classification systems. High phosphate sorption capacity defines the Kuroboku soil group in the classification of Japanese cultivated soils. The Kuroboku soil group corresponds to Andisols in the Soil Taxonomy (ST) of the United States Department of Agriculture (Soil Survery Staff, 1999; 2006), and Andosols of the World Reference Base for Soil Resources (WRB) (FAO, 2006). Abundant oxalate-extractable Al and Fe, low bulk density and high phosphate retention are the important requirements to define matured Andisols and Andosols (WRB). Volcanic glass content is also used to characterize young Andisols and vitric Andosols (WRB). Subdivision into allophonic and nonallophanic ones according to the predominance of allophane-imogolite or Al-humus complex is included at least partly in all the classification systems of the Kuroboku soil group, Andisols and Andosols (WRB).

f. Genesis

Ando soils are mostly formed on uplands under humid climates (Shoji et al., 1993; 2006). Volcanic glass, commonly rich in Si, is dissolved forming Al-rich colloidal materials that are allophane, imogolite

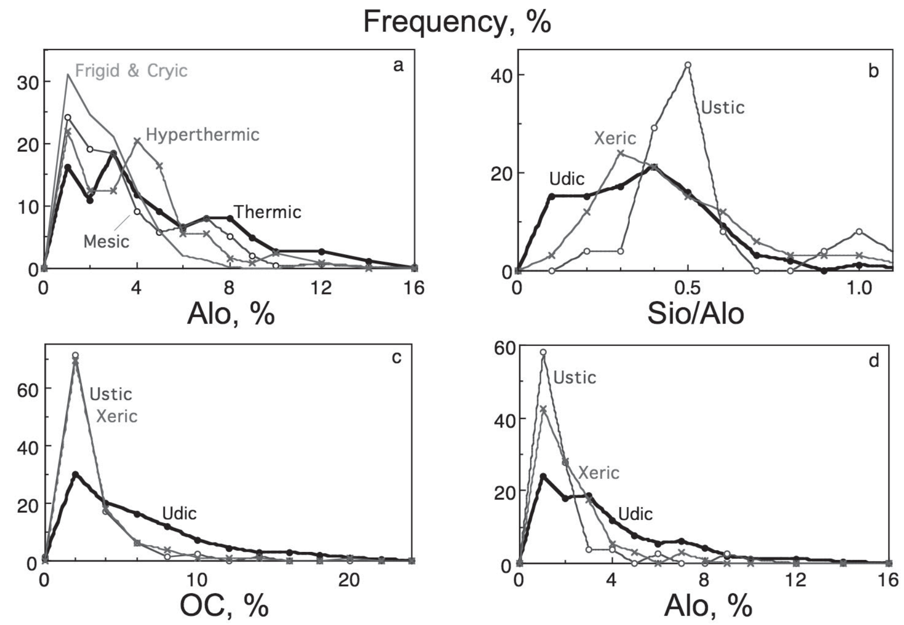

Fig. 1. Effect of climate on Ando soil formation (Shoji, et al., 2006).

and Al-humus complex and Fe-rich ferrihydrite. Rapid dissolution of volcanic glass and removal of Si and basic cations needs humid climate and location on uplands with good drainage (Fig. 1). Inceptisols are also formed under semi-dry and dry climates and in the poorly drained areas possibly due to slower removal of Si. Spodosols are possibly formed under humid and cold climate due to intensive formation of soluble chelating organic materials in the overlying organic layer (Shoji et al., 2006).

g. Utilization

Ando soils in Japan were previously the problem soils due to phosphorus deficiency, high Al toxicity of non-allophanic Ando soil, Cu and Zn deficiency and so on. These chemical problems have been amended and the Ando soils are used as excellent upland fields having good physical properties such as high air and water permeability, and high water holding capacity (Shoji et al, 1993). Root crops such as horse raddish, chinese yam, burdock, are especially suitable for Ando soils as well as many other upland crops. In the tropical countries, Ando soils are relatively graded better than in Japan possibly due to high temperature enhancing phosphorus release, nitrogen mineralization and plant growth.

2. Studies on volcanic ash soils in Japan

It is almost a century since Seki's early work on volcanogenous loam was published (Shoji et al., 1993). Several monographs on volcanic ash soils were published in English in the latter half of the 20th century. In 1964, the Ministry of Agriculture and Forestry (1964), Japanese Government, compiled "Volcanic Ash Soils in Japan". The book includes ten chapters that are distribution of volcanic ash soils, land use, soil minerals, physical properties, soil erosion, chemical properties, microbiological properties, classification, valuation on productivity of volcanic ash soils, and development of soil productivity. By that time, variable charge properties (Iimura, 1966) and high phosphate sorption capacity of Ando soils were recognized, and Yoshinaga and Aomine (1962) discovered imogolite. Humic acid type in Ando soils was found to resemble that of Tsuernozems by Kumada et al. (1967). In 1986, Wada published "Ando Soils in Japan". This book includes detailed soil characterization data of 26 soil profiles covering south to north of representative sites in Japan (Wada, 1986). By that time, opalline silica was reported by Shoji and Masui (1969) in the A horizon of young Ando soils. Then, unique shape of allophane particles was described by Kitagawa (1971) and was confirmed by Henmi and Wada (1976). A comprehensive book "Volcanic Ash Soils-genesis, properties and utilization was published by Shoji, Nanzyo and Dahlgren (1993) integrating the developments made by International Committee on the Classification of Andisols (ICOMAND) and other research works from all over the world as well as those from Japan. By this time, the Andisol order was established in ST as the eleventh soil order (Eswaran and Beinroth, 2000).

Moreover, many valuable review papers and special issues on Ando soils were published by Japanese authors as follows: Amorphous clay constituents of soils (Wada and Harward, 1974), Physical properties of allophane soils (Maeda et al., 1977), The distinctive properties of Andosols (Wada, 1985), Allophane and imogolite (Wada, 1989), Clay mineralogy and chemistry of soils formed in volcanic material in diverse climatic regions (Mizota and Reeuwijk, 1989), Volcanic ashes and their soils (Matsumoto, 2002), The nature, properties and management of volcanic soils (Dahlgren et al., 2004), and Factors of soil formation: climate. As exemplified by volcanic ash soils. (Shoji et al., 2006).

3. International collaboration

Many collaborative works between Japan and overseas countries have been done to develop sciences on volcanic ash soils. The name "Ando soils" was introduced in 1947 during reconnaissance soil survey in Japan by American soil scientists (Simonson, 1979; Hirai and Hamazaki, 2004). In 1964, FAO soil correlation meeting on volcanic ash soils was held in Tokyo. During this meeting, the attendants visited 8 pedons in Hokkaido, Kanto and Kyushu districts, and definition of Kurobokudo were discussed based on their properties (Oyama, 1965). Two seminars on amorphous materials in soils were held at Kyushu University and Oregon State University in 1969 and 1976, respectively, for the direct exchange of information and cooperative studies (Van Olphen, 1971; Haward and Wada, 1976). In 1978, ICOMAND was established after the Andisol proposal of G.D. Smith. Many workshops and meetings were held during the ICOMAND activities for more than 10 years (Eswaran and Beinroth, 2000). The 9th International Soil

Fig. 2. Participants to 9th International Soil Classification Workshop.

Classification Workshop was held in Kanto, Tohoku and Hokkaido districts, Japan, in 1987 (Fig. 2). The tour guide describing geological and climatic information, morphology of soil profiles and characterization data of 23 pedons were delivered at the meeting (SMSS and Japanese Committee of the Ninth International Soil Classification Workshop, 1987; Shoji and Otowa, 1987) and the proceedings were published by Kinloch et al. (1988). The number of attendants was about 120 from Japan and 40 from 16 overseas countries. The central concept of Andisols was revised from the exchange complex dominated by amorphous materials to abundant active Al and Fe including humus-Al complex during the ICOMAND activities. Collaborative works were also done in Indonesia (Miyake, 1983) and Philippines (Otsuka et al., 1988; Otsuka, 1991; Yoshida and Takahashi, 1992; BSWM and SRDC, 1993; Samonte et al. 1995; Nanzyo, 1996; Nanzyo et al, 1999) under the projects and supports of the former Tropical Agricultural Research Center, Japan International Cooperative Agency, the Japanese Government, and the Ministry of Education, Science, Sports and Culture of Japan.

Many Japanese researchers visited USA, New Zealand, European countries etc., to attend meetings and to study Ando soils in overseas countries. The meeting on soils with variable charge was held in New Zealand in 1980 (Theng, 1980). International symposium was held on Rehabilitation and Improvement of Productivity in Pinatubo Lahar and Ashfall Areas in Central Luzon, Philippines (National Research Council of the Philippines, 1997). A series of meetings were held between 1998 and 2004 as the European Cooperation in the field of science and technical research (COST) action titled Soil Resources of European Volcanic Systems (COST-622) (Bartoli et al., 2003; Arnalds and Stahr, 2004; Oskarsson and Arnalds; 2004; Arnalds et al., 2007; Buurman et al., 2007). The Field Science Center, Tohoku University held an meeting on New Perspectives of Volcanic Ash Soils in the Integrated Ecosystems in 2004 having 6 speakers from overseas countries in the Circum Pacific Volcanic Zone (Nanzyo et al., 2005). Recent developments of the studies on Ando soils were discussed and a field workshop was held in the Mt Fuji area in Japan (Takesako, 2006; Lowe, 2006). The main objectives of IVth International Symposium on Deteriorated Volcanic Soils (ISVO'06) were to promote the exchange and discussion about the general problem of deteriorated volcanic soils, the improved management approaches and the challenges that lie ahead of the agricultural and soil scientists, and particularly of the farmers living in volcanic regions all over the world (Bravo et al., 2006). Participants were from Central and South America, Europe, USA and Japan. Intensive research activies of the European soil scientists in collaboration with the Central and South American countries were introduced in this meeting.

The titles of symposium related to Andosols in the recent World Congresses of Soil Science are "Physical, chemical and mineralogical characteristics of Ando soils" at Kyoto in 1990, "Indurated volcanic soils: use and management" at Acapulco in 1994, "Crystal chemistry of trace elements and evolution in soils of short range ordered minerals" at Montpellier in 1998 and "Andisols and related soils" at Philadelphia in 2006. Many presentations on the clay fraction of Ando soils and a session on "soil and non-crystalline clays" were included in the International Clay Congress held in Japan in 1969 (Heller, 1969; 1970) and in 2005 (Narita, 2006), respectively.

4. Perspectives

Human impacts on soils and environments are increasing now. Even under these situations, objectives of soil science are to elucidate material cycles quantitatively in the surface layer of the earth, to control the material cycles for environmental conservation and sustainable crop production, to keep the soil quality high, etc. High buffering capacities of Ando soils in many reactions appear useful to ameliorate some environmental problems. International collaboration will contribute to exchange our information and help our development because the properties of Ando soils are dependent on regional climates and human activities. Integration of developments in the different scientific fields and new fact-findings will also be effective to approach our goals.

Acknowledgement

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Relationship between watershed environments and growth of coastal diatoms

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Abstract

Effect of watershed environments on river water quality and the subsequent influence of water quality on the growth of diatoms in coastal seawater were studied. Land use in the upper and lower site of the Ohkawa River (O-up and O-low) and the upper site of the Nanakita River (N-up) were dominated by forestry, whereas the lower site of the Nanakita River (N-low) was characterized by urbanization. Seasonal changes in nutrients in the Ohkawa and Nanakita Rivers suggested that the concentrations of NH_4-N, NO_3-N, PO_4-P and acid extractable-Fe were influenced by human activities, while Si concentration reflected geological conditions. The average concentrations of fulvic acid-like Fe (FA-Fe), closely associated with the growth of coastal diatoms, were 1 and 16 μg L^{-1} at the O-up and O-low sites, respectively, while those of the Nanakita River were 5 μg L^{-1} (N-up) and 53 μg L^{-1} (N-low). For each river, FA-Fe concentrations of the lower sites were much higher than the upper sites. Moreover, the concentration of FA-Fe at N-low was much higher than at O-low. Therefore, it was concluded that FA-Fe originates not only from forest vegetation but also from urban activity. The growth of the *Skeletonema*, a typical diatom of coastal waters, was stimulated by the addition of O-low river water compared to addition of O-up, reflecting the FA-Fe content. Diatom growth stimulation with the addition of lower river water was much more prominent in the Nanakita River, whose watershed is characterized by runoff from Sendai city.

Introduction

Since the late 1960s, the production of the both oyster and laver has been decreasing in Kesennuma Bay in Miyagi Prefecture. Fishermen considered that some nutrients from upstream sites, and transported to the coast by the Ohkawa River, may have been reduced by deforestation in mountainous areas. Therefore, they started the afforestation movement “Mori wa Umi no Koibito”, meaning “Forest is a sweetheart for Sea”, by transplanting broadleaf trees on the mountain areas of Mt. Murone and Mt. Yagoshi, which are the watersheds of the Ohkawa River (Hatakeyama, 2003).

