This file was prepared from the original book by OCR. Though the text was proofread several times, I regret to say that there might still be some errors.

STUDIES ON THE SELECTION OF CULTIVARS, GENOTYPE-ENVIRONMENT INTERACTION AND GROWTH CONTROL OF DIRECT-SEEDED RICE

WON JONG GUN

2000

STUDIES ON THE SELECTION OF CULTIVARS, GENOTYPE-ENVIRONMENT INTERACTION AND GROWTH CONTROL OF DIRECT-SEEDED RICE

by

WON JONG GUN

A DISSERTATION SUBMITTED TO THE DIVISION

OF AGRICULTURE GRADUATE SCHOOL KYUSHU UNIVERSITY FOR

THE FULFILLMENT OF THE PHILOSOPHY OF DOCTOR DEGREE

OF AGRICULTURE IN AGRONOMY

LABORATORY OF CROP SCIENCE

DIVISION OF AGRICULTURE

JULY 2000

The major part of this research was conducted from October 1997 to June 2000 in the Division of Agriculture, Graduate School, Kyushu University. Parts of the contents were published or are preparing for publication;

1. Won, J.G. Hirahara, Y. and Yoshida, T. 1998. Selection of cultivars for direct seeding in rice based on the development of root system analysis. J. Fac. Agr., Kyushu Univ. 43:31 - 37.

2. Won, J.G. Hirahara, Y., Yoshida, T. and Imabayashi, S. 1998. Selection of rice lines using SPGP seedling method for direct seeding. Plant Prod. Sci. 1 :280 - 285

3. Won, J.G. and Yoshida T. 1999. Selection of rice cultivars for wet and dry direct-seeding. Proc. Int. Symp. -World Food Security, Kyoto: 265-268.

4. Won, J.G. Choi, C.D. and Lee, S.C. 1999. Interaction between N application and water management in dry-seeded rice. Plant Prod. Sci. 2 109 - 114.

5. Won, J.G., Choi, C.D. and Lee, S.C. 1999. Tillering, lodging and yield under deep water treatment in direct-seeded rice. Plant Prod. Sci. 2:200 - 205.

6. Won, J.G., Yoshida, T. and Uchimura, Y. 1999. Genotype-environment interactions of selected rice lines in direct water-seeded culture. Plant Prod. Sci. 2:252 - 257.

7. Won, J.G. and Yoshida, T. 2000. Screening cultivars under low dissolved oxygen level for water-seeded rice. Plant Prod. Sci. (in printing).

8. Won, J.G. and Yoshida, T. 2000. Varietal differences on seedling traits under low dissolved oxygen level in water-seeded rice. Plant Prod. Sci. (submitted) .

9. Won, J.G. and Yoshida, T. 2000. Combining ability and heterosis in selected lines for direct-seeded rice. Plant Prod. Sci. (submitted) .

CONTENTS

GENERAL SUMMARY

The reduction of labor force has driven changes of rice cultivation technologies to labor-saving cultivation and needs of new cultivars with lodging tolerance. This study was carried out to select promising lines or candidates of parental lines for direct-seeded rice, to evaluate the effect of environments, yield stability and their performance of selected lines under different environments and to develop a useful cultivation method for controlling the over-growth of direct-seeded rice.

Wide varietal differences on root traits and shoot traits under the low dissolved oxygen condition were found and several promising cultivars were screened. They might be very useful genetic sources in improving the establishment of the rice seedlings for water-seeding.

Some promising lines and candidate parental lines with thick roots were selected by using seed pack growth pouch seedling method and the field evaluation. By the regression method, adaptability was evaluated among genotypes and one line selected in this study showed high average yield and good adaptability. Through a factorial crossing among four selected lines and three check cultivars, general (GCA) and specific (SCA) combining ability, and degree of heterosis were estimated in F1 populations. GCA predominated for almost all yield characteristics. Some parents and hybrids were found to be potential for high yielding and lodging resistance.

The deep water treatment was effective to suppress the growth of non-productive tillers. Deep water treatment also improved the lodging tolerance by the thicker culm and increased breaking weight. The suppression of tiller formation by deep water improved the yield determinants and utilization efficiency of indigenous soil N.

SUMMARY

To develop rice cultivars and improve rice cultivation for high yield with lodging tolerance in direct-seeded rice, a series of experiments was carried out. Results are summarized as follows;

1. In water-seeded rice, the failure of rice to emerge through soil and water has been attributed to the lack of O_2. Therefore, it is necessary to screen or develop cultivars which have tolerance to low dissolved oxygen conditions. The low dissolved oxygen level enhanced coleoptile elongation and inhibited root and shoot growth of the rice seedlings and there were the genotype differences for the morphological development. The significant difference among genotypes was found at 2.0 - 2,5 mg L^{-1} dissolved oxygen level.

2. Under low dissolved oxygen condition, root number was correlated with root length, coleoptile length and shoot length. Root length was also significantly correlated with coleoptile length and shoot length.

3. Several cultivars with high tolerance to the low dissolved oxygen level were identified, judging from the root number, root length, coleoptile length and shoot length. These cultivars might be very useful genetic sources in improving the establishment of the rice seedlings for water-seeding.

4. To select cultivars at the early stage for root system with lodging tolerance, transparent polyethylene seed pack growth pouch (SPGP) was used. Root thickness of SPGP seedlings was positively correlated with pushing resistance of field test (r= 0.46**). The root thickness of SPGP also had a positive correlation with root thickness of field test.

5. Considering root and culm thickness, grain yield and amylose content, several promising lines were selected for water-seeding cultivation or candidate parental lines for next crossing cycle.

6. To estimate general (GCA) and specific (SCA) combining ability, and heterosis for direct-seeded rice, a 4 x 3 factorial crossing (Design II) was completed and the 12 Fl hybrids and their 7 parents, including selected lines, were evaluated. GCA was significant for culm length, culm thickness, panicle length, 1000-grain weight and grain yield, indicating the importance of additive gene effects for these traits. Dominance gene effects were highly significant for culm length, culm thickness, 1000-grain length and grain yield, indicating that these traits were controlled by the nonadditive gene action. Some parents with positive GCA for yield, culm thickness, panicle length were found and they could contribute to developing cultivars for direct-seeding.

7. Mid-parent heterosis for yield ranged from -16.3% to 37%, with average value of 17.3% for all hybrids. The mid-parent heterosis for culm length ranged from -1.7% to 30.0% with average value of 13%. The mid-parent for culm thickness ranged from -6.1% to 23.9% with average value of 4.2%.

8. The effect of genotype on seedling growth and the interaction between genotype and environment under dry and wet direct-seeding conditions were examined. The effects of genotype (G), seeding date (S) and cultivation method (C) on the days to emergence and emergence rate were highly significant. The interaction was significant in S-C, G-C and G-S-C for both emergence traits, and in G-S for the days to emergence, suggesting varying of genotypic response depending on cultivation

methods and seedling date. Days to emergence was negatively correlated with emergence rate, root length at day 18 after seeding, root thickness, plant height and leaf age at day 28. Positive correlation coefficients were obtained between the values measured at day 18 and 28 in each plant characteristic such as root length, thickness, plant height and leaf age.

9. Five rice genotypes including 4 breeding lines selected in this study were grown under various environmental conditions (Year. Location, Density and Nitrogen) to determine the genotype - environment (G-E) interactions and adaptability in water-seeded rice. No G-Y interactions in yield and yield component were detected. The interaction of G-D and G-N were significant only in percentage of filled grains. G-L interaction was significant for yield and almost all yield components. The difference in adaptability among genotypes evaluated by a regression method was found and one line (L42) showed high average yield and higher yield in high-yielding conditions. L 42 was selected for direct-seeded culture.

10. In direct-seeded rice, one of the most serious problems is over-growth of tillers and this leads to taller plants with weaker culms, increasing the lodging. Therefore, it is necessary to suppress the growth of non-productive tillers to obtain larger panicles and strong culms. In this study, the author confirmed that deep-water treatment was effective to suppress the growth of non-productive and weaker tillers and to increase the panicle size and tiller productivity. It also improved the lodging tolerance by increasing the thickness and breaking weight of the culm.

11. There were significant differences in yield components and yield between the deep and ordinary-water treatments. Deep-water treatment increased the percentage of

ripened grain and grain yield, and decreased panicle number per m^2. More tillers were produced in ordinary-water than in deep-water. The percentage of productive tiller was higher in deep-water than in ordinary-water.

11. The partial factor productivity (PFP) of applied N was significantly higher in deep-water than in ordinary-water at all levels of nitrogen application. Agronomic nitrogen-use efficiency (ANUE) was not different between the two water treatments. Therefore, the suppression of tiller formation by elevated water level improved the yield determinants and utilization efficiency of indigenous soil N, which consequently helped to increase yield.

13. In conclusion, through these studies, several genotypes with tolerance to low dissolved oxygen, with lodging tolerance and good yield capacity and with positive combining ability were screened. They could be very important as new genetic sources, could improve the potential of increasing yield and could contribute to developing cultivars for direct seeding. By the test of genotype-environment and adaptability, one promising line was selected for direct-seeding. It was revealed that the deep-water treatment was very effective to control the over-growth of direct-seeded rice, improve the utilization efficiency of indigenous soil N and increase the yield determinants.

I. INTRODUCTION

Under the UR and WTO worldwide trading system, in the early future, free trade of agricultural products will be faced inevitably in Japan and Korea. Practically the prices of rice as a principle food in these countries are expensive and about 3 ~ 5 times higher compared to those of foreign markets. To overcome these situations, attention has been paid on cultivation method, such as direct seeding, which can reduce production cost, save labor and increase international competition. However, there are many problems in the direct-seeding cultivation in rice. For the establishment of this method, the development of adaptable rice cultivar to high planting density with lodging tolerance, effective seedling stand at low temperature and under low dissolved oxygen condition, weed control, irrigation management, and so on are necessary.

The acreage of the direct-seeded rice was increased gradually, and it occupied about 10% of the total rice area in Korea. However, because of those reasons mentioned above, the increasing rate was remained plateau or reduced from 1995 (Fig. 1). In Japan, even though the history of study on direct-seeding cultivation was long, the acreage of direct-seeded rice was decreased gradually and it extended only 0.4% of total rice area in 1996 (Maruyama and Matsumura, 1996).

Until now, in order to improve seedling establishment and reduce lodging damage, attention was given to the aspect of cultural technology than to the aspect of breeding. Although Mitsuishi (1975) reported that the percentage of successful seedling establishment did not vary among domestic varieties, there were differences among domestic and foreign varieties on the seedling establishment ability

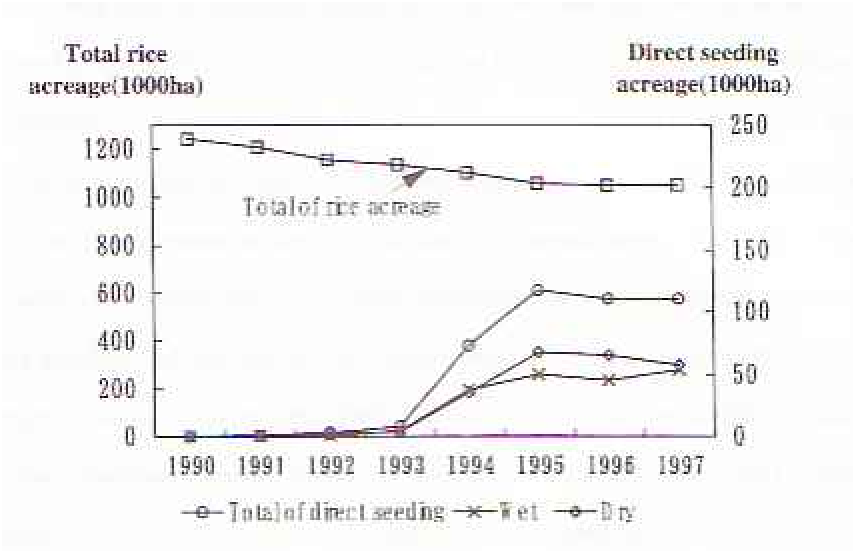

Fig. 1. The acreage changes of the total rice cultivated area and direct-seeded rice area in Korea (Lee et al., 1996).

(Amano et al., 1993; Ioue et al., 1997; Arai et al., 1999; Saka and Izawa, 1999). Thus, it is very important to screen or select cultivars adaptable to the direct-seeding method among the various varieties. And then, the introduction and utilization of screened or selected cultivars as new genetic sources may be effective for the genetic improvement for direct-seeding.

The basic method of the direct-seeding cultivation of rice are dry-seeding and water-seeing (Fig. 2). In the dry-seeding technique, the seeds are sown in the soil and allowed to develop to about the five-leaf stage and then a permanent flood is established on the field (Westcott et al., 1986). In water seeding, the pre-soaked seeds are sown into the flooded field and the land is continuously submerged after seeding to some depth until the rice is mature enough to be drained for harvest (Jones, 1933). The seeds, covered with soil and water, often fail to germinate or establish completely, producing only plumules, and the radicles and crown roots fail to develop due to the lack of oxygen (Dore and Thevan, 1959; Finfroock and Miller, 1958; Jones, 1933; Kordan, l974a). Therefore, it may be very useful as genetic sources for direct-seeding if some varieties, which can develop root well under low oxygen level, are screened.

Lodging of rice clearly limited the yield and the potential of increasing yields in unfavorable weather conditions in direct-seeding cultivation (Fig. 3). Lodging was divided into four types and, among them, two types of lodgings, root lodging and culm breaking, mostly occurred in direct-seeding cultivation (Seko, 1954). Miyasaka (1970) concluded in his report that root strength at ripening stage had a close relationship not only with root lodging but also with culm breaking lodging. Most researches on lodging of rice plant have involved the relationship between lodging and root system.

Fig. 2. The major two methods of the direct-seeding, dry-seeding (above) and water-seeding (below)

Fig. 3. Lodging is one of the major problems in direct-seeded rice.

Lodging tolerance of rice in direct-seeding cultivation was affected by root thickness, root distribution and dry weight of root (Miyasaka, 1970; Ogata and Matsue, 1996b; Terashima et al., 1995). Thus, to reduce lodging damages in direct seeding, selection or development of cultivars with good root systems is very important.

The notion of good combining ability implies the capacity of a parent to produce superior progenies when combined with another parents . There are general and specific combining abilities. General combining ability (GCA) is the average value of a parent estimated on the basis of its performance when crossed with other parents. Specific combining ability (SCA) is the behavior of a parent when crossed with another parent. The average value of that specific combination may diverge from the average general combining ability of these two parents. Jinks (1955) and Hayman (1958) considered general combining ability to be a result of additive gene action, and specific combining ability a result of epistasis, i.e., interallelic interaction. Falconer (1967) associated differences in general combining ability to the additive component of genetic variance and to interaction of alleles and differences in specific combining ability to the non-additive variance, i.e., dominance and epistasis, and their interactions.

Knowledge of the underlying gene action within the breeding population is a key to selecting procedures that will maximize gains in yield. If additive gene action is predominant in a self-pollinated species such as rice, then the breeder can effectively select at various levels of inbreeding, because additive effects are readily transmissible from one generation to another (Gravois and McNew, 1993a). Several studies on the combining ability have been conducted in rice plants for grain yield, low temperature germinability, tiller number and callus growth (Gravois and Mcnew, 1993a; Kang et al., 1997; Kuroda et al., 1998; Murai and Kinoshita, 1986; Xu and Shen, 1991). However, combining ability and heterosis estimates for direct-seeded rice are lacking.

Two or more genotypes grown in different environmental conditions may exhibit different relative performances. This phenomenon is called genotype-environment (G-E) interaction. Growers need cultivars that have high yield potential consistently across a wide array of stress conditions and even under the conditions improved (Peterson et al., 1997).

The phenotype is determined by the genotype, environmental factors and their interaction. If no G-E interaction is present, the difference between genotypes evoked by phenotypes in different environments would be consistent. Significant G-E interactions resulted from the difference in the magnitude of the response of each genotype to various environmental factors or from the changes in relative ranking of the genotypes under different environmental conditions (Allard and Bradshaw, 1964; Cornelius et al., 1993; Fernandez, 1991). That is, a non-crossover G-E interaction and a crossover G-E interaction. In the latter case, the genotype selected for high yield under one environmental condition may not always be superior to other genotypes under another environmental conditions (Baker, 1988; Cornelius et al., 1993). To select the genotypes with wide environmental adaptation, plant breeders should look for the genotypes showing non-crossover G-E interaction (Matus et al., 1997).

It is important to develop cultivars adapted to the direct-seeding, and besides, it is also important to improve the lodging tolerance and yield capacity by the cultural technology such as improving the seedling establishment in wet seeding by seed coating with calcium peroxide (Yamada, 1952 and Yamauchi, 1999) or improving the lodging resistance in dry-seeding by hill-seeding method (Won et al. 1996). One of the most serious problems is over-growth of tillers and this lead to taller plants with weaker culms, increasing the lodging in direct seeded rice. Because of greater tiller number, faster crop establishment and subsequent N dilution in the tissue, foliar N content decreased more rapidly (Dingkuhn et al., 1990; Schnier et al., 1990). Therefore, it is necessary to suppress the growth of non-productive tillers to obtain larger panicles and strong culms. Hanada and Kagawa (1985), Kawashima and Murakami (1985), and Furuya et al. (1991) reported that the deep-water treatment (DW) suppressed the overgrowth of tillers in transplanted rice. It has been reported that the culm diameter of all cultivars at the ripening stage was markedly large and the breaking strength of the basal elongated internodes tended to increase under DW (Ohe et al., 1996; Won et al., 1997). In this point of view, the deep-water treatment was tried to reduce the risk of lodging and to improve the N use efficiency by the growth control of the direct-seeded rice.

In this thesis, several experiments were conducted for planning an effective breeding program for cultivars with high grain yield, lodging tolerance, good root system, and related subjects in direct-seeded rice, which included the following matters:

1) Determination of the effect of dissolved oxygen concentration and screening promising cultivars tolerant to low dissolved oxygen concentration for water direct-seeded rice.

2) Development of a useful method for selection of cultivars based on root system analysis.

3) Selection of promisng lines using SPGP method for direct-seeding and the relationship among root traits, pushing resistance, yield and yield components.

4) Estimation of the combining ability, degree of heterosis and identification of promising parents with good combining ability.

5) Evaluation of the selected lines under several environmental conditions, determination of the genotype-environment interaction and adaptability by the regression technique.

6) Over-growth control and increasing the lodging tolerance by water management in direct-seeded rice.

7) Interaction between N application and water management, and improvement of N use efficiency.

The overall of this study can be classified into three main aspects : (1) Breeding strategy - Screening of promising genotypes, estimating combining ability, heterosis and their implication in selection for high grain yield, and lodging tolerance. (2) Genotype-environment interaction and adaptability - Determination of the G-E interaction and adaptability to environmental conditions on selected lines. (3) Growth control for direct-seeded rice - Effects of over-growth control of the direct-seeded rice for N use efficiency, lodging, yield by deep water treatment.

Fig. 4 illustrates the three main aspects of the entire of the study, which implies the systematical method that employed.

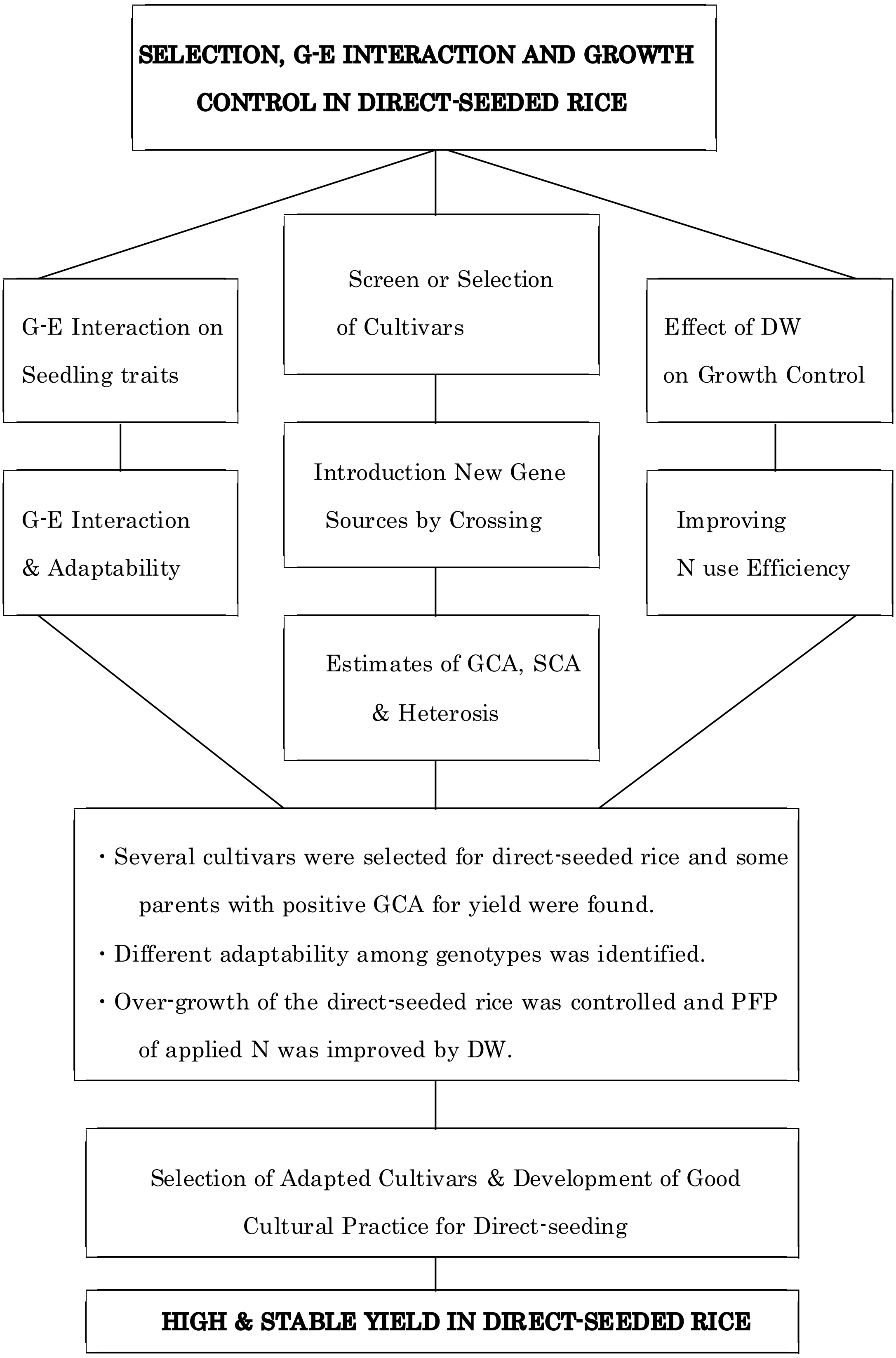

Fig. 4. Flowchart showing the three main aspects and related subjects in this thesis.

