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Comparison of Yield and Growth Characteristics of Korean High Yielding Cultivars and IRRI's New Plant Type Rice Line

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ABSTRACT

Yield and growth characteristics were compared for five rice cultivars; a new Tongil-type, so called "super-rice", Dasanbyeo, an old Tongil-type Milyang 23, two *japonicas* Dongjinbyeo and Ilpumbyeo, and a new plant type (NPT) line IR65600-27-1-2. The objective of this study was to clarify the high yielding capacity of Dasanbyeo in terms of growth characteristics. The average grain yield (9 t/ha) of Dasanbyeo was higher than that of Milyang 23 by ca. 9%, that of *japonicas* by 20 to 30%, and that of NPT line by ca. 100%. The higher grain yield of Dasanbyeo was attributable not only to the greater dry matter production but also to the higher harvest index (HI). Dasanbyeo showed the greatest dry matter at harvest owing not only to the rapid leaf expansion at early growth stage and the resulting high LAI through the entire growth stage but also to the high NAR despite the high LAI. The rapid leaf expansion of Dasanbyeo at early growth stage seemed to be related in part to the profuse tillering capacity. HI was 0.53 in Dasanbyeo, 0.51 in Milyang 23, 0.41 in *japonicas*, and 0.35 in NPT line. Dasanbyeo was indebted for its higher HI to the relatively high grain filling ratio in spite of a much greater sink size than the other cultivars. Dasan had a greater source to sink ratio during grain ripening as measured by LAD/spikelet and dry matter production/spikelet which showed positive correlations with the grain ripening ratio. New plant type (NPT) line showed the lowest grain yield owing to the small sink size and the low grain filling ratio which seemed to have resulted from the abundant occurrence of weak-strength spikelets. The weak sink strength, in turn, seemed to have suppressed photosynthesis during the grain ripening stage.

Key words: growth, new plant type, rice, Tongil type, yield.

Thanks to the development of IR8 in IRRI in 1965 and of Tongil in Korea in 1971, yield potential of rice has recorded a quantum leap. This improvement has largely resulted from morphological changes from the tall, droopy-leaved traditional cultivars to the short, erect-leaved cultivars with a semi-dwarf gene (Chandler, 1969; Lee, 1982). The semi-dwarf cultivars with short stature and erect leaves had greater nitrogen responsiveness, improved canopy architecture for efficient light interception, and efficient partitioning between grain and straw, which have resulted in high-yielding performance (Lee, 1982; Saitoh et al., 1990; Takeda, 1984). Later-generation varieties since IR8 have been improved substantially in terms of pest resistance, grain quality, and reduced crop duration. However, yield potential have increased only marginally (Pingali et al., 1997). Many Tongil-type varieties with better grain quality and higher yield than Tongil had been developed in the 1970s in Korea. Thereafter, the yield potential of Tongil-type varieties have not been improved and even the farmer's productivity of rice has remained relatively stagnant as the cultivation area of them has decreased drastically since the 1980s due to their low palatability and the drawback of low temperature sensitiveness (Lee et al., 1996). To cope with the stagnated yield potential of rice, IRRI proposed NPT varieties which have 4~5 productive tillers but with no unproductive tillers and larger panicles of 250 grains, as compared to 20~25 tillers and 100~120 grains per panicle of current varieties, and thick sturdy stems in order to bear the weight of the larger panicles and greater grain weight. NPT varieties, with which they are expecting a yield increase of 20~25 percent, have been developed using tropical *japonica* varieties as donors for larger panicles, sturdy stems and low tillering (Dingkuhn et al., 1991; Peng et al., 1994). Korean breeders developed new Tongil type cultivars, Dasanbyeo and Namcheonbyeo, so called "super-rice", which have larger panicles and higher yield potential than the existing high-yielding Tongil-type cultivars by 7~17% (Kim et al., 1996; Choi et al., 1997). The objective of the present study was to compare a new Tongil-type cultivar Dasanbyeo with the existing cultivars of Tongilb type and *japonica* type, and the NPT line, and to clarify its high-yielding potential in terms of growth characteristics.