Phytoplankton plays an important role in primary production in the sea and nutrients for their growth are supplied from rivers flowing into the coastal areas. Of these nutrients, recent research has shown that iron-binding organic matter played significant role in the growth of diatoms and seaweeds in coastal regions (Matsunaga et al., 1998a, 1998b). These authors have suggested that the form of iron is a fulvic acid-like iron (FA-Fe), originating from forest ecosystems. Generally, it has been considered that river water quality affects coastal ecosystems to a significant degree. Therefore, the influence of watershed environments on river water quality and how nutrients in river water affect primary production in coastal ecosystems deserves further study. However, there is little research on the relationship between watershed environments and coastal sea ecosystems.

The seasonal changes in water quality in the Ohkawa and Nanakita Rivers, which have different watershed environments, and especially the concentration of FA-Fe in river water, were studied in detail. The effect of water quality, e.g. FA-Fe, on the growth of a typical coastal diatom (*Skeletonema*) was also investigated.

Materials and Methods

Study area

Figs. 1 and 2 showed the watershed of the Ohkawa and Nanakita River, respectively. The source of the Ohkawa River lies near Mt. Toishi in the south of Iwate Prefecture and the river flows into Kesennuma Bay in the north of Miyagi Prefecture. The river is about 25 km long and the area of the watershed is about 16 700 ha. Forest vegetation occupies a considerable area of the Ohkawa River watershed and the well-known, reforestation strategy has been implemented at Mt. Yagoshi since 1993. The surface geology at the upper river region is mostly plutonic rock.

The source of the Nanakita River lies near Mt. Izumigatake in Miyagi Prefecture and the river flows into Sendai Bay. The river is about 40 km long and the area of the watershed is about 22 300 ha. Forest occupies the upper region but urban areas also lies along the middle and lower regions, with paddy and upland fields also developed along the river. The Nanakita dam lies on the upper river. The surface geology of the upper region is mostly volcanic rock.

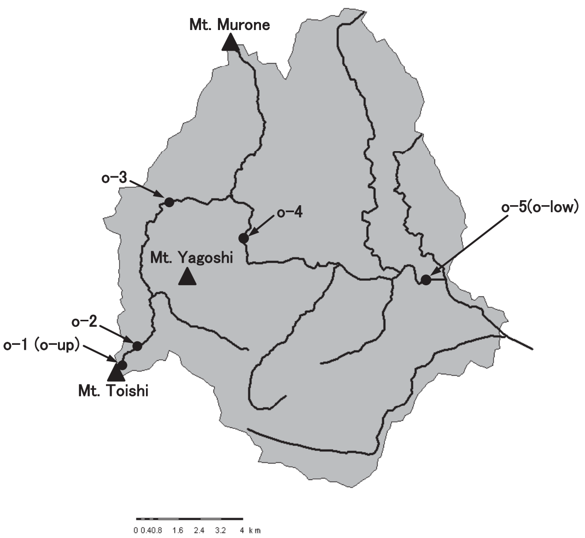

Figure 1. Watershed of the Ohkawa River

Watershed River Sampling site

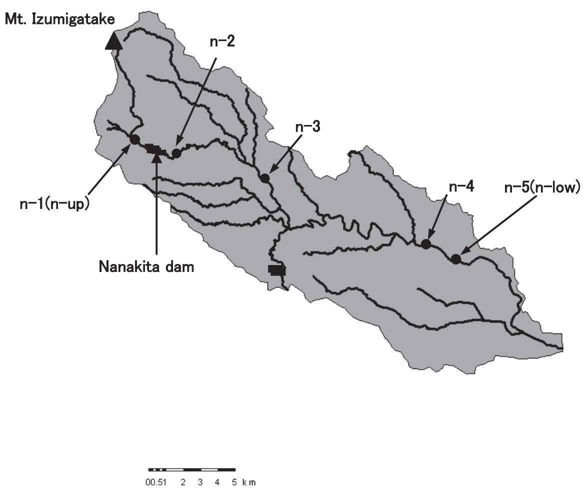

Figure 2. Watershed of the Nanakita River

Watershed River Sampling site

Nutrient analysis of river water

River water was sampled from June 2003 to April 2004. The sampling sites on the Ohkawa and Nanakita Rivers are shown in Figs. 1 and 2, respectively, listed as o-1 to o-5 for the Ohkawa river and n-1 to n-5 for Nanakita river. The concentrations of Si, NH_4-N, NO_3-N, PO_4-P and acid extractable-Fe (Acid-Fe), pH and EC were recorded. Water samples were collected directly in polyethylene bottles at each site. The samples, except for Acid-Fe, were filtered though 0.45-μm Millipore filters and kept in a refrigerator at 5°C until analyses. HNO_3 was added to the samples for Acid-Fe analysis at a final concentration of 10% and kept in a refrigerator at 5°C. All elements were analyzed following the established methods (The Japanese Society for Analytical Chemistry, 1994).

Iron analysis

River water samples were collected at the up- and down-stream sites in each river from June to November 2005. The concentration of acid-dissolved iron (Acid-Fe), total dissolved iron (D-Fe) and fulvic acid-like iron (FA-Fe) were analyzed by the ferrozine method (Stookey, 1970) after the following treatments. To 100-ml of river water for Acid-Fe analysis was added 10 ml of 3 M HCl and boiled; then the samples were analyzed. The river water for both D-Fe and FA-Fe analysis were filtered through 0.45 μm Millipore filters. FA-Fe is the fraction in the D-Fe adsorbed by the anion exchange resin. The method for elution of FA-Fe followed the procedure of Igarashi et al. (1982).

Cultivation of the diatom

Coastal water was collected at Kesennuma Bay in Miyagi Prefecture in November 2005. Salinity of the seawater was 31‰. River water samples were collected at the upper and lower sites of the Ohkawa River (O-up and O-low) and Nanakita River (N-up and N-low) on the same day. *Skeletonema* from stock species was cultivated in media treated with different river water samples. The treatments for cultivation are shown in table 1. The cultivation media were prepared by adding river water to the coastal seawater (1:10). Diatom was cultured at 20°C under 61 $\mu mol^{-1}\ m^{-2}$ fluorescent light (12-h light/dark cycle) for 5 days. The samples were stirred three times a day. After 5 days, samples were place on a 100-mm^3 glass chamber for counting diatom cells (MATSUNAMI Co. MPC-200) and counted under an inverted light microscope (Nikon Co. ECLIPSE TE300).

Table 1. Treatment of diatom

Treatment	media	added river water	diatom
DW	coastal water	DW	*Skeletonema*
o-up	"	collected at o-up site	"
o-low	"	collected at o-low site	"
n-up	"	collected at n-up site	"
n-low	"	collected at n-low site	"

Coastal water was sampled at the Kesennuma Bay (Salinity = 30‰). DW means deionized water. *Skeletonema* was the stocked species.
o-up: Sampling site at upper river of the Ohkawa River
o-low: Sampling site at lower river of the Ohkawa River
n-up: Sampling site at upper river of the Nanakita River
n-low: Sampling site at lower river of the Nanakita River

Results and Discussion

Nutrient dynamics in river water

Figure 3 shows the nutrient dynamics for the Ohkawa and Nanakita Rivers. The abscissa shows the distance of sampling site from the source of the stream; the vertical axis shows the concentration of each nutrient. In both rivers, the variation of Si concentration was small versus distance and seasons, but the Si concentration of down-stream water tended to decrease compared to up-stream water. NH_4-N concentration of the Ohkawa River was low and varied little; however, but in the Nanakita River it was also low in the upper sites but showed a high concentration and large variation in the lower sites. NO_3-N concentration of the Ohkawa River showed little variation, except in June, while in the Nanakita River it was low in upper sites but showed a high concentration and large variation in the lower sites. PO_4-P concentrations showed no steady patterns but large seasonal variations were recorded in both rivers. Acid-Fe concentration showed a large variation for both distance and season.

Large variations in nutrient concentration seem to be influenced by extraneous factors, such as precipitation, drainage from agricultural fields, urbanization, river conservation works, etc. However, the amount of precipitation on the sampling days was small (0-13 ml day^{-1}) and, thus, the level of water in the river was unchanged. Therefore, the variation in NH_4-N, NO_3-N, PO_4-P and Acid-Fe concentrations may originate from human activities, while that of Si does not.

Relationship between watershed environment and FA-Fe concentration

The FA-Fe, D-Fe and Acid-Fe concentrations at the upper and lower sites of both rivers are shown in Fig. 4. FA-Fe concentrations at upper site of the Ohkawa River (O-up) for each month ranged 0-2 $\mu g\ L^{-1}$ with an average of 1 $\mu g\ L^{-1}$, whereas those at lower site (O-low) were 9-26 and 16 $\mu g\ L^{-1}$, respectively. The FA-Fe concentration at upper and lower site of the Nanakita River (N-up and N-low) were 4-7 $\mu g\ L^{-1}$ (average: 5 $\mu g\ L^{-1}$) and 43-73 $\mu g\ L^{-1}$ (average: 53 $\mu g\ L^{-1}$), respectively. Similar data were reported from the lower site in a previous paper: 7-28 $\mu g\ L^{-1}$ (average: 16 $\mu g\ L^{-1}$) (Matsunaga et al. 1998b). In both the Ohkawa and Nanakita River, the FA-Fe concentra-

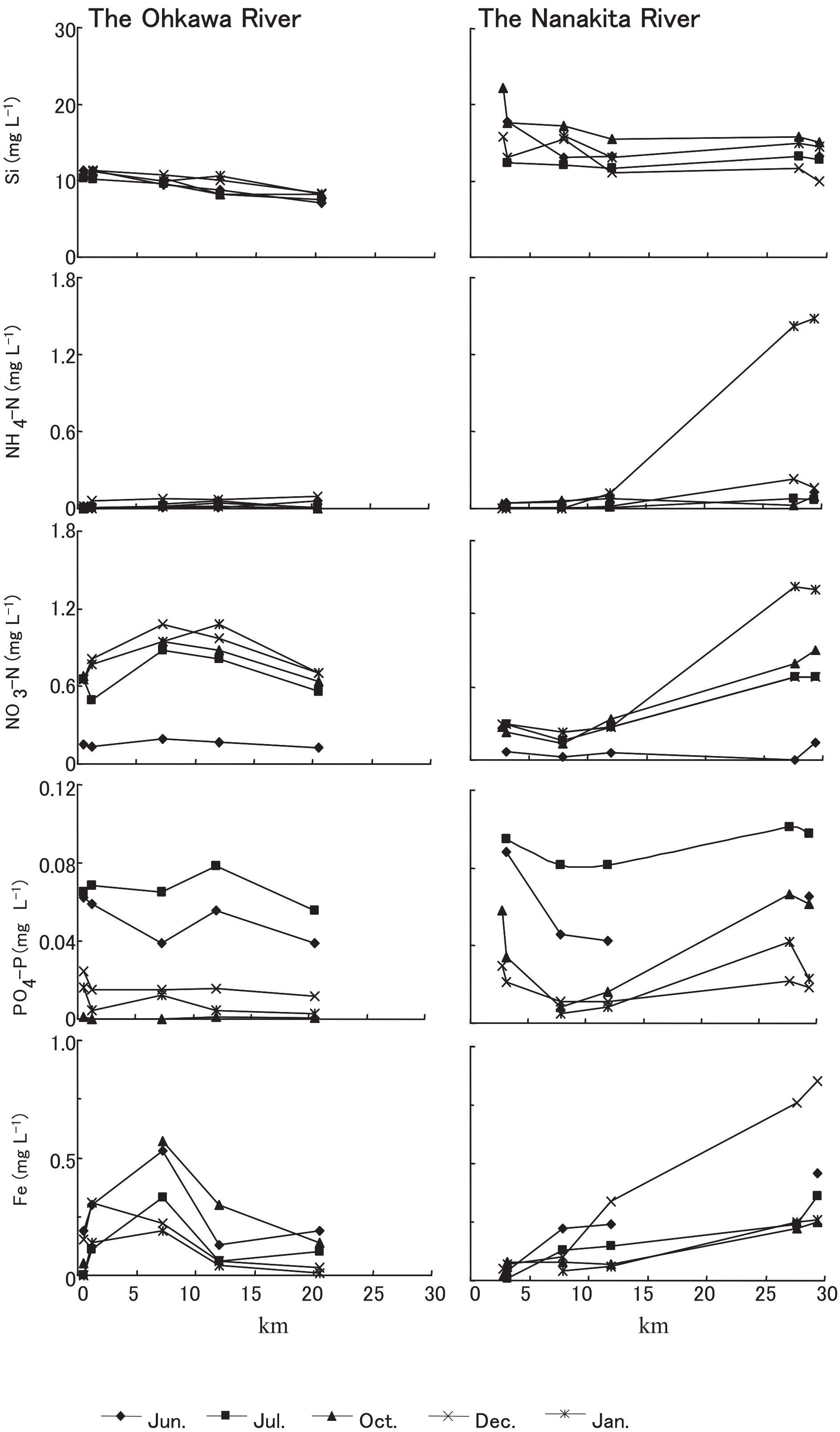

Figure 3. Nutrient dynamics in the river water

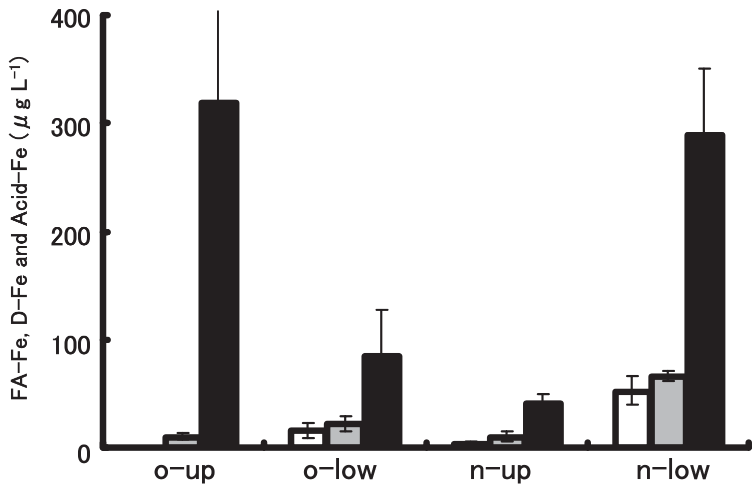

Figure 4. Concentration of FA-Fe, D-Fe and FA-Fe in the river water

＊Error bars mean SD

tions at the lower site were, on average, more than 10 times higher than those of the upper stream site. Furthermore, the FA-Fe concentration at lower site of the Nanakita River was 3.3 times higher than that of the Ohkawa River. Both acid-Fe and D-Fe concentration in each site showed a similar tendency to that shown for FA-Fe concentration.