II. SCREENING CULTIVARS UNDER LOW DISSOLVED OXYGEN LEVEL

1 . Effect of Low Dissolved Oxygen Concentration in Rice Seedling Traits

Rice seed will not usually emerge through both soil and flood water (Kordan, 1977). The failure of rice to emerge through soil and water has been attributed to the lack of O_2 (Dore and Thevan, 1959; Finfroock and Miller. 1958; Jones, 1933; Kordan 1974a). The anaerobic coleoptile was quite thin and fragile despite its greater length (Kordan, 1977; Sasaki, 1926; Takahashi, 1978; Tener et al., 1981). With respect to dry weight, protein content, cellulose and sugar content, and various enzyme activities, the resulting coleoptile was markedly deficient compared to coleoptiles in air (Alpi and Beevers, 1983).

Terner et al. (1981) showed that the low O_2 levels enhanced coleoptile elongation and inhibit root and shoot elongation of rice seedlings. Their data further illustrate cultivar differences in effects of O_2 on seedling development. The cultivars they used were medium or long grain cultivars. Therefore, investigation using several genotypes including Japonica and Indica type cultivars under different dissolved oxygen levels are needed.

The objective of this study are to determine the effect of dissolved oxygen (DO) concentration on the growth of rice seedlings under different DO levels in water and to identify the optimum DO level for screening rice cultivars which may be tolerant to low DO levels during the seedling stage especially on root growth.

Materials and Methods

Six genotypes, two Japonica type cultivars (Koshihikari and Sasanishiki), two medium grain cultivars from America (M302 and Magnolia) and two Indica type cultivars (IR661 and Lemont) were used. Rice seeds were sterilized with 70% ethanol for 30 second and 2% sodium hypochloride for 15 minutes successively. Ten presprouted seeds from each genotype were placed in the seedbeds and then these seedbeds were submerged into oxygen-controlled water boxes with 7 cm water depth. The water boxes containing the seedbed were placed in a growth chamber, which provided 25°C air temperature under 400 μ mol m^{-2} s^{-1} light intensity for 12 hours per day.

Five DO concentrations were adjusted using olive oil (0-0.5 mg L^{-1}), N2 gas (1.0-1.5 and 2.0-2.5) and air pump (4.0-4.5 and 6.5-), respectively (Fig. 5). To obtain the 0-0.5 mg L^{-1} DO level, first the DO of the sterilized water was adjusted 0.45 mg L^{-1} using N2 gas (99.995%), which was bubbled through distilled water and then overlaid with a 0.7 cm thick layer of olive oil to prevent contacting with O^2 in air (Kordan, 1974). To obtain the 1.0-1.5 and 2.0-2.5 mg L^{-1} DO level, the DO concentration was controlled every day within the respective level using N2 gas. One air pump was used continuously for maintaining 4.5-5.0 DO level and two air pumps for over 6.5 DO level. A O_2/DO meter (SIBATA, model ODT- 101) was used to continuously monitor the DO level.

At eight days after placing seeds in the seedbed, the root number (longer than 0.5 cm), length of longest root, length of coleoptile, length of shoot and leaf age were measured for 5 randomly selected seedlings from each cultivar. All treatments were carried out with two replications. Analysis of variance (ANOVA) of this study was done using IRRISTAT program (IRRI, 1993).

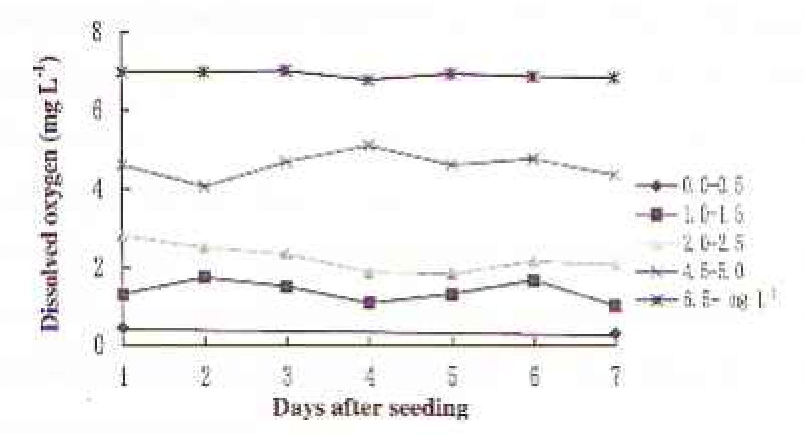

Fig. 5. Changes of the dissolved oxygen concentrations with time during the experiment.

Results and Discussion

The genotypic variation in the effect of DO was highly significant ($p < 0.01$) on the all of the seedling traits (Table 1). This suggests the possibility of the screening of the cultivars tolerant to low DO conditions. The interactions of the DO x Genotype were detected on the all of the seedling traits except the root number.

Fig. 6 shows the growth of seedlings as affected by the different DO levels. The growth of root was extremely poor at the 0-0.5 mg L^{-1} DO level (Fig. 7). The mean root number of six genotypes at this DO level was 0.07 per seedlings and the mean length of the longest root in six genotypes was 0.3 mm. The root growth was somewhat improved at 1.0-1.5 mg L^{-1} DO level. However, there was no difference among the genotypes. At DO levels lower than 2.0-2.5 mg L^{-1}, the root growth was poor, but, several genotypes, especially Sasanishiki, had more roots and a longer root than other genotypes. Jones (1933) also reported that oxygen was decidedly beneficial to the development of radicles in the germinating rice seeds.

The lower the DO levels, the longer the coleoptile (Fig. 8), which was in agreement with the result reported by Turner et al. (1981) who used various O_2 levels. They reported that the coleoptile was the longest at 0% O_2. Previous studies (Kordan 1974a,b; Takahashi, 1978; Turner et al., 1981) suggested that the elongation of the coleoptile at low O_2 levels was an adaptive response of the seed for acquiring O_2 for seedling development. The elongated coleoptile could possibly extend to an aerobic zone and allow O_2 necessary for the shoot and root with needed O_2. The length of coleoptile was significantly different among the genotypes at low DO levels (0-0.5, 1.0-1.5 and 2.0-2.5 mg L^{-1}), however, it was not different at higher DO levels.

Table 1. Mean squares of analysis of variance for root number, length, coleoptile length, shoot length and leaf age for dissolved oxygen levels and genotypes.

Sources	df	Root number[2]	Root length (mm)	Coleoptile length (mm)	Shoot length (mm)	Leaf age
Replication	1	0.003	5.4	0.28	3.0	0.0
Treatment	29	4.466**	1137.9**	116.09**	672.5**	1.01**
DO[1] (O)	4	29.663 **	7254.5**	601.07**	4308.6**	6.74**
Genotype (G)	5	1.1 59**	444.8**	137.05**	218.5**	0.19**
G X G	20	0.253	87.8**	13.86*	58.7**	0.07**
Error	29	0.030	21.8	6.35	14.2	0.12

1) DO : Dissolved oxygen level.

2) Root number longer than 5 mm.

* **: Significant at the 0.05 and 0.01 level of probability, respectively.

Fig. 6. The growth of seedlings as affected by the different dissolved oxygen level.

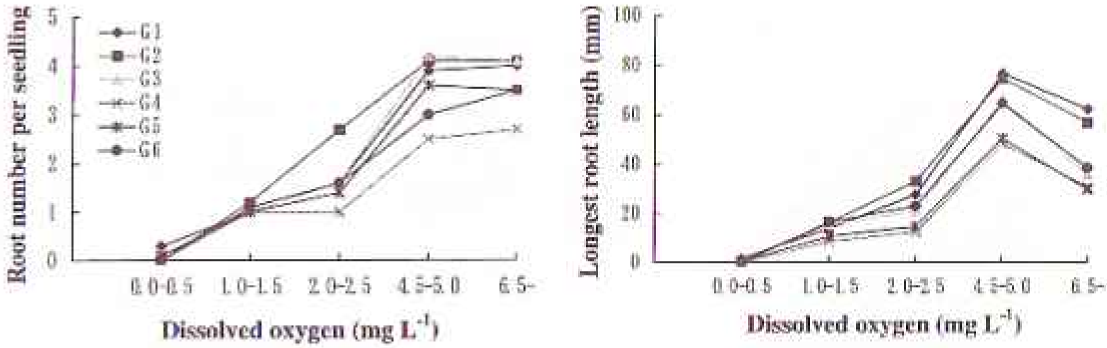

Fig. 7. Effects of dissolved oxygen levels on the root number and longest root length in six genotypes after 8-day incubation (G1: Koshihikari, G2: Sasanishiki, G3: M302, G4: Magnolia, G5: IR661, G6: Lemont).

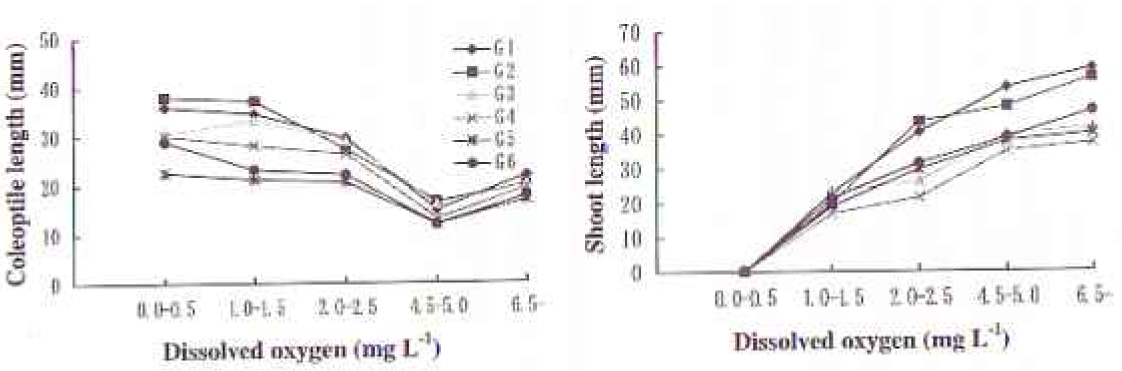

Fig. 8. Effects of dissolved oxygen levels on the coleoptile and shoot length in six genotypes after 8-day incubation (G1: Koshihikari, G2: Sasanishiki, G3: M302, G4: Magnolia, G5: IR661, G6: Lemont).

In the low DO conditions, the coleoptile elongated markedly, but the shoot did not developed (Fig. 8). At the 0-05 mg L^{-1} DO level, the primary leaf did not grow. The higher the DO level, the longer the shoot length. The pattern of -shoot growth was similar to that of the root growth. At the lower DO levels, the initiation and elongation pattern of the root was the same as that of the shoot but different from that of the coleoptile. This means that the elongation of the coleoptile is influenced by the O_2 concentration but that the elongation of the shoot and root is not. The difference of shoot length among genotypes was observed at 1.0-1.5 mg L^{-1} DO level. Among the six genotypes used in present study, the Japonica type cultivars (Koshihikari and Sasanishiki) had better seedling traits in low DO conditions.

The present study suggests the presence of genotype differences in effects of DO on morphological development. The seedling traits were not different among genotypes at 0-0.5 and 1.0-1.5 mg L^{-1} DO levels except for coleoptile length. At the 2.0-2.5 mg L^{-1} DO level, all the seedling traits were different. Thus, it may be possible to screen the genotypes tolerant to low DO levels at the DO concentration of 1.5-2.5 mg L^{-1}.

2. Varietal Differences on Seedling Traits under Low Dissolved Oxygen Level

No or poor root growth occurs and the growth of the primary leaf is barely detectable in an anaerobic condition (Nagai, 1916; Sasaki, 1926). Terner et al. (1981) and the author in the previous chapter suggested that there were cultivar differences in tolerance to low O_2 levels during the seedling stages. The objective of this study is to screen several promising rice cultivars, which may be tolerant to low DO levels during the seedling stage especially on root growth for further study of water-seeded rice.

Materials and Methods

Selection was carried out at the range of 1.5-2.5 mg L^{-1} DO concentration as described in the previous chapter. The DO concentration was controlled using N2 gas which was bubbled through distilled water container, and every day the DO concentration was checked and controlled within 1.5-2.5 mg L^{-1}.

Seventy genotypes, fifty from Japan, three from Korea, three from IRRI, seven from America, four selected lines (Won et al., 1998) and others three from Portugal, Philippines and Hungary were used. The methods, procedures, conditions and observations of seedling growth were similar to those of the previous chapter.

All treatments were carried out with two replications. Analysis of variance (ANOVA) and simple linear correlations among the seedling traits were done using IRRISTAT program (IRRI, 1993).

Results and Discussion

The effects of genotypes were highly significant ($p < 0.01$) for all of the seedling traits such as root number, longest root length, coleoptile length and shoot length (Table 2, Fig. 9).

Table 2. Mean squares of analysis of variance for root number, longest root length, coleoptile length and shoot length for genotypes under the low dissolved oxygen level.

Source of variation	df	Root number[1)]	Longest root length (mm)	Coleoptile length (mm)	Shoot length (mm)
Genotype	69	1.32**	125.8**	37.5**	502.1**
Error	70	0.49	27.4	18.9	101.9
Total	139				

1) Root number longer than 5 mm.

**: Significant at the 0.01 level of probability.

Fig. 9. Genotypic differences in tolerance to low dissolved oxygen levels during the seedling stages.

The range of the seedling traits of seventy genotypes were 0 - 5.1 roots per seedling in root number, 0 - 42.6 mm in longest root length, 0 - 32.3 mm in coleoptile length and 0 - 112.9 mm in shoot length, respectively (Fig. 10). The mean of seventy genotypes were 3.2 roots per seedling, 23.6 mm, 25.1 mm and 58.1 mm for root number, longest root length, coleoptile length and shoot length, respectively. Fig. 10 shows that the range of coleoptile length was narrower and the difference among the cultivars was not so clear than that of other traits of the seedling.

Fig. 11 shows the relationship among the seedling traits under low DO. There were significant positive correlations among root and shoot traits (r = 0.623**). Even though the correlation coefficients of the coleoptile length with root number or longest root length were significant, the values were lower than those of shoot length with root number and longest root length. This results somewhat agreed with the previous chapter that, in the lower DO levels, the initiation and elongation pattern of the root was the same with shoot but not with coleoptile.

The best ten cultivars for root number, longest root length, coleoptile length and shoot length among the seventy cultivars grown in low DO level are shown in Table 3. Among the cultivars, Arroz da Terra from Portugal was included in the best ten for all of the seedling traits. Shinriki and Italica Livorno were included in the best ten for all of the seedling traits except the root number Therefore Arroz da Terra Shinrikl and Italica Livomo were considered as the most tolerant to the low DO condition in present study. In case of Arroz da Terra, Inoue et al. (1997) reported that it showed a high rate of seedling establishment due to the low percentage of floating seedlings and

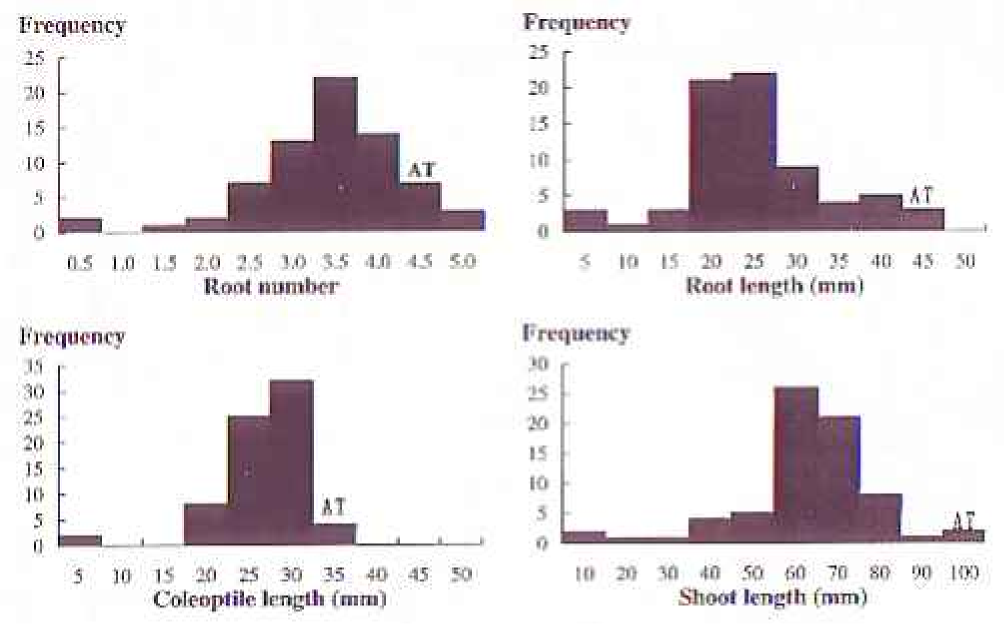

Fig. 10. Distribution of root number, root length, coleoptile length and shoot length under low dissolved oxygen condition (n = 70). AT: Arroz da Terra.

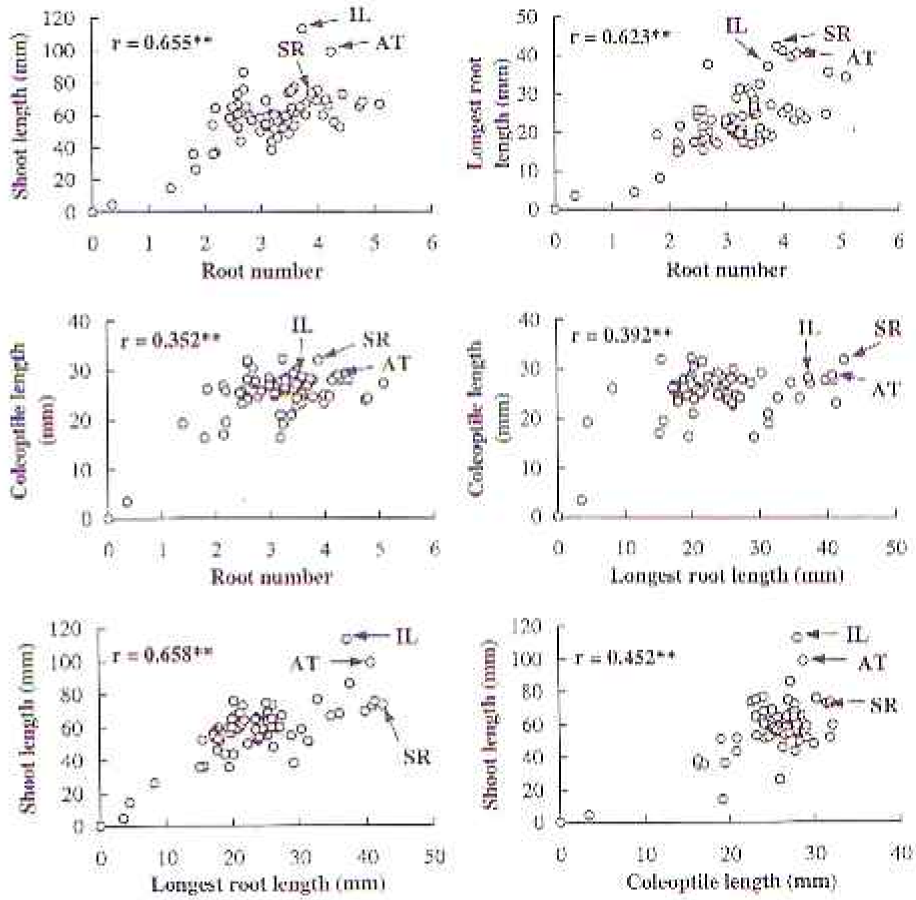

Fig. 11. Relationship among the seedling traits under low dissolved oxygen condition (n = 70; AT: Arroz da Terra, IL: Italica Livorno, SR: Shirinki). ** : Significant at the 0.01 probability level.

Table 3. The best ten cultivars for root number, Iongest root length, coleoptile length and shoot length among seventy cultivars under low dissolved oxygen level.

Rank	Root number	Longest root length (mm)	coleoptile length (mm)	Shoot length (mm)
1	Kinmaze (5.1)	Shinriki (42.6)	Aikoku (32.3)	I. L.(112.9)
2	N. S.[1)] (4.8)	C./F.6- 103- 15[3)] (41.4)	Shinriki (32.0)	A.T.(98.9)
3	Asahi (4.8)	Takara (41)	Kwanganbyeo (32.0)	Kamenoo (86.1)
4	Takara (4.5)	A. T. (40.8)	Yumetsukushi (31.6)	Line 53[5)] (76.8)
5	Benisengoku (4.4)	Norin 18 (39.9)	Kinuhikari (30.4)	Kinuhikari (75.8)
6	Akebono (4.3)	Kamenoo (37.7)	Nonghobyeo (30.0)	C./F.6-103-15 (75.2)
7	A. T.[2)] (4.3)	I. L.[4)] (37.3)	Benisengoku (29.2)	Omachi (74.7)
8	Shiranui (4.2)	N. S.(36.1)	Koshijiwase (29.2)	Moritawase (73.8)
9	Norin 18 (4.1)	Kinmaze (34.8)	A. T(28.9)	Shinriki (73.3)
10	Kanto 18(4.1)	Line 53 (32.8)	I.L.(28.2)	Yumetsukushi(72.9.)
Total mean	3.2	23.6	25.1	58. 1

1) Nakateshinsenbon, 2) Arroz da Terra(Portugal),

3) Cawwa/Fortuna 6- 103-15 (Philippine), 4) Italica Livorno (Hungary),

5) Line 53 (Selected line).

seedling mortality. Among the cultivars, Kinmaze, Nakateshinsenbon, Takara and Norin 18 were included in the best ten for root number and longest root length, suggesting that they had relatively good characteristics on root trait. On the contrary. Yumetsukushi and Kinuhikui had good characteristics on upper part traits. The cultivars of Benisengoku, Cawwa/Fortuna 6-103-15, Kamenoo and Line 53 showed the somewhat strong tolerance to both root and shoot traits.

Many researchers considered the tolerance to low DO condition as one of the main factors concerning to the good establishment of the seedlings in the water-seeded rice. In the present study, there were wide varietal differences on root traits and shoot traits under the low DO condition and several promising cultivars had been screened. It may be difficult to introduce these cultivars for the water-seeding directly but they might be very useful genetic sources in improving the establishment of the rice seedlings for water-seeding.

