Korean J. Crop Sci. 44(4) : 309~315(1999)

Evaluation of Root Characters Associated with Lodging Tolerance by Seedling Test in Rice

Si-Yong Kang*†, Won-Ha Yang**, and Hyun-Tak Shin***

ABSTRACT

Rice seedling test was conducted to check the lodging tolerance at ripening stage through evaluating the root characters. Thirteen Korean and foreign rice cultivars with direct seeding adaptable or high quality characteristics were grown in a cell pot and under submerged paddy. The root characters and pushing resistance of rice hill were determined at seedling and ripening stage, respectively. The diameter of crown root at the 7th and 8th leaf stages was thicker in lodging tolerance cultivars than those of others and showed significant-positive correlation with both pushing resistance and crown root diameter of mature plants. Also, the tensile strength of crown root at the 7th and 8th leaf stage showed highly positive correlation with the tensile strength of crown root of mature plants. The number of crown root at 7th leaf stage was significant-positively correlated with that of mature plant. The diameter of seminal root was not significantly correlated with the diameter of crown root throughout the whole growth stage. These results indicate that the diameter, tensile strength and number of crown root associated with root lodging tolerance can be detected with the seedling at about 7th or 8th leaf stage, and the seedling test using the cell pot is an useful and practical method to select lodging tolerant cultivars or lines of rice based on root characters, especially diameter of crown root.

Keywords: direct seeding cultivar, lodging tolerance, rice, root, root diameter, seedling test.

Water direct seeding of rice on the flooded surface of soil is considered as one of most effective culture methods for labor saving and weed control in Korea. In direct seeded rice on flooded surface, however, the lodging is frequently observed and considered to be one of the serious problems. In particular, the rice lodging occurred in ripening stage reduced the yield and quality of rice (Lee et al., 1993). In order to stabilize the productivity of the water direct seeding of rice on the flooded surface, the development of rice cultivars having high lodging tolerance is necessary. The root characters of rice related to root lodging have been reported as the diameter, number, and tensile strength of crown roots, and root distribution rate in deep soil layer, etc. (Kim et al., 1995a, b; Terashima, 1997; Kang et al., 1998; Lim et al., 1991).

In the process of rice breeding, the degree of lodging tolerance was usually evaluated by either the field surveying or the investigation of lodging related to shoot characters at ripening stage. Since the determination of root characters for the grown rice on field at ripening stage is laborious and time-consuming, it is necessary to develop a rapid method for evaluation of the root characteristics of cultivars or lines. In the previous study (Kang & Yang, 1998), we suggested that the rooting characteristics of crown roots of rice including the growth direction formed at mid-late growth stage and related to their lodging tolerance can be effectively evaluated using the water culture method of a leaf-stem cuttings which coincided with 7th to 9th dethached phytomers. However, this method also requires a long period and some skills for preparing and water-culturing of a leaf-stem cuttings. Therefore, in order to improve the rice breeding efficiency for selection of lodging tolerance genotypes, the establishment of methods to measure and evaluate the root characters of many genotypes quickly and efficiently at early growth stage of rice in the indoor condition will be quite required. If the evaluation of lodging related root characters might be possible during the rice seedling, only the selected promising lines or cultivars could be moved to the field trial. In general, the evaluation of lodging related characters of seedlings has been done mainly in upland crops, such as corn (Arihara & Crosbie, 1982; Nass & Zuber, 1971; Stamp & Kiel, 1992) and wheat (Oyanagi et al., 1993), but not yet sufficient in rice (Ogata & Matsue, 1996; Won et al., 1998).

The objective of this study was to clarify the possibility of seedling test on determining the root characters related with field lodging or root anchorage ability, i.e., diameter, tensile strength and number of crown roots.