Land use in the watersheds of each sampling site is shown in table 2. In up-stream sites of both rivers, forest vegetation was dominant. On the other hand, land use at the watershed of the O-low site was also dominated by forestry (9185 ha or 73% of water-

Table 2. Land use area of each river watersheds

the area of land use (ha)	o-up		o-low		total	
forest area	29	(100)	9185	(73)	12179	(73)
agricultural area	0	(0)	2235	(18)	2840	(17)
urban area	0	(0)	179	(1)	550	(3)
other area	0	(0)	929	(7)	1175	(7)
total	29	(100)	12529	(100)	16744	(100)

the area of land use (ha)	n-up		n-low		total	
forest area	797	(70)	7923	(47)	8090	(36)
agricultural area	117	(10)	2662	(16)	3498	(16)
urban area	10	(1)	4756	(28)	8647	(39)
other area	216	(19)	1459	(9)	2068	(9)
total	1140	(100)	16800	(100)	22303	(100)

Data was obtained from HP of Ministry of Land, Infrastructure and Transport Japan and the land use was divided into 4 groups ; forest, agricultural area, urban area and other area. The parentheses mean the rate of land use in the watershed (%)
o-up: Sampling site at upper river of the Ohkawa River
o-low: Sampling site at lower river of the Ohkawa River
n-up: Sampling site at upper river of the Nanakita River
n-low: Sampling site at lower river of the Nanakita River

shed), but that of N-low site was characterized by urban areas (forest: 7923 ha or 47% and urban area: 4756 ha or 28%). At the watershed of the O-low site, both the afforested acreage and forest proportion to total land use were higher than those of the N-low site, while the urban area acreage and utilization rate were the converse. Recently, the existence of fulvic-like organic matter, originating from human activity in river water near urban areas, has been reported (Takahashi et al., 2003). Therefore, it seems that the FA-Fe in river water originated, not only from forest vegetation in up-stream natural ecosystems, but also from human activity in urban areas.

Effect of river water quality on the growth of diatoms in coastal region

Fig. 5 showed the nutrient status of the river water added to the media used for diatom culture. N, P, Si and FA-Fe were focused on in this study as nutrients of diatoms. The concentration of all nutrients in river water, except FA-Fe at the O-up site, were higher than those of the O-low site, while those at the N-low site, except Si, were higher than those at the N-up site. The effect of added river water on the growth of *Skeletonema*, a representative diatom in coastal seawater, is shown in Fig. 6. The initial number of diatoms was 2110 cells ml^{-1}. After 5 days, cell numbers for each treatment increased in following order: 9.8×10^4 cells ml^{-1} (N-low) > 8.0×10^4 cells ml^{-1} (N-up) > 6.9×10^4 cells ml^{-1} (O-low) > 6.0×10^4 cells ml^{-1} (O-up) > 5.5×10^4 cells ml^{-1} (DW). The effects of all added river waters on the growth of diatom (cell numbers) were greater than that of control (distilled water). Among the river water, the water collected at lower sites seemed to be more effective for diatom growth than that from upper river sites, especially in Nanakita River. Regardless of the higher nutrient concentration (N, P, Si) in the O-up water, the growth of diatoms in the O-low water treatment was significantly increased compared to O-up water treatment. This is due to the fact that FA-Fe concentration of O-low water was 10 times higher than that of O-up water, as shown in a previous report suggesting the importance of FA-Fe on the growth of diatoms (Matsunaga et al., 1998b). The numbers of diatoms in N-low water treatment was remarkably higher than that of the O-low water

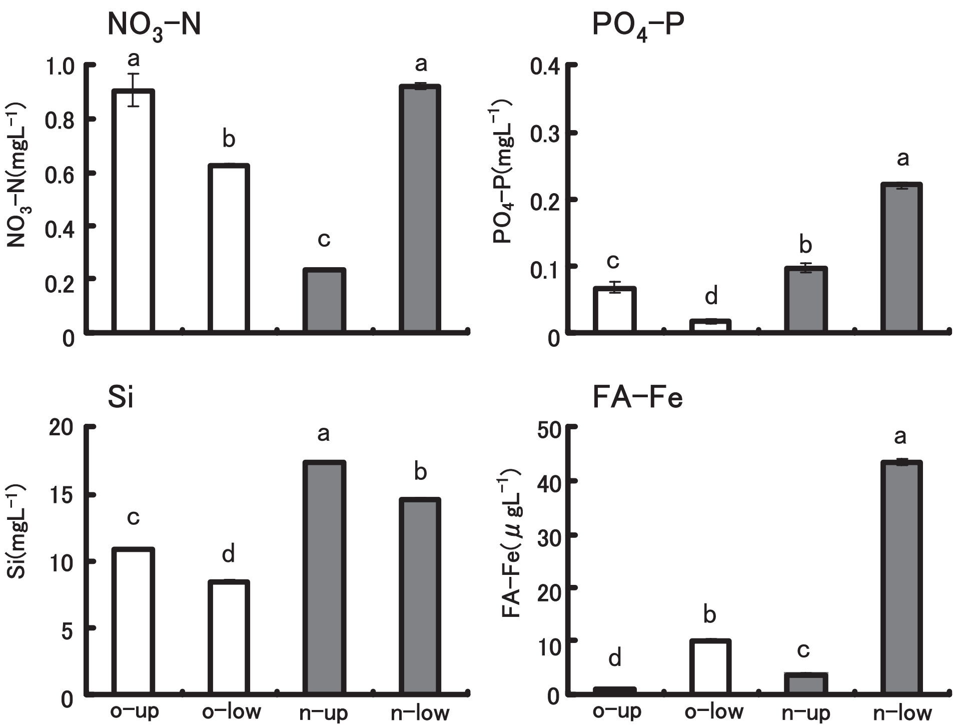

Figure 5. Nutrient status of the river water added to the media for diatom culture

＊Error bars mean SD

＊ α=0.1 (Tukey method)

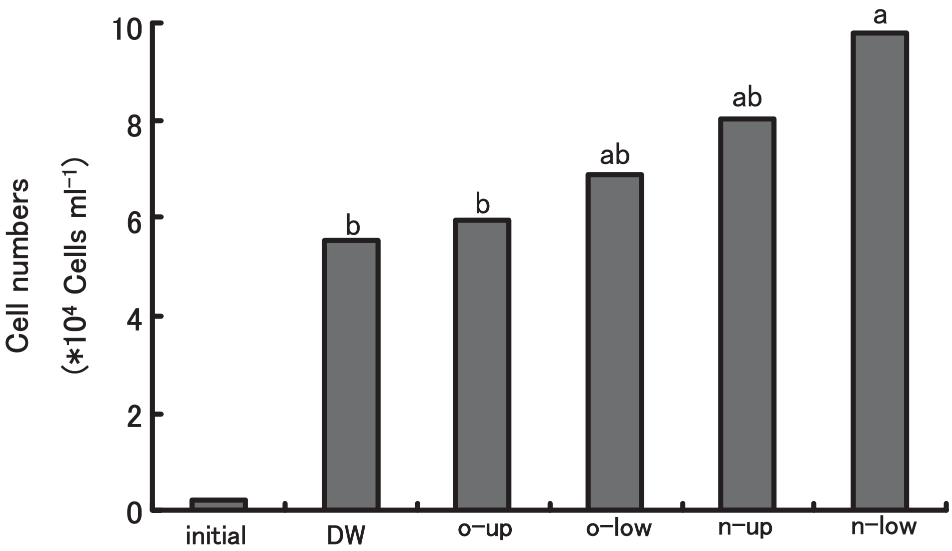

Figure 6. Influences of river water added on the growth of *Skeletonema*

Skeletonema

* α=0.1 (Tukey method)

treatment, also suggesting the possible importance of other nutrients on the growth of coastal diatoms. In particular, Si is an important element for the growth of diatoms. The Si concentration of the Nanakita River was significantly higher than the Ohkawa River due to the surface geology of volcanic rock in upper region; in the Ohkawa River the surface geology was plutonic rock. It has also been reported that water originating from the watershed dominated by volcanic rock was much higher in Si than that dominated by plutonic rock (Kobayashi, 1961). This suggests that the quality of river water may greatly influence the growth of coastal diatoms. In particular, FA-Fe originating from urbanized drainage water may have as important a role as afforestation in terms of watershed environment. Further detailed study is required to clarify the effects of forest vegetation on coastal primary production.

Acknowledgement

We thank Dr. Kinuko Ito for her generous gift of stock diatom species, *Skeletonema*, and her expert advice on diatom cultivation.

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JIFS, 4 : 87 − 92 (2007) original paper

Effects of FeAgri, a novel iron-containing material, on the growth of dicotyledonous crops grown on river sand

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Keywords: Cabbage, Chinese cabbage, crown daisy, growth, iron nutrition, lettuce

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Abstracts

The effects of “FeAgri”, a novel iron-containing material, on the growth of lettuce (*Lactuca sativa*), crown daisy (*Chrysanthenum coronarium*), cabbage (*Brassica oleracea*) and Chinese cabbage (*Brassica campestris*) were studied in the greenhouse using Wagner pots with river sand. Cabbage showed the most significant responses in terms of leaf color and fresh weight to different levels of the Fe-containing material. There were also some differences in plant length, leaf width, shoot and root dry weight, but they were not statistically significant. Lettuce showed a significant difference in leaf color and also showed some differences in other growth factors and iron concentration of leaf. Chinese cabbage showed a significant difference in fresh weight and some differences in other growth factor. However, in the case of crown daisy, there were differences in plant length, leaf color, fresh weight, and root and shoot dry weights, but no statistically significant differences in all growth factors examined.

Introduction

Fe is an essential microelement for plant metabolism, growth and crop productivity. Its importance is based on its ability to form two stable ions, Fe^{2+} and Fe^{3+}. Though iron is the second most abundant metal in nature and the fourth most abundant element in the Earth’s crust, plants can still suffer from iron deficiency, chlorosis. This results in growth and yield losses and a decrease in the nutritional quality of the edible parts of plants, especially when grown in calcareous soils. This is due to the fact that the Fe^{2+} form is relatively soluble but is readily oxidized by atmospheric oxygen to ferric ions, which again precipitate (Guerinot and Yi, 1994). On the other hand, solubility of Fe^{3+} decreases dramatically with increasing pH values. In aerobic soils with neutral pH, the concentration of soluble Fe^{3+} ranges from 10^{-11} to 10^{-10} M (Lindsay and Schwab, 1982). These concentrations are not sufficient to meet optimal plant growth, which requires between 10^{-4} and 10^{-8} M Fe^{3+}. The concentrations of Fe^{3+} in neutral soils are already lower than the optimal concentration for plants (Hell et al. 2003). As a result, iron deficiency in plants occurs and is a major problem in agriculture, since 30% of the world’s arable lands consist of calcareous and alkaline soils (Chen and Barak, 1982; Hell et al. 2003).

In Japan, there are, generally, no alkaline soils under natural condition due to high precipitation. However, the soils used for prolonged vegetable cultivation in greenhouses tend to increase in pH due to the accumulation of large amount of bases; thus crops grown on these soils may show iron deficiency or be potentially iron-deficient. The possibility of iron deficiency in vegetable cultivation may be acerbated by the accumulation of phosphates, which easily form very low soluble compound with metals.

Different methods have been reported to correct iron deficiency, including application of iron salts, phosphoric or sulfuric or nitric acid, organic amendments (Chen and Barak, 1982; Emery, 1982; McCaslin et al. 1987; Hughes, 1992; Dick et al. 1993), or Fe chelators (Dick et al. 1993; Stevenson, 1994).

In this study, a new iron-containing material (FeAgri) is considered and the growth responses of lettuce, crown daisy, cabbage and Chinese cabbage, grown on river sand with different levels of FeAgri, are assessed.