III. SELECTION OF RICE CULTIVARS FOR DIRECT-SEEDING

1. The Relationship between SPGP Method and Field Test

Even though the history of study on direct-seeding cultivation was long, the area of cultivation has not been increased because of the instability of the yield. Lodging of rice plant is a major problem. In one study, the lodged semidwarf rice had a 35% reduced yield relative to plants held erect (IRRI, 1986). Most researches on lodging of rice plant have involved the relationship between lodging and root system. Lodging tolerance of rice in direct seeding cultivation was affected by root thickness, root distribution and dry weight of root (Miyasaka, 1970; Ogata and Matsue, 1996a; Terashima et al., 1995). It may be effective if promising cultivars could be selected at seedling stages for some agronomically important characters. Ogata and Matsue (1996b) reported the possibility of early selection at 18 days rice seedling stage, and suggested that the crown root thickness of seedlings at 18 days after seeding (DAS) had a positive correlation with the crown root thickness and pushing resistance of the plant in 15 days after heading.

Kujira (1991) showed the method and the application for measuring root system by using seed pack growth pouch (SPGP), and mentioned the convenience and effectiveness of the investigation for root systems.

The objectives of this study are: 1) to develop a useful method for selection of promising cultivars with suitability for direct-seeding cultivation at early seedling stage, 2) to study the relationship between this method and the agronomic traits of direct-seeded rice in field.

Materials and Methods

Eighty F4 breeding lines, which were developed from crossings aimed at direct seeding by Fukuoka Agr. Res. Center (Table 4), and several check cultivars were used in both the seed pack growth pouch (SPGP) and field experiments in 1996. Transparent polyethylene SPGP (Kujira, 1991) was used. In the modified SPGP method, once-folded paper towel (Kim-wipeR) was inserted into each SPGP and pre-sprouted seeds were seeded on the upper part of the SPGP. The lower part was cut away and soaked into a bed containing HyponexR solution. HyponexR was used diluted 5000 times (N-10ppm) and adjusted to pH 5. The experimental design was a completely randomized design with six replications. The pre-sprouted seeds were grown in the dark at 20°C, and the length, number and thickness of roots were measured at 18 days after seeding (DAS). The root thickness was scored on a scale of 1 (thin)-3 (thick) and the root length was shown by the total root length divided by root number (Fig. 12).

In the field trial, the rice seeds were directly hand-drill-seeded in the plots withstanding water after the plots were thoroughly puddled and leveled, at the experimental field of Kyushu University (lat. N 33.5, long. E 130.4) in 1996. There were two replications. Each plot consisted of one 1m row with a 25cm space between rows. The seedlings were thinned to a space of 10cm between plants at 18 and 30 DAS. Basal fertilizer was applied at sowing at a rate of 5, 5 and 5 g m^{-2} of N, P_2O_5 and K_2O, and top-dressed at a rate of 3, 3 and 3 g m^{-2} at tillering stage and 1.5, 1.5 and 1.5 g m^{-2} at panicle initiation stage, respectively. At 18 and 30 DAS, the root length and root thickness were determined using 5 seedlings that were removed at thinning. The seedlings were taken from the field and washed on the net to remove soil. The root

Table 4. F4 lines and check cultivars used for selection by SPGP method.

Lines and cultivar	Pedigrees
No. 1 - 50	Aoinokaze//Lemont/Hinohikari
No. 51 - 80	Yumehikari//Lemont/Hinohikari
Aoinokaze	Check cultivars
Hinohikari	
Lemont	
Koshihikari	

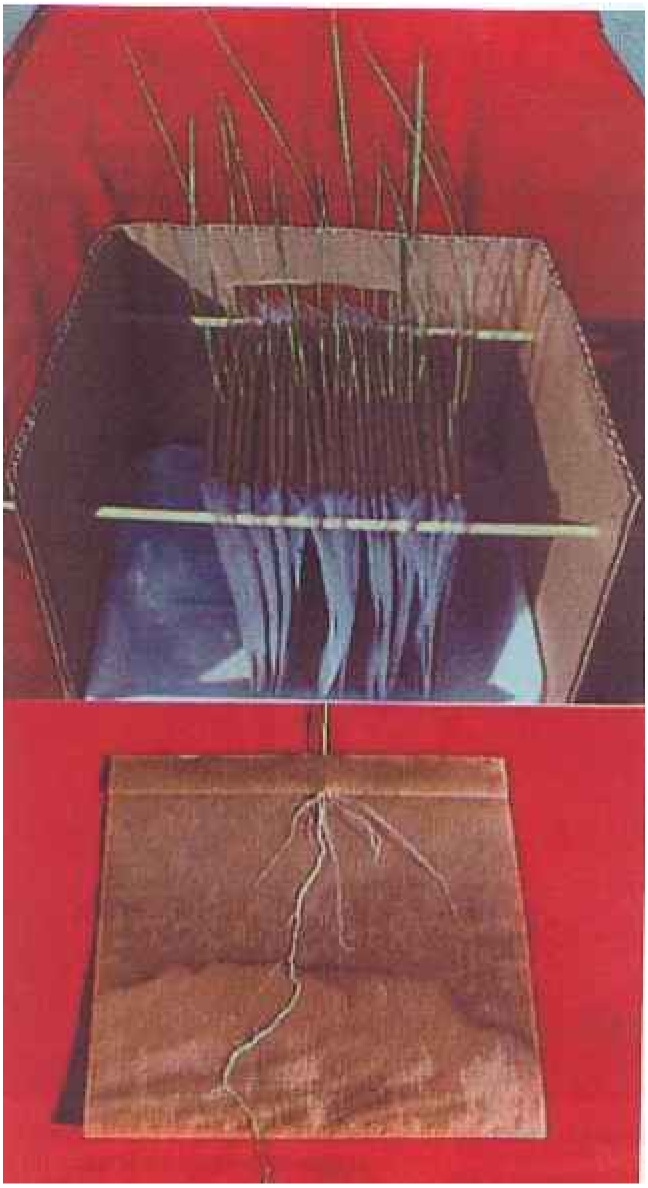

Fig. 12. Rice seedlings and root grown on the seed pack growth pouch at 18 days after seeding.

Fig. 13. Measurement of pushing resistance at 10 cm above the soil surface to bend the culm to an angle of 45 degree.

thickness and root length were measured by the same method as in SPGP. Pushing resistance has been reported to be correlated with lodging resistance in the field (Terashima et al., 1992 ; Ogata and Matsue, 1996b) and was measured following the procedure of Terashima et al.(1992) as shown in Fig. 13.

Results and Discussion

Table 5 shows the correlations of root thickness by SPGP methods and that in field test. For the F4 lines, root thickness was significantly correlated not only with that of 30 DAS seedling (r = 0.45*) but also with that of 18 DAS seedling (r = 0.44*) in field test. However, for the check cultivars, only root thickness was significantly correlated with the root thickness of 30 DAS seedling in field test (r = 0.95*).

Correlations between pushing resistance and root parameters measured in SPGP and in field test were presented in Table 6. The correlation was obtained separately in F4 lines and check cultivars. Among the root parameters of SPGP seedlings, only root thickness of F4 lines was positively correlated with pushing resistance in field (r = 0.46*). On the contrary, root length of cultivars was negatively correlated with pushing resistance. Among root parameters in field, root thickness of both 18 and 30 DAS seedlings of F4 lines was positively correlated (r = 0.32*, r = 0.28*, respectively) with pushing resistance. The root thickness of cultivars was not significantly correlated with pushing resistance because of the small df number, though high values of 0.73 and 0.76 were obtained for 30 DAS in field and SPGP. It indicates that the root thickness of rice plant is closely related with lodging resistance, and this relationship is very useful and practical in rice breeding program for the selection of cultivars suitable for direct-seeding cultivation,

Table 5. Coefficients of correlation between root thickness in field and that in 18 and 30 DAS .

	F4 lines	Check cultivars
Root thickness of 18 DAS[1)]	0.44*	0.17
Root thickness of 30 DAS	0.45*	0.95*
Pushing resistance	0.41*	0.70

1) DAS : days after seeding.

*: Significant at the 0.05 probability level.

Table 6. Coefficients of correlation between pushing resistance and root parameters.

		F4 lines	Check cultivars
18 DAS[1)] (field test)	Root length	0.11	-0.93
	Root thickness	0.32*	-0.24
30 DAS (field test)	Root length	0.30*	0.23
	Root thickness	0.28*	0.73
SPGP[2)]	Root length	0.01	-0.82
	Longest root length	0.00	-0.81
	Root angle	0.09	0.15
	Root thickness	0.46*	0.76
	Root number	-0.08	-0.79

1) DAS: days after seeding.

2) SPGP: seed pack growth pouch.

*: Significant at the 0.05 probability level.

Table 7. Correlation coefficients among several root characteristics and pushing resistance in 1996.

	X1	X2	X3	X4	X5	X6	X7	X8
Root length at 18 DAS (X1)	1.000	0.020ns	0.127ns	0.003ns	0.011ns	0.087ns	0.064ns	0.057ns
Root thickness at 18 DAS (X2)		1.000	0.099ns	0.378**	0.207ns	0.130ns	0.346**	0.309**
Root length at 30 DAS (X3)			1.000	0.277*	0.001ns	0.062ns	0.323**	0.271 *
Root thickness at 30 DAS (X4)				1.000	0.070ns	0.102ns	0.512**	0.306**
Root length of SPGP (X5)					1.000	0.092ns	0.087ns	0.02lns
Root number of SPGP (X6)						1.000	0.046ns	-0.096ns
Root thickness of SPGP (X7)							1.000	0.495**
Pushing resistance (X8)								1.000

X1, X2. X3 X4 X8; Root characteristics and pushing resistance measured in the field trial.

*, **, ns: Significant at the 0.05 and 0.01 probability level, and not significant, respectively.

Correlations between pushing resistance and root parameters measured in a field trial and in SPGP in 1996 are shown in Table 7. Among the root parameters in the field trial, root thickness of seedlings at both 18 and 30 DAS were positively correlated with pushing resistance (r = 0.309**, r = 0.306**, respectively). Although the root length of seedlings at 18 DAS in the field trial was not correlated with pushing resistance (r = 0.057), the length at 30 DAS showed a positive correlation (r = 0.271*). Among the root parameters of SPGP seedlings, only root thickness had a relatively high positive correlation with pushing resistance (r = 0.495**), and the correlation coefficient was higher than those in the field trial. The root thickness of SPGP also had a positive correlation with root thickness in the field trial (18 DAS : r = 0.346**, 30 DAS: r = 0.512**). These results indicate that the root thickness of rice plants is related to pushing resistance and that the results obtained in SPGP and in the field trial are comparable. Thus, the SPGP method can be used instead of a field trial to select lodging resistant lines based on root thickness. By this SPGP method, we can preliminarily screen rice lines in the laboratory, and save labor in the field trials.

From these results the author concluded that, the root thickness of early stage seedling was closely related with pushing resistance in field. The root thickness of modified SPGP method had higher correlation with pushing resistance than that of field test and the direct effect on pushing resistance was also relatively higher than that of field test. It indicates that indirect selection based on root thickness in SPGP is more accurate and effective than that in field.

2. Selection of Rice Lines Using SPGP Seedling Method

Gravois and McNew (1993b) reported a positive genetic correlation between panicle weight and rice yield, and negative correlation between panicle number and yield, in long-grain rice from southern U.S. Kim and Vegara (1990) reported that close-spacing adaptability was higher in low-tillering cultivars than in high-tillering cultivars. Excessive plant stands or tillers can lead to taller plants and weaker culms, increasing the potential for crop losses due to lodging and more severe disease pressure (Gravois and Helms, 1996). Therefore, a low-tillering cultivar with large panicles may be an ideotype for the direct-seeded rice plant.

Therefore, the objectives of this chapter are to make a farther selection for improving lodging resistance using seedlings in SPGP and to evaluate them in the field condition for selecting promising lines.

Materials and Methods

Experiments were conducted over a 2-year period in puddled wet-fields and in seed pack growth pouches (SPGP). In 1996, eighty F4 breeding lines and several check cultivars were used in both the seed pack growth pouch (SPGP) and field experiments as mentioned in the previous chapter (Table 4). The methods, procedures, conditions and observations of seedling growth were also similar to those of the previous chapter.

In 1997, 12 F5 lines were selected based on the root thickness in the 1996 SPGP trial and were compared with some check cultivars including 5 Korean cultivars (see Table 11), which were developed for direct seeding. The rice seeds were directly hand-drill-seeded in the plots in early June. The field was prepared as in 1996. Each plot consisted of two 1 m rows, with a space of 25 cm between rows, in two replications. After establishment, seedlings were thinned to 20 seedlings for each line leaving 10 cm between seedlings. The root thickness of 6 SPGP seedlings was measured at 1 cm below the seed position by a caliper under a dissecting microscope at 18 days after seeding.

At 30 days after heading, the degree of lodging in the field trial was recorded on the scale of 0(none) to 9 (severe lodging). Because of the late stage of lodging, damage to neighboring lines was slight. Prior to harvest, ten plants per line were measured for culm thickness, culm length, panicle length and panicle number. At harvest, ten panicles were randomly chosen for each line, and after one week of drying, the spikelet number per panicle and the weight of panicle were measured. After the number of panicles per hill was recorded, ten hills per line were hand harvested to determine the plant dry weight and grain weight determination. Amylose content of brown rice was measured following the procedure of Juliano (1971).

Results and Discussion

In the previous chapter, it was shown that indirect selection based on root thickness in SPGP was very useful and effective. The relationship between root thickness in SPGP and pushing resistance in the field in 1996 trial is presented in Fig. 14. The significant positive correlation between them (r = 0.495**, n = 86) indicates that the larger the root diameter, the higher the pushing resistance.

Based on the root thickness in SPGP and in the field and pushing resistance, 12 lines were selected from the 80 breeding lines for 1977 trial (Fig. 14). The correlation coefficients between root thickness in SPGP seedlings, culm thickness, and culm length, panicle number, panicle weight or pushing resistance in the field of these 12 selected lodging resistant lines and 13 check cultivars examined in 1997 are shown in Table 8. A strong positive correlation was observed between pushing resistance and culm thickness in the field (r = 0.809**) or root thickness in SPGP (0.694**) seedlings, suggesting that these two were effective selection criteria for increasing pushing resistance.

The correlation coefficients among yield components, harvest index and grain

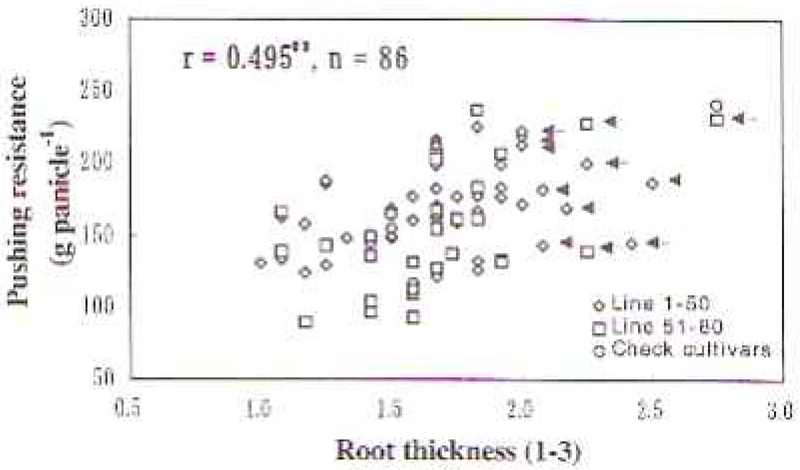

Fig. 14. The relationship between root thickness which was scored by the degree of thickness (1 thin - 3 thick) of SPGP seedlings and pushing resistance in the field in 1996 trial(←: selected 12 lines). ** : Significant at 0.01 level.

Table 8. Correlation coefficients among root thickness, culm thickness, plant height, panicles, panicle length and lodging in 1997.

	Root thickness (mm)	Culm thickness (mm)	Culm length (cm)	Panicle number ($hill^{-1}$)	Plant dry weight (g)	Pushing resistance (g $panicle^{-1}$)
Root thickness	1.000	0.628**	-0.449**	-0.719**	-0.292ns	0.694 * *
Culm thickness		1.000	-0.431 *	-0.611 **	-0.163ns	0.809**
Culm length			1.000	0.477**	0.702**	-0.454**
Panicle number				1.000	0.346*	-0.563**
Plant dry weight					1.000	-0.221ns
Pushing resistance						1.000

*, **, ns: Significant at the 0.05 and 0.01 probability level, and not significant, respectively.

Table 9 Correlation coefficients among yield components, harvest index and yield in 1997.

	Panicle number $(hill^{-1})$	Panicle weight (g)	Spikelet number $(panicle^{-1})$	Straw dry weight (g)	Harvest index (%)	Grain yield (gm^{-2})
Panicle number	1.000	-0.512**	-0.511 **	0.499**	-0.432*	-0.007ns
Panicle weight		1.000	0.857**	0.160ns	0.369*	0.601 *
Spikelet number			1.000	-0.00lns	0.390*	0.436*
Straw dry weight				1.000	-0.634**	0.241ns
Harvest index					1.000	0.586**
Grain yield						1.000

*, **, ns: Significant at the 0.05 and 0.01 probability level, and not significant, respectively.

yield in 1997 are shown in Table 9. Panicle weight was positively correlated with spikelet number (r = 0.857**) and grain yield (r = 0.601**). Grain yield was positively correlated with spikelet number (r = 0.436*) and harvest index (r = 0.586**), but not with panicle number (r = -0.007ns) or straw dry weight (r = 0.241ns). Panicle number had a positive correlation with straw dry weight but a negative correlation with panicle weight, spikelet number and harvest index. In the panicle-weight type, the panicle number was lower, but the yield was higher than in the panicle-number type because of a large number of spikelets, higher grain weight per panicle and higher harvest index (Kim and Vergara, 1991 ; Wang et al., 1997). Gravois and McNew (1993b) also reported similarly that at both the additive and broad-sense genetic levels, the yield was positively correlated with panicle weight but negatively correlated with panicle number. In the present study, harvest index was negatively correlated with panicle number (r = -0.432*) and straw dry weight (r = -0.634**), but positively correlated with panicle weight (r = 0.369*), spikelet number (r = 0.390*) and grain weight (r = 0.586**).

Among the characteristics related to lodging, root and culm thickness were greater in the selected lines than in the check cultivars, and the lodging in the field was greatly reduced in the selected lines (Table 10). Grain yield was higher in the selected lines than in the check cultivars, although the mean panicle number per hill was lower in the selected lines. These results indicate that selection for lodging resistance resulted in the selection of lines with higher panicle weight and higher yield capacity. Therefore, the selection using SPGP appears to be useful and practical to select lodging resistant cultivars based on root thickness.

To select parental lines suitable for direct seeding, the lodging and yield characteristics of 12 selected breeding lines (L9 - L76) and some check cultivars were examined in 1997 (Table 11).

Table 10. Means of characteristics of all lines, selected lines and check cultivars in 1997.

	Root thickness (mm)	Culm thickness (mm)	Field lodging (0-9)	Panicles per hill	Panicle weight (g)	Spikelets per panicle	Grain yield (g m^{-2})
Means of							
All lines	0.321 ±0.049	6.24 ± 0.61	3.0 ± 1.8	9.12 ± 1.27	35.5 ± 4.46	116 ± 17.8	657 ± 34
Selected lines	0.336 ± 0.044	6.56 ± 0.39	1.9 ± 0.9	8.89± 1.00	36.5 ± 4.49	116 ± 14.2	702 ± 38
Check cultivars	0.308 ± 0.051	5.97 ± 0.65	4.0± 1.9	9.31± 1.46	34.7 ± 4.43	115 ± 20.9	623 ± 30

± S.E.

Table 11 . Grain yield and agronomic characteristics of 12 selected lines and check cultivars in direct-seeding in1997.

Lines and cultivars	Root thickness (mm)[1)]	Culm thickness (mm)	Field lodging (0-9)	Panicles per hill	Panicle weight (g)	Spikelets per panicle	Grain weight (m^{-2})	Amylose cont. (%)
L9	0.327 c-h[2)]	6.67 e-I	3.5 bcd	8.1 a-f	41.5 ghi	121 b-g	722 abc	16.7
12	0.353 e-h	6.50 d-h	1.5 ab	9.2 d-h	39.0 d-i	126 d-g	728 abc	15.5
22	0.373 gh	6.28 c-g	2.0 abc	10.5 gh	33.7 a-f	l07 a-e	726 abc	16.5
33	0.267 a-d	6.21 b-g	1.0 a	10.2 e-h	31.4 abc	l05 a-d	678 abc	14.4
34	0.357 e-h	6.70 e-I	2.0 abc	9.1 d-h	36.0 b-g	115 a-f	641 abc	16.7
38	0.380 h	6.1 1 b-f	2.0 abc	8.9 c-,h	36.3 b-g	123 c-g	837 c	22.6
42	0.363 fgh	6.22 b-g	3.5 bcd	8.4 b-g	44.1 i	134 e-h	948 d	14.3
43	0.293 a-g	6.41 c-h	3.0 a-d	8.0 aH~	32.0 a-d	95 ab	691 abe	20.8
48	0.313 b-h	6.80 e-I	1.0 a	9.4 d-h	40.4 f-i	125 d-g	722 abc	15.7
53	0.377 gh	7.44 I	1.5 ab	8.7 b-h	38.0 c-i	136 fgh	632 abc	l2.4
54	0.253 abc	6.36 c-h	1.0 a	9.4 d-h	28.7 a	92 a	514 a	22.0
76	0.370 gh	7.01 f-I	1.0 a	6.8 abc	36.8 b-h	121 b-g	586 ab	22. l
Aoinokaze	0.240 ab	6.68 e-I	2.0abc	10.2 fgh	36.6 b-g	116 a-f	782 bc	15.8
Lemont	0.380 h	7.23 hi	1.5 ab	6.7 ab	40.5 f-i	145 gh	642 abc	21.6
Hinohikari	0.330 c-h	5.70 a-d	4.0 cde	9.8 d-h	32.6 a-e	100 a-d	644 abc	14.4
Koshihikari	0.273 a-e	5.34 ab	6.0 efg	10.7 h	28.4 a	91 a	609 abc	l 2.4
L-202	0.360 fgh	5 .60 a-d	3.5 bcd	8.2 a-f	35.6 a-g	114 a-f	516 a	-
M-302	0.273 a-e	6.26 c-g	3.0 a-d	9.5 d-h	28.6 a	93 ab	587 ab	-
Yumehikari	0.213 a	6.40 c-h	4.5 def	10.8 h	34.9 a-g	114 a-f	689 abc	16.0
Nipponbare	0.347 d-h	5.33 ab	7.5 g	9.6 d-h	30.4 ab	96 abc	618 abc	15.8
Daesanbyeo †	0.343 d-h	5.55 abc	3.0 a-d	9.8 d-h	34.2 a-f	111 a-f	828 c	15.9
Nonganbyeo †	0.347 d-h	7.07 ghi	4.0 cde	6.3 a	43.9 hi	158 h	738 abc	l3.6
Juanbyeo †	0.280 a-f	5.20 a	6.5 fg	10.5 gh	31.8 a-d	121 b-g	726 abc	12.8
A sanbyeo †	0.260 abc	5.62 a-e	l.5 ab	7.9 a-d	39.5 e-i	147 gh	772 bc	13.l
Donganbyeo †	0.347 d-h	6.00 a-e	2.0 abc	9.7 d-h	34.2 a-f	104 a-d	512 a	16.2
Mean	0.321**	6.28**	2.9**	9.1 **	35.6**	116**	684**	16.4
cv %	13.3	5.9	32.2	9.7	8.4	9.7	12.9	-

1) Root thickness of SPGP.
2) Means followed by the same letter are not significantly different at 0.05 level according to Duncan's multiple range test.
† :Korean cultivars.
**: Significantly different at 0.01 level.