MATERIALS AND METHODS

Employed were five rice cultivars, a new Tongil-type cultivar, Dasanbyeo bred in National Crop Experiment Station, Korea in 1995 (Choi et al., 1997), an existing Tongil-type high-yielding cultivar Milyang 23, two recommended *japonica* cultivars Dongjinbyeo and Ilpumbyeo, and an NPT line IR65600-27-1-2 from IRRI. The cultivars were compared for yield and growth characteristics at two planting spaces of 30×15 cm and 25×10 cm in 1997 in which higher temperature and greater solar radiation than the normal prevailed during the rice growing season. Split plot design with three replications

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was applied for the layout of the field experiment at the Experimental Farm of Seoul National University at Suwon, Korea. Nitrogen fertilizer at the rate of 180 kg N/ha was applied in a triple split, basally, at early tillering and at panicle initiation. Potassium (120 kg K_2O/ha) and phosphorus (100 kg P_2O_5/ha) fertilizers were applied basally. 35-day old seedlings were transplanted with three plants per hill. Samples for growth and chemical analyses were taken at every 15 days begining 15 days after transplanting and continued until 45 days after heading. Samples were separated into three parts; leaf blade, leaf sheath plus culm, and panicle, and dried at 80℃ for 48 hours. Leaf area was measured with a leaf area meter (Li-Cor Inc). After drying, samples were weighed and ground for chemical analyses. Growth analysis parameters such as LAI, LAD, NAR, and CGR were calculated with the data of leaf area and dry matter weight. Yield and yield components were measured with samples from 3.3 m^2 of each plot at harvest. Sink size and HI were calculated by multiplying the spikelet number per unit area with the average filled grain weight and by dividing the filled grain weight with the shoot dry weight at harvest, respectively. Total nitrogen and total nonstructural carbohydrate (TNC) contents were measured by micro-Kjeldhal and anthrone methods, respectively.

RESULTS

Yield Components and Yield

As there were no interaction effects between plant spacing and cultivar for yield components and yield, the results of two plant spacings were averaged and presented in Table 1. Tongil type cultivars Dasanbyeo and Milyang 23 showed much lower percentage of productive tillers than *japonica* ones, but had a slightly smaller number of panicles per unit area than *japonica,* revealing that they had a profuse tillering habit in the early growth stage and many prematurely-dying tillers as well. NPT line IR65600 had the smallest number of panicles because of low tillering capacity, though it had almost no prematurely-dying tillers. The number of spikelets per panicle was greatest in IR65600, followed by Tongil type cultivars and *japonica* ones. There was no significant difference in the spikelet number per panicle between Dasanbyeo and Milyang 23 which produced the greatest number of spikelets of more than 40 thousand per square meter. They had a relatively greater number of panicles and larger panicles than NPT line and *japonica* cultivars, respectively. Dasanbyeo showed the greatest sink size of 10.88 ton/ha, followed by Milyang 23 and the other cultivars. The sink size of Dasanbyeo was greater than Milyang 23 by about 10 percent, merely as the former had much heavier grain than the latter. Dasanbyeo showed the best yield performance of 9.00 ton/ha which was greater by about 9 percent than that of the second high yielder Milyang 23. The higher grain yield of Dasanbyeo was due not only to a relatively higher grain filling ratio but also to the greater sink size than the other cultivars. In spite of a much greater sink size, Dasanbyeo showed almost the same grain filling ratio as the *japonica* cultivars. However, Milyang 23 showed a lower grain filling ratio than *japonica* cultivars even though it had a smaller sink size than Dasan. IR65600 showed the lowest grain yield of 4.61 ton/ha which amounted to only 64 percent of that of *japonica* cultivars, even though its sink size was similar to that of the latter cultivars. The low yield of IR65600 was mainly due to the low grain filling ratio of less than 60%. HI was the highest in Dasanbyeo at 0.53, followed by Milyang 23, and was the lowest in IR65600 at 0.35.

Dry Matter Production Characteristics

Table 2 presents shoot dry weight at heading and harvest, and average growth parameters during active tillering, reproductive and grain filling stages. Tongil type cultivars produced a little smaller shoot dry matter before heading than the other cultivars. This might be due to the shorter vegetative growth duration of the former cultivars than the latter ones by six to ten days as shown in Table 1. However, Tongil type cultivars, especially Dasanbyeo, showed greater shoot dry weight than the other ones at harvest as the former produced a much greater shoot dry matter than the latter during the grain filling period.

CGR during 30 days after heading was greater in Tongil type cultivars, especially in Dasanbyeo, than in *ja-*

Table 1. Yield components and yield of five rice cultivars at two plant spacings. Data were averaged across plant spacings as there were no cultivar × plant spacing interactions.