* Region. Res. Cent. for Subtrop. Hort., Cheju Nat'l Univ., Cheju 690-756., Korea. ** Nat'l Crop Exp. Sta. RDA, Suwon, Kyonggi 441-100, Korea. *** Nat'l Honam Agri. Exp. Sta., RDA, Iksan, Chonbuk 570-080, Korea. †Corresponding author: (E-mail) kangsyong@hanimail.com (Phone)+82-64-754- 2317.
Received 14 Sep., 1999.

MATERIALS AND METHODS

Plant materials

Total 13 rice (*Oryza sativa* L.) cultivars were used for cell pot and field trial in this study, namely 9 Korean cultviars of both 7 Japonica type (Dongjinbyeo, Hwaseongbyeo, Juanbyeo, Ansanbyeo, Donganbyeo, Daesanbyeo and Iksan 425) and 2 hybrid type of Indica × Japonica (Nonganbyeo and Dasanbyeo), 3 USA cultivars (S-201, Lemont and M-202), and a Japanese cultivar (Kanto 165). The 5 Korean cultivars of Juanbyeo, Ansanbyeo, Donganbyeo, Daesanbyeo and Nonganbyeo, and 4 foreign ones were bred as the adaptable cultivars of the direct seeding. These cultivars showed differences in characteristics of lodging tolerance and rooting habit each other (Kang et al., 1998; Kang & Yang, 1998).

Seedling test using a cell pot

The evaluation of root characters of seedling was done using a rice cell pot (62.0 × 31.5 × 2.5 cm, W ×L×H, 448 cells per pot) used for raising the mature seedling. Upon sterilization with mixed solution of Prochloraz and Fenthion, the rice seeds of 13 cultivars were pregerminated in an incubator under 31℃ for 2 days. On April 15, 1997, a rice seed per cell was planted on the pots which were previously filled with a commercial rice nursery soil (NPKO, Poongnong Co., Korea) containing chemical fertilizers and organic matters. Two pots per cultivar were randomly placed on the bed of water growing in a greenhouse, which filled with shallow water (2 cm in depth) to sustain water supply from bottom hole of cell. The air temperature of the greenhouse was maintained with 30 ± 5℃ and 25 ± 3℃ for day and night, respectively.

The measurement of root characters of rice seedlings was done two times at the 5th leaf stage that was coincided at 17th day after seeding (DAS) and the 7th leaf stage (30 DAS). Forty plants of each cultivar (two replications of 20 plants per pot) were randomly selected, and then roots were washed out. After counting the crown roots of seedlings, longer than 1cm in length, the longest and shortest diameter of both seminal and crown roots was measured at 1cm region from each base of root axes using a stereoscopic microscope. Using the seedlings at the 7th leaf stage, the tensile strength of a crown root axis was measured. The crown root axis at 2.5 cm region from root base was hooked with a metal hook attached to a force gage (FGX-5R, Shimpo Co., Japan) and the two axes were gripped behind 1 cm region with the thumb and forefinger. And the hand grasped root was slowly pulled until cutting of root and the maximum resistance weight was recorded.

Field trial

On May 15, 1997, the pregerminated seeds of the 13 cultivars, using for the seedling test, were directly hand-hill-seeded on the surface of flooded paddy field, silty loam soil, of the experimental field of National Honam Agricultural Experiment Station (NHAES), Rural Development Administration (RDA), Korea. The plot size was 10 m long and 1.8 m wide with 6 rows (row distance: 30 cm, hill distance: 15 cm) and there were two replications. Nitrogen fertilizer of 110 kg N ha^{-1} was seperately applied at the rate of 40-30-30% at seeding, tillering, and panicle formation stage, respectively. Phosphorus fertilizer of 70 kg P_2O_5 ha^{-1} was totally applied before seeding. Potassium fertilizer of 80 kg K_2O ha^{-1} was applied at split rate of 70-30% at seeding and panicle formation stage, respectively. The seedlings were thinned to 2 plants per hill at 25 DAS. Other cultural practices were followed the standard method of NHAES.