Among the check cultivars, Lemont and Ansanbyeo were the most tolerant to lodging. All of these characteristics related to lodging and yield were significantly different at the 0.01 probability level. Although L33, 48, 54 and 76 seem to be the most tolerant to lodging, the coefficient of variation in field lodging was very high because of large differences between replications. Therefore, the selection for lodging resistant cultivars by root thickness, culm thickness or pushing resistance may be more efficient than that by field lodging itself. L22, 34, 38, 42, 53 and 76 can be selected by these criteria. The character considered to be important for an ideotype of direct-seeded rice is the panicle-weight type, which has low-tillering with large panicles (Kim and Vergara, 1990). L9, 12, 42, 53 and 76 are closest to the ideotype as they have fewer panicles per hill, heavier panicle weight and large number of spikelets per panicle. Mean grain yield was 711 g m^{-2} in breeding lines and 623 g m^{-2} in check cultivars, and the highest yielding lines were L42 (948 g m^{-2}) and L38 (837 g m^{-2}). The amylose contents of L38, 54, 76 and Lemont were high and those of L42 and 53 were as low as Koshihikari, a high quality cultivar in Japan. Since rice with a low amylose content has a relatively high consumer preference in Japan, amylose content can be used as a criterion for selecting highly desirable genotypes (Oosato et al., 1998). Considering all the characteristics, L42 and 53 seemed to be the best line for the direct seeding cultivation. L38 and 76 are candidate parental lines for the next cycle of crossing for direct-seeded rice breeding programs because of their good characteristics except for a minor deficit such as high amylose content or field lodging.

In this chapter, it is shown that the SPGP seedlings method is considered to be useful for screening a large number of lines quickly and efficiently for resistance to lodging. Correlations of grain yield with panicle weight, harvest index and spikelet number showed that the low-tillering panicle-weight type was favorable for direct seeding. Considering all the characteristics, some promising lines and candidate parental lines for next crossing cycle for direct seeding were identified.

3. Combining Ability and Heterosis in the Selected Rice Lines

By analyzing combining ability and estimating degree of heterosis, clues about the nature of gene action, desirable parents and important yield traits will emerge (Can et al., 1997). Vasal et al. (1993a, b) reported that information on the combining ability and heterosis pattern of CIMMYT'S malze germplasm was of great value to malze breeders worldwide for hybrid development. In case of rice, Gravois and McNew (19 93a) reported that general combining ability (GCA) was more important than specific combining ability (SCA) in the U.S. southern long-grain rice, accounting for 70% of the variation for yield, 89% for plant height, 84% for panicle number, 60% for panicle length, 69% for panicle weight. Xu and Shen (1991) also reported that additive effects were more important than dominance effects in determining rice tiller number. Murai and Kinoshita (1986) estimated the general and specific combining ability for rice yield in Japan and Kang et al. (1997) estimated for low temperature germinability of rice in. Korea.

However, combining ability and heterosis estimates for direct-seeded rice are lacking. The objectives of this study was to estimate the GCA, SCA and heterosis of selected lines for rice yield, yield components and culm traits under water-seeding condition and identify promising parents with good general combining ability for breeding program of direct-seeded rice.

Materials and Methods

In the summer of 1998, one 4 x 3 factorial crossing (Design II mating scheme; Comstock and Robinson, 1948) was completed using 7 parents (Table 12). Among the

Table 1 2. Origins of the 7 parents used in the 4 x 3 factorial crossing.

	Parent	Description
Male	Ansanbyeo	Japonica type cultivar from Korea
	Hinohikari	Japonica type cultivar from Japan
	Lemont	Indica type cultivar from USA
Female	L 38	Selection from Aoinokaze // Lemont / Hinohikari
	L 42	Selection from Aoinokaze // Lemont / Hinohikari
	L 53	Selection from Yumehikari // Lemont / Hinohikari
	L 76	Selection from Yumehikari // Lemont / Hinohikari

parents, four lines selected in the previous chapter for direct-seeding (L38, L42, L53 and L76) were used as female mainly by lodging tolerance, yield and quality. Three check cultivars (Ansanbyeo, Hinohikari and Lemont) were used as male parents. The resulting 12 Fl hybrids of this cross and 7 parents were included in an experiment conducted in 1999 at the experimental field of Kyushu University. The seeds of F1 hybrids and parents were sterilized with 70% ethanol for 30 second and 2% sodium hypochlonde for 15 minutes successfully and then soaked in water at 25°C for 2 days The pre-sprouted seeds were directly hand-drill-seeded in the plots withstanding water after the plots were thoroughly puddled and leveled on May 20. After seeding, the water was irrigated with 2-3 cm water depth continuously and at 10 days after seeding (DAS) the water was once drained for the root anchorage. There were two replications. Each plot consisted of one 1m row with a 20cm space between rows and 10 seeds were sown on each row.

From the total fertilizer, 8, 8 and 8 g m^{-2} of N, P_2O_5 and K_2O, basal fertilizer was applied at sowing at a rate of 50% of N, P_2O_5 and K_2O, and top-dressed at a rate of 30% at tillering stage and 20% at panicle initiation stage, respectively. Prior to harvest, five plants in center of each row were measured for culm length, culm thickness, panicle length and panicle number. At harvest, the five plants in center area of each row were chosen and hand-harvested to determine the 1000-grain weight and single plant grain yield. Grain yield and 1000-grain weight were measured with head brown rice.

The data were analyzed using the analysis of variance. Variation due to 12 crossings was divided into the variation due to female parents, male parents and female x male interaction. The expectations of variation due to female and male parents are equivalent to GCA, and the female x male interaction is equivalent to SCA (Hallauer and Miranda, 1981). Because there are two sets of parents in design II, there are two independent estimates of GCA. Appropriate F-tests were made to test for the differences among males and among females and for the interaction of males and females. The sum of squares percentages for the crosses attributable to GCA and SCA for each traits were calculated as follows;

Sum of squares percentages for Male (%) = $[SS_m / (SS_m + SS_f + SS_{mf})] \times 100$

Sum of squares percentages for Female (%) = $[SS_f / (SS_m + SS_f + SS_{mf})] \times 100$

Sum of squares percentages for M x F (%) = $[SS_{mf} / (SS_m + SS_f + SS_{mf})] \times 100$;

where SS_m is sum of squares for Male, SS_f is sum of squares for Female, and SS_{mf} is sum of squares for Male x Female interaction.

Both mid-parent heterosis and high-parent heterosis were calculated as follows;

Mid-parent heterosis (%) = $[(F1 - MP) / MP] \times 100$

High-parent heterosis (%) = $[(F1 - HP)/ HP] \times 100$

Where F1 is performance of hybrid, MP is the average performance of parents and HP is the performance of the higher parent.

Results and Discussion

Generally, the mean yield and yield related values of hybrids was higher than that of parents except number of panicles (Table 13). For the gram yield, it seemed somewhat high in this study because of the small experiment plot size and intensive field management. But it was regarded that the tendency was not so different among the entries. Table 14 presented the results of ANOVA.

Table 13. Mean values of parents and F1 hybrid of rice for several traits.

Parents & Hybrid Parent	Culm length (cm)	Culm thicknes (mm)	Panicle length (cm)	No. of panicles	No. of pikelets	1000-G weight (g)	Grain yield (plant^{-1})
Ansanbyeo	66.2 a*	5.7 a	22.8 bcd	12.8 d	127 b-e	20.4 cd	24.2 f-j
Hinohikari	81.3 ef	6.2 a-d	20.8 a	7.5 abc	115 ab	21.1 def	15.7 abc
Lemont	70.7 b	7.2 ghi	26.8 g	7.7 abc	137 b-e	21 .6 efg	25.0 b'-j
L 38	85.3 gh	6.0 abc	22.7 bcd	9.0 c	138 b-f	20.9 cde	16.0 ab
L 42	86.4 ghi	6.2 bcd	22.7 bcd	7.2 ab	125 abc	24.5 k	26.2 hij
L 53	73.9 bc	7.4 hi	21.0 a	6.3 a	111 a	22.8 hi	15.0 a
L 76	70.5 b	7.0 fgh	20.4 a	6.3 a	143 c-f	20.2 bc	16.7 abc
Hybrid							
L38 x A1	83.5 fg	5.8 ab	24.4 ef	6.8 ab	154 d-g	21 .6 fg	21.0 d-g
L38 x H2	85.9 ghi	6.1 a-d	22.3 bc	6.8 ab	117 ab	22.2 gh	17.0 a-d
L38 x L3	97.3 j	7.1 gh	28.4 h	6.8 ab	162 fgh	19.4 a	27.2 ijk
L42 x A	80.3 ef	6.3 efg	22.7 bcd	6.6 ab	138 b-e	23.2 ij	22.1 e-h
L42 x H	82.5 efg	6.5 cde	21.5 ab	8.0 abc	111 a	23.7 j	23.3 e-I
L42 x L	102.2 k	8.3 k	27.0 g	7.0 ab	188 i	22.0 g	31.1 k
L53 x A	75.1 cd	6.2 a-d	23.7 def	6.5 ab	155 e-h	20.7 cd	19.7 b-e
L53_ x H	83.1 fg	6.8 efg	21.5 ab	8.2 bc	1 33 a-e	20.7 cd	21.1 efg
L53 x L	89.6 i	7.7 ij	24.9 f	6.7 ab	178 hi	19.7 ab	25.3 hij
L76 x A	78.7 de	6.2 a-d	23.4 cde	7.5 abc	145 c-f	20.3 bc	27.1 ijk
L76 x H	80.3 ef	6.6 def	20.2 a	7.4 abc	131 a-d	20.9 cde	20.6 c-f
L76 x L	88.3 hi	8.1 I	24.2 ef	7.4 abc	174 ghi	20.3 bc	27.8 jk
Means							
Total	82.1	6.7	23.2	7.5	141.6	21.3	22.2
Parents	76.3	6.5	22.4	8.1	128.5	21.6	19.8
Hybrids	86.6	6.8	23.7	7. l	149.2	21.6	23.6

1) Ansanbyeo, 2) Hinohikari, 3) Lemont.
*: Means followed by the same letter are not significantly different at 0.05 level according to Duncan's multiple range test.

Table 14. Mean square values in analysis of variance of culm traits, yield and yield components of direct-seeded Fl hybrids.

Source of variance	df	Culm length (cm)	Culm thickness (mm)	Panicle length (cm)	No. of panicles	No. of spikelets	1000-G weight	Grain yield plant^{-1}
Replication	1	1.3	0.06	0.2	0.3	144	0.4	5.4
Crosses	11	121.8*	1.38**	11.0**	0.6	1180**	13.1**	33.7**
Female (F)	3	74.8**	0.59**	6.4**	0.4	156	2.2**	24.0**
Male (M)	2	487.8*	6.38**	45.5**	1.3	5578**	17.1**	115.8*
F X M	6	23.2**	0.10**	1.9*	0.5	227	17.3**	11.1*
Error	11	1.2	0.02	0.4	0.5	105	0.1	3.6
Total	23							

* **: Significant at 5% and 1% level, respectively.

Mean squares of cross were significant for all the traits except number of panicle length. Male and female mean squares were both significant for culm length, culm thickness, panicle length, 1000-grain weight and grain yield, indicating the importance of additive genetic effects. The mean squares of male for all traits except number of panicles were significant and larger in magnitude than those of female, suggesting that the role of cytoplasmic inheritance for these traits was not so important in rice crosses (Gravois and McNew, 1993a). Dominance gene effects, deducible from the mean squares of male x female interaction, were highly significant for culm length, culm thickness, 1000-grain length and grain yield. This result indicates that these traits are also controlled by the nonadditive gene actions.

In detail, sum of squares percentages for the crosses attributable to GCA and SCA for the seven traits were presented in Table 15. About 82% of the cross combination variation for yield was attributable to GCA and 18% of the cross combination variation to SCA. This result was agreed with Gravois and McNew (1993a) in the U.S. southern long-grain rice. More than 90% of the sum of squares for the crosses was attributable to GCA for culm length, culm thickness, panicle length and spikelet number. Brim and Cockerham (196 1) reported that the dominance was less important in self-pollinating species, and Gravois and McNew (1993a) confirmed it in their study. However, SCA for some traits were also significant, indicating that nonadditive gene action affected yield and other traits as well. Although additive gene action accounted for a majority of the genetic variation among hybrids for most traits, nonadditive gene action, as indicated by SCA, was sizeable for panicle number (43%) and more for 1000-grain weight (72%).

Table 15. Sum of squares percentages for the crosses attributable to general (GCA) and specific combining ability (SCA) for the traits.

Traits	Male GCA[1)]	Female GCA[2)]	SCA[3)]
		%	
Grain yield	62.5	19.5	18.0
Culm length	72.9	16.7	10.4
Culm thickness	84.2	1 1 .9	3.9
Panicle length	74.9	15.8	9.3
No. of panicles	39.6	1 7.4	43.0
No. of spikelets	85.9	3.6	10.5
1000-G weight	23.7	4.5	71.8

1) $[SS_m / (SS_m + SS_f + SS_{mf})] \times 100$

2) $[SS_f / (SS_m + SS_f + SS_{mf})] \times 100$

3) $[SS_{mf} / (SS_m + SS_f + SS_{mf})] \times 100$;

where SS_m is sum of squares of Male. SS_f is sum of squares of Female, and SS_{mf} is sum of squares of M x F in Table 14.

Table 16. Estimates of GCA and SCA effects for several traits of direct-seeded rice.

Parents & Hybrid	Culm length (cm)	Culm thicknes (mm)	Panicle length (cm)	No. of panicle	No. of spikelets	1000-G weight (g)	Grain yield (plant-1)
Parent		GCA* effect					
Ansanbyeo	-6.17	-0.68	-0.13	-0.29	-0.9	0.23	-5.7
Hinohikari	-2 .62	-0.31	-2.3 1	0.46	-25 .9	0.65	-15.5
Lemont	8.78	0.99	2.44	-0.17	26.9	-0.88	21.2
L 38	3.33	-0.48	1.35	-0.34	-4.5	-0.16	-9.4
L 42	2.76	0.23	0.05	0. 06	-3.2	1.74	9.5
L 53	-2.97	0.09	-0.32	-0.01	6.8	-0.86	-7.9
L 76	-3.13	0.16	-1.08	0.29	1.0	-0.72	7.8
Hybrid		SCA** effect					
L38 x A1)	0.77	0.15	-0.50	0.29	10.6	0.3 1	2.0
L38 x H2)	-0.38	0.08	-0.42	-0.46	-1.5	0.48	-8.1
L38 x L3)	-0.38	-0.23	0.93	0.17	-9.1	-0.79	6.1
L42 x A	-1.87	-0.05	-0.90	-0.31	-7.1	0.01	11.3
L42 x H	-3.22	-0.23	0.08	0.34	-8.8	0.08	4.5
L42 x L	5.08	0.28	0.83	-0.03	1 5.9	-0.09	6.8
L53 x A	-1.33	-0.02	0.47	-0.34	0.7	0.11	-6.0
L53 x H	3.12	0.21	0.44	0.61	3.6	~).32	10.9
L53 x L	-1.78	-0.19	-0.91	-0.27	-4.3	0.21	-4.9
L76 x A	2.43	-0.08	0.93	0.36	-4.3	-0.42	15.3
L.76 x H	0.48	-0.06	-0.09	-0.49	6.7	-0.25	-7.3
L76 x L	-2.92	0.14	-0.84	0.13	-2.4	0.68	-8.0

1) Ansanbyeo, 2) Hinohikari, 3) Lemont. *: General combining ability. **: Specific combining ability.

The GCA effects for grain yield were positive for Lemont, L 42 and L 76, indicating that the use of these three parents in direct-seeded rice breeding programs could be promising for higher grain yield (Table 16). Culm thickness GCA effects were positive for Lemont, L42, L53 and L76, suggesting the importance of these parents for increasing the lodging tolerance in direct-seeded rice breeding programs. The GCA effects for panicle length were positive for Lamont, L38 and L42. Lemont showed positive GCA effects for spikelets number and L42 showed positive GCA effects for panicle number and 1000-grain weight.

The parents selected for a particular trait were not always acceptable for other traits. Thus, the simultaneous selection of rice lines for all traits will be difficult. In present study, Lemont and L42 were considered to be good combiners for overall traits.

High and positive SCA effects were observed for L38 x Lemont, L42 x Lemont, L53 x Hinohikari and L76 x Ansanbyeo (Table 16). These hybrids also had positive SCA effects for panicle length and panicle number. Considering the SCA effects for several traits, L53 x Hinohikari and L42 x Lemont hybrids were selected as a good hybrid combination for yield, panicle traits, spikelet number and culm thickness.

Mid-parent heterosis for yield ranged from -16.3% (L42 x Ansanbyeo) to 37% (L53 x Hinohikari), with average value of 17.3% for all hybrids and high-parent heterosis for yield was somewhat lower (Table 17). Crosses of L42 x Lemont, L53 x Hinohikari and L76 x Hinohikari showed large and positive high-parent heterosis value. Certain parents, L76 and Lemont, produced large and positive yield heterosis. The mid-parent heterosis for culm thickness ranged from - 6.1% (L53 x Ansanbyeo) to 23.9% (L42 x Lemont) with average value of 4.2%. Especially crossing combinations with parents of L42 or Lemont produced good heterosis for culm thickness.

Table 17. Estimates of mid-parent and high-parent heterosis (%) for several traits of direct-seeded rice.

Hybrid	Culm length (cm)		Culm thickness (mm)		Panicle length (cm)		1000-G weight (g)		Grain yield (plant^{-1})	
	MP*	HP*	MP	HP	MP	HP	MP	HP	MP	HP
L38 x A[1)]	10.2	26. 1	-1 .7	-3.3	7.0	7.0	4.3	3.3	4.5	-13.2
U8 x H[2)]	3.1	5.7	0	-1.6	2.3	-1.8	5.7	5.2	7.2	6.3
U8 x L[3)]	24.7	37.6	7.6	-1.4	15.5	6.0	-8.9	-10.2	32.0	8.8
L42 x A	5.2	21.3	5.0	1.6	-0.4	0.4	3.1	-5.3	-16.3	-19.5
L42 x H	-1.7	1.5	4.8	4.8	-1.4	-5.3	3.9	-3.3	1.4	-18.7
L42 x L	30.0	44.6	23.9	15.3	8.9	0.7	-5.2	-10.2	21.5	18.7
L53 x A	7.1	13.4	-6.1	16.2	8.2	3.9	-4.2	-9.2	0.5	-18.6
L53 x H	7.1	12.4	0	-8.1	2.9	-1.0	-5.9	-9.2	37.0	34.4
L53 x L	23.9	26.7	5.5	4.1	4.2	-7.1	-11.3	-13.6	26.5	1.2
L76 x A	15.1	19.2	-3.1	-11.4	8.3	2.6	0	-0.5	32.5	2.0
L76 x H	5.8	13.9	0	-5 .7	-1.9	-2.9	1.0	-0.9	27.2	23.4
L76 x L	25. 1	25.2	14.3	12.5	2.5	-9.7	-2.9	-6.0	33.7	11.2
Mean	13.0	20.6	4.2	-0.8	4.7	-0.7	-1.7	-5.0	17.3	3.0

1) Ansanbyeo, 2) Hinohikari, 3) Lemont.

*: Mid-parent heterosis calculated from 100 x [(F1 - MP) / MP], where F1 indicates performance of hybrid. MP indicates average performance of parents.

**: High-parent heterosis calculated from 100 x [(F1 - HP) / HP], where F1 indicates performance of hybrid. HP indicates average performance of higher parents.

It was concluded in this chapter that GCA was more important than SCA for grain yield, culm length, culm thickness, panicle length and spikelet number, confirming the additive gene action for a majority of the genetic variation among hybrids for these traits. Lemont and L42 were considered to be good combiners for overall traits of grain yield, culm thickness and other traits.

IV. GENOTYPE-ENVIRONMENT INTERACTION AND ADAPTABILITY OF THE SELECTED LINES

1 . Genotype-environment Interaction on Seedling Traits and Their Relationship

It has been reported that the ideal types of cultivars for direct-seeding have the characteristics of adaptability to denser plant population, reduction of vegetative growth with high productive tiller rate, good nitrogen absorbability, and lodging resistance (Miyasaka and Takaya, 1982; Park and Lee, 1992). Also considered were good seedling growth to compete with weeds in seedling stage, as well as good emergence ability at a lower temperature and in deep soil (Park et al., 1995).

Seedling vigor has been defined as the ability of plant to emerge its aerial parts from the soil (or water) in a suboptimal environment (McKenzie et al., 1980). Seedling vigor is especially important in rice growing regions where partially germinated seeds are direct-sown in preflooded fields (Owen, 1971; Jones and Peterson, 1976). Emergence rate is used in forage breeding programs for the evaluation of seedling vigor and speed of emergence (days to emergence) is one of the oldest concepts of seedling vigor (Maguire, 1962). Genotypic differences of rice were highly significant for seedling vigor traits in growth chamber, greenhouse, and field (Redona and Mackill, 1996).

This study was, therefore, conducted to determine the difference in genotypes for seedling traits, the interaction between genotype and environment under different seeding dates and cultivation methods, dry or wet direct-seeding, and the relationships among seedling traits.