Cultivars	Heading date	Panicles per m^2	Productive tiller ratio (%)	Spikelets per m^2	Spikelets per panicle	Ripening ratio (%)	1,000-grain weight (g)	Grain yield (ton/ha)	Harvest index	Sink size (ton/ha)
Dongjinbyeo	Aug. 22	372a†	81b	34643bc	93.5c	85.0a	25.4b	7.19c	0.42b	8.80c
Ilpumbyeo	Aug. 24	376a	86b	31796c	85.2d	86.1a	25.0b	7.17c	0.41b	7.94cd
Milyang 23	Aug. 14	363a	66c	42887a	117.3ab	80.1ab	23.1c	8.28b	0.51a	9.88b
Dasanbyeo	Aug. 10	358a	65c	40258a	114.3ab	84.2a	27.1a	9.00a	0.53a	10.88a
IR65600	Aug. 20	257b	90a	32293bc	127.7a	58.2c	26.3a	4.61d	0.35c	8.53c

† The common letters in a column mean no significant difference at 5% probability by DMRT.

Table 2. Average values of CGR, NAR, and LAD during 30 days after transplanting (30DAT), after panicle initiation (30DAP), and after heading (30DAH), and shoot dry weight.

Parameter	Stage	Dongjin	Ilpum	Mil. 23	Dasan	IR65600
CGR	30DAT	7.5	6.1	8.1	9.3	5.8
$g/m^2/day$	30DAP	20.7	17.6	21.2	22.2	20.6
	30DAH	15.8	12.2	19.6	20.9	6.3
NAR	30DAT	7.8	7.6	6.4	6.7	5.9
$g/m^2/day$	30DAP	2.9	2.6	3.3	2.8	2.7
	30DAH	2.9	2.3	2.9	3.0	1.0
LAD	30DAT	45	33	57	69	45
day	30DAP	216	207	195	228	225
	30DAH	186	162	204	210	195
Shoot	Heading	1,121	981	924	987	1,022
D.W.(g/m^2)	Harvest	1,594	1,346	1,595	1,638	1,211

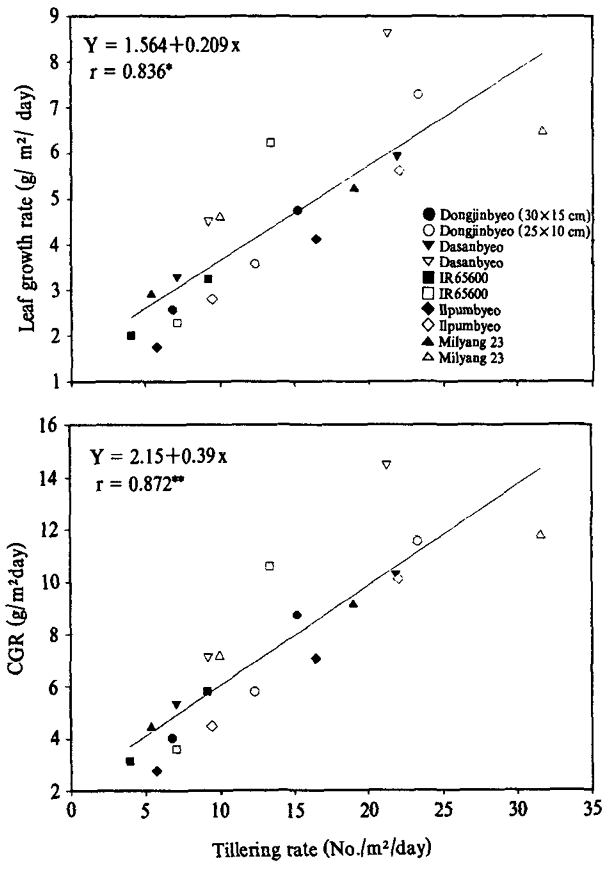

Fig. 1. The relationship between tillering rate, and leaf growth rate, and crop growth rate at early growth before maximum tiller stage.