Materials and Methods

Experiment was conducted in a greenhouse at the Experimental Farm of Tohoku University between September and December 2005.

Three kg of river sand with pH 6.6 and different amounts (0, 10, 50 g) of the Fe-containing material (FeAgri) were placed in Wagner pots. The composition of FeAgri is FeO (70%), ZnO (6%), Al_2O_3 (6%), Fe_3O_4 (5%) CaO (5%), MgO (3%), SiO_2 (3%) and others (2%). There were three replicates for each treatment (control, 10-FeAgri, 50-FeAgri). Each pot was also supplied with 1.0 g N, 0.85 g P_2O_5, and 1.0 g K_2O per pot, using a controlled-release NPK-type fertilizer (CRF-NPK) containing no micronutrients, through co-situs application. Co-situs application method refers to the application of fertilizer locally, in contact with roots of the crops (Morikawa et al. 2004).

Seedlings of lettuce (*Lactuca sativa*), crown daisy (*Chrysanthenum coronarium*) cabbage (*Brassica oleracea*) and Chinese cabbage (*Brassica campestris*) were transplanted in the pots on 30 September 2005. Pots were placed in the greenhouse and rotated every week among the treatments until the end of the study.

During cultivation, growth parameters, such as plant length, leaf width and leaf color, were measured. Harvesting was done on 4 November for lettuce and crown daisy; 22 November for Chinese cabbage and 27 December for cabbage. After harvesting, fresh weight of the shoot, and dry weight of shoots and roots were measured. Shoots were dried at 70° C for 48 h for iron content analysis. The dried shoots were ground and ashed in a muffle furnace at 500°C. The ash was treated with acid solution on a hot plate according to the method of Howitz (1980). The iron content was analyzed using atomic absorption spectrometry. Iron content of the shoot and iron uptake of the plant were also determined. All data were subjected to Tukey`s studentized range test at a 0.05 level of significance.

Results and discussion

With an increase of pH of the soil, iron bioavailability decreases to a value considered low for the optimal growth of plants. The most common symptom is chlorosis or the "yellowing of leaves" in younger leaves if the plant cannot absorb sufficient amounts of soluble Fe from the soil. Application of Fe compounds, such as FeAgri, could be one way to correct iron deficiency. The following are the results of the growth responses of selected crops grown on river sand at pH 6.6 to different levels of FeAgri, namely 0, 10 and 50 g pot^{-1}. (The data on leaf width and dry weight of shoot are not shown)

Growth responses of lettuce to different level of FeAgri are shown in Fig. 1 Lettuce plants responded well to the iron treatment, specifically in terms of leaf color. There was a 13 and 34% increase in leaf color as measured in SPAD units for 10-FeAgri and 50-FeAgri treatments, respectively, compared to controls. The difference between the control and 50-FeAgri treatment was significantly different using Tukey`s studentized range test at a 5% level of significance. There was also a ~8% increase in plant length and fresh weight of the shoot, and a 10% increase in leaf width and dry weight of the shoot and root for the 10-FeAgri and 50-FeAgri treatments compared to controls. However, the differences were not statistically significant.

Growth of crown daisy (Shungiku in Japanese) plants increased in terms of plant length, leaf color, fresh weight of shoot, and dry weights of shoot and root. However, these differences were not statistically significant, as shown in Fig. 2.

Cabbage crops exposed to different levels of FeAgri material also showed statistically significant differences in leaf color values, particularly those between control and 50-FeAgri (Fig. 3). Compared to the plants grown on control plot, there was a 25 and 39% increase in the leaf color index of 10-FeAgri and 50-FeAgri treatments, respectively. These increased values were higher than those found in the lettuce plants. In addition, the fresh weight of shoot in FeAgri-treated plants also showed statistically significant differences to those in control plots. Plant length, leaf width, dry weights of shoot and root also tended to increase with FeAgri treatment but were not statistically significant. The increased values were <10% in leaf width, and >10% in the other three parameters.

In the case of Chinese cabbage, there was a statistically significant difference in shoot fresh weight only between the control and 50-FeAgri treatment, as shown in Fig 4. However, the other parameters, such as plant length, leaf color, leaf width, dry weights of both shoot and root in FeAgri-treated plots also increased compared to control plots.

Iron content and iron uptake analyzed for the shoots of these crops are shown in Fig 5. Lettuce

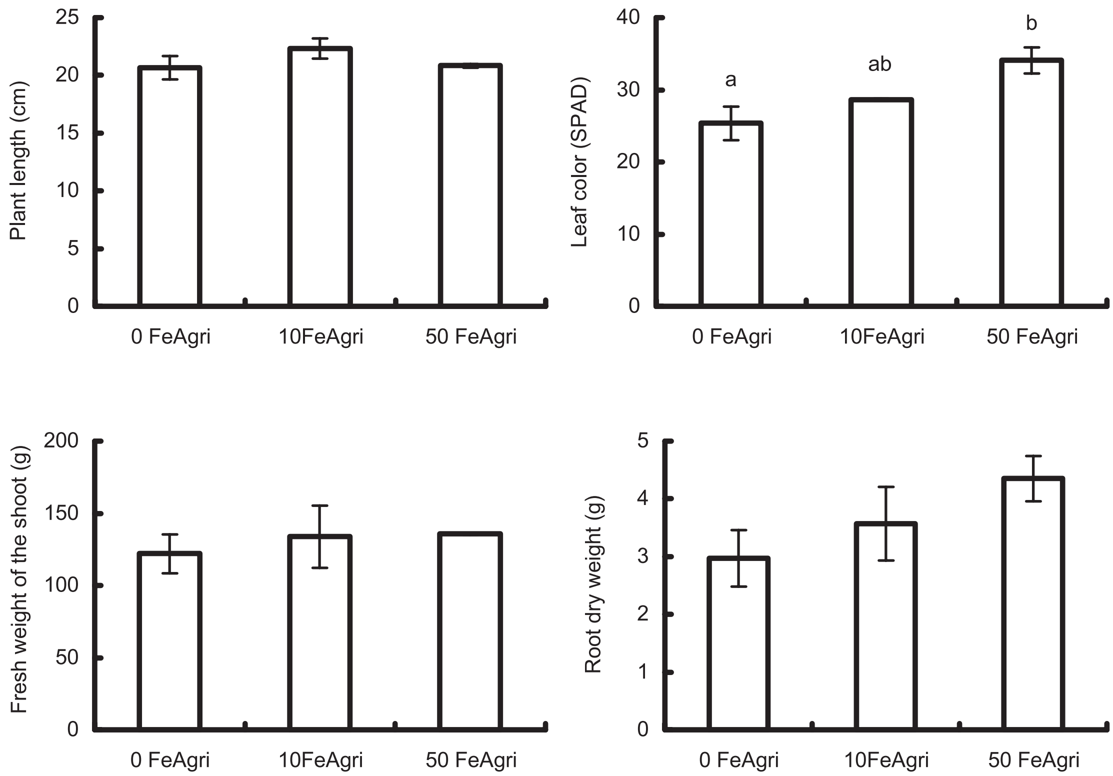

Figure 1. Growth responses of lettuce to different levels of FeAgri material

• Different letters show significant difference using Tukey`s studentized range test (P=0.05)

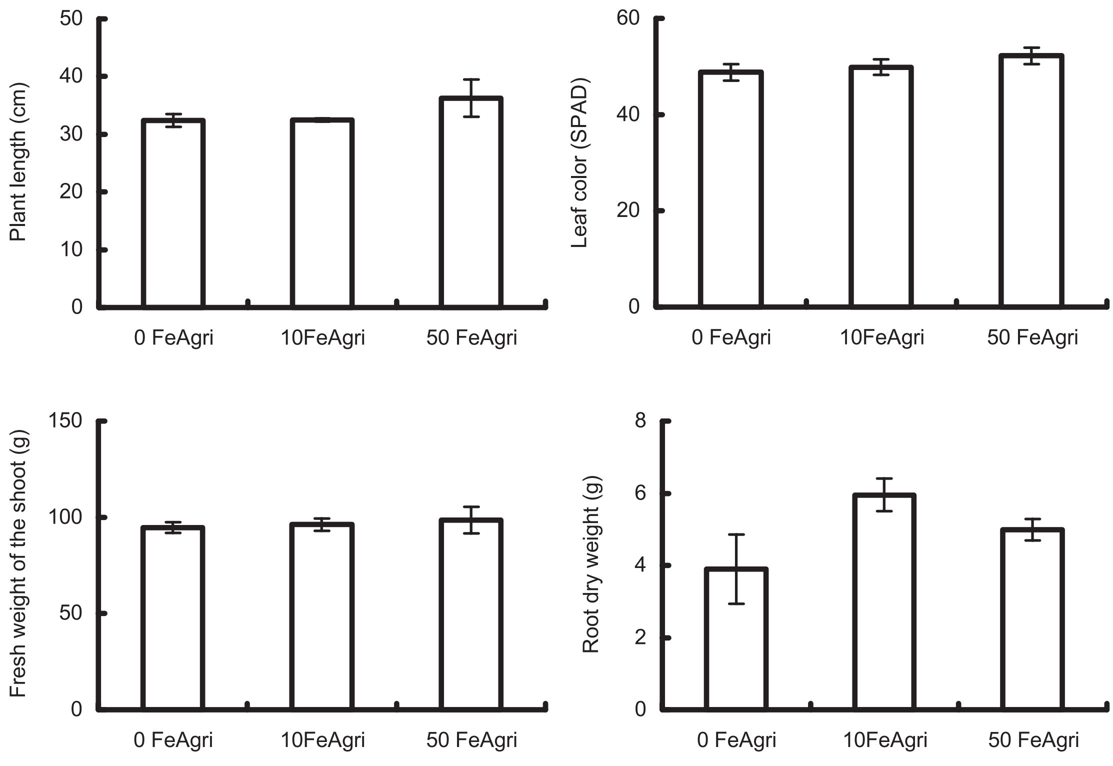

Figure 2. Growth responses of crown daisy to different levels of FeAgri material

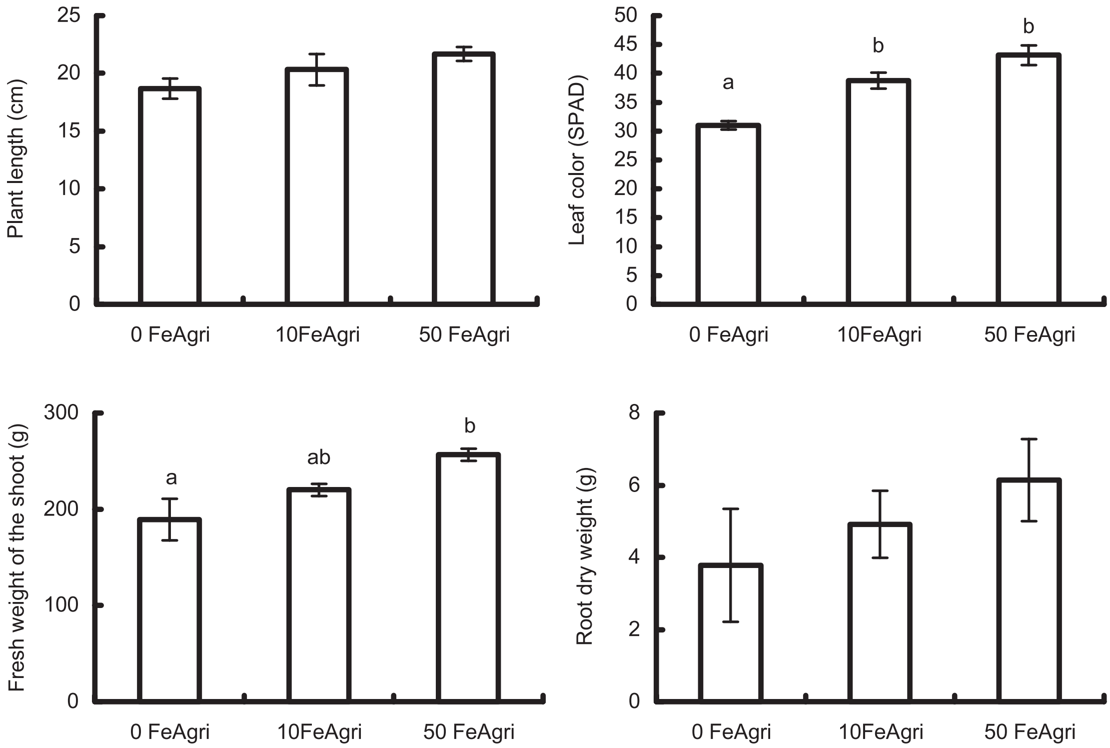

Figure 3. Growth responses of cabbage to different levels of FeAgri material

• Different letters show significant difference using Tukey`s studentized range test (P=0.05)