Materials and Methods

Four rice breeding lines, which were selected mainly by root thickness with lodging resistance and yield as described in the previous chapter, and 6 check cultivars were sown two times by one week interval in the experimental field of Kyushu University in 1998. Two kinds of direct-seeding methods, dry seeding and wet seeding, were applied with four replications. The first seeding was on April 20 for dry seeding and April 24 for wet seeding, and the second seeding on April 27 for dry seeding and May 1 for wet seeding. In dry seeding, the dried seeds were directly hand-drilled and buried about 1 cm depth. In wet seeding, the seeds were soaked in water at 25°C for 2 days and the pre-sprouted seeds were hand-drilled on the plots after the plots were thoroughly puddled, leveled and drained. After seeding, the dry seeded field was irrigated occasionally and the wet seeded field was continuously flooded. Each plot consisted of one 1m row with a 20cm space between rows and 25 seeds were sown on each row. Basal fertilizer was applied before sowing at a rate of 5, 5, 5 gm^{-2} of N, P_2O_5 and K_2O. The emergence was checked every day and days to emergence was represented by the days required for the emergence of 50% seeds after seeding. At day 18 after seeding, all of the emerged seeds were counted and converted to percentage. At day 18 and 28, the root length, root thickness, root dry weight, seedling height, leaf age and dry weight of aerial part were measured. Five seedlings per replication were taken from the field and washed carefully on the net to remove soil. The root thickness was measured at the 1 cm below the base by caliper under the dissecting microscope. The root length was shown by the total root length divided by number of roots.

Results and Discussion

Emergence

Results of ANOVA for the days to emergence and emergence rate showed that the effects of genotype, seeding date and cultivation method were highly significant (Table 18). The significant difference of emergence traits among genotypes suggested that we might be able to select some promising genotypes which emerge rapidly at a high emergence rate. The significant genotype and cultivation (G-C) interaction for the days to emergence and emergence rate was indicated that the rank of emerging ability of each genotype varied with whether it was grown under dry seeding or wet seeding condition. Therefore, cultivars appropriate to each direct-seeding method must be evaluated under the corresponding cultivating condition. Seeding date and cultivation (S-C) interaction was also highly significant. This means that the responses of emergence traits to different seeding date are different between dry and wet seeding. The comparisons of emergence traits between cultivation methods and between seeding dates are shown in Table 19. Days to emergence was shorter in the second seeding than in the first seeding, as well as under wet seeding condition than under dry seeding condition. The significant S-C interaction showed that earlier emergence in the second seeding was enhanced by the wet seeding method and that in the wet seeding was enhanced by the second seeding. The emergence rate in the second seeding was higher than that in the first seeding in dry seeding, in contrast to no difference between two seeding dates under wet seeding condition. The significant interaction for emergence rate showed that high emergence rate in the second seeding was enhanced by dry direct-seeding (Table 19).

Table 18. Mean squares of analysis of variance for days to emergence and emergence rate in direct-seeded rice seedlings.

Source of variation	df	Days to emergence	Emergence rate (%)
Rep (R)	3	4.83**	693.97**
Treatment	39	26.66**	498.82**
Genotype (G)	9	5.96**	187.97**
Seeding date (S)	1	354.03**	7742.31**
Cultivation method(C)	1	570.04**	612.31**
GxS	9	0.98ns	190.75**
GxC	9	1.84* *	216.20**
SxC	1	24.03 * *	3619.51**
GxSxC	9	1.40*	236.17**
Error	117	0.59	68.40

* **: Significant at the 5% and 1% level of probability, respectively.

Table 19. Comparison of the days to emergence and emergence rate between cultivation methods and between seeding dates.

Cultivation	Days to emergence			Emergence rate(%)		
	First seeding	Second seeding	Diff. between seeding date	First seeding	Second seeding	Diff. between seeding date
Dry direct seeding	12.33	10.13	2.20**	71.38	94.80	-23 .43 * *
Wet direct	9.32	5.58	3.75**	84.80	89.20	-4.40ns
Diff. between cultivation	3.00**	4.55**	-	-13.43*	5.60ns	-

* **, ns: Significant at the 0.5 and 0.01 Ievel of probability, and not significant, respectively

First seeding: Apr. 20 for dry seeding, Apr. 24 for wet seeding.

Second seeding: Apr. 27 for dry seeding, May I for wet seeding.

Seedling traits

Results of ANOVA for root and aerial part traits showed significant difference in most traits among genotypes, seeding dates and cultivation methods (Table 20). In root trarts G-S interactions were detected for root length and root dry weight, G-C interaction for only root dry weight, and in S-C interaction for root length, root thickness and root dry weight. In aerial part traits, G-C: interactions were detected for leaf age and dry weight and in S-C for only dry weight. Therefore, selection of genotypes for the above traits should also be conducted in the specific environment. The root length and thickness, leaf age and plant height were superior in dry seeding compared with wet seeding, although the interaction between seeding date and cultivation method were detected for root length and root thickness. There was no S-C interaction in leaf age or plant height.

The relationship among the seedling traits

The relationships among the traits of emergence, root and aerial part are presented in Table 21. Days to emergence was negatively correlated with emergence rate, root length at day 18, root length, thickness, plant height and leaf age at day 28. On the contrary, emergence rate was positively correlated with root length, thickness, plant height and leaf age at day 28. These relationships suggest that the genotypes which emerge rapidly at a high emergence rate have good seedling traits. These results agreed with McKenzie et al. (1980) and Jones and Peterson (1976). McKenzie et al. (1980) reported that most seedling mortality occurred before emergence from the water in water seeded rice. Therefore emergence percentage was thought to be one of the good indicators of seedling vigor.

Table 20. Mean squares of analysis of variance for seedling characteristics at day 18 after seeding in direct seeded rice seedlings.

Source of variation	df	Root length (cm)	Root thickness (μ m)	R.D.W. (g/50 seedlings)	Leaf age	Plant height (cm)	A.D.W. (g/50 seedlings)
Rep(R)	3	0.40ns	4.5*	0.006*	0.018ns	0.29ns	0.02*
Treatment	39	1.61**	15.9**	0.019**	0.399**	21.04**	0.14**
Genotype(G)	9	0.82ns	49.4**	0.008**	1.104**	34.69**	0.05**
Seeding date(S)	1	27.40**	7.4*	0.053**	1.444**	47.09**	0.26**
Cultivation method(C)	1	4.39**	97.5**	0.391**	2.809**	382.54**	3.88**
G x S	9	1.12*	0.5ns	0.005*	0.022ns	2.08ns	0.01ns
G x C	9	0.81ns	1.0ns	0.010**	0.108**	3.77ns	0.03**
S x C	1	3.28**	38.8**	0.006*	0.042ns	0.08ns	0.14**
G x S x C	9	0.32ns	1.9ns	0.008**	0.018ns	2 .90ns	0.03**
Error	117	0.45	1.4	0.002	0.037	1.97	0.01

* **, ns: Significant at the 0.5 and 0.01 level of probability, and not significant, respectively.

R.D.W: root dry weight, A.D.W: aerial part dry weight.

Table 21. Correlation coefficients among emergence and several seedling traits.

	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	-0.44**	-0.199*	0.097	0.266**	0.292**	-0.653**	-0.216**	-1.414**	-0.435**
X2	1.000	0.144	0.113	0.061	0.004	0.332**	0.169*	0.326**	0.354**
X3		1.000	0.348**	0.490**	0.467**	0.412**	0.239**	0.265**	0.300**
X4			1.000	0.323**	0.416**	-0.183*	0.646**	-0.028	0.039
X5				1.000	0.856**	0.118	-0.017	0.364**	0.384**
X6					1.000	0.086	0.097	0.152	0.214**
X7						1.000	0.136	0.457**	0.469**
X8							1.000	0.146	0.206**
X9								1.000	0.910**
X10									1.000

X1: days to emergence, X2: emergence rate, X3: day 18 root length, X4: day 18 root thickness,

X5: day 18 seedling height, X6: day 18 leaf age, X7: day 28 root length, X8: day 28 root thickness,

X9: day 28 plant height, X10: day 28 leaf age.

* **: Significant at the 0.5 and 0.01 level of probability, respectively.

Jones and Peterson (1976) also reported that the highest emergence percentage was found in the most vigorous seedlings. Each value of root length, thickness, plant height and leaf age at day 18 after seeding had positive correlations with each value of the same traits at day 28, indicting that seedling vigor in the early stage could be a selection indicator for screening of the plants with better growth in the late stage. These results suggest that the rapid emergence at high emergence rate and the seedling vigor are important traits to select promising cultivars for direct-seeding.

2 . Genotype-environment Interactions and Adaptability of the Selected Rice Lines.

The result of the genotype-environment (G-E) interaction is expressed as the adaptability and stability of the genotype. Finlay and Wilkinson (1963) reported that the regression technique was particularly effective in emphasizing the actual trend of varietal yield responses to a range of natural environments and therefore was suitable for evaluating the adaptability of genotypes.

The G-E interaction has been reported for rice yield in some countries (Brown et al., 1983; Mahajan and Rao, 1982; Redona and Sebstian, 1996). In Japan, Oosato et al. (1996) and Imabayashi et al. (1997a,b) reported the G-E interaction and adaptability of palatable rice cultivars. Several promising breeding lines were selected for direct seeding in the previous chapter. In this chapter, they were evaluated under various environmental conditions (year, location, plant density and nitrogen), (i) to determine the relative importance of the G-E interaction effects for yield and yield components and (ii) to determine yield adaptability by the regression technique for the lines selected for direct seeding.

Materials and Methods

Five genotypes consisting of four breeding rice lines, L38, 42 53 and 76 and a reference cultivar Hinohikari, were used (Fig. 15). Seeds were soaked in water at 25°C for 2 days, and the pre-sprouted seeds were directly hand-drill seeded in the plots withstanding water after the plots were thoroughly puddled and leveled. After seeding, the plots were irrigated at a water depth of 2-3 cm continuously. At 10 days after seeding (DAS), the plots were once drained for the anchorage of the root.

Fig. 15. Field trial of the four selected lines and Hinohikari for genotype-environment interaction and adaptability.

Genotype-year (G-Y) interaction

The five genotypes were seeded at the experimental field of Kyushu University in early June in 1997 and early May 1998. Each plot consisted of two 1 m rows with a 25 cm space between rows. Fifty seeds were sown on the surface of the paddy soil in each row. The experiments were duplicated. The seedlings were thinned to a space of 10 cm between plants at 18 and 30 DAS to adjust plant density to 40 plants m^{-2}. The fertilizer consisting of 8, 8 and 8 g m^{-2} of N, P_2O_5 and K_2O, respectively, was applied. Basal fertilizer of N, P_2O_5 and K_2O was applied at seeding at a rate of 50%, and top-dressed at a rate of 30% at the tillering stage and 20% at the panicle initiation stage, respectively.

Genotype-location (G-L) interaction

In 1998, the five genotypes were tested at the Fukuoka Agricultural Research Center (Chikushino, lat. N33.2, long E130.3). The plot consisted of eight 6 m rows with a 15 cm space between rows with two replications. The fertilizer consisting of 10, 10 and 10 g m^{-2} of N, P_2O_5 and K_2O, respectively, was applied by the same method as at Kyushu University and the seeds were seeded about 1 cm depth in early June. The plant density was adjusted to 80 plants m^{-2}.

Genotype-plant density (G-D) and genotype-nitrogen (G-N) interaction

The five genotypes and additional two cultivars (Lemont from America and Ansanbyeo from Korea) were seeded at the experimental field of Kyushu University in early May in 1998. Each plot consisted of two 1m rows with a 20cm space between rows and 50 seeds were sown on each row. At 20 and 30 DAS, the seedlings in separate groups were thinned to 10 and 20 plants per 1 m row to adjust plant density to 40 and 80 plants m^{-2}, respectively. Two levels of the fertilizers consisting of 8, 8 and 8 g m^{-2} of N, P_2O_5 and K_2O, respectively, and 16, 16 and 16 g m^{-2} of N, P_2O_5 and K_2O, respectively, were applied with two replications. Basal fertilizer (N, P_2O_5 and K_2O) was applied at seeding at a rate of 50%, and top-dressed at a rate of 30% at the tillering stage and 20% at the panicle initiation stage, respectively.

Data collection

Prior to harvest, ten hills in the center of each row were chosen to determine panicle number per square meter. At harvest, ten panicles in the center area of each row were randomly chosen for each line, and after one week of drying, the spikelet number per panicle and the panicle weight were determined. The grains were divided into filled and unfilled grains to calculate the percentage of grain filling. After the number of panicles per hill was recorded, ten hills per line were hand-harvested to determine the 1000-grain weight with head brown rice and the grain weight per square meter.

Palatability was evaluated for breeding lines harvested in Fukuoka by the sensory evaluation test (Matsue et al., 1991) in comparison with transplanted Koshihikari as a reference cultivar.

Adaptability analysis

The data of the five genotypes grown under various environmental conditions (year, location, plant density and nitro gen) were used for adaptability analysis. According to the method of Finlay and Wilkinson (1963), the linear regression of individual yield on the mean yield of all genotypes over all environmental conditions was calculated for each genotype.

Results and Discussion

G-Y interaction

Grain yield and yield components varied with the genotype and year; grain yleld was from 440 (L76 in 1997) to 740 g m^{-2} (L42 in 1998), the number of panicles from 204 (L76 in 1997) to 366 m^{-2} (Hinohikari in 1998), the number of spikelets from 24578 (L76 in 1997) to 38096 m^{-2} (L38 in 1998), and 1000-grain weight from 20.3 (L53 in 1997) to 25.3 g (L42 in 1997) (Fig. 16). The year showed a significant effect on panicle number and 1000-grain weight (Table 22). The effect of genotypes were significant in panicle number, spikelet number, 1000-grain weight and grain yield. Thus the variation among genotypes in yield and yield components was wide, but no G-Y interaction was detected. In the panicle number, 1000-grain weight and grain yield, the ranking among the genotypes was not different between 1997 and 1998 (Fig. 16), indicating that all genotypes responded to environmental factors similarly.

Because of the different weather conditions, significant G-Y interactions have often been detected in the yield of many crops (Baba et al., 1998; Imabayashi et al., 1997a; Sayre et al., 1997). However, during this study in 1997 and 1998, the weather condition was similar and there was no serious damage from typhoon or low temperature. Additional tests in different years are needed to confirm the above results.

G-L interaction

Grain yield and yield components varied with the genotype and location; grain yield was from 466 (L76 in Fukuoka) to 760 g m^{-2} (L42 in Fukuoka), the number of panicles from 241 (L76 in Chikushino) to 376 m^{-2} (Hinohikari in Fukuoka), the number of spikelets from 24550 (L76 in Chikushino) to 36525 m^{-2} (L38 in Chikushino), 1000-grain weight from 19.6 (L53 in Fukuoka) to 26.2 g (L42 in Chikushino) and the percentage of filled grain from 70.6 (L53 in Fukuoka) to 93.9 % (L53 in Chikushino)

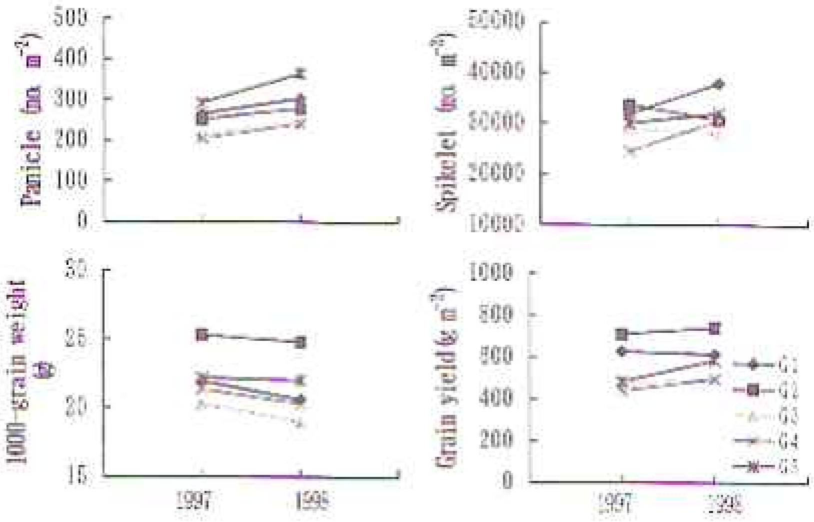

Fig. 16. G-Y interactions for panicle number, spikelet number, 1000-grain weight and grain yield in 1997 and 1998 (G1: L38, G2: L42, G3: L53, G4: L76 and G5: Hinohikari).

Table 22. Analysis of variance for G-Y interaction in water-seeded rice.

Source of variation	df	Mean squares			
		Panicle (no. m^{-2})	Spikelet (no. m^{-2})	1000-grain weight	Grain Yield
Treatment	9	4428.3*	25479778	7.88**	22015 *
Year (Y)	1	8946.5*	20214572	3.87**	8201
Genotype (G)	4	7405.1**	35391534*	16.50**	45667**
Y x G	4	322.1	16884323	0.26	1817
Error	9	378.6	8277746	0.23	3914

*,**: Significant at the 0.05 and 0.01 level of probability, respectively.

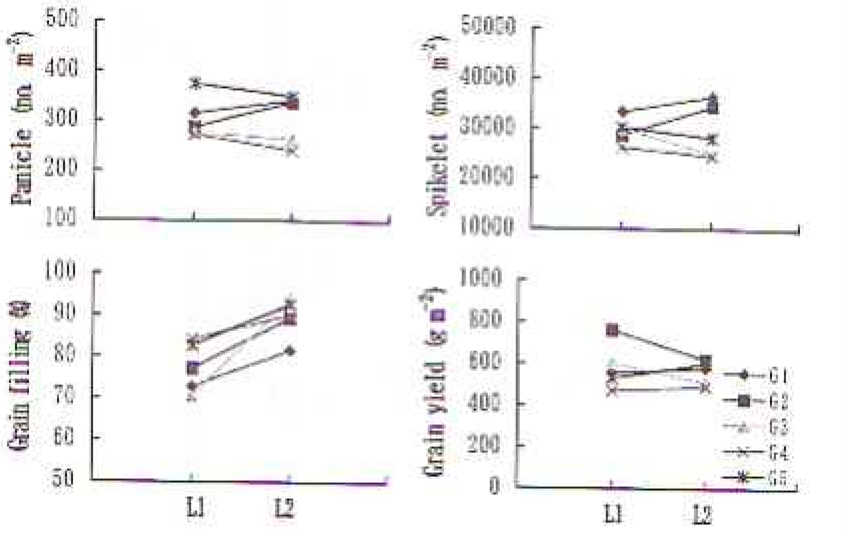

Fig. 17. G-L interactions for panicle number, spikelet number, grain filling and grain yield at Fukuoka and Chikushino in 1998 (G1: L38, G2: L42, G3: L53, G4: L76 and G5: Hinohikari; L1: Fukuoka, L2: Chikushino).

Table 23. Analysis of variance for G-L interaction in water-seeded rice.

Source of variation	df	Panicle (no. m^{-2})	Spikelet (no. m^{-2})	1000-grain weight (g))	Grain filling (%)	Grain yield (g m^{-2})
		Mean squares				
Treatment	9	3917.7*	32801624**	10.85**	132.2**	14099**
Location (L)	1	4.1	4292	5.73**	716.4**	1620
Genotype (G)	4	7589.9**	55256931**	22.54**	72.5*	22439**
L x G	4	1223.9	18545650*	0.45*	45.8*	8979*
Error	9	847.7	4273694	11.7	11.7	2167

*,**: Significant at the 0.05 and 0.01 level of probability, respectively.

(Fig. 17). The effect of genotype was significant for all yield components and yield ('Table 23). The effect of location was also significant for 1000-grain weight and the percentage of filled grains but not for grain yield. The interaction of G-L was detected for yield and all yield components except panicle number. There were significant differences in the ranking among genotypes for spikelet number, percentage of filled grain and grain yield between Fukuoka and Chikushino, whereas there were no differences in the ranking panicle number. According to Fig. 17, L42 is ranked the highest in yield at both locations but the ranks of L38, 53 and reference cultivar were changed by the location.

G-D and G-N interaction

As shown in Table 24, the number of panicles and percentage of filled grains were significantly influenced by plant density. The panicle number, spikelet number, 1000-grain weight and yield were also significantly influenced by nitrogen levels.

The interactions of G-D and G-N were significant only in the percentage of filled grains. Especially the ranking of L53 changed the ranking among genotypes for percentage of filled grains was lowered by plant density, and raised by the nitrogen level (Fig. 18). However, the G-D and G-N interactions for other yield traits were not significant, indicating that the ranking of rice genotypes for yield traits remained constant across plant densities and nitrogen levels. The G-D and G-N interactions for grain yield were not significant.

In the present study, the interaction of genotype with the year, plant density and nitrogen were not detected, but the interaction with location was detected in almost all yield traits, showing the importance of yield testing at various locations.

Table 24. Analysis of variance for G-D and G-N interaction in water-seeded rice.

Source of variation	df	Mean squares				
		Panicle (no. m^{-2})	Spikelet (no. m^{-2})	1000-grain weight (g)	Grain filling (%)	Grain yield (m^{-2})
Replication	1	1650	1	0.10	1.54	297
Treatment	27	6120**	134170954**	6.65**	31.27**	26148**
Plant density (D)	1	17573**	561922	0.18	116.29**	4375
Nitrogen (N)	1	62578**	2405265573**	1.51**	1.06	93759**
Genotype (G)	6	12445**	167890611 **	28.71**	49.87**	83996**
D x N	1	4681	3184 1722	1.45* *	32.25*	2517
D x G	6	345	6350265	0.26	16.34*	2598
N x G	6	244	16217230	0.23	28.78**	6407
Error	27	1179	25164141	0.12	6.29	544 3

*, **: Significant at the 0.05 and 0.01 level of probability, respectively.