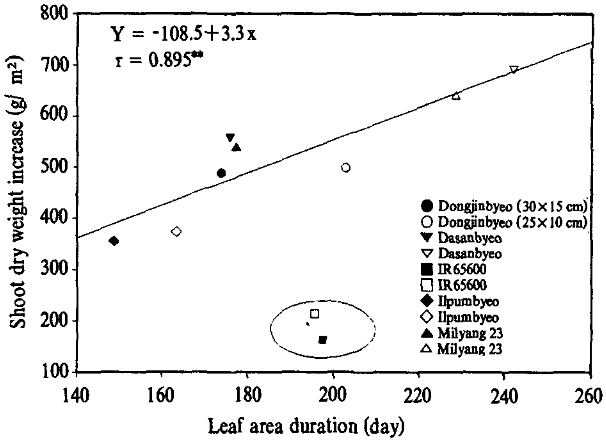

Fig. 2. The relationship between leaf area duration and shoot dry weight increase from heading to 30days after heading.

ponica ones and was smallest in the NPT line which had the lowest NAR. The greatest CGR of Dasanbyeo resulted from the fact that it had greater LAD due to its rapid leaf area expansion rate at the early growth stage and had relatively high NAR. As shown in Fig. 1, tillering rates showed significantly positive correlations with leaf growth rates and CGR's before maximum the tiller stage, implying that the greater LAD in Dasanbyeo and the resulting higher CGR was attributable in part to its profuse tillering capacity. During 30 days before heading Dasanbyeo also maintained the highest CGR of 22.2 $g/m^2/day$ as it had the greatest LAD and relatively high NAR of 2.8 g/m^2 leaf/day. CGR during grain filling stage was the highest in Dasanbyeo which showed not only the greatest LAD but also relatively high NAR, and was the lowest, amounting to only one third of the other cultivars, in NPT line in spite of the LAD not being smaller than the other cultivars. Excluding the data of NPT line, shoot dry matter production during grain filling stage showed highly significant positive correlation with LAD during that period as shown in Fig. 2. However, NPT line showed much lower shoot dry matter production than expected from its LAD. NAR of NPT line during grain filling period showed a drastic decrease as compared to the previous growth stage and had only one third of the other cultivars, while the other cultivars showed only a little drop. Even though Dasanbyeo had the shortest growth duration, it produced the greatest shoot dry matter by maturity because it maintained not only greater LAD which resulted from rapid leaf growth at early growth stage but also relatively high NAR through the entire life span. The high NAR of Dasanbyeo in spite of its greater LAI might have resulted from the improved canopy structure.

Nitrogen and TNC

The leaf nitrogen contents as measured by percent dry

Table 3. Average leaf nitrogen content at each growth stage and total nitrogen amount in the shoot at harvest

Parameter	Stage	Dongjin	Ilpum	Mil.23	Dasan	IR65600
Leaf N (%)	30DAT	4.4	4.2	4.1	4.3	4.4
	30DAP	2.8	2.9	3.1	3.1	3.2
	30DAH	2.0	2.1	2.1	2.2	2.2
Shoot N (g/m^2)	Harvest	13.4	11.9	14.1	15.1	12.8

* Abbreviations for stage are as in Table 2.

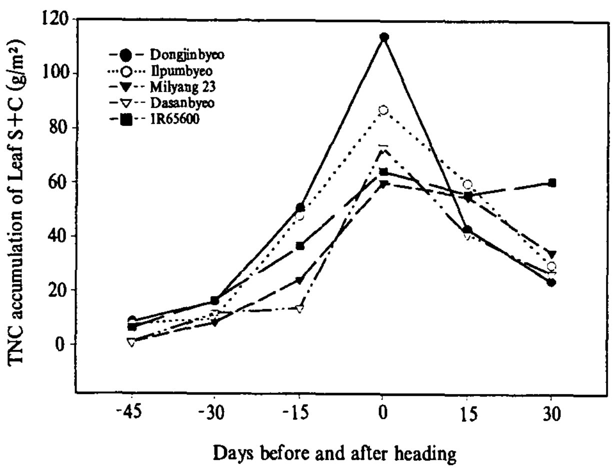

Fig. 3. Changes in the amount of total non-structural carbohydrates in leaf sheath plus culm before and after heading.

weight tended to be a little higher in NPT line than the other cultivars regardless of growth stage, and to be a little higher in Tongil type cultivars than *japonica* ones following the panicle initiation stage. However, its varietal difference was minimal (Table 3). The cultivars differed greatly in the amount of total nitrogen contained in the shoot at harvest. Tongil type cultivars, especially Dasanbyeo which produced the greatest shoot dry matter by maturity, had a greater amount of nitrogen in the shoot at harvest.