At 8th leaf stage (35 DAS) of rice plants, ten plants per plot were sampled with the soil of 10 cm width and depth. After washing out the soil from the roots, the number, diameter and tensile strength of crown roots of seedlings were measured by the same method done in the cell pot experiment.

At 10th day after heading, three hills of each cultivar with average stem number were selected and then a plastic cylinder (15 cm in diameter and 30 cm in height) was inserted vertically into soil at the center of the rice hill to cut crown roots in soil *in situ*. Soil monolith with plant was drug out and then root system was washed out. To determine the diameter and number of roots, 30 axes of crown root per hill were randomly selected between the 2nd to 4th nodes formed from the highest rooting node of main stem and primary tillers of each cultivar. The diameter of a crown root was averaged at 2 cm region from the base of root axes upon measuring the longest and the shortest diameter using a stereoscopic microscope. The tensile strength of a crown root axis was measured by the same method done in the seedling test. Finally, elongated total crown roots longer than 1 cm in length were counted for three hills of each cultivar.

The measurement of pushing resistance was done to 10 rice hills per plot at 20th day after heading of each cultivar. Firstly, the rice hill was counted for stem number and was then banded at 20 cm height from soil surface with vinyl tape. A steel adaptor of 'Y' shape with 15 cm in length and 10 cm in width which connected to the force gage (FGX-5R, Shimpo Co., Japan) was touched at banding part of rice hill and horizontally pushed. The pushing resistance was defined as maximum resistance value during inclination

of shoot to 45° toward the vertical direction. Prior to the measurement, neighbor hills were pushed out to exclude the interference, and the pushing of rice hill was always to row direction. To reduce the experimental errors influenced by soil hardness among the field sites and measuring times, the field was maintained to the irrigated condition with 2 cm in depth during the measuring.

The field lodging was surveyed at 40th day after heading following the standard method of RDA with the scale of 0 (none) to 9 (severe lodging).

RESULTS AND DISCUSSION

Table 1 shows the heading date, number of culm, root characters, pushing resistance and lodging degree of 13 rice cultivars examined from the field trial. Average culm number per hill showed relatively higher in S-201, Hwaseongbyeo, Iksan 425, and Kanto 165 than those in Nonganbyeo, Dasanbyeo and Daesanbyeo. Those cultivars with fewer culm number showed higher pushing resistance and lower field lodging compared to those with higher culm number. Diameter of crown root was significantly larger in Lemont, Nonganbyeo, M-202 and Daesanbyeo than did other cultivars. Lemont had the strongest tensile strength of crown root. Next strongest cultivars were M-202, Daesanbyeo and S-201. On the other hand, cultivars of Ansanbyeo, Juanbyeo, Kanto 165 and Hwaseongbyeo had weak tensile strength of crown root. The number of crown root was significantly lower in Lemont, but significantly higher in Juanbyeo and Iksan 425, compared with others. The pushing resistance per hill was relatively higher in Daesanbyoe, Lemont, Iksan 425, Donganbyeo and Nonganbyeo, while relatively lower in Hwaseongbyeo, Kanto 165 and Ansanbyeo.

Root characters measured at the 5th and 7th leaf stage in cell pot are shown in Table 2 and Table 3, respectively. The diameters of crown root at both stages were thicker in Lemont, Nonganbyeo, Daesanbyeo and M-202, while thinner in Hwaseongbyeo, Donganbyeo, Dasanbyeo and Dongjinbyeo. That measured at the 8th leaf stage in the field trial also showed a similar tendency of cultivar differences (Table 4). The crown root diameters of the seedlings showed significant-positive correlations with that of mature plant. The correlation coefficients were highest at the 7th leaf stage ($r = 0.763^{**}$) followed by the 8th ($r = 0.775^{**}$) and the 5th leaf stages ($r = 0.551^{*}$) (Fig. 1). And the diameter of crown root also had significant positive correlation with pushing resistance of rice hill measured at ripening stage, which showed higher at the 7th ($r = 0.546^{*}$) and 8th ($r = 0.544^{**}$) leaf stages than the 5th ones ($r = 0.467$ns) (Fig. 1).