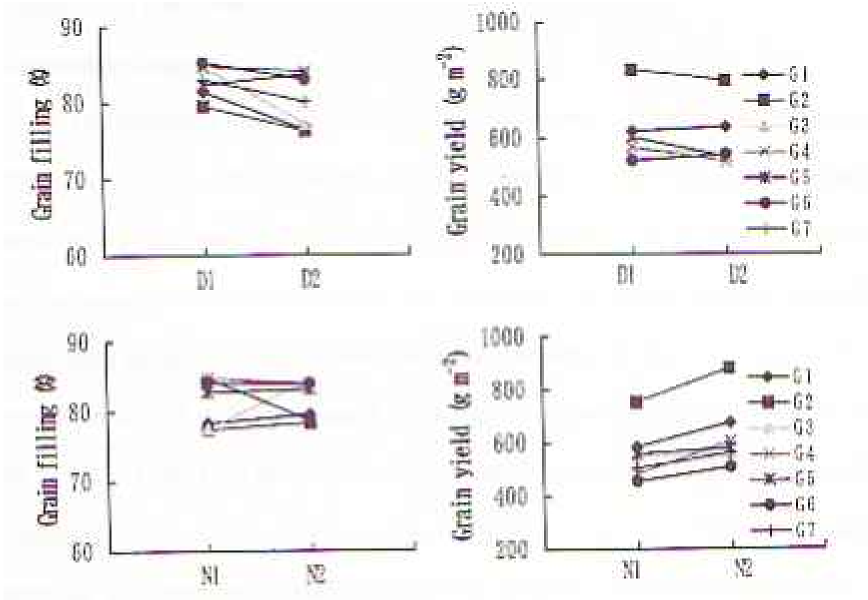

Fig. 18. G-D and G-N interactions for grain filling and grain yield in 1998 (G1: L38, G2: L42, G3: L53, G4: L76, G5: Hinohikari, G6: Lemont and G7: Ansanbyeo; D1: 40 plants m^{-2}, D2: 80 plant m^{-2}; N1: 8 g m^{-2}, N2: 16 g m^{-2}).

Under the four environmental conditions tested in this study, the high ranking of some lines did not change for certain yield traits; Hinohikari for panicle number. L38 for spikelet number, L42 for 1000-grain weight and L38 and 42 for yield. This suggests that these lines are relatively stable for these yield traits across a wide range of environmental conditions.

Adaptability analysis

The regression lines were obtained by the method of Finlay and Wilkinson (1963) for the yield of five genotypes (Fig. 19). Genotypes with regression coefficients of less than 1.0 are less sensitive to environmental conditions. L38, L53 and Hinohikari had the regression coefficient of 0.62. 0.84 and 0.59, respectively, showing relatively stable yield under all environmental conditions. The order of their yield was L38 > Hinohikari > L53. This means that L38 is adapted to low-yielding environments. On the contrary, L42 (1.49) and L76 (1.59) were relatively sensitive to the changes in the environmental conditions. Generally, the plants of this type have high genetic yield potential and perform exceedingly well in favorable conditions but poorly in unfavorable conditions (Finlay and Wilkinson, 1963). L76 produced below-average yields and the response to environmental conditions was relatively high. L42 produced a higher mean yield than the others, and as the environment was improved it produced much higher yields. Therefore, L42 is considered to have general adaptability and is adapted to high-yielding environments with a regression coefficient greater than 1.0 (L42 = 1.49). These results suggest that the lines suitable for water direct-seeding with high yield and adaptability can or must be selected under the water direct-seeding condition .

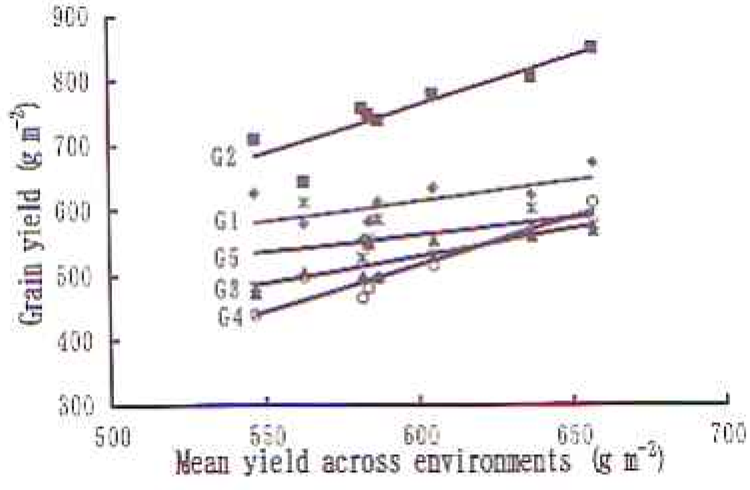

Fig. 19. Regression lines and population mean yield of five genotypes of rice grown under different environmental conditions (G1: L38, G2: L42, G3: L53, G4: L76 and G5 : Hinohikari).

Table 25 shows the means of yield components, yield and palatability across all environmental conditions. L42 exhibited heavier 1000-grain weight and higher yield compared to the other genotypes. The palatability of L42 was similar to that of the reference cultivar, Koshihikari, implying that L42 is a very promising line for water direct-seeding or can be used as a cross parent of the breeding program.

In this chapter it can be concluded that the yield difference among genotypes varies with the location and the lines selected for direct seeding show various adaptability to the environmental conditions. We should be able to select a promising line with high yield by testing the G-E interaction and adaptability as conducted in this study.

Table 25. Mean yield and yield components of five genotypes across all environmental conditions tested.

Genotype	Panicle (no. m^{-2})	Spikelet (no. m^{-2})	1000-grain weight (g)	Grain filling (%)	Grain yield (gm^{-2})	Palatability[2)]
Line 38	320 ab[1)]	37047 a	20.7 c	79.1 b	605 b	-2.44
Line 42	300 b	33303 ab	25.3 a	81.0 b	744 a	-0.12
Line 53	267 b	30897 ab	19.7 d	82.2 ab	530 c	0.19
Line 76	259 b	29468 ab	21.0 c	85.7 a	501 c	-2.38
Hinohikari	364 a	32205 ab	22.4 b	84.8 a	557 bc	-
Mean	3 02	32584	21.8	82.6	587	-

1) Within columns, means followed by the same letter are not significantly different at 5 % using Duncan's multiple range test.

2) The reference cultivar for the sensory test was Koshihikari.

V. GROWTH CONTROL OF DIRECT-SEEDED RICE

1. Effect of Deep Water Treatment on the Over-growth Control in Direct-seeded Rice

In direct-seeded rice, one of the most serious problems is over-growth of tillers, because the seeds are sown at the surface of the soil and a large number of tillering nodes develop than in transplanted rice. Excessive plant stands lead to taller plants with weaker culms, increasing the lodging and severe disease pressure, especially sheath blight (Lee, 1995; Gravois and Helms, 1996).

Deep water treatment (DW) suppresses the over-growth of tillers in transplanted rice. Growth of the tillers which had already emerged from the subtending leaf sheaths of the main stem at the start of DW was promoted, while that of the tillers which were growing inside the subtending leaf sheaths was inhibited by DW (Hanada and Kagawa, 1985; Furuya et al., 1991). It has been reported that the culm diameter of all cultivars at the ripening stage was markedly large and the breaking strength of the basal elongated internodes tended to increase under DW (Ohe et al., 1996).

These effects of DW on the tillering and lodging tolerance observed in transplanted rice may be applicable to the direct-seeded rice. However, little information has been reported about such effects except for the report of Kabaki and Kon (1991). Although they showed the regulation of tillering by DW in rice broadcasted under submerged conditions, they did not examine the culm characteristics related to the lodging tolerance. In addition, few workers compared the response of the rice plant to DW under transplanting, dry-seeding and wet-seeding cultivation. Therefore, the author examined the effect of DW on the tillering, lodging tolerance and yield components of two types of direct-seeded rice plants (dry and water) in comparison with transplanted rice.

Materials and Methords

The study was conducted in 1994 and 1995 at the field of Kyungpuk Provincial Rural Development Administratron (Taegu Korea 35°51'N latitude, 128°35'E longitude silty clay loam), using Whayoungbyeo, a medium maturing, high yield and high quality Japonica type cultivar, developed in Korea

The mean temperature and sunshine hours during the growing season in this study are shown in Fig. 20. The average mean temperature and total sunshine hours during the growing season were 23.5°C and 1397 hours, respectively, in 1994, and 21.9°C and 1191 hours, respectively, in 1995 (data from Taegu Meteorological Office, Korea).

Three kinds of cultivation were employed in this study, (1) Machine transplanting: 10-day-old seedlings at 2.7-2.9 leaf ages were transplanted (5-7 seedlings per hill) mechanically on May 20, with a density of 30 x 14cm. Fertilizers were applied at the rate of 110 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1} in total. (2) Water-seeded rice: pre-germinated seeds were broadcasted manually at the rate of 50 kg dry seeds ha^{-1} to the flooded paddy field on May 1. Fertilizers were applied in the same way as for machine transplanting. (3) Dry-seeded rice: seeds were sown on hills at the rate of 50kg ha^{-1} by hill seeding machine on May 1 with a density of 25 x 17cm. Fertilizers were applied at the rate of 150 kg N ha^{-}1, 70 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1} in total. In dry seeded rice, 7-10 seeds were buried in a small hole 2-3 cm in depth and covered with soil.

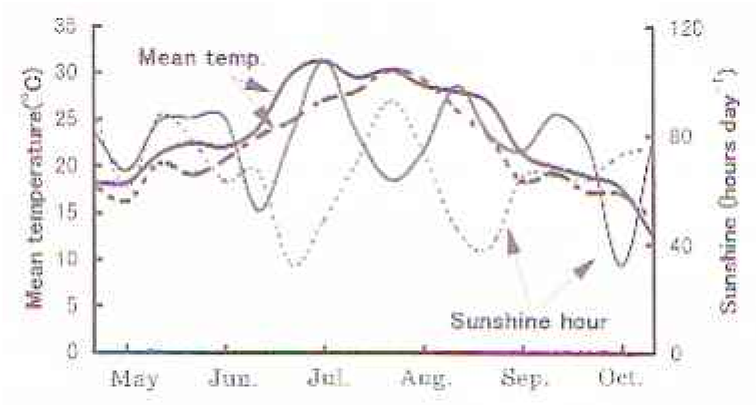

Fig. 20. Mean temperature and sunshine hours during the growing season for the growth control study (———— 1994, ········· 1995).

As the basal application, 40%o of N, all of P_2O_5 and 70% of K_2O were broadcasted just prior to transplanting or sowing. Top dressings of N and K_2O were equally applied at tillering stage and shortly after the panicle initiation stage.

The experimental design was a split plot design with 3 replications. The cultivation method was designed as the main plot and irrigation method as a subplot. In both transplanted and water-seeded rice, the water level was kept at 2-3 cm (ordinary) until the start of DW. In dry-seeded rice, the water flood was started when the rice plant was at the four- or five-leaf stage. DW was started at the 8-leaf stage. The incomplete leaf was counted as the 1st leaf.

Before deep-water treatment, the ridge of the field was raised to 30 cm height and plastered with mud from the paddy field to prevent water flow. In deep-water treatment, the author raised the water depth level 1-2 cm above the auricle of the latest leaf as the leaves were developed. The last depth of water became 25 cm and this depth was continued until the maximum tiller stage (80 days after seeding) for about 30 days (Fig. 21). In the ordinary-water treatment, the author kept the water depth level at 2-3 cm and drained at the maximum tiller stage for 10 days to dry the field. Then, the field was flooded again until the ripening period.

From 45 days after seeding, the numbers of tillers of 20 hills in transplanted and dry-seeded were counted at 10-day intervals. The tiller number of water-seeded plants was counted for a 0.5 x 0.5 m quartet. Then the number of tillers per square meter was calculated. Thirty days after heading, 10 plants were obtained from three hills for the measurement of culm traits relating to lodging tolerance. The length from the culm base to the ear neck was measured for culm length, and the diameter at the

Fig. 21. Water treatments at maximum tillering stage - Ordinary water (above) and deep water treatment (below).

middle part of the 4th internode for culm diameter. Lodging index was calculated {(bending moment / breaking weight) x 100}, and bending moment as (culm length x plant fresh weight) (Seko, 1962). The breaking weight is the force required to break the 4th internode, and was measured with a spring balance. Field lodging was recorded at 40 days after heading.

Results and Discussion

Tillering

Among the three groups with different cultivation methods, the number of tillers was the largest in water-seeded rice, followed by transplanted and dry-seeded rice under both DW and OW (Fig. 22, Table 26.). In the case of water-seeded rice, the seeds were broadcasted on the surface of the field and were not buried. This might cause the development of a larger number of tiller-produceble nodes than in transplanted or dry-seeded rice. In the case of dry-seeded rice, 7-10 seeds were seeded into each small hole and the competition of the seedlings in the hole might be higher resulting in a fewer number of tillers than in other cultivation groups as reported by Won et al. (1996) and Yoshinaga et al. (1997).

Results of the analysis of variance (ANOVA) showed that the effects of cultivation method, water treatment and year were highly significant ($p < 0.01$) in the tillering characteristics, except for the effect of water treatment in productive tillers (Table 27). DW suppressed the development of non-productive and weaker tillers and increased the percentage of productive tillers in direct-seeded rice. This is in agreement with the results reported by Hanada (1983), Hanada and Kagawa (1985), Kawashima and Murakami (1985) and Ohe et al. (1994) who used transplanted rice. The significant

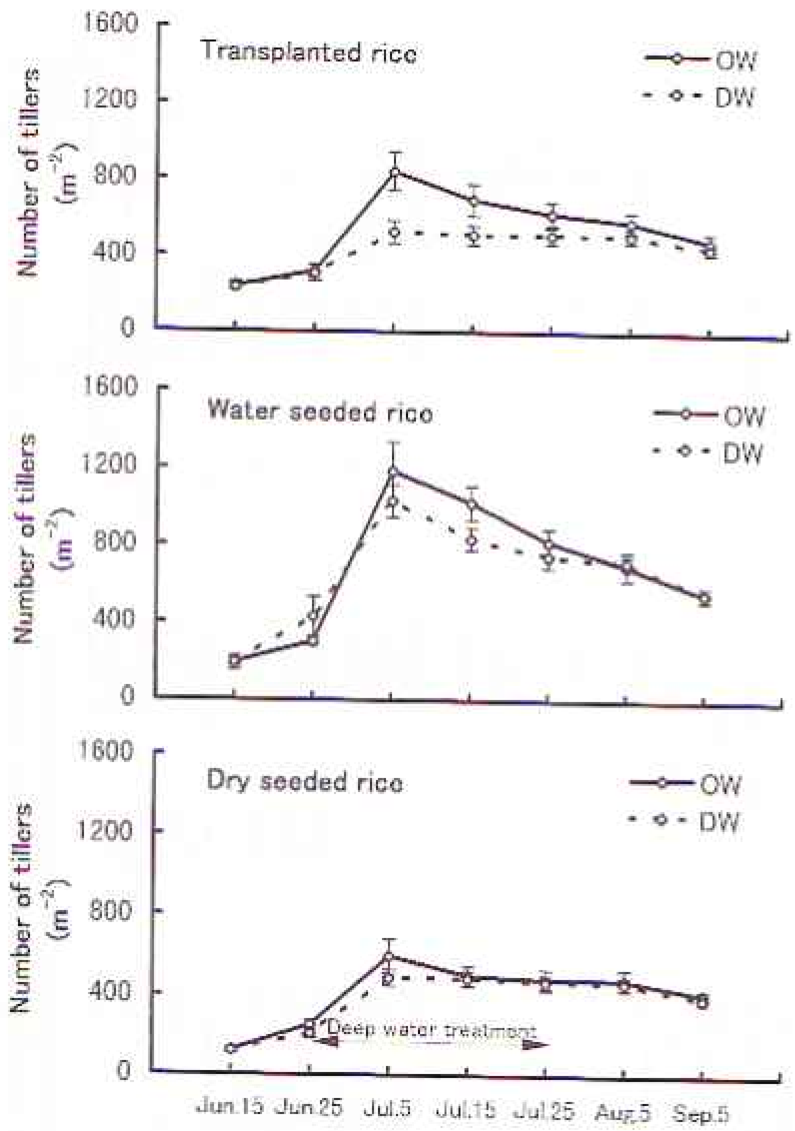

Fig. 22. Time course of rice tiller development as affected by deep water treatment in three different cultivation groups in 1995 (OW: ordinary water treatment, DW: deep water treatment). Vertical bars indicate the standard deviations.

Table 26. Number of tillers before deep water treatment, maximum tiller number, percentage of tillers increased and productive tille.rs as affected by deep water tre.atment.

Cultivation	Water Treatment	Tillers (No, m^{-2}) (A)[2]	Maximum tillers (No. m^{-2}) (B)	Percentage of tillers increased (%)[3]	Productive tillers (No. m^{-2}) (C)	Percentage of productive tillers (%)[4]
1994						
Trans-planting	DW[1]	502 b[5]	635 b	26 ab	536 b	84 b
	OW	526 b	845 c	61 cd	518 b	61 a
Water-seeding	DW	721 d	889 c	23 a	585 b	66 a
	OW	613 c	1081 d	76 de	571 b	53 a
Dry-seeding	DW	299 a	438 a	46 bc	390 a	89 b
	OW	275 a	528 ab	92 e	418 a	79 b
1995						
Trans-planting	DW	315 c	526 ab	67 a	447 bc	85 d
	OW	317 c	843 c	166 b	485 c	57 b
Water-seeding	DW	434 d	1032 d	139 b	558 d	54 ab
	OW	305 c	1184 e	288 c	561 d	47 a
Dry-seeding	DW	207 a	489 a	138 b	388 a	79 d
	OW	254 b	598 b	139 b	412 ab	69 c

1) DW: deep water treatment, OW : ordinary water treatment.

2) Tiller density before deep water treatment.

3) ((B - A) / A) x 100, 4) (C / B) x 100.

4) Means followed by the same letter within a column in the same year were not significantly different at the 5% level of probability.

Table 27. Mean squares of combined analysis of variance for maximum tillers, productive tillers and percentage of productive tillers.

Source of variation	df	Maximum tillers (No. m^{-2})	Percentage of tillers increased(%)	Productive tillers (No. m^{-2})	Percentage of productive tillers(%)
Replication	2	6151	195	683	23
Treatment	11	195116**	16647**	16886**	615**
Cultivation (C)	2	871603 * *	7918**	84318**	1807**
Water treatment (W)	1	286581**	36481**	930	2058**
Year (Y)	1	16473*	92964**	7022*	416**
C x W	2	20539**	4556**	736	251**
C x Y	2	24425**	8656**	2587	63
W x Y	1	1877	3260**	1167	0.1
C x W x Y	2	4106	4068**	669	22
Error	22	3523	303	1005	34

*, **: Significant at the 0.05 and 0.01 level of probability, respectively.

interactions of the cultivation x water treatment were also detected for the number of maximum tillers, percentage of tiller increase and percentage of productive tillers, indicating that the response of these tillering characteristics to DW was changed by cultivation methods. The number of maximum tillers under DW on the average of two years was 581 in transplanted, 961 in water-seeded and 464 in dry-seeded rice (mean 669), while that under OW was 844, 1133 and 563 (mean 847): respectively. The percentage of tiller increase after the start of DW was 47% in transplanted, 81% in water-seeded and 92 % in dry-seeded rice (mean 73 %) while that under OW was 114, 182 and 116 % (mean 137%), respectively. The meteorological conditions at the tillering stage in 1994 and 1995 were different (Fig. 20). Because of the lower mean temperature and fewer sunshine hours from late of May to early of June in 1995, the tillering ability was lower in 1995 than in 1994. However, in 1995 the temperature was raised from the middle of June, and the tillering ability was recovered. Thus, the percentage of tillers increased (% of tiller number increased after the start of DW to maximum tiller number) was relatively high in 1995. The percentage of productive tillers under DW was 85% in transplanted, 60% in water-seeded and 84% in dry-seeded rice (mean 76%), while that under OW was 59, 50 and 74 (mean 61%), respectively. Generally, the time course of tillering was similar among the three cultivation groups. However, water-seeded rice showed a different tillering pattern from dry-seeded or transplanted rice (Fig. 22). The maximum number of tillers in transplanted and dry-seeded rice under DW were nearly the same as the numbers of panicles but the number in water-seeded rice was higher. Therefore, the percentage of productive tillers in water-seeded rice in DW was markedly lower than that in other cultivation groups. This may indicate that the suppression of the development of non-productive tillers by DW was relatively weak in water-seeded rice.

Recently, Kim and Vergara (1990) claimed that low-tillering cultivars with large and fewer panicles would be more suitable for dense planting or direct seeding of rice. Donald (1968) proposed a uniculm plant as an ideotype for cereal crops, although Yoshida and Parao (1972) emphasized the importance of high tillering cultivars for an ideotype. It is also necessary to suppress the growth of non-productive and weaker tillers to obtain larger panicles and strong culm.

Culm characteristics relating to lodging tolerance

Culm length was slightly and diameter of culm was significantly increased by DW (5.70 mm under DW and 5.25 mm under OW), but the difference among the three cultivation groups was obscure (Table 28). The fresh weight of the whole plant was also heavier under DW than under OW. Longer culm and heavier fresh weight resulted in a larger bending moment (culm length x plant fresh weight) under DW. However, the heavier weight of stem base and heavier breaking weight under DW brought the lower lodging index { (breaking weight / bending moment) x 100} under DW. Even though the bending moment affected the lodging tolerance negatively under DW, the thicker culm and heavier culm breaking weight surpassed the effect, resulting in the promotion of the resistance to the lodging under DW. For the culm thickness, Won et al. (1997) reported that the deep water condition made the leaf sheath develop plainly and Ohe et al. (1996) also reported that the culm diameter of all the cultivars was markedly increased and the breaking strength of the basal internodes tended to be increased by DW.

Table 28. Characteristics of lodging as affected by deep water treatment in three different cultivation groups.

Cultivation	Water Treat-ment	Culm length (cm)	Culm diameter (mm)	Plant fresh weight (g))	Culm base weight (g)	Breaking weight (g)	Lodging index	Field lodging (0-9)[3]
1995								
Trans-	DW[1]	82.9 c[2]	5.35 ab	9.67a	1.76 b	355 b	226 cd	1
planting	OW	79.0 ab	5.15 a	9.61 a	1.69 a	310 a	245 d	1
Water	DW	82.4 bc	6.05 c	11.6 a	2.20 d	449 d	213 bc	6
seeding	OW	81.6 bc	5.15 a	10.93 ab	1.90 c	382 bc	234 cd	9
Dry	DW	80.7 abc	5.70 b	10.12 b	1.81 b	469 d	174 a	1
seeding	OW	77.5 a	5.45 ab	9.64 a	1.78 b	404 c	185 ab	3

1) DW: deep water treatment, OW: ordinary water treatment.

2) Means followed by the same letter within a column were not significantly different at the 5% level of probability.

3) 0: Not lodged, 9: Extremely lodged.