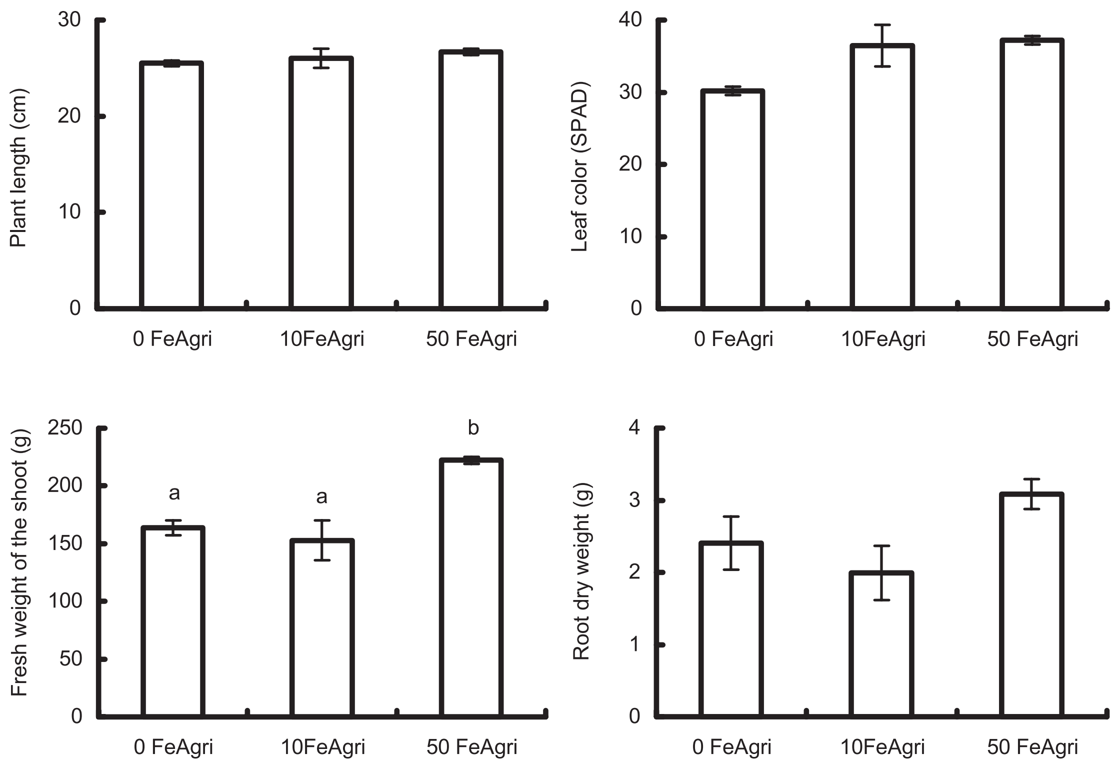

Figure 4. Growth responses of Chinese cabbage to different levels of FeAgri material

• Different letters show significant difference using Tukey`s studentized range test (P=0.05)

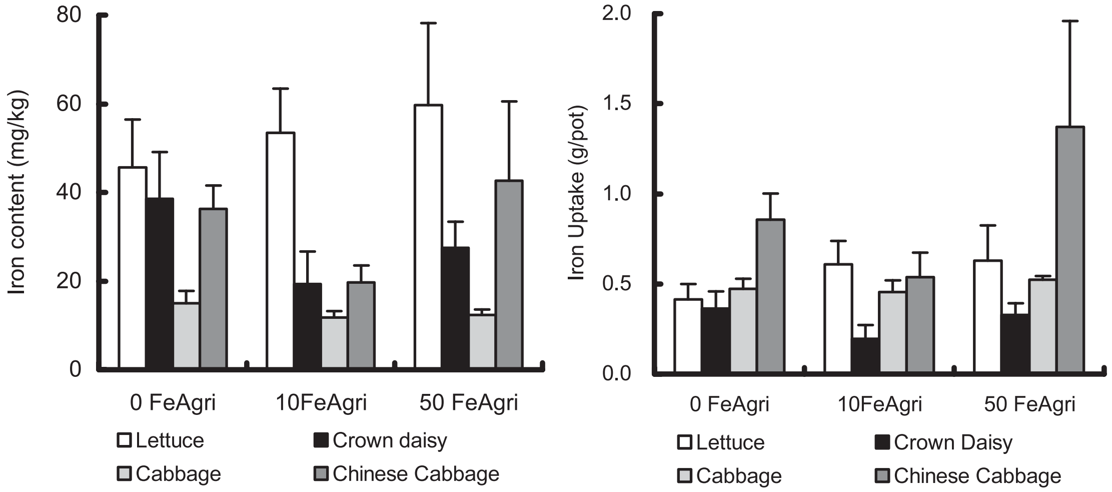

Figure 5. Iron content and Iron uptake of the shoot in each crop.

plants showed a 17 and 31% increase in iron content and a 48 and 53% in iron uptake for the 10-FeAgri and 50-FeAgri treatments, respectively, compared to controls. These increases in iron in lettuce are also be supported by the differences in leaf color between control and FeAgri treatments, as shown above, and shows the importance of Fe as a microelement for plants. Fe is involved in chlorophyll synthesis and is essential for the maintenance of chloroplast structure and function (Abadia, 1992). Therefore, plants deficient in iron nutrition tend to show yellowing of leaves or chlorosis. Chinese cabbage also exhibited a >2-fold increase in iron uptake in the 50-FeAgri plot compared to the control. However, the iron content of crown daisy, cabbage and Chinese cabbage grown in the FeAgri treatments did not increase compared to those in control plots. The levels of iron uptake in these plants were not significantly different among the treatments. The selected crops grown in river sand responded differently to the iron-containing material. These crops belong to Strategy I plants, which utilize a reduction mechanism to acquire iron in soluble form. However, whether or not Fe-containing material really helps plants to maximize the reduction process in reducing Fe^{3+} to the Fe^{2+} form, thereby receiving considerably amounts of iron for optimum growth and development, remained unclear. River sand had a pH 6.6, which is in the neutral range. It is most probable that crops could have still acquired sufficient soluble iron from the substrate, particularly from the river sand itself. This explains some of the insignificant differences in the results among the treatments.

On the other hand, variations in crop growth responses were also revealed. This could be attributed to different pH requirements of plants for cultivation. Cabbage and lettuce have almost same pH requirements, ranging pH 6.0-7.5. On the other hand, Chinese cabbage and crown daisy can tolerate more acidic conditions-around pH 5.5.

It can be concluded that, among the crops studied, cabbage responded the most significantly to FeAgri treatment in terms of leaf color and fresh weight of shoot. On the other hand, crown daisy showed the least response, with no statistically significant differences among all growth parameters. Nevertheless, all plants used in this experiment showed an increase in all growth parameters, such as plant length, leaf color index, leaf width, fresh weight and dry weights of both shoot and root. More detailed experiments on the effects of the novel FeAgri material on the growth of vegetables are required.

Acknowledgment

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JIFS, 4 : 93 − 99 (2007) original paper

A System Development for Remote Sensing, and Interpretation for Rice Fields in the World Using Satellite Data

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Keywords: Remote Sensing, System development, ASTER, Rice Fields, GIS

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Abstract

Remote Sensing Laboratory, Field Science Center, Graduate School of Agriculture Science, Tohoku University started at April 2004. For the studies and education at the laboratory we are now developing the system of remote sensing and GIS. Our system consists of ordinary PCs, one digitizer and one color laser printer. The PCs are assembled by us for the optimal performance and the low cost. Gigabit LAN connects each PC, and one PC is used as file server to store remote sensing images and GIS data such as digital maps, geocoded satellite images and digital elevation models (DEM). The file server has RAID system for safety storage from HD trouble. We use ARC/GIS as GIS software and many kinds of Remote Sensing software such as, ERDAS/Imagine, ENVI, eCognition, PG-Steamer and SILCAST. Using the developing system, we understand and teach for regional differences of agriculture especially with the interpretation of ASTER data analysis.

A kind of project “Determination of Local Characteristics at Global Agriculture Using archive ASTER Data” was started at the middle of November 2005. We establish data processing system and get some results. Paddy rice fields analysis was started at first, we analyze 1) the Shonai Plains in Japan, 2) the Yangtze River delta in Middle-East China, 3) Mekong Delta in South Vietnam, 4) North-east Thai Plaines, Thailand, 5) Sacrament Valley, California, USA.

The results of this studies are as follows, 1) Using ASTER images, we can easily understand agricultural characteristics of each local area. 2) ASTER data have high accuracy for location, and the accuracy is suitable for global study without the fine topographical maps, 3) By five years observation of ASTER, there are huge numbers of ASTER scenes, but not enough volumes for cloud free data for seasonal analysis. It means that follow-on program of ASTER is necessary, 4) We need not only paddy field, but also all crop fields and all area, 5) The studies are necessary to international corroboration.

1. Introduction

Recently, the importance of terrestrial and marine field sciences might be realized in many courtiers including Japan, and remote sensing and GIS are powerful tools for the study[1,2]. For this reason, Remote Sensing Laboratory, Field Science Center, Graduate School of Agriculture Science, Tohoku University in Japan started at April 2004, and at the time, there was nothing about Remote Sensing and Geographical Information System (GIS) tools. First, we developed analytical system for the remote sensing and GIS using hand made PCs at the lowest cost.

In 1983, Dr. Joji Iisaka etc. published the beautiful color book named “World Agricultural Surveyed from Space”[3] using Landsat/MSS images. Unfortunately it was written in Japanese, if it had been written in English, it would be the famous book in the world. More than 20 years from the publication, we hope to renew the book using Terra/ASTER data. We used archive ASTER data and analyzed the data for the purpose.

2. Developments of Remove Sensing System Using GIS

For studies and educations at the laboratory, we developed the system of remote sensing and GIS. Our system consists of hand made PCs, one digitizer, one color laser printer and one scanner, and outline is listed Fig. 1. We assemble the PCs for the optimal performance and the lowest cost. A gigabit LAN connects each PC, and one PC is used for file server to store common data such as maps, remote sensing images, and GIS data. The file server has RAID system for safety storage from HD trouble. Main-use software is ArcGIS and ERDAS/Imagine and we use them jointly with floating licenses. Multi-Spec, eCognition, PG-Steamer of remote sensing software were already installed on some PCs and we hope some more software such as ENVI and ER-Mapper will be installed.

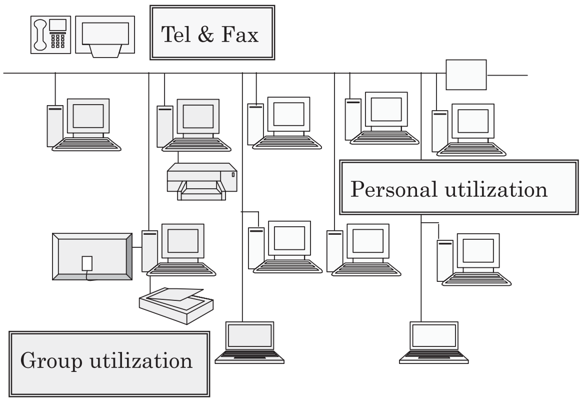

Fig. 1 Developing system of Remote Sensing Laboratory, Field Science Center, Graduate School of Agriculture Science, Tohoku University

Our System has seven desktop PCs and two laptop PCs that are connected to Gigabit LAN using Hub in our room and 100-mega bps LAN to outside. Each desktop PC has 1.8-2.8 GHz CPU, 1-2 GB random access memory, high performance graphic board, and 100-400 GB hard disk. Our laboratory has two staffs, eight students, and some visitor scientists and/or students. Four desktop PCs were almost personal use; and these PCs can use Erdas/Imagine and ARC/GIS by floating license system. One desktop PC is a data server using RAID system and two desktop PCs for the use of more difficult analysis of remote sensing and GIS with high level performance and special analysis software, and manages the floating license.

3. Image Interpretation of Archive ASTER Data

3.1. Characteristics of ASTER data and Procedures

To elucidate the mechanism of climate change in particular, which is the one of the most profound concern among the changes foresaid, NASA promotes Earth Observing System Project (EOS Project) where systems has been/will be developed for observing the Earth from space by satellites and of data processing and various research programs for data application has been/will be conducted. 24 sensors including ASTER are planned as part of instruments for use in the EOS Project. The features of ASTER Sensor are, high spatial and radiometric resolution, broad spectral coverage (visible- through thermal-infrared), and stereo capability on a single path[4].

We want to more precision understanding of the local characteristics using ASTER data. First we check the advantages of ASTER data, and the results are as follows,

1. High-resolution and the large swath
2. Large wavelength and many bands
3. High-revel of geographical location
4. Stereo pair images
5. High performance data searching system
6. High speed data delivery system
7. Cheap price
8. Large volume archive by seven years observation

A kind of project “Determination of Local Characteristics at Global Agriculture Using Archive ASTER Data” was started at the middle of November 2005. We establish data processing system and get some results. The procedure is listed in Fig. 3. At first, we survey target and request the data at level 1A data for analyses using ASTER Ground Data System (GDS). Next, The level 1A data are processed to ortho image of ENVI format with UTM coordination and made to Digital Elevation Model (DEM). At last, we use the data for understanding localities of agriculture using package software such as ENVI, Erdas/Imagine, and PG-Steamer.