The tensile strength per crown root of seedlings at the 7th and 8th leaf stages showed highly significant-positive correlations with those at ripening stages (Fig. 2). However, the tensile strength at the 7th and 8th leaf stage of seedling was not significantly correlated with the pushing resistance of rice hill at ripening stage.

Previously, we reported that the field lodging and pushing resistance at ripening stage were closely related with the diameter and tensile strength of

Table 1. Heading date, number of culm, characters of crown roots of mature plant, pushing resistance and field lodging degree of 13 rice cultivars cultured by water direct hill seeded on flooded surface of paddy field.

Cultivar†	Heading date	No. of culm (panicle) per hill	Diameter of crown root (μm)	Tensile strength (g/root)	No. of crown root per hill	Pushing resistance (g/hill)	Field lodging (0~9)
1. Dongjinbyeo	Aug. 19	13.5 bcd	914 b	539 c-f	882 ab	1174 cde	5
2. Hwaseongbyeo	Aug. 10	16.1 ab	859 b	480 def	923 ab	920 e	7
3. Nonganbyeo	Aug. 13	11.3 d	1102 a	569 b-e	778 ab	1450 a-d	1
4. Juanbyeo	Aug. 12	14.4 a-d	866 b	425 f	1101 a	1185 cde	1
5. Ansanbyeo	Aug. 8	14.3 a-d	904 b	419 f	667 ab	1049 e	3
6. Donganbyeo	Aug. 18	14.5 a-d	927 b	585 bcd	1002 ab	1455 a-d	1
7. Daesanbyeo	Aug. 21	12.3 cd	1060 a	644 bc	871 ab	1604 a	0
8. Iksan 425	Aug. 16	15.4 abc	934 b	521 c-f	1047 a	1527 abc	0
9. Dasanbyeo	Aug. 20	11.3 d	919 b	498 def	1024 ab	1248 a-e	0
10. S-201	Aug. 5	17.0 a	834 b	602 bcd	878 ab	1119 de	5
11. Lemont	Aug. 17	13.1 bcd	1155 a	1048 a	605 b	1581 ab	0
12. M-202	Aug. 2	13.8 a-d	1084 a	691 b	742 ab	1229 a-e	1
13. Kanto 165	Aug. 11	15.3 abc	931 b	475 def	681 ab	927 e	5

† 1, 2: High quality cultivars (Japonica), 3~8: direct seeding adapting cultivars bred in Korea (3: Indica×Japonica hybrid, others: Japonica), 9: high yielding cultivar as indica×japonica hybrid, 10~12: direct seeding cultivars from USA, 13: direct seeding cultivar from Japan. Means with the same letters within columns are not significantly different at $P < 0.05$ (DMRT).

Table 2. Characters of rice seedling root at 5th leaf stage grown with a cell pot and their correlation coefficient with pushing resistance at ripening stage.

Cultivar	Leaf age	No. of crown root	Diameter of seminal root (μm)	Diameter of crown root (μm)	Root dry weight (mg/10 plant)
Dongjinbyeo	4.3 ab	10.1 cde	612 a-e	614 bc	100
Hwaseongbyeo	4.3 ab	8.2 fg	580 c-f	571 d	65
Nonganbyeo	4.2 bc	9.6 c-f	535 f	620 bc	75
Juanbyeo	4.4 a	9.4 def	667 a	614 bc	85
Ansanbyeo	4.3 ab	10.8 bcd	563 ef	631 b	55
Donganbyeo	4.4 a	11.1 bc	575 def	593 bcd	65
Daesanbyeo	4.4 a	9.0 ef	590 b-f	601 bcd	80
Iksan 425	4.2 bc	9.7 c-f	662 a	618 bc	80
Dasanbyeo	4.1 cd	15.7 a	602 a-f	591 cd	85
S-201	4.1 cd	12.0 b	646 abc	630 b	90
Lemont	3.3 e	7.0 g	633 a-d	680 a	95
M-202	4.0 d	10.7 bcd	649 ab	625 bc	115
Kanto 165	4.0 d	10.5 b-e	617 a-e	570 d	105
Correlation coefficient with pushing resistance at ripening stage	-	-0.222	0.006	0.467	-0.042

Means with same letters within columns are not significantly different at P<0.05 (DMRT).