Fig. 3 presents the patterns of TNC fluctuations in the storage organs (leaf sheath and culm) during reproductive and grain filling period. The amount of TNC increased rapidly starting from 30 days before heading, reached maximum level at heading, and decreased rapidly after heading except for NPT line. The maximum level of TNC at heading showed clear differences among cultivars. *Japonica* cultivars with longer duration of vegetative growth accumulated greater amount of TNC than Tongil type ones, but NPT line had similar amount of TNC to Tongil type cultivars in spite of its longer vegetative growth duration. In all cultivars except NPT line, TNC decreased rapidly following heading to a minimum level at one month after heading. NPT line showed little decrease of TNC through grain filling period, suggesting that it might have had weak sink strength.

DISCUSSION

In terms of dry matter production and partitioning, grain yield can be expressed as the multiplication of shoot dry weight at harvest and HI. From this context grain yield may be enhanced by increasing either or both of dry matter production and HI. Dasanbyeo produced the greatest shoot dry matter by maturity (Table 2) and had the highest HI of 0.53, showing the highest grain yield among the cultivars tested (Table 1). On the contrary, NPT line IR65600 showed the lowest grain yield due not only to the lower dry matter production, especially during grain filling period, but also to the lowest HI of 0.35. The greater dry matter production of Dasanbyeo resulted not only from the rapid leaf expansion partly attributable to the profuse tillering (Fig. 1; Fusisawa, 1996) at the early growth stage and the resulting high LAI through the entire growth stage but also from the high NAR despite of high LAI, implying that Dasanbyeo might have displayed the improved canopy architecture for more efficient interception of solar radiation. However, further investigation is needed to clarify this point. The low dry matter production by maturity of NPT line resulted from the low CGR especially during the ripening stage. During this period, NPT line showed the lowest CGR amounting to only one third of the other cultivars in spite of similar leaf nitrogen content and LAI to the other ones. The low CGR of NPT line was attributable to the low NAR which might be caused by the weak sink strength during the ripening stage.

HI is limitted by sink size and grain filling rate. Dasanbyeo had the greatest sink size as expressed by the multiplication of spikelet number per unit area and average filled grain weight, and NPT line had sink size as low

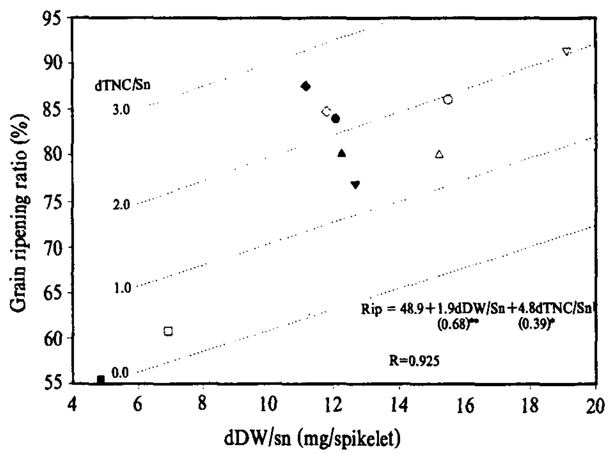

Fig. 4. The relationship between grain ripening ratio and shoot dry weight increase and non-structural carbohydrate decrease per spikelet during 30 days of grain ripening.

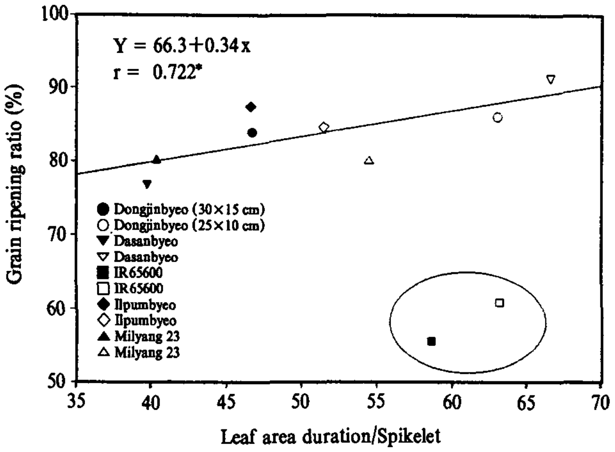

Fig. 5. The relationship between grain ripening ratio and source / sink ratio at heading.