Paddy rice fields analysis was started at first, we analyze four areas in Asia and one area in America, as follows;

1) The Shonai Plains in Japan

2) The Yangtze River Delta in Middle-East China
3) North-east Thai Plaines, Thailand
4) Mekong Delta in South Vietnam
5) Sacrament Valley, California, USA

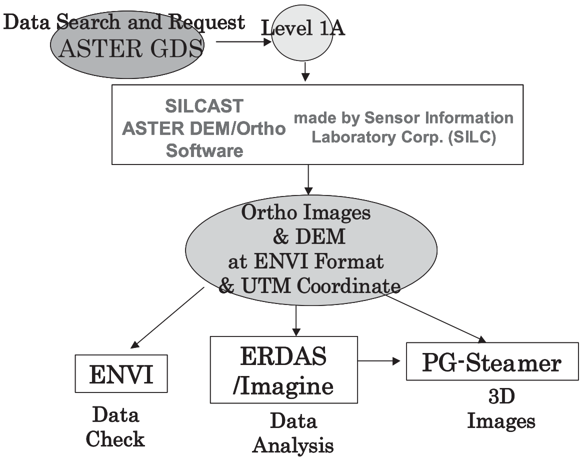

Fig. 2 Data processing procedure and using software

3.2. The Shonai Plains in Japan

The results of the Shonai Plains in Japan are listed in Fig. 3. Shonai district is located in the west side of Yamagata Prefecture and the district faces the Sea of Japan (Fig. 3, upper). There are Mt. Chokai in the north, Dewa mountains in the east and Asahi mountains in the south and Japan sea in the west. In the district, it snows heavily in the winter, and paddy agriculture is widely performed using the water resources. Shonai area is a typical paddy area in Japan (Fig. 3, middle).

Recently, rice has been overproduced in Japan and some parts of rice cultivation fields are changed to other crops. Soybean area is enlarged in the district. Images of Fig. 3 are taken in the end of May, and dark area is rice paddy and bright area is soybean field in lower image. In this area, fields shape is the rectangle and size is large in Japan (Fig. 3, lower).

3.3. The Yangtze River Delta in Middle-East China

The Yangtze River delta in Middle-East China is listed in Fig. 4 and this delta was famous rice production area. Upper left is 3D image, and we can recognize almost flat plain. Only lakeside area is high elevation, and this area is park for recreation. Upper right is closeup image, and we can recognize field shape and size. Paddy field shape is both of the rectangular and irregular. Lower images of Fig. 4 are time series in May, June and July.Dark area at 3 times is fishpond and dark only in June image is paddy rice.

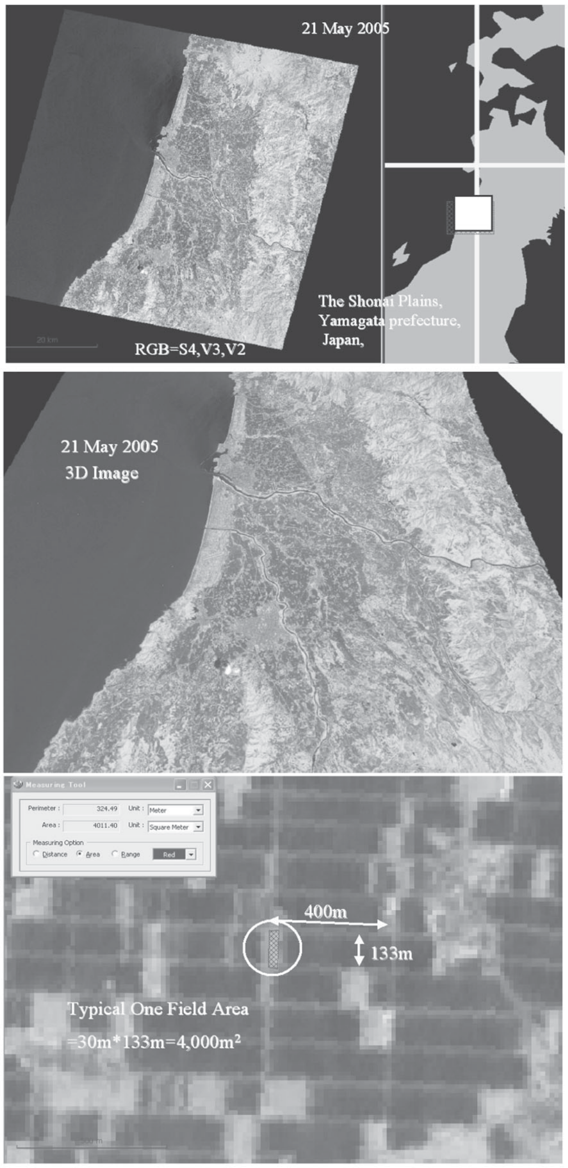

Fig. 3 Paddy fields at the Shonai Plains in Japan
Upper: Total scene of ASTER data and the map of location
Middle: 3D image of the Shonai Plains
Lower: Field size of the Plains

3.4. North-east Thai Plaines, Thailand

Fig. 5 is the image of paddy fields at North-east Thai Plaines, Thailand. In this area, there are paddy fields more than 50% in Thailand. Fig. 5 upper photos are time series images in July, November and January. In this area, rainy season is from April to October, and July and November have vegetation. January is in the middle of dry season, and there are almost no vegetation. Fig. 5 lower left is 3D image and this area is very flat. Fig. 5 lower right is closeup image, and paddy fields are small and irregular.

3.5. Mekong Delta in Vietnam

Images of Fig. 6 are the Mekong Delta in South part of Vietnam. Lower left is the 3D image, and we can understand very flat area. Upper left are 3 times images in November, January and February., Rice crop grow in dry season in the area, because in rain season there are excess water for rice plant. Both two photos of right side are closeup images, and there are very small and very big paddy fields in the area.

3.6. Sacrament Valley, California, USA

Sacrament (Central) Valley, California, USA is listed in Fig. 7. Upper left is total scene and locates on small world map. Upper right are two seasonal images in May and July. Water covers paddy field in May and vegetation as rice body covers the filed.

We can understand the area has mountains in both side and middle in left two images in Fig. 7. Lower right indicates the field size is very large in the area.

3.7 Summarization of each Characteristics

We perform almost same procedure to Yangtze River delta in Middle-East China, Mekong Delta in South Vietnam, and North-east Thai Plaines, Thailand. The results of five areas are listed in Table 1.

The Shonai Plains is typical paddy fields area in Japan, and has well-developed irrigation and drainage systems. The Yangtze River delta in Middle-East

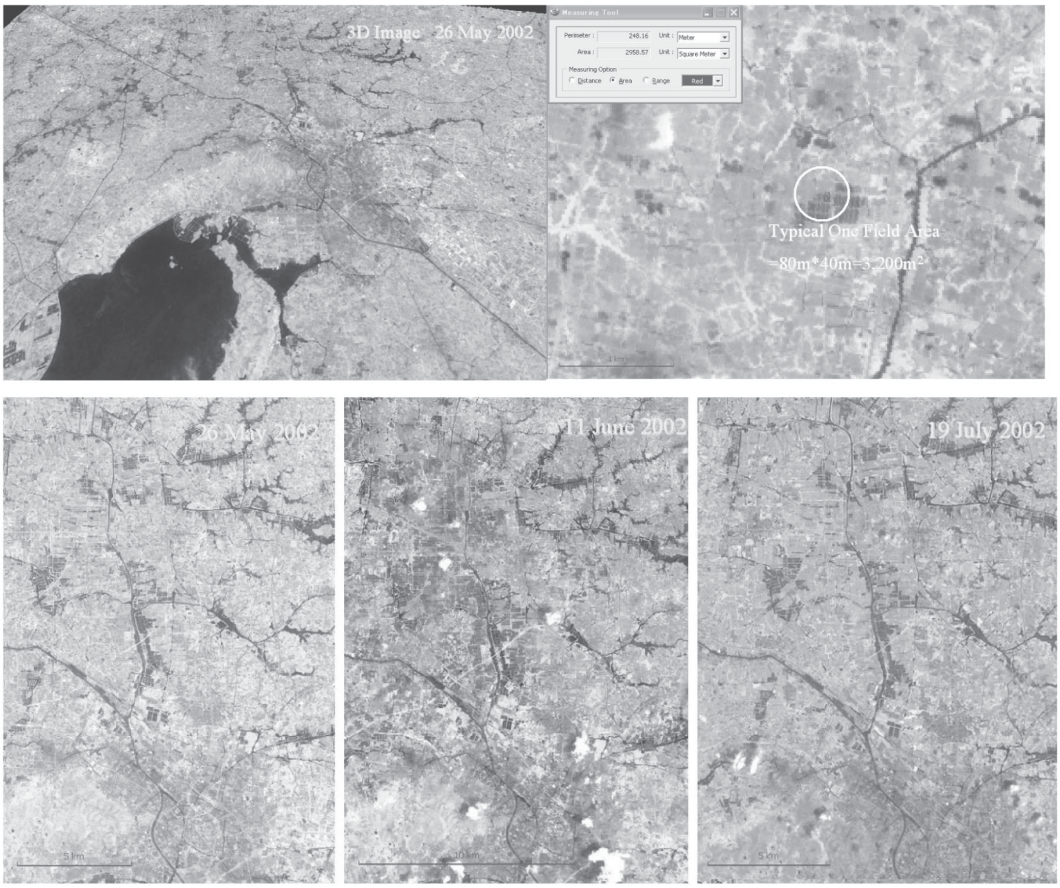

Fig. 4 Paddy fields at the Yangtze River Delta in Middle-East China
Upper left: 3D image of the paddy field. Upper right: Field size of the fields
Lower: The images of in May, June and July

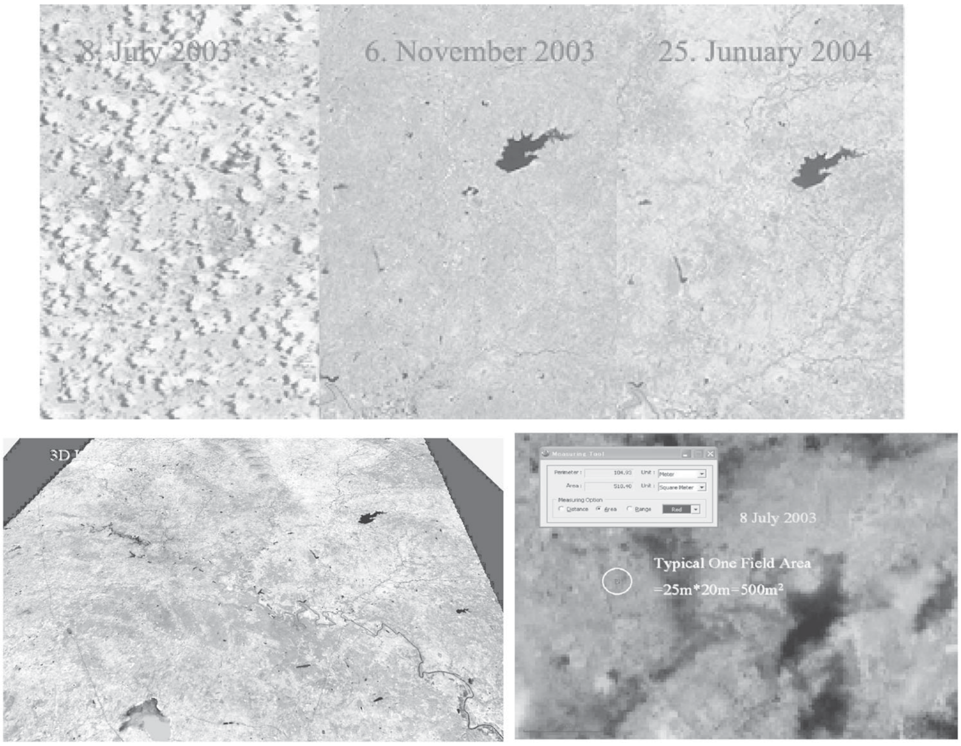

Fig. 5 Paddy fields at North-east Thai Plaines, Thailand
Upper: The images of July, November and January
Lower left: 3D image of the paddy field. Lower right: Field size of the fields