Table 3. Characters of rice seedling root at the 7th leaf stage grown with a cell pot and their correlation coefficient with pushing resistance at ripening stage.

Cultivar	Leaf age	Crown root		
		No. per plant	Diameter (μm)	Tensile strength (g/root)
Dongjinbyeo	6.2 bcd	20.2 bcd	603 e	152 d
Hwaseongbyeo	6.5 a	17.6 de	551 f	151 d
Nonganbyeo	6.5 a	17.5 de	721 b	220 bc
Juanbyeo	6.5 a	21.9 b	664 c	157 d
Ansanbyeo	6.4 ab	18.3 cde	634 d	233 b
Donganbyeo	6.5 a	21.4 b	608 de	161 d
Daesanbyeo	6.2 bcd	16.6 ef	680 c	207 bcd
Iksan 425	6.1 cd	20.6 bc	608 de	188 bcd
Dasanbyeo	6.3 abc	24.9 a	624 de	205 bcd
S-201	6.1 cd	22.4 ab	664 c	193 bcd
Lemont	5.1 e	14.6 f	916 a	367 a
M-202	6.0 d	19.8 bcd	684 c	172 cd
Kanto 165	6.0 d	20.1 bcd	616 de	152 d
Correlation coefficient with pushing resistance at ripening stage	-	-0.297	0.546*	0.507

Means with same letters within columns are not significantly different at P<0.05 (DMRT).

*: Significant at P<0.05.

crown roots of mature plant (Kang et al., 1998). Other researchers also reported the significant relationships among anchoring ability or field lodging of rice cultivars and their root diameter (Kim et al., 1995a; Terashima, 1997; Ogata & Matsue, 1996; Won et al., 1998), and root tensile strength (Miyasaka, 1970) of seedling or mature plant. The diameter of crown roots of rice at seedling stage showed some varietal variation (Haga et al., 1977; Takita & Kushibuchi, 1983; Terashima et al., 1987).

Such results of this and previous studies indicate that the diameter and the tensile strength of crown roots which developed at mid-late growth stage and importantly contributed to the lodging tolerance could

Table 4. Characters of seedling root at the 8th leaf stage grown under submerged paddy field and their correlation coefficient with pushing resistance at ripening stage.

Cultivars	Leaf age	No. of tiller	Crown root		
			No. per plant	Diameter (μm)	Tensile strength (g/root)
Dongjinbyeo	7.7 ab	4.1 a	28.1 abc	732 e	278 def
Hwaseongbyeo	7.5 abc	3.4 ab	28.5 abc	712 e	271 ef
Nonganbyeo	7.5 abc	3.1 ab	21.1 bcd	823 bcd	351 bcd
Juanbyeo	7.9 ab	4.0 a	30.4 a	743 de	273 def
Ansanbyeo	7.7 ab	3.7 ab	28.8 ab	761 cde	282 c-f
Donganbyeo	8.0 a	3.8 ab	27.3 abc	762 cde	336 b-e
Daesanbyeo	7.4 bc	3.6 ab	20.5 cd	841 bc	294 b-f
Iksan 425	7.9 ab	3.7 ab	22.9 a-d	794 b-e	246 f
Dasanbyeo	7.7 ab	3.7 ab	30.8 a	717 e	259 ef
S-201	7.7 ab	3.6 ab	27.0 abc	830 bcd	359 bc
Lemont	7.0 c	3.1 ab	15.2 d	969 a	552 a
M-202	7.5 abc	2.5 b	23.0 a-d	872 b	371 b
Kanto 165	7.8 abc	4.0 a	28.3 abc	787 b-e	283 c-f
Correlation coefficient with pushing resistance at ripening stage	-	-	-0.728**	0.544*	0.392

Means with same letters within columns are not significantly different at P<0.05 (DMRT).