as *japonica* cultivars (Table 1). Tongil type cultivars show high efficiency of spikelet formation as they have short culm and thus spikelet formation compete less with culm growth for assimilates (Park, 1993). Dasanbyeo and Milyang 23 produced a similarly larger number of spikelets (sn) of more than 40,000 per square meter, but Dasanbyeo had greater sink size than Milyang 23 because of larger grain. Grain filling ratio showed linearly increasing relation with the apparent-translocated TNC (dTNC / sn) and the shoot dry weight increase (dDW / sn) per spikelet (sn) during grain filling period as in Fig. 4, and also, if the data of NPT were excluded, had positive correlation with source to sink ratio (LAD / sn) as calculated by the ratio of LAD during grain filling to the spikelet number as in Fig. 5. Tongil type cultivars, especially Dasanbyeo, showed higher dDW / sn and LAD / sn than *japonica* cultivars, but lower dTNC/sn as Tongil type cultivars accumulated less amount of TNC and produced a greater number of spikelets. The smaller amount of TNC allocated to each spikelet in Tongil type cultivars seemed to have resulted in a little lower grain ripening ratio than japonica ones. Of the two Tongil type cultivars Dasanbyeo had higher source to sink ratio and dTNC/sn as well, showing relatively higher grain filling ratio. NPT line showed the lowest grain filling ratio of below 60%. In spite of the smallest number of spikelets and relatively high LAD during grain filling period it had smaller dDW/sn and dTNC/sn. This suggested that NPT line would have produced many spikelets with weak strength, and the weak sink strength, in turn, might have suppressed photosynthetic activity during grain filling stage (Figs. 2 and 5). The weak strength of the panicle in NPT line may be discerned from the fact that the preheading stored TNC did not decrease following heading (Fig. 3). However, the reason why so many weak spikelets occurred at the very early grain filling stage remains to be clarified.

REFERENCES

Chandler, R. F. Jr. 1969. Plant morphology and stand geometry in relation to nitrogen. In Physiological Aspects of Crop Yield (J. D. Eastin, F. A. Haskins, C. Y. Sullivan, and C. H. M. van Bavel, ed.). A.S.A. Madison. Wisconsin.

Choi, Y. G., M. K. Kim, H. P. Moon, S. Y. Cho, B. T. Jun, K. H. Jung, J. H. Lee, H. C. Choi, N. K. Park, H. W. Park, K. H. Hwang, J. I. Kim, R. K. Park, Y. S. Kim, and J. Y. Cho. 1997. A new high yielding disease resistant and lodging tolerant rice cultivar "Dasanbyeo". RDA J. Agric. Sci. 39(1):68-75 (in Korean with English abstract).

Dingkuhn, M., F. W. T. Penning, S. K. De Datta, and H. H. van Laar. 1991. Concepts for a new plant type for direct seeded flooded tropical rice. In Direct Seeded Flooded Rice Type in the Tropics. IRRI.

Fuzisawa, K. 1996. Ecological studies on heavy-panicle type and yield potential. M.S. dissertation, Tokyo University, Japan (in Japanese).

Kim, H. Y., S. J. Lim, S. J. Yang, H. K. Hwang, U. S. Yeo, B. G. Oh, S. C. Kim, S. K. Lee, G. S. Chung., and Y. J. Oh. 1996. A super yield potential and multiple disease resistant rice variety "Namcheonbyeo". RDA J. Agric. Sci. 38(2):68-75 (in Korean English abstract).

Lee, E. W. 1982. Variation of rice production for two decades before and after breeding Tongil variety in Korea. Korean J. Crop Sci. 27(3):183-192.

______, B. W. Lee, J. C. Shin, and H. Y. Kim. 1996. Changes in rice cultivation practices in Korea. J. Korean Academy of Sci. 35 (Natural Sci.):155-218 (in Korean with English abstract).

Park, D. H. 1993. The effect of nitrogen level and application method and shading treatment during reproductive stage on sink formation in rice. M. S. dissertation, Seoul National University, Korea (in Korean with English summary).

Peng, S., G. S. Khush, and K. G. Cassman. 1994. Evolution of the new plant ideotype for increased yield potential. In Breaking the Yield Barrier: Proc. of a Workshop on Rice Yield Potential in Favorable Evioronments. (Ed. K. G. Cassman.) pp. 5-20. IRRI Pingali, P. L., M. Hossain, and R. V. Gerpacio,. 1997. Asian rice bowls : the returning crisis? CAB International and IRRI.

Saitoh, K., H. Shimoda, and K. Ishihara. 1990. Characteristics of dry matter production in high yielding varieties. I. Canopy structure and light intercepting characteristics. Jpn. J. Crop Sci. 59(1):130-139 (in Japanese with English abstract).

Takeda, T. 1984. Physiological and ecological characteristics of high yielding varieties of lowland rice. In Proc. Intl. Crop Science Symposium. Fukuoka, Japan.