In water-seeded rice, since the seeds were sown on the surface of soil, the root lodging was serious (Table 28). This may be the reason why the score of field lodging was high in water-seeded rice, though it was similar to that in transplanted rice. This means that the lodging degree was affected not only by DW but also by the cultivation method. However, the lower lodging score under DW in both water- and dry-seeded plants indicated that the thicker culm and heavier culm breaking weight caused by DW somewhat contributed to the reduction of culm-breaking lodging in direct-seeded rice. In direct-seeding, some farmers plant more seeds than the standard rate in consideration of poor emergence. Dense seeding is profitable for obtaining a sufficient number of panicles. However, the culm becomes weak and it often causes serious lodging. In this case, DW may reduce the rate of non-bearing tillers and strengthen the culm, increasing the resistance to lodging.

In this study, the author confirmed that DW was effective to suppress the growth of non-productive and weaker tillers and to increase the panicle size and tiller productivity. It also improved the lodging tolerance by increasing the thickness and breaking weight of the culm. In water-seeded rice, the suppression of the development of non-productive tillers and the improvement of lodging tolerance by DW were relatively weaker than in transplanted and dry-seeded rice. However, still the author observed some improvement of culm traits and productivity by DW in water-seeded rice. Therefore, DW may be one of the available growth control methods for direct-seeded rice to improve grain yield to resemble a low-tillering panicle weight type.

2. Interaction between N Application and Water Management in Direct-seeded Rice

In direct-seeded rice, because of greater tiller number and faster crop establishment and subsequent N dilution in the tissue, foliar N content decreased more rapidly (Dingkuhn et al., 1990; Schnier et al., 1990). However, Shnier et al., (1990) concluded that direct seeding had the potential for further increasing yield, provided that the excessive biomass production and the resulting foliage N deficiency were controlled.

In the previous chapter, the author revealed that the excessive growth of non-productive tillers of direct-seeded rice was reduced and the excessive vegetative growth could be controlled by deep-water treatment, the yield capacity being improved. On the other hand, Castillo et al. (1992) pointed out that the internal nitrogen-use efficiency (kg grain per kg aboveground-plant N) and agronomic nitrogen-use efficiency (kg grain per kg fertilizer N applied) were significantly influenced by water depth. Thus, under different water treatments, the efficiency and response of rice to N might be different.

Even though there are some reports about the N-use efficiency in direct-seeded rice (Westcott et al., 1986; Norman et al., 1992), there are only a few reports about the response of dry-seeded rice to different amount of N application under a deep-water condition. The objectives of this study were to determine the response of dry-seeded rice to N application under deep-water treatment and the interaction between N application and water management in dry-seeded rice.

Materials and Methods

Whayoungbyeo, a high-yielding and high quality Japonica rice cultivar, developed in Korea, was grown in a field of the Kyungpuk Provincial Rural Development Administration in 1995 and 1996. During the study, the average mean temperature were 21.9°C in 1995 and 22.4°C in 1996. In 1995, only one level of N (150 kg ha^{-1}) was tested with three replications under ordinary-water (OW) and deep-water (DW). In 1996, a split plot design was used, the water treatment was designed as the main plot and four N levels of 0, 70, 150 and 220 kg ha^{-1}, as subplots. The size of each subplot was 15 x 10 m. All treatments were replicated five times. The rice was dry sown on a hill at the rate of 50 kg ha^{-1} at the density of 25 x 17cm early in May. Seven to ten seeds were buried in a small hole at a 2-3 cm depth and covered with soil. As a basal application, 40% of N (0, 28, 60 and 88 kg ha^{-1}), all P (70 kg ha^{-1}) and 70% of K_2O (56 kg ha^{-1}) were broadcasted just prior to sowing on dry soil and tilled into the soil with the rotary tiller attached to a tractor, and the remainder of the basal application of N (0, 21, 45 and 66 kg ha^{-1}) and K_2O (24 kg ha^{-1}) was applied shortly after the panicle initiation stage. Top-dressed N was split equally, with the first one applied at the tillering stage.

The water treatments were the same as mentioned in the previous chapter (Fig. 21). Prior to harvest, the panicle number in 20 hills were counted to estimate the number per m^2. Five hills were randomly selected from each plot for determination of yield components and 100 hills were harvested for grain yield analysis. Twenty panicles were randomly selected from the 5 hills to count unfilled grains and filled grains. The 1000-grain weight was measured for brown rice, and the grain weight was adjusted to that with a 14% moisture content. Twenty leaves from 5 hills were sampled and dried for N analysis. The total nitrogen in plant tissue was analyzed by the Kjeldahl method (IRRl, 1972). Partial factor productivity (PFP) from applied N (N.) was calculated as : grain yield / Nx, and agronomic nitrogen-use efficiency (ANUE) was calculated as : (yield at Nx - yield at No) / Nx (Peng et al., 1996; Cassman et al., 1998).

Analysis of variance (ANOVA) of a split-plot design was divided into the main-plot analysis and the subplot analysis by using IRRISTAT (IRRI, 1993). Comparisons of treatment means among the levels of N were performed with DMRT and the means between water treatment were tested by t-test.

Results and Discussion

Yield and yield components

Panicle number, spikelet number, 1000-grain weight, percentage of ripened grain and yield were significantly influenced by the amount of N applied (Table 29, Table 30). Spikelet number, percentage of ripened grains, 1000-grain weight and grain yield increased with the increase in the amount of N applied up to 150 N kg ha^{-1}, then decreased at 220 N kg ha^{-1}, such an effect of N application was evident especially in percentage of ripened grain. The number of panicles increased with increasing amount of N applied in either OW or DW. Fig. 23 shows the relationship between the number of panicles and amount of N applied in OW and DW. The number of panicles was highly and positively correlated with the amount of N applied in both water treatments. Grain yield and yield components such as spikelet number, 1000-grain weight and the percentage of ripened grain were higher in DW in both years. Vlek et al. (1979) mentioned that the panicle number was highly responsive to N in N-responsive cultivars but this gain in yield might bc lost by compensating reductions in other yield components because N caused excessive vegetative growth after panicle

Table 29. Effect of water treatment on yield and yield components at different amount of N applied in dry-seeded rice.

Year	Applied N (kg ha^{-1})	Panicles (no. m^{-2})	Spikelets (no. m^{-2})	1000-grain weight(g)	Percentage of ripened grain(%)	Grain yield (t ha^{-1})
		Ordinary water treatment				
1995	150	418	35329	21.4	89.8	4.69
1996	0	339 c[1)]	28,725 c	21.1 c	85.2 b	3.02 d
	70	362 c	32.423 b	22.0 b	87.4 ab	3.68 c
	150	402 b	34,925 a	22.6 a	88,6 a	4.64 a
	220	431 a	33,125 b	22.1 b	79.9 c	4.04 b2)
	Mean	384	32,300	22.0	85.3	3.85
		Deep-water treatment				
1995	150	384	36,265	21.6	92.5	5.04
1996	0	301 c	30,247 c	21.6 c	89.6 b	3.72 c
	70	322 c	35,240 b	22.7 a	91.7 a	4.29 b
	150	355 b	36,206 a	22.8 a	92.4 a	5.17 a
	220	421 a	35,647 b	22.3 b	86.9 c	5.07 a
	Mean	350	34,335	22.4	90.2	4.56
T-test between	1995	34n s	944ns	0.2*	2.7*	0.35*
OW and DV	1996	34**	2,035**	0.4**	4.9**	0.71**

1) Means followed by the same letter within a column in the same water treatment are not significantly different at the 5 % level of probability by DMRT.

2) There was a severe lodging at 220 N kg ha^{-1} in ordinary water treatment.

*,**, ns: Significant at the 0.05 and 0.01 level of probability, and not significant, respectively.

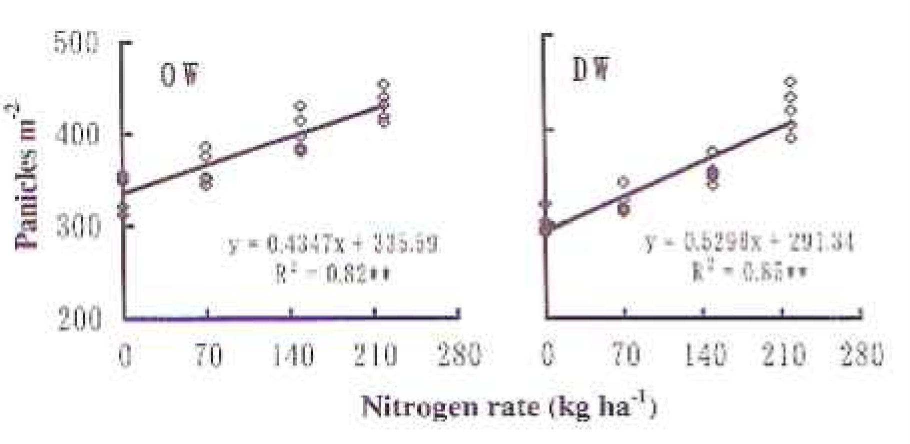

Fig. 23. Relationship between the number of panicles per m and amount of N applied in ordinary water (OW) and deep-water (DW) treatment (n = 20, **: significant at the 0.01 probability level).

Table 30. Mean squares of ANOVA for panicles, spikelets, 1000-grain weight, percentage of ripened grain and grain yield in 1996.

Sources	df	Panicles ($no.m^{-2}$)	Spikelets ($no.m^{-2}$)	1000-grain weight (g)	Percentage of ripened grain(%)	Grain yield ($t\ ha^{-1}$)
Replication	4	1368 .42	33798.8	0.042	2.81	0.0127
Applied N(N)	3	56111.42**	2313898.1**	3.894**	64.55**	4.3102**
Error	12	1761.74	71284.6	0.066	4.92	0.0936
Water treatment(W)	1	46270.03**	967312.8**	4.350**	336.44**	4.9701**
N x W	3	2831.33	62890.0	0.654**	3.19	0.0286
Error	16	2483.63	72349.5	0.111	13.71	0.1131

*, **, ns: Significant at the 0.05 and 0.01 level of probability, and not significant, respectively.

initiation. The analysis of variance (Table 30) showed a highly significant interaction effect between the amount of N applied and water treatment for 1000-grain weight, indicating that the differences in 1000-grain weight due to the N Ievel was not the same at different water treatments and, similarly, the response to water treatment differed with the amount of N tested .

Table 31 shows the correlation coefficients between yield components and yield in OW and in DW. The number of panicle was negatively, though not significantly in OW, correlated with the percentage of ripened grain (r = - 0.357 for OW, r = - 0.444* for DW), and the number of spikelets was positively correlated with 1000-grain weight (r = 0.868** for OW, r = 0.611** for DW) and with grain yield (r = 0.977** for OW, r = 0.883* for DW). Grain weight (1000-grain weight) was also positively correlated with the yield (r = 0.898** for OW, r = 0.676** for DW). In DW, the number of panicles was lower than that in OW, but the percentage of ripened grain was higher. The higher the number of panicles, the lower the percentage of ripened grains. However, the suppressive effect of the high amount of N applied on the percentage of ripened grains or OW treatment was compensated by DW treatment, and the suppressive effect of deep-water on the panicle number could be compensated by increasing N. Although the number of panicles was lower in DW, the other yield components and yield were significantly higher in DW, where excessive vegetative growth was suppressed (Table 29, 30).

N content and N-use efficiency

Generally, nitrogen concentration in the flag leaf is closely related to photosynthetic rate and is positively correlated with grain yield (Wells and Faw, 1978;

Table 31. Correlation coefficients among N-rate, yield components and yield in ordinary and in deep-water treatment in 1996.

	Panicles	Spikelets	1000-grain weight	% of ripened grain	Grain yield
Ordinary water treatment					
Panicles	1.000	0.656**	0.652**	-0.357	0.669**
Spikelets		1.000	0.868**	0.263	0.870**
1000-grain weight			1.000	0.206	0.898**
% of ripened grain				1.000	0.168
Grain yield					1.000
Deep-water treatment					
Panicles	1.000	0.411	0.336	-0.444*	0.777**
Spikelets		1.000	0.611*	0.129	0.586**
1000-grain weight			1.000	0.375	0.676**
% of ripened grain				1.000	0.051
Grain yield					1.000

*, **; Significant at the 0.05 and 0.01 level of probability, respectively.

n = 20.

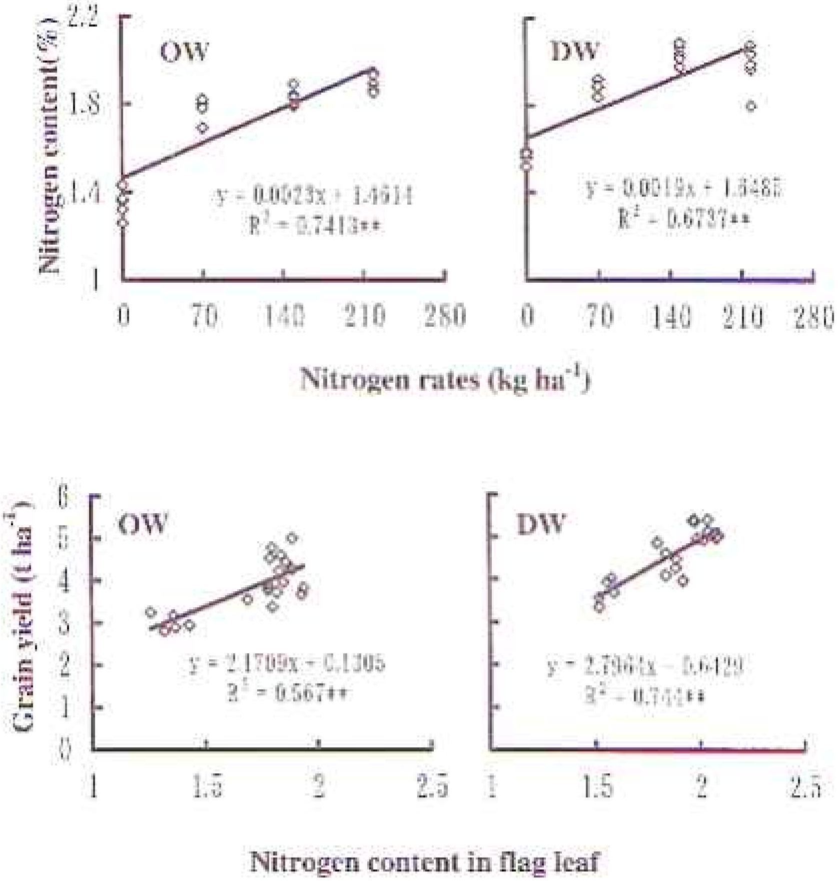

Fig. 24. Relationship between nitrogen content in fiag leaf and amount of N applied (above), and relationship between grain yield and nitrogen content in flag leaf in ordinary water (OW) and deep-water (DW) treatment (below) (n = 20, **: significant at the 0.01 probability level).

Peng et al., 1995). Fig. 24 shows the relationship between the amount of N applied and nitrogen content in the flag leaf, and that between grain yield and nitrogen content in the flag leaf in OW and DW. The nitrogen content in the flag leaf was positively correlated with the amount of N applied (r = 0.861** in OW, r = 0.820** in DW). However, the increasing rate of nitrogen in the leaf was somewhat lowered at high N levels. The grain yield was highly and positively correlated with nitrogen content in the flag leaf in both OW and DW (r = 0.753** in OW and r = 0.860** in DW). The nitrogen content in the flag leaf was higher in DW (1.78 in OW, 1.86 in DW) and the grain yield was also greater in DW. De Datta et al. (1987) reported that the highest partial pressure of NH_3 was observed when N fertilizer was topdressed at 10 days after transplanting into 50 mm standing water; hence, lower values were recorded at 100 and 150 mm water due to dilution and lower floodwater pH and temperature. Therefore, the volatilization loss of N could be prevented by DW. Schnier et al. (1990) and Hasegawa et al. (1994) reported that vigorous biomass growth with heavy dilution of the N content in plants up to the panicle formation stage could result in inefficient use of N for spikelet formation. Therefore, the prevention of N-volatilization loss and dilution of N content in rice plants in DW must have increased the N content in the flag leaf.

The partial factor productivities (PFP) from applied N (Nx) and the ANUE {(yield at Nx - yield at No) / Nx } under two water treatments were shown in Table 32. The PFP was significantly different between OW and DW at all levels of N application while the ANUE was not different between OW and DW. The mean PFP in OW was 34.0 and that in DW was 39.6 kg kg^{-1} applied N. PFP from applied N is a useful measure of nutrient-use efficiency because it provides an integrative index of the total

Table 32. Effect of water treatment on partial factor productivity of N applied and agronomic nitrogen-use efficiency for different amount of N applied in 1996.

	PFP[1)]			NUE[2)]		
N rate	OW	DW	T-test between OW and DW	OW	DW	T-test between OW and DW
kg ha^{-1}	-------------------	g kg^{-1} N	-------------------			
70	52.6	61.3	**	9.4	8.1	ns
150	30.9	34.5	**	l0.8	9.7	ns
220	18.4	23.0	**	4.6	6.1	*
Mean	34.3	39.6	**	8.3	8.0	ns

1) Partial factor productivity: Yield / Nx.

2) Agronomic nitrogen use efficiency: (Yield at Nx - yield at No)/applied N at Nx.

*,**, ns: Significant at the 0.05 and 0.01 level of probability, and not significant, respectively.

economic output relative to the utilization of all nutrient resources in the system including indigenous soil nutrients and applied N, while ANUE represents the efficiency in utilization of applied N (Peng et al., 1996; Cassman et al., 1998). Therefore, these results suggest that the utilization-efficiency of indigenous soil nutrients was improved in DW through the suppression of non-productive tiller formation by elevated water level, and it would improve the yield determinants such as the number of spikelets, 1000-grain weight and the percentage of ripened grain, which consequently might lead to an increase in yield production.

In direct seeding, some farmers plant more seeds than the standard rate in consideration of poor emergence and there is no transplanting shock which causes greater tiller number and rapid development of foliage. Dense population is profitable for obtaining a high number of panicles, but the greater biomass production during the vegetative and early reproductive phase in direct-seeded rice results in greater N dilution and lower tissue N concentration during the reproductive phase, and, hence, affects sink formation (Schnier et al., 1990). In this study, the deep-water treatment prevented the excessive vegetative growth, and improved the percentage of productive tillers and other yield components. In DW treatment, the concentration of nitrogen in leaf and partial factor productivity of applied N were higher than in OW treatment. These results suggest that the suppression of tiller formation by elevated water level would improve the yield determinants and utilization efficiency of indigenous soil N, which consequently could help to increase yield production.

CONCLUSION

The necessity of reduction of labor and production cost under the UR and WTO worldwide trading system drove changes of the rice cultivation technology to labor-saving cultivation. Among them, the changes of the cultivation technology to direct-seeding seems most urgent and needs the development of the new rice genotype with low dissolved oxygen tolerance, high lodging tolerance and high yield capacity. In this thesis, the author carried out several experiments about screening or selection cultivars for direct-seeded rice, gene action with general and specific combining ability, and genotype-environment interaction in direct-seeded rice. He also studied about how to control over-growth of direct seeded rice

In water-seeded rice, the failure of rice to emerge through soil and water has been attributed to the lack of O_2. The author found there were the genotype differences for coleoptile elongation and root and shoot growth in the low dissolved oxygen (DO) level. The difference among genotypes was found at 1.5 - 2.5 mg L^{-1} dissolved oxygen level, indicating the possibility of screening cultivars between this DO level. Judging from the root number, root length, coleoptile length and shoot length, several cultivars with high tolerance to this low dissolved oxygen level were identified. These cultivars might be very useful genetic sources in improving the establishment of the rice seedlings for water-seeding.

The SPGP (seed pack growth pouch) method was shown to be very useful to select cultivars at the early stage for root system. Root thickness of SPGP seedlings was positively correlated with root thickness and pushing resistance of field test. Therefore, the author could select cultivars with lodging tolerance in early seedling stage using SPGP. Considering root and culm thickness of SPGP, grain yield and grain quality, several promising lines were selected for water-seeding cultivation or candidate parental lines for next crossing cycle.

Knowledge of the underlying gene action within the breeding population is a key to selecting procedures that will maximize gains in yield. Factorial crossing (Design II) showed that GCA dominated for culm length, culm thickness, panicle length, 1000-grain weight and grain yield, indicating the importance of additive gene effects for these traits. Some parents with positive GCA for yield, culm thickness, panicle length were found. They could contribute to developing cultivars for direct-seeding.

Growers need cultivars that have high yield potential consistently across a wide array of stress conditions and even under the conditions improved especially for direct-seeding cultivation. The study of genotype-environment interaction under various environmental conditions (Year, Location, Density and Nitrogen) showed that no G-Y interactions in yield and yield component were detected. The interaction of G-D and G-N were significant only in percentage of filled grains. G-L interaction was significant for yield and almost all yield components. The difference in adaptability among genotypes evaluated by a regression method was found and one breeding line (L42) selected by the author in this study showed high and stable yield.

In direct-seeded rice, one of the most serious problems is over-growth of tillers and this leads to taller plants with weaker culms, increasing the lodging. In this study, the author confirmed that deep-water treatment was effective to suppress the growth of non-productive and weaker tillers and to increase the panicle size, tiller productivity and yield. It also improved the lodging tolerance by increasing the thickness and breaking weight of the culm. The control of non-productive tillers by deep-water also increased the N utilization in direct-seeded rice. Although agronomic nitrogen-use efficiency (ANUE) was not different between the two water treatments, the partial factor productivity (PFP) of applied N was significantly higher in deep-water. Therefore, the author concluded that the suppression of tiller formation by elevated water level improved the yield determinants and utilization efficiency of indigenous soil N, which consequently helped to increase yield.

In conclusion, this thesis revealed several basic and practical information including not only breeding strategies but also cultivation technologies for direct-seeding. Selected genotypes with tolerance to low dissolved oxygen, with lodging tolerance or with good yield capacity could be very important new genetic sources. They could improve the potential of increasing yield and contribute to developing cultivars for direct seeding. By the estimation of GCA, SCA, heterosis and adaptability, one promising line with high and stable yield with good combining ability could be selected for direct-seeding. For developing a new agricultural technology, direct-seeding, both of good cultivars and adapted cultural practice is necessary. In the cultivation aspect, the author also revealed that the deep-water treatment was very effective to control the over-growth of direct-seeded rice, and it improved the lodging tolerance and utilization efficiency of indigenous soil N and increased the yield determinants.

ACKNOWLEDGEMENTS

The LORD is my shepherd, I shall not want; he makes me lie down in green pastures. He leads me beside still waters (Psalms 23).

The present study was carried out in the Laboratory of Crop Science, Division of Agriculture, Graduate School, Kyushu University, Japan. The completion of this work is the result of the encouragements and supports of numerous persons.