*: Significant at P<0.05, **: Significant at P<0.01.

be evaluated with crown roots of seedling. The correlation coefficients of crown roots between seedlings and ripening stages were lower at the 5th leaf stage ($r = 0.551^{*}$) than the 7th leaf stage ($r = 0.763^{**}$). This might be due to the fact that most crown roots of rice plant at the 5th leaf stage should be formed at coleoptile and first node on main stem, and cultivar difference on diameter of crown roots was not clear at such early stage (Watanabe & Takahashi, 1997).

The primary roots of a mature rice plant consist of a seminal root and several hundreds of crown roots (Abe & Morita, 1994). The diameter of seminal root was not significantly related to diameter of crown root at any stage (Table 5), which means that it is impossible to characterize the cultivar difference of crown roots through measuring the seminal root.

Based on path coefficient analysis of pushing resistance in rice, our previous study (Kang et al., 1998) indicated that the number of crown root per hill is secondarily important contributor following diameter of crown root, although the correlation analysis was not significant. The crown root number of seedling was higher in Dasanbyeo, S-201, and Donganbyeo, but lower in Lemont, Daesanbyeo,

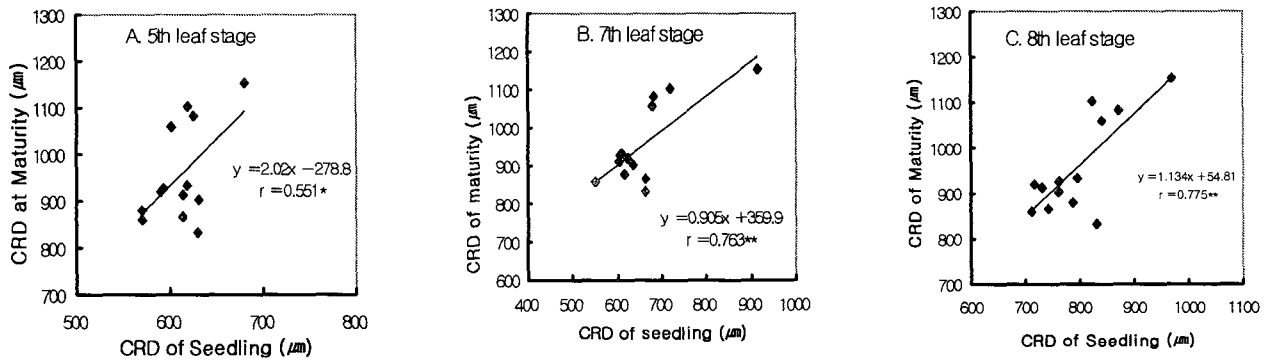

Fig. 1. Scatter diagrams of relationship of crown root diameter (CRD) between seedling stages and heading stage grown under field condition, the 5th leaf stage (A), and the 7th leaf stage grown with a cell pot (B) and the 8th leaf stage grown under paddy field (C). *: Significant at P<0.05, **: Significant at P<0.01.