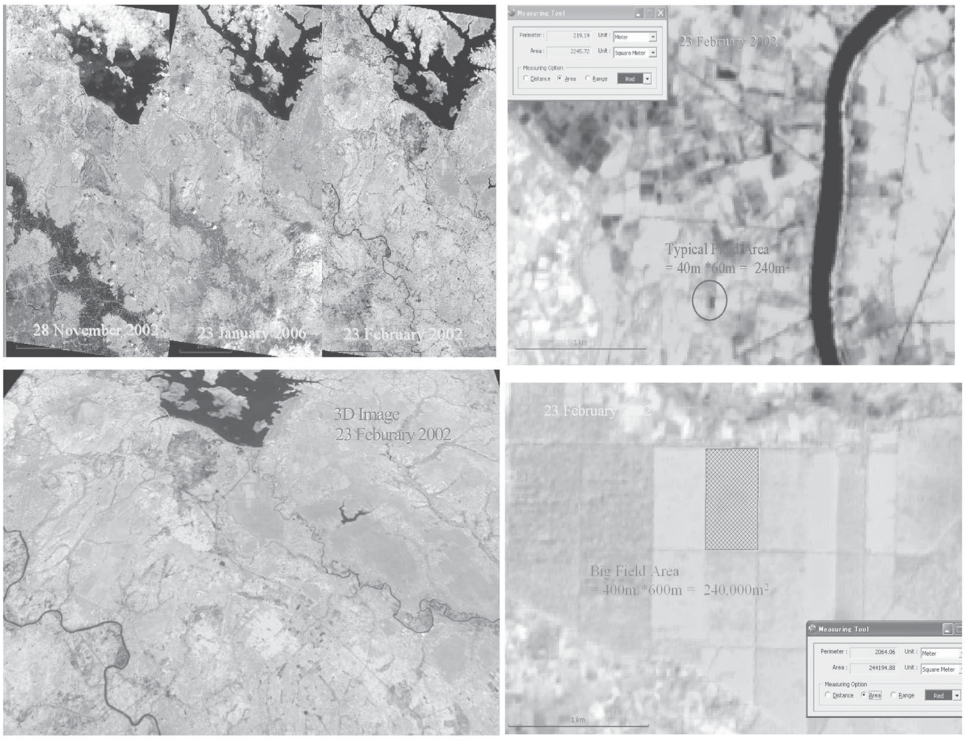

Fig. 6 Paddy fields in the Mekong Delta in South Vietnam
Upper left: The images of in November, January and February. Upper right: Field size of the ordinary fields
Lower left: 3D image of the paddy field. Lower right: Field size of the large fields

Table 1. Characteristics of Each Paddy Field

	Regional Topography	Growing Season	Field Size	Field Shape
Shonai, Japan	Mountainous	Summer	Middle	All Rectangle
MW-China China	Almost Flat	Summer	Middle	Half Irregular Half Rectangle
NE-Thai, Thailand	Very Flat	Rainy	Small	Almost Irregular Same Rectangle
Mekong Delta, Vietnam	Very Flat	Rainy	Mainly Small Minority Large	Rectangle
California USA	Almost Flat	Summer	Large	Almost Rectangle Same Irregular

China is the famous paddy fields area on a global scale. The area of Mekong Delta in South Vietnam and Northeast Thai Plaines are famous to produce exporting rice. At the area, there is enough temperature, but limitation of rice growth is water. Northeast Thai Plaines have severe dry season, and at the season, rice cannot grow. Mekong Delta area is attached to South China Sea and has a big river. At the area, rice grows not only in rainy season but also dry season. Sacrament Valley, California, USA is also very famous commercial rice producing area. At the area each paddy field size is almost ten times larger than Japanese large paddy felid. We can easily understand that it is very difficult to make the rice at same cost in Japan and USA.

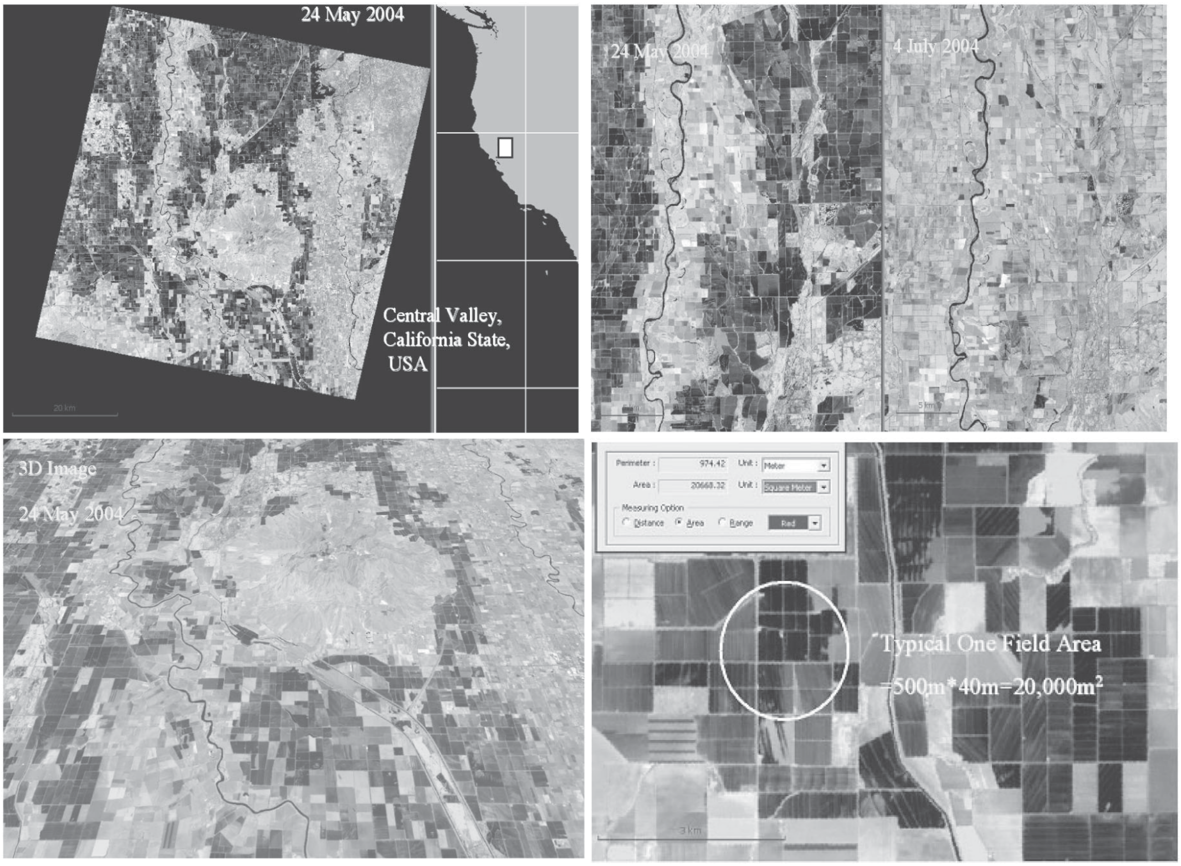

Fig. 7 Paddy fields in the Sacrament Valley, California, USA
Upper left: Total scene of ASTER data and the map of location Upper right: The images of in May and July
Lower left: 3D image of the Valley, California, USA Lower left: Field size of the valley

5. CONCLUSIONS

The study of "Determination of Local Characteristics at Global Agriculture Using Archive ASTER Data" has been developed and we have some results until now. The conclusions of the study at now are as follows,

1) Using ASTER images, we can easily understand agricultural characteristics of each local area.
2) ASTER data have high accuracy for location, and the accuracy is suitable for global study without the fine topographical maps.
3) By five years observation of ASTER, there are huge numbers of ASTER scenes, but not enough volumes for cloud free data for seasonal analysis. It means that follow-on program of ASTER is necessary.
4) We need not only paddy field, but also all crop fields and all area.
5) The studies are necessary to international corroboration.

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Marine Bio-production Group

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Integrated Field Control Group

Iwasa R., T. Sugihara, F. Namiwa, K. Osawa and G. Saito (2006) Biomass Estimation at Miyagi Prefecture in Northeast Japan Using RS and GIS. Proceedings of the 27th Asian Conference on Remote Sensing, CD-ROM.

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4th International Workshop of Integrated Field Science, 3rd International Symposium of Agricultural Science, and The 100th Anniversary of Tohoku University, International Symposium

"Frontiers in Rice Science-from Gene to Field"

6-8 November 2006
Sendai International Center, Sendai, Japan

Program

(Oral session: *presenting author)
6 November

8:00-9:00 Registration

9:00-9:30 **Official opening**
Chair: Makie Kokubun (Tohoku University)
Prof. Yukio Akiba (Dean, Graduate School of Agr. Sci., Tohoku University)
Prof. Masahiko Saigusa (Chair, Organizing Committee)

9:30-12:30 **Session 1: Molecular biology and breeding**
9:30-10:00 Development of a novel breeding method using SNP-based selection of rice genotypes
T. Nishio*, K. Shirasawa, S. Shiokai, H. Maeda and S. Kishitani (Tohoku University, Japan)
10:00-10:20 Transcript profiling of the anoxic rice coleoptile
R. Lasanthi-Kudahettige[1)], L. Magneschi[1)], E. Loreti[2)], S. Gonzali[1)], F.Licausi[1)], G. Novi[1)], A. Alpi[3)], P. Perata*[1)] ([1)]Sant'Anna School of Advanced Studies, Italy; [2)]IBBA-CNR, Italy; [3)]University of Pisa, Italy)
10:20-10:40 Mechanism of nitrogen remobilization in rice
M. Tabuchi, T. Hayakawa and T. Yamaya* (Tohoku University, Japan)

10:40-11:10 Coffee break

11:10-11:30 Molecular study on cytoplasmic male sterility in rice
K. Toriyama* (Tohoku University, Japan)
11:30-11:50 Comparative genome-wide transcriptional profiling of rice pollen and sperm cells
M. B. Singh* (The University of Melbourne, Australia)
11:50-12:10 Toward understanding the molecular mechanism of CW-type cytoplasmic male sterility in rice
S. Fujii* and K. Toriyama (Tohoku University, Japan)
12:10-12:30 Breeding and QTL analysis of rice lines having extremely high cold tolerance at booting stage
K. Nagano*, B. Chiba, K. Sasaki and K. Wagatsuma (Furukawa Agr. Exp. Stn., Japan)

12:30-13:30 Lunch

13:30-16:30 **Session 2: Physiological approaches to enhancement of productivity**
13:30-14:00 Improvement of internal N-use efficiency in rice plants
T. Mae* (Tohoku University, Japan)
14:00-14:20 Changes in ribulose-1, 5-bisphosphate carboxylase/oxygenase turnover is the key to photosyn-

thetic acclimation to elevated CO_2 in rice
S. Seneweera*[1)], A. Makino[2)], J. Conroy[1)] and T. Mae[2)]
([1)]University of Western Sydney, Australia; [2)] Tohoku University, Japan)

14:20-14:40 Rubisco and photosynthesis in rice
A. Makino* (Tohoku University, Japan)

14:40-15:00 Strategies for reversing the yield decline of continuous aerobic rice system
S. B. Peng*, L. Nie, B. A. M. Bouman, R. M. Visperas and H. K. Park (IRRI, Philippines)

15:00-15:30 Coffee break

15:30-15:50 Mechanisms controlling ripening in rice
M. Kokubun*[1)], T. Nakamura[1)] and Wen-Hui Zhang[2)] ([1)]Tohoku University, Japan; [2)]Lioacheng University, China)

15:50-16:10 The impact of free-air CO_2 enrichment (FACE) on growth, yield and quality of rice crops
Y. L. Wang*, L. X. Yang, J. Y. Huang and G. C. Dong (Yanzhou University, China)

16:10-16:30 Identification and characterization of quantitative trait loci in nitrogen utilization of rice
M. Obara*[1)], W. Tamura[1)], H. Ono[1)], T. Ebitani[2)], M. Yano[3)], T. Sato[1)] and T. Yamaya[1)] ([1)]Tohoku University, Japan; [2)]Toyama Agr. Res. Center, Japan; [3)]National Institute of Agrobiological Sci., Japan)

16:30-17:00 Poster introduction

18:00-20:00 Reception (Washington Hotel)

7 November

9:00-12:00 **Session 3: Soil science and production technology**

9:00-9:30 Innovative fertilizer application in rice culture using controlled availability fertilizer
M. Saigusa* (Tohoku University, Japan)

9:30-9:50 Studies on the interaction between upland rice and other crops in intercropping system
Djoko Prajitno* (Gadjah Mada University, Indonesia)

9:50-10:10 Clay mineralogical characteristics of paddy soils in Miyagi prefecture, northeastern Japan
O. Sano*[1)], T. Ito[1)], T. Ando[2)], M. Nanzyo[1)], G. Saito[1)], K. Saito[3)] and M. Saigusa[1)] ([1)]Tohoku University, Japan; [2)]Yamagata Pref. Government, Japan; [3)]Furukawa Agr. Exp. Stan., Japan)

10:10-10:30 Recent trends in the nutrient status of the paddy field soil in Japan and related topics
M. Nanzyo*, T. Takahashi and H. Kanno (Tohoku University, Japan)

10:30-11:00 Coffee break

11:00-11:20 Pedological characteristics and heavy metals cantamination in rice production of the paddy soils in Taiwan
Z. Y. Hseu*[1)], Z. S. Chen[2)] and S. H. Jien[2)] ([1)]National Pingtung University of Sci. and Tech., Taiwan; [2)]National Taiwan University, Taiwan)

11:20-11:40 Development of rice cultivation under a water storage-type deep-irrigation regime
T. Ishibashi*[1)], Y. Goto[1)], M. Saito[2)], T. Nakamura[1)], S. Nakamura[2)] and M. Kokubun[1)] ([1)]Tohoku University, Japan; [2)]Miyagi University, Japan)

11:40-12:00 Heavy metal contamination and remediation of paddy soil in Korea
W. I. Kim*, G. B. Jung, J. S. Lee, J. H. Kim and J. T. Lee (National Institute of Agr. Sci. and Tech., Korea)

12:00-12:20 Soil properties and rice growth in winter flooded paddy field with organic farming
T. Ito*[1)], C. Kon[2)], H. Watanabe[1)], T. Komiyama[1)], N. Tanikawa[1)] and M. Saigusa[1)] ([1)]Tohoku Uni-

versity, Japan; [2]Aomori Pref. Agric. and Forestry Res. Center, Japan)