The author wishes to express his most propound gratitude and heartfelt thanks to Dr. Tomohiko Yoshida, for his invaluable advice, enthusiastic guidances and encouragements throughout the study.

The author would also like to express his deep appreciation to Prof. Dr. M. Fukuyama. Prof. Dr. A. Yoshimura and Dr. T. Furuya for their guidances and criticisms. The author thanks to Dr. T. Mochizuki and Dr, S .H. Zheng for their invaluable suggesting and supports during the study.

The special thanks are due to Prof. Dr. S . C. Lee and all members of Department of Agronomy, College of Agriculture, Kyongpuk National University, Korea for their constant supports and encouragement. Special thanks are also due to the Government of Kyongbuk Province and Agriculture Technical Administration, Taegu, Korea for allowing him to study in Japan.

The author cannot but thank all members of Crop Science Laboratory, Mr. Anas, Ms. A, Shigemune, Mr. H. Nakamoto, Mr. K. Takahashi, Dr. A.D.H. Totok, Dr. N.D. Can, Mr. S. Shimamura, Ms. M. Watarai and Mr. Y. Fukugawa, for their kindness, helps.

Appreciation is due to the Japanese Government and Kyushu University for providing a long-term financial supports throughout the course of this study. Appreciation is also due to the Fukuoka Agriculture Research Center for their providing invaluable materials and their cooperation.

The author want to express his deep appreciation to his parents, parents-in-low and other members of the family for their loves, encouragement and their constant trust in him. Finally, the author dedicates this work to his wife, Kim Jin Suk, two daughters, Hee Yun and Da yun, and his son, Kwang Yun, who always prayed for him and gave him loves, stimulation and thrust.

REFERENCES

Allard, R.W. and Bradshaw, A.D. 1964. Implications of genotype-environment interactions in applied plant breeding. Crop Sci. 4:503 - 508.

Alpi, A. and Beevers, H. 1983. Effect of O_2 concentration on rice seedlings. Plant Physiol. 71 :30- 34.

Amano, T., Tanaka, H. and Inoue, N. 1993. Varietal differences in seedling establishment of water-sown rice at cool temperature. Bull. Exp. Farm, Fac. Agr., Kyoto Pref. Univ. 16: 12- 21.

Arai, T., Inoue, N., lkeda, R.,Hirasawa, H., Ujihara, A. and Minami, M. 1999. Evaluation of screening methods for higher seedling establishment rate of direct-seeded rice on the soil surface in flooded paddy field. Jpn. J. Trop. Agr. 43:5 - 10.

Baba, T., Yamaguchi, O. and Furusho, M. 1998. Genotype x year interaction in yield and grain quality of malting barley. Jpn. J. Crop Sci. 67:5 10 - 5 15*.

Baker, R.J. 1988. Test for crossover genotype-environmental interaction. Can. J. Plant Sci. 68:405 -410.

Brim, C.A. and Cockerham, C.C. 1961 . Inheritance of quantitative characters in soybeans. Crop Sci. 18:533 -536.

Brown, K.D., Sorrells, M.E. and Coffman, W. R. 1983 A method for classification and evaluation of testing environments (Rice cultivar, genotype x environment interaction). Crop Sci. 23:889 - 893.

Can, N.D., Nakamura, S. and Yoshida, T. 1997 Combining ability and genotype x environment interaction in early maturing grain sorghum for summer seeding. Jpn. J. Crop Sci. 66:698 - 705.

Cassman, K.G., Peng, S., Olk, D.C., Ladha, J.K., Reichardt, W., Dobe.rmann, A. and Singh, U. 1998. Opportunities for increased nitrogen-use efficiency form improved resource management in irrigated rice system. Field Crop Res. 56:7 - 39.

Castillo, E. G., Buresh, R. J. and Ingram, K. T. 1992. Lowland rice yield as affected by timing of water deficit and nitrogen fertilization. Agron. J. 84: 152 - 159.

Comstock, R.E. and Robinson H.F. 1948. The components of genetic variance in populations of biparental progenies and their use in estimating the average degree of dominance. Biometrics. 4:254 - 266

Cornelius, P.L.,Van Sanford, D.A, and Seyedsadr, M.S. 1993. Clustering cultivars into groups without rank-change interactions. Crop Sci. 33: 1193 - 1200.

De Datta, S.K., Obcemea, W.N., Chen, R.Y., Calabio, J.C. and Evangelista, R.C. 1987. Effect of water depth on nitrogen efficiency and nitrogen- 15 balance in lowland rice. Agron. J. 79:210 - 216.

Dingkuhn, M., Sehnier, H.F., De Datta, S.K., Wijangco, E. and Dorffling, K. 1990. Diurnal and developmental changes in canopy gas exchange in relation to growth in transplanted and direct seeded flooded rice. Aust. J. Plant Physiol. 17: 119 - 134.

Donald, C. M. 1 968. The breeding of crop ideotypes. Euphytica 17:385 - 403.

Dore, J. and Thevan, P.V. 1959. Studies on seed germination and seedling growth in rice (*Oryza sativa*). Trop. Agric. Trin. 36: 15-34.

Falconer, D.S. 1967. Introduction to quantitative genetics. R. MacLahose and Co. Ltd., Glazgow, Ronald press, New York, 3rd edition. 1 - 365.

Fernandez, G.C.G. 1991. Analysis of genotype x environment interaction by stability estimates. Hort. Science 26:947 - 950.

Finfrook. D.C. and Miller,M.D. 1958 Establishing a rice stand California Univ. Agric. Exp. Stn. Ext. Ser. Leaflet 99.

Finlay, K.W. and Wilkinson,G.N. 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res. 14:742 -752.

Furuya, S., Kabaki, N. and Kojima, K. 1991. Effects of water management on growth and yield of rice with emphasis on deep water irrigation. Bull. Hokuriku Natl. Agric. Exp. Stn. 33:29-53.*

Gravois K.A. and McNew, R.W. 1993a. Combining ability and heterosis in U.S. southeen long-grain rice. Crop Sci. 33:83 - 86.

Gravois K. A. and McNew, R. W. 1993b. Genetic relationships among and selection for rice yield and yield components. Crop Sci. 33 : 249 - 252.

Gravois, K. A. and Helms, R. S. 1996. Seeding rate effects on rough rice yield, head rice, and total milled rice. Agron. J. 88 : 82- 84.

Hallauer, D.S. and Miranda, J.B. 1981. Quantitative genetics in maize breeding. Iowa State Univ. Press, Ames. 45 - 113.

Hanada, K. 1983. Growth of internodes, leaves and tillers of floating and non-floating rice varieties under deep-water conditions. Japan. J. Trop. Agr. 27:221 - 236.

Hanada, K. and Kagawa, K. 1985. Growth of tiller buds of a floating rice variety under deep-water with special reference to submergence of the subtending leaf sheaths. Jpn. J. Trop. Agr. 29:9 - 16.

Hasegawa, T., Kuroda, Y. Seligman, N.G. and Horie, T. 1994. Response of spikelet number to plant nitrogen concentration and dry weight in paddy rice. Agron. J. 86:673 - 676.

Hayman, B.I. 1958. The theory and analysis of diallel crosses. II. Genetics 43:64 - 85.

Imabayashi, S., Matsue, Y., Hamachi, Y. and Yoshida, T. 1997a. Genotype x environment interaction for early-maturing rice cultivars with high palatability in northern Kyushu. I. Yield. Jpn. J. Crop Sci. 66:538 - 544*.

Imabayashi, S., Matsue, Y., Hamachi, Y. and Yoshida, T. 1997b. Genotype x environment interaction for early-maturing rice cultivars with high palatability in northern Kyushu. II. Heading date and culm length. Jpn. J. Crop Sci. 66:545-550*.

Inoue, N., Amano, T. and Khoko, K. 1997. Seedling establishment of rice sown on soil surface in flooded paddy field. I. Varietal difference in seedling establishment. Jpn. J. Crop Sci. 66:632-639.

IRRI. 1972. Laboratory manual for physiological studies of rice. 11 - 12.

IRRI. 1993. IRRISTAT user's manual version 3/93. International Rice Research Institute, Los Banos, Philippines. 94 - 246.

IRRI. 1986. Program Report for 1985. International Rice Research Institute, Los Banos, Philippines. 8 - 10.

Jinks, J.L. 1955. A survey of the genetical basis of heterosis in a variety of diallel crosses. Heredity. 9:223 - 238.

Jones, D.B, and Peterson, M. L. 1976. Rice seedling vigor at suboptimal temperatures. Crop Sci. 16:102- 105.

Jones, J.W. 1933. Effect of reduced oxygen pressure on rice germination. J. Am. Soc. Agron. 25:69-81.

Juliano, B.O. 1971. A simplified assay for milled rice amylose. Cereal Sci. Today 16 : 334-360.

Kabaki, N. and Kon, T. 1991. Growth regulation in direct sowing cultivation of rice broadcasted in high density. Bull. Hokuriku Natl. Agric. Exp. Stn. 33:55 - 81*.

Kang,J.R., Ko,M.S., Kim,H.Y., Lim,S.J. and Kim,S.C. 1997. Genetic analysis of low temperature germinability of rice. Korean J. Crop Sci. 42:766 - 777.

Kawashima, C. and Murakami, T. 1985. An example of growth in deeply submerged paddy field. Tohoku Branch. Crop Sci. Soc. Jpn. 28:33 - 35**

Kim, J. K. and Vergara, B.S. 1990. Tillering behavior of low and high tillering rice. Korean J. Crop Sci. 35:5 12- 5 17.

Kim, J. K. and Vergara, B. S. 1991. A low tillering ideotype of rice plant for increasing grain yield potential. Korean J. Crop Sci. 36 : 134- 142.

Kordan, H.A. 1974a. The rice shoot in relation to oxygen supply and root growth in seedlings germination under water. New Phytol. 73:695-697.

Kordan, H.A. 1974b. Patterns of shoot and root growth in rice seedlings germinating under water. J. Appl. Ecol. 11:685-690.

Kordan, H.A. 1977. Latent effect of anaerobiosis on root growth in germinating rice seedlings. Plant Sci. Lett. 9:53-56.

Kujira, Y. 1991 . Methods and applications for measuring root systems by using seed pack growth pouch - Varietal differences of roots systems in rice plant at the early stage. Hokuriku Crop Sci. 26 : 31 - 34*.

Kuroda, S., Kato, H. and Ikeda, R. 1998. Heterosis and combining ability for callus growth rate in rice. Crop Sci. 38:933-936.

Lee, M.H., Oh,J.O.and Park, R.K. 1991. Lodging mechanisms and reducing damage of rice plant. Korean J. Crop Sci. 36:383 - 393.

Lee, M.H., Yun, Y.D. and Park, K.H. 1996. Present status of rice direct seeding technology in Korea. Japan-Korea seminar on direct-seeded rice. Japan IRC for Agr. Sci. and NARC. 1 - 10.

Lee, S.Y. 1995. Development of rice direct seeding cultivation in Korea. Korea and Japan Seminar in Direct Seeded Rice. 164- 185.

Lim, J.T., Kwon, B.S. and Jung,B.G. 1991 Relationship between lodging related characteristics and field lodging in rice. Korean J. Crop Sci. 36(4) : 319-323****.

Maguire, J. D. 1962. Speed of emergence-aid in selection and evaluation for seedling emergence and vigor. Crop Sci. 2: 176 - 177.

Mahajan, R.K.. and Rao, A.V. 1982. Regression analysis of genotype x environment interaction in rice. Indian J. Agric. Sci. 52: 14 - 16.

Maruyama, K. and Matsumura, O. 1996. Present status of direct seeded rice in Japan. Japan-Korea seminar on direct-seeded rice. Japan IRC for Agr. Sci. and NARC. 11 - 18 ***.

Matsue, Y., Mizuta, K. and Yoshida, T. 1991 . Varietal difference in palatability of stored rice. Jpn. J. Crop Sci. 60:537 - 542.

Matus, A., Slinkard, A.E. and Kessel,C.van 1997 Genotype x environment interaction for carbon isotope discrimination in spring wheat. Crop Sci. 37:97 -102 .

McKenzie, K. S., Rutger, J. N. and Peterson, M. L. 1980. Relation of seedling vigor to semidwarfism, early maturity, and pubescence in closely related rice lines. Crop Sci. 20: 169 - 172.

Mitsuishi,S. 1975. Study on the direct under-ground sowing in the submerging field of rice. Special Bull. Ishikawa Agr. College 4: 1 - 59.

Miyasaka,A. 1970. Studies on the strength of rice root..II. On the relationship between root strength and lodging. Proc. Crop Sci. Soc. Japan. 39:7 - 14.

Miyasaka, A. and Takaya, T. 1982. Prevention of lodging of rice plants under direct sowing culture on well-drained paddy field. I. Varietal differences in lodging resistance under dense sowing. Japan Jour. Crop Sci. 51:360- 368.

Murai,M. and Kinoshita,T. 1986. Diallel analysis of traits concerning yield in rice. Jpn. J. Breed. 36:7 - 15.

Nagai, I. 1916. Some studies on the germination of the seed of *Oryza sativa*. Jour. Col. Agr., Imp. Univ. Tokyo 3: 109 - 158.

Norman, R.J., Helms R.S. and Wells,B.R. 1992 Influence of delaying flood and preflood nitrogen application on dry-seeded rice. Fertil. Res. 32:55 - 59.

Ogata, T. and Matsue, Y. 1996 a. Studies on direct sowing culture of rice in Northern Kyushu. I. Evaluation of lodging tolerance. Jpn. J. Crop Sci. 65 : 87-92**.

Ogata, T. and Matsue, Y. 1996 b. Studies on direct sowing culture of rice in Northern Kyushu. II. Evaluation of lodging tolerance by crown root thickness during seedling stage. Jpn. J. Crop Sci. 65 : 502 - 508**.

Ohe, M., Goto,Y. and Hoshikawa, K. 1994. Effects of the deep water treatments on the emergence of tillers of rice plant. Jpn. J. Crop Sci. 63 :576 - 581.

Ohe, M., Tamura, A. and Mimoto, H. 1996. Effects of deep water treatment on the growth of culms and the lodging resistance in Japonica type paddy rice (*Oryza sativa* L.) cultivars. Jpn. J. Crop Sci. 65:238 - 244.*

Oosato, K.F., Hamachi, Y., Matsue, Y. and Yoshida, T. 1996. Genotype x environment interaction of palatability in rice. Jpn. J. Crop Sci. 65:585 - 589*.

Oosato, K. F., Hamachi, Y., Kawamura, Y. and Imabayashi, S. 1998. Selection for high palatability lines by amylose content adjusted by heading date for rice breeding. Jpn. J. Crop Sci. 67 : 36-40**.

Owen, P. C. 1971. The effects of temperature on the growth and development of rice. Field Crop Abstr. 24: 1 - 8.

Park, H. Y., Moon, H. P. and Choi, I. S. 1995. Breeding of rice varieties for direct seeding in Korea. Korea and Japan seminar on direct seeded rice. 143 - 156.

Park, S. H. and Lee, C. W. 1992. Development of direct seeded rice cultivation in the future. Korean J. Weed Sci. 12:292 - 308.

Peng, S.. Cassman, K.G, and Kropff, M.J. 1995. Relationship between leaf photosynthesis and nitrogen content of field-grown rice in the tropics. Crop Sci. 35: 1627 - 1630.

Peng. S., Garcia, F.V., Laza, R.C.. Sammon, M.L., Sanico, A.L., Visperas, R.M. and Cassman, K.G. 1996. Nitrogen use efficiency of irrigated tropical rice established by broadcast wet-seeding and transplanting. Fertil. Res. 45: 1 23 - 1 34.

Peterson, C.J., Moffatt, J.M. and Erickson, J.R. 1997. Yield stability of hybrid vs. pureline hard winter wheats in regional performance trials. Crop Sci. 37: 116 - 120.

Redona, E. D. and Mackill D.J. 1996 Genetic variation for seedling vigor traits in rice Crop Sci. 36:285 -290.

Redona, E. D. and Sebastian,L.S. 1996 Genotype x environment interaction analysis in national irrigated lowland rice yield trials. Philippines J. Crop Sci. 21 :3.

Saka,N. and Izawa,T. 1900. Varietal differences in the survival rate of sprouting rice seed (*Oryza sativa* L.) under highly reduced soil conditions. Plant Prod. Sci. 2: 136 - 137.

Sasaki, T. 1 926. Abnormal germination of low-land rice seeds under the limitation of air supply. Report Agr. Sci. Soc. 288:461 -469*.

Sayre, K.D., Rajaram. S. and Fischer. R.A. 1997. Yield potential progress in short wheats in northwest Mexico. Crop Sci. 37:36 -42

Schnier, H.F., Dingkuhn, M., De Datt,S.K., Mengel, K. and Faronilo, J.E. 1990. Nitrogen fertilization of direct-seeded flooded vs . transplanted rice : I. Nitrogen uptake, photosynthesis, growth, and yield. Crop Sci. 30: 1276 - 1284.

Seko, H. 1954. Lodging in rice plant and its testing method. A separate volume of the Japanese Journal of Breeding. Vol. 4. Studies on rice breeding. 185 - 198.

Seko, H. 1962. Studies on lodging in rice plants. Bull. Kyushu Agic. Exp. Stn.7:419-499*.

Takahashi, N, 1978. Adaptive importance of mesocotyl and coleoptile growth in rice under different moisture regimes. Aust. J. Plant Physiol. 5 :511 - 517.

Terashima, K., Akita,S. and Sakai,N. 1992. Eco-physiological characteristics related with lodging tolerance of rice in direct sowing cultivation. I. Comparison of the root lodging tolerance among cultivars by the measurement of pushing resistance. Jpn. J. Crop Sci. 61 :380- 387.

Terashima, K., Akita, S. and Sakai, N. 1995. Eco-physiological characteristics related with lodging tolerance of rice in direct sowing cultivation. III. Relationship between the characteristics of root distribution in the soil and lodging tolerance.

Jpn. J Crop Sci. 64 243 - 250.

Turner, F.T., Chen,C.C. and McCauley,G.N. 1981. Morphological development of rice seedlings in water at controlled oxygen levels. Agron. J. 73:566-570.

Vasal,S.K., Srinivasan,G., Pandey,S., Gonzalez,C.F., Crossa,J. and Beck,D.L. 1993a. Heterosis and combining ability of CIMMYT's quality protein maize germplasm: I. Lowland tropical. Crop Sci. 33:46 - 51.

Vasal, S.K., Srinivasan, G., Gonzalez,C.F., Beck,D.L. and Crossa,J. 1993b Heterosis and combining ability of CIMMYT's quality protein maize germplasm: I. Subtropical. Crop Sci. 33:46 - 51.

Vlek, P.L.G., Hong, C.W. and Youngdahl, L.J. 1979. An analysis of N nutrition on yield and yield components for the improvement of rice fertilization in Korea. Agron. J. 71 :829 - 833.

Wang, Y., Kuroda, E., Hirano, M. and Murata, T. 1997. Analysis of high yielding mechanism of rice varieties belonging to different plant types. Jpn. J. Crop Sci. 66 : 293 -299.

Wells, B.R. and Faw, W.F. 1978. Short-statured rice response to seeding and N-rate. Agron. J. 70:477 -480.

Westcott, M.P., Brandon, D.M.. Lindau, C.W., and Patrlck,W.H.Jr. 1986. Effects of seeding method and time of fertilization on urea-nitrogen- 15 recovery in rice. Agron. J. 78:474 -478.

Won, J.G., Lee, W. H., Choi, C. D., Kim, C. R. and Choi, B. S. 1996. Growth characteristics and yield of hill-seeded rice in direct seeding. Korea RDA. J. Agric. Sci. 38:49-55***

Won, J. G., Choi,C.D., Lee,W.H., Kim,C.R. and Lee,S.C. 1997. Influence of deep continuous flooding on rice growth and yield in dry-seeded paddy field. Korean J. Crop Sci. 42: 166- 172****.

Won,J.G., Hirahara,Y. and Yoshida,T. 1998a. Selection of cultivars for direct seeding in rice based on the development of root system analysis. J. Fac. Agr., Kyushu Univ. 43:3 1 - 37.

Won,J.G., Hirahara,Y., Yoshida,T. and Iabayashi,S. 1998b. Selection of rice lines using SPGP seedling method for direct-seeding. Plant Prod. Sci. 1 :280 - 285.

Won, J.G. and Yoshida,T. 1999a Selection of rice cultivars for wet and dry direct-seeding. Proc. Int. Symp. - World Food Security -, Kyoto: 265-268.

Won, J.G., Choi, C.D. and Lee, S.C. 1999b. Interaction between N application and water management in dry-seeded rice. Plant Prod. Sci. 2: 109 - 114.

Won, J.G., Choi, C.D. and Lee, S.C, 1999c. Tillering, lodging and yield under deep water treatment in direct-seeded rice. Plant Prod. Sci . 2:200 - 205 .

Won,J.G., Yoshida,T. and Uchimura,Y. 1999d. Genotype-environment interactions of selected rice lines in direct water-seeded culture. Plant Prod. Sci. 2:252 - 257.

Won, J.G. and Yoshida, T. 2000. Screening cultivars under low dissolved oxygen level for water-seeded rice. Plant Prod. Sci. 3 (in printing).

Won, J.G. and Yoshida. T. Varietal differences on seedling traits under low dissolved oxygen level in water-seeded rice. Plant Prod. Sci. (submitted).

Won, J.G. and Yoshida, T. Combining ability and heteosis in the selected lines for direct-seeded rice. Plant Prod. Sci. (submitted).

Xu, Y.B, and Shen, Z.T. 1991 . Diallel analysis of tiller number at different growth stages in rice (*Oryza sativa* L.). Theor. Appl. Genet. 83:243 - 249.

Yamada, N. 1952. Calcium peroxide as an oxygen supplier for crop plant. Proc. Crop Sci. Soc. Jpn. 21:65 - 66**.

Yamauchi,M. 1999. Stabilization of rice seedling establishment in wet direct sowing in temperate and tropical regions with emphasis on anaerobic seedling growth. Proc. Int. Symp. -World food security-, Kyoto: 261 - 264.

Yoshida,S. and Parao,F.T. 1972. Performance of improved rice varieties in the tropics with special reference to tillering capacity. Exp. Agric. 8:203 - 212.

Yoshinaga,S., Shimotsubo,S., and Togashi,T. 1997. Studies on the submerged direct seeding rice combined puddling with seeding operation. 3. Growth of the hill seeded rice plant. Jpn. J. Crop Sci. (Extra 1) 66:7 - 8.

* In Japanese.

** In Japanese with English abstract or summary.

*** Translated from Japanese by the author.

**** In Korean with English abstract or summary.