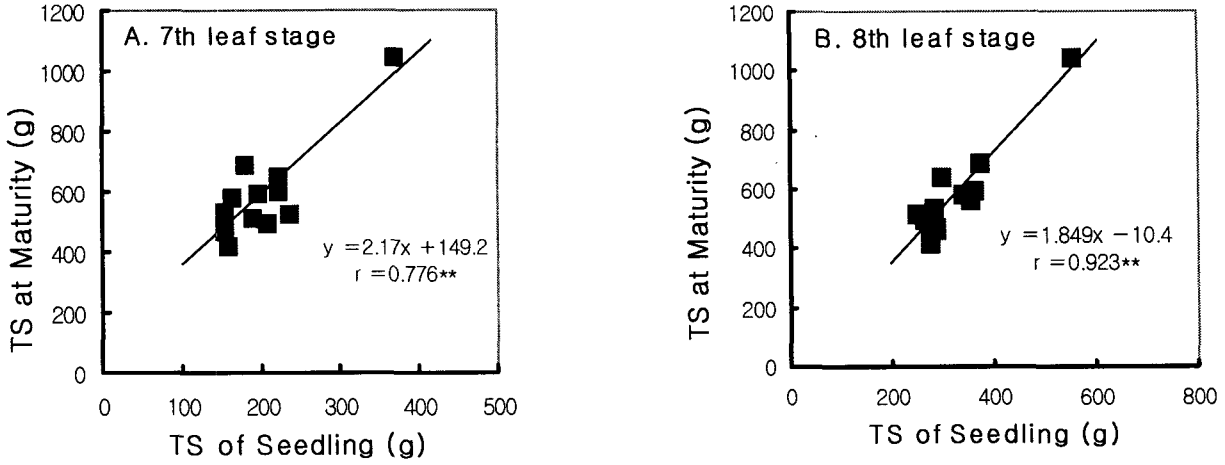

Fig. 2. Scatter diagrams of relationship on tensile strength (TS) of crown root between seedling stages and heading stage, the 7th leaf stage grown with cell pot (A), and the 8th leaf stage grown under paddy field (B). **: Significant at P<0.01.

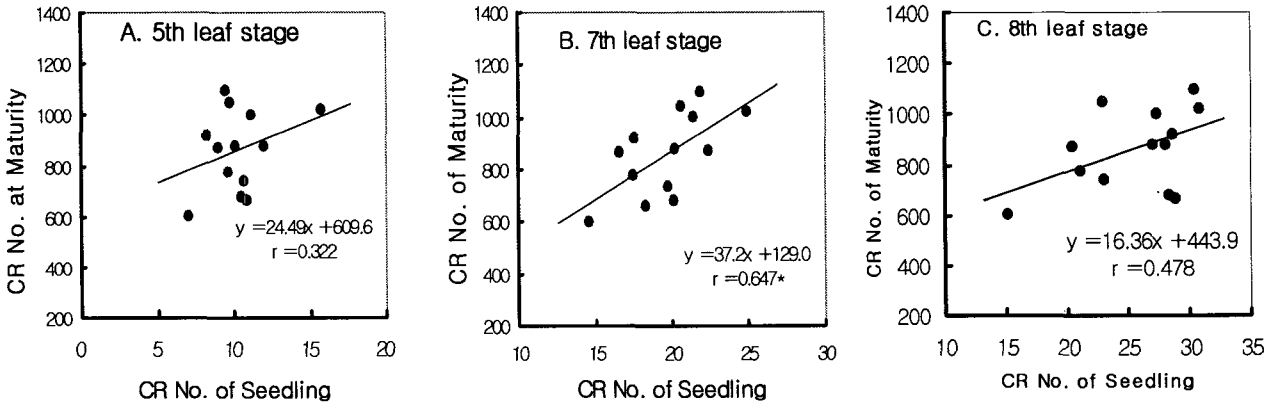

Fig. 3. Scatter diagrams of relationships on crown root number (CR No.) between seedling stages and heading stage, the 5th leaf stage (A) and the 7th leaf stage grown with cell pot (B), and the 8th leaf stage grown under paddy field (C). *: Significant at P<0.05.

Table 5. Correlation coefficients between diameters of a seminal and crown roots of each stage.

	Diameter of crown root at			
	5th leaf stage in cell pot	7th leaf stage in cell pot	8th leaf stage in field	heading stage in field
Diameter of seminal root in cell pot	0.257 ns	0.134 ns	0.295 ns	-0.157 ns

ns: Not significant at 5% level.