12:20-13:20 Lunch

(Poster session)

13:20-15:00 **Poster viewing**

1. QTL analysis of rice grain quality under the high-temperature-stress condition in the grain filling period
   K. Shirasawa[1], K. Nagano[2], S. Kishitani[1] and T. Nishio[1] ([1]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan and [2]Miyagi Furukawa Agr. Exp. Stn., Osaki, Japan)
2. Detection and identification of single nucleotide polymorphisms (SNPs) in *japonica*rice cultivars
   H. Maeda, K. Shirasawa, S. Kishitani and T. Nishio (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
3. Mapping of a mutant gene for genic male sterility in rice
   S. Shiokai, Y. Hori and T. Nishio (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
4. Selection of silent mutants in rice for identification of production areas
   Y. Takahashi[1], Y. Sato[2], K. Shirasawa[1], M. Nishimura[3] and T. Nishio[1] ([1]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [2]Grad. Sch. Agr. and Life Sci., Univ. of Tokyo, Tokyo, Japan; [3]Institute of Radiation Breeding, National Institute of Agrobiological Sci., Ibaraki, Japan)
5. A novel *wx* allele having non-autonomous retrotransposon-like sequence in its exon
   Y. Hori and T. Nishio (Grad. Sch. Agr. Sci., Tohoku Univ., Japan)
6. Expression analysis of *WRKY16* regulated by *HSP101* promoter in transgenic rice
   X. L. Wu, Y. Shiroto, S. Kishitani and K. Toriyama (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
7. Molecular mapping of the fertility restorer gene for LD-type cytoplasmic male sterility of rice
   N. Iwata, S. Fujii and K. Toriyama (Grad. Sch. Agr. Sci., Sendai, Japan)
8. An approach toward understanding the function of a CMS-associated gene, *orf79*, of rice
   H. Kojima[1], T. Kazama[2], S. Fujii[2] and K. Toriyama[2] ([1]Depart. Agr., Tohoku Univ., Sendai, Japan; [2] Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
9. An approach toward producing insect-resistant crops expressing yam tuber lectin (DB1)
   T. Kato[1], A. Sasaki[2], T. Ogawa[3], M. Hori[2] and K. Toriyama[2] ([1]Faculty of Agr., Tohoku Univ., Sendai, Japan; [2]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [3]Grad. Sch. Life Sci., Tohoku Univ., Sendai, Japan)
10. A novel mutated acetolactate synthase gene conferring specific resistance to pyrimidinyl carboxy herbicides in rice
    A. Okuzaki[1], T. Shimizu[2], K. Kaku[2], K. Kawai[2] and K. Toriyama[1] ([1]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [2] Kumiai Chemical Industry Co., Shizuoka, Japan)
11. Post-transcriptional regulation of mitochondrial *atp6* RNA by fertility restorer genes in LD-type and BT-type cytoplasmic male sterile rice
    E. Itabashi, T. Kazama and K. Toriyama (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
12. Changes in the mRNA levels of the *rbc*S gene family during leaf development in rice
    R. Yoshizawa, Y. Suzuki, K. Imai, A. Makino and T. Mae (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
13. Increased Rubisco content in transgenic rice transformed with “sense” *rbc*S gene.
    Y. Suzuki, M. Ohkubo, H. Hatakeyama, K. Ohashi, R. Yoshizawa, S. Kojima, T. Hayakawa, T. Yamaya, T. Mae and A. Makino (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
14. Epistatic interaction of QTLs controlling leaf bronzing in rice (*Oryza sativa* L.) grown in a saline paddy field
    H. Takehisa[1], T. Ueda[2], Y. Fukuta[3], M. Obara[4], T. Abe[5], M. Yano[2], T. Yamaya[4], T. Kameya[1], A. Higashitani[1] and T. Sato[1] ([1]Grad. Sch. Life Sci., Tohoku Univ., Sendai, Japan; [2]Depart. Molecular Genetics, Na-

tional Institute of Agrobiological Sci., Tsukuba, Japan; [3)]Japan International Research Center for Agr. Sci., Tsukuba, Japan; [4)]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [4)]RIKEN, Wako, Japan)

15. Characterization of quantitative trait loci controlling seed longevity of rice (*Oryza sativa* L.) using chromosome segment substitution lines
K. Sasaki[1)], Y. Fukuta[2)] and T. Sato[1)] ([1)]Grad. Sch. Life Sci., Tohoku Univ., Sendai, Japan; [2)] Japan International Research Center for Agr. Sci., Tsukuba, Japan)
16. S deficiency symptom of rice and amelioration with $CaSO_4$ application
K. Sasaki[1)], T. Hayashi[1)], M. Nanzyo[1)], H. Kanno[1)], T. Takahashi[1)], E. Hasegawa[2)], M. Honna[3)], Y. Aikawa[3)] and K.Yoshihara[3)] ([1)]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [2)]Miyagi Pref. Furukawa Agr. Exp. Sta.; [3)]Hosokura Environment Research Center, Central Research Institute, Mitsubishi Materials Corp.)
17. Changes in available N content of soil with time during soybean cultivation
R. Maekawa[1)], K. Yoshizumi[2)], M. Nanzyo[1)] and T. Takahashi[1)] ([1)]Grad. Sch. Agr. Sci., Sendai, Japan; [2)]National Agr. Research Center for Tohoku Region, Morioka, Japan)
18. Persistence of $CaCl_2$ washing effect for amelioration of Cd contaminated soil
T. Hayashi[1)], T. Kida[1)], M. Nanzyo[1)], T. Takahashi[1)], M. Honna[2)], Y. Aikawa[2)] and K. Yoshihara[2)] ([1)]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [2)]Hosokura Environment Research Center, Central Research Institute, Mitsubishi Materials Corp.)
19. Improvement of rice growth in direct seeding cultivation by application of gibberellin in combination with ethylene-releasing agent ethephon
H. Watanabe, S. Hase and M. Saigusa (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
20. Population density of aquatic oligochaetes in winter flooded rice fields with organic farming
T. Ito, K. Hara, T. Hirai, C. Kon, A. Mitamura, H. Heinai, M. Kawase and M. Saigusa (Grad. Sch. Agr. Sic., Tohoku Univ., Sendai, Japan)
21. Effects of climatic conditions on degraded rice grain quality in Miyagi Prefecture
N. Miyano and M. Kokubun (Grad. Sch. Agr. Sic., Tohoku Univ., Sendai, Japan)
22. Effect of high night temperature on grain ripening in large-grain rice cultivar, Akita 63
K. Kanno, A. Makino and T. Mae (Grad. Sch. Agr. Sic., Tohoku Univ., Sendai, Japan)
23. Varietal differences in effects of deep-water irrigation on yield and floral sterility of rice cultivars in the cool summer of 2003
T. Ishibashi[1)], M. Saito[2)], M. Kokubun[1)], S. Nakamura[2)] and Y. Goto[1)] ([1)]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [2)]Miyagi Univ., Sendai, Japan)
24. Production of rice plant rich in anti-angiogenic tocotrienol
P. Sookwong[1)], K. Nakagawa[1)], K. Murata[2)] and T. Miyazawa[1)] ([1)]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [2)]Toyama Agr. Res. Center, Japan)
25. Biomass analysis at Miyagi Prefecture in Japan using Landsat/TM data
R. Iwasa[1)], T. Sugihara[1)], F. Namiwa[1)], K. Osawa[2)] and G. Saito[2)] ([1)]Faculty of Agr., Tohoku Univ., Sendai, Japan; [2)]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
26. Analysis of salt-damage on rice by the typhoon 15 in 2004 using SPOT-5/HRG satellite images and DEM data
K. Osawa[1)], M. Hanayama[1)], G. Saito[1)], Y. Kosugi[2)], N. Kosaka[2)], K. Uto[2)], S. Hoshino[2)], A. Imagawa[3)] and K. Oda[3)] ([1)]Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan; [2)]Interdisciplinary Grad. Sch. Sci. Engineering, Tokyo Institute Tech.; [3)]Shonai Branch, Yamagata General Agr. Research Center)
27. Paddy field extraction at Shonai district in Japan using satellite data
F. Namiwa[1)], K. Osawa[1)], G. Saito[1)], A. Imagawa[2)], K. Oda[2)], Y. Kosugi[3)] and N. Kosaka[3)] ([1)]Faculty Agr., Tohoku Univ., Sendai, Japan; [2)]Shonai Branch, Yamagata General Agr. Research Center; [3)]Interdisciplinary Grad. Sch. Sci. Engineering, Tokyo Institute Tech.)
28. Undrerstanding for paddy fields in the world using ASTER data
G. Saito, K. Osawa and M. Hanayama (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)
29. Research on production of the ethanol fuel by the rice and construction of the social system

K. Morozumi (Grad. Sch. Agr. Sci., Tohoku Univ., Sendai, Japan)

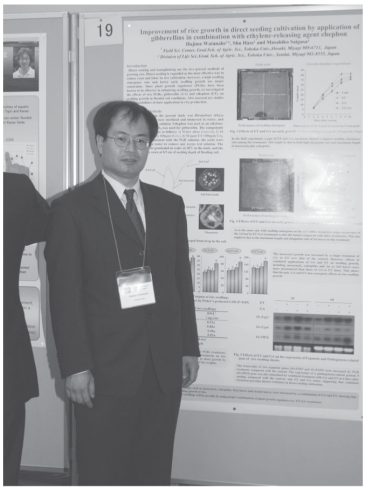
(Excursion)
7 November

15:30 Leave Washington Hotel, 17:30 Arrive at Bentenkaku Hotel, 18:30 Dinner

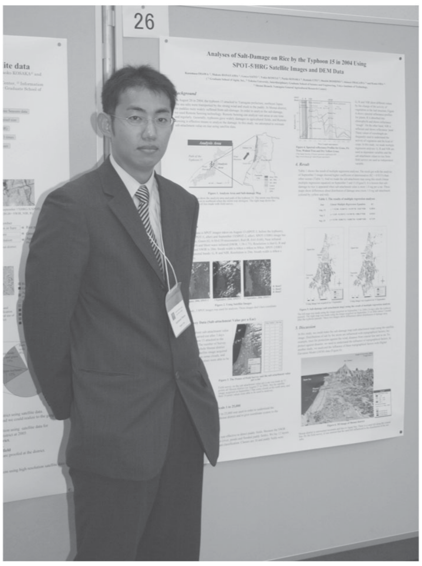
8 November

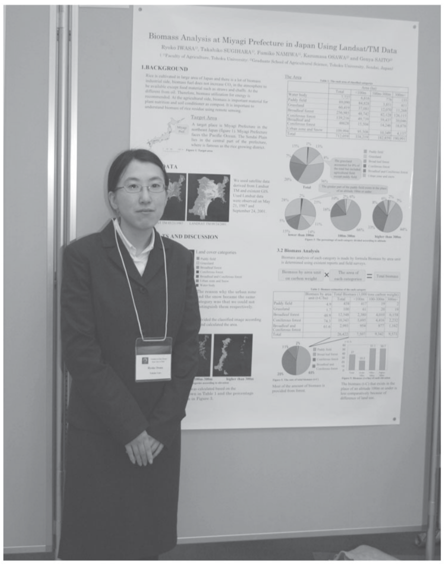
09:30 Leave hotel, 09:50 Visit Field Science Center (Compost processing facility, P1 field, Andisol profile), 11:50 Lunch at Ara Datena Michino Eki, 13:30 Visit Furukawa Agr. Exp. Stn. (Cold tolerance evaluation facility, Greenhouse for generation acceleration, Alluvial soil profile), 17:30 Back to Washington Hotel

The Photographs of 4th IW-IFS


19
Improvement of rice growth in direct seeding cultivation by application of gibberellins in combination with ethylene-releasing agent ethephon


15
14


26
Analyses of Salt-Damage on Rice by the Typhoon 15 in 2004 Using
SPOT-5/HRG Satellite Images and DEM Data


Biomass Analysis at Miyagi Prefecture in Japan Using Landsat/TM Data

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.

Our journal publishes one volume in principle every year, and we publish at ordinary printing matter, and all of the manuscripts on the web site as e-journal.

Manuscript creation point

Please write a contribution paper according to the form of the paper of our journal. In your paper, (1) Title, (2) running title, (3) Affiliation and its address, (4) e-mail address of corresponding author, (5) key words (five to seven words not appearing in the title), (6) Abstract (about 250 words), (7) Introduction, Materials and Method, Results, Discussion (Results and Discussion), (Acknowledgement), References, Table file, Figure file, Legend of figure are included.

All of your paper will be written in A4 size paper by Word file or a text file. Tables are made by excel file and figures are made by tiff or jpeg file, or Power Point file. Both files (on the PC diskette or CD-R, or CD-RW file) and two copies of printed paper (or PDF file) are sent to our editorial board by attached files of e-mail or ordinary mail. If you do not make your paper by the software, please contact our committee.

Next Publication

The vol.4 of JIFS will be published in March 2007. If you want to appear your study in the volume, please send your manuscript to us until November 30, 2006.

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