Nonganbyeo and Hwaseongbyeo. And the root number of seedlings was positively correlated with that of mature plant, while significant relationship (r=0.647*) was showed only at the 7th leaf stage grown in cell pot (Fig. 3). However, a negative correlation was observed between crown root number of seedlings and pushing resistance in field trial, especially significant relationship at 8th leaf stage in field (Table 2, 3, 4). These results imply that the rice cultivars with high pushing resistance showed a tendency of having thick and small number of crown root.

REFERENCES

Abe, J. and S. Morita. 1994. Growth direction of nodal roots in rice: its variation and contribution to root system formation. Plant and Soil 165:333-337.

Arihara, J. and R. M. Crosbie. 1982. Relationships among seedling and mature root system traits of maize. Crop Sci. 22:1197-1202.

Haga, M., T. Kaomura, M. Takamatsu, and I. Shaku. 1977. Research for the breeding of suitable varieties to direct seeding cultivation. 1. Root lodging tolerance in direct seeded rice cultivar to submerged field. Res. Bull. Aichi Agric. Res. Cent. A9:13-23.

Kang, S. Y., W. H. Yang, H. T. Shin, and S. Y. Cho. 1998. Searching for root characters and their evaluation method associated with root lodging in direct seeding adapting rice cultivars. 1. Characteristics of shoot and root characters of direct seeded rice on flooded paddy surface at ripening stage and their relation to lodging resistance. RDA. J. Agri. Sci. (Post Doc.) 40:95-106.

Kang, S. Y. and W. H. Yang. 1998. Evaluation of root chatacteristics related with lodging tolerance using leaf-stem cutting method in rice. Korean J. Breed. 30:361-368.

Kim, B. K., J. I. Chong, H. T. Shin, and S. Y. Lee. 1995a. Relationship between root characters and lodging resistance of rice in direct seeding on flooded paddy surface. Korean J. Breed. 27:276-283.

Kim, J. K., J. I. Lee, K. H. Park, and M. H. Lee. 1995b. Characteristics of the rice plant associated with lodging highly adapted in broadcast-seeded cultivation. RDA. J. Agri. Sci. 37:20-28.

Lee, S. Y., S. S. Kim, M. G. Choi and S. J. Seok. 1993. Direct seeding culture of rice in Honam region of Korea. *In* Crop Production and Improvement Technology in Asia. KSCS, Korea. pp. 39-55.

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

Miyasaka, A. 1970. Studies on the strength of rice. 2. On the relationship between root strength and lodging. Proc. Crop Sci. Soc. Jpn. 39:7-14.

Nass, H. G. and M. S. Zuber. 1971. Correlation of corn (*Zea mays* L.) roots early in development to mature root development. Crop Sci. 11:655-658.

Ogata, T. and Y. Matsue. 1996. 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.

Oyanagi, A., T. Nakamoto, and M. Wada. 1993. Relationship between root growth angle of seedlings and vertical distribution of roots in the field in wheat cultivars. Jpn. J. Crop Sci. 62:565-570.

Stamp, P. and C. Kiel. 1992. Seedling traits of maize as indicators of root lodging. Agronomie 12:157-162.

Takita, T. and K. Kushibuchi. 1983. Meaning of root thickness selection and its method in rice breeding for direct seeding. Bull. Nat'l. Agric. Res. Cent. 1:1-8.

Terashima, K., H. Hiraoka, and I. Nishiyama. 1987. Varietal difference on rice root. 1. Morphology of crown roots. Jpn. J. Crop Sci. 56:521-529.

Terashima, K. 1997. Eco-physiological study of root lodging tolerance in direct-seeded rice cultivars. JARQ 31:155-162.

Watanabe, H. and K. Takahashi. 1997. Morphological observation of the rice cultivar with six coleoptilar node roots. Jpn. J. Crop Sci. 66:507-508.

Won, J. G., Y. Hirahara, T. Yoshida, and S. Imabayashi. 1998. Selection of rice lines using SPGP seedling method for direct seeding. Plant Prod. Sci. 1(4):280-285.