

## Growth and Yield in F<sub>1</sub> Hybrids of Rice (*Oryza sativa* L.)

Md. Nurul Alam KHAN, Seiichi MURAYAMA\*, Yukio ISHIMINE\*,  
Eiji TSUZUKI\*<sup>2</sup>, K. MOTOMURA\* and Ichiro NAKAMURA\*

United Graduate School of Agricultural Sciences, Kagoshima University, Kagoshima 890-0065, Japan

\* Faculty of Agriculture, University of the Ryukyus, Nishihara, Okinawa 903-0129, Japan

\*<sup>2</sup> Faculty of Agriculture, Miyazaki University, Miyazaki 889-2192, Japan

**Abstract** Growth and yield of two F<sub>1</sub> hybrids along with their parents were studied. F<sub>1</sub> hybrids produced a higher grain yield per plant than the respective mid-parents in both F<sub>1</sub> cross-combinations. Average heterosis value for yield was 1.14. Higher yield in the F<sub>1</sub> plants was mainly due to the higher number of spikelets per panicle. Dry matter accumulation in the F<sub>1</sub> hybrids was higher than that of the mid-parents in both hybrid combinations and it was associated with a higher number of tillers and larger leaf area. Post anthesis decline in leaf area at the ripening stage was faster in the F<sub>1</sub> hybrids compared with the inbred parent cultivars. The F<sub>1</sub> plants showed a higher apparent translocation than the inbred parent cultivars in both F<sub>1</sub> cross-combinations.

**Key words** F<sub>1</sub> hybrid, Growth, Heterosis, Rice, Translocation, Yield

イネ (*Oryza sativa* L.) の F<sub>1</sub> 雑種の生育および収量 M.N.A.KHAN・村山盛一\*・石嶺行男\*・続 栄治\*<sup>2</sup>・本村恵二\*・仲村一郎\* 鹿児島大学大学院連合農学研究科 〒890-0065 鹿児島市郡元1-21-24 \*琉球大学農学部 〒903-0129 西原町字千原 \*<sup>2</sup>宮崎大学農学部 〒889-2192 宮崎市学園木花台西1-1

**要 約** 二組の F<sub>1</sub> 雑種とその親品種の生育及び収量について研究した。F<sub>1</sub> 雑種は、両組合せとも中間親よりも一単位当たりの子実収量が高く、平均ヘテロシスは、1.14 を示した。F<sub>1</sub> 雑種における高い収量は、主に一穂当たり粒数の増加に起因していると思われる。F<sub>1</sub> 雑種における乾物生産量は、中間親より高く、その原因は、分げつ数と葉面積の増加に起因すると思われた。出穂後の葉面積の減少は、親品種と比べ F<sub>1</sub> 雑種が早かった。また、F<sub>1</sub> 雑種は、両組合せとも転流は親品種よりかなり高く、この事も子実収量で F<sub>1</sub> 雑種がヘテロシスを示す原因の一つと考えられる。

**キーワード** イネ, F<sub>1</sub> 雑種, 生育, 収量, 転流, ヘテロシス

### Introduction

F<sub>1</sub> hybrids in rice produced a yield 20–30% higher than the best check varieties in replicated yield trials in China<sup>10</sup>. MURAYAMA *et al.*<sup>12</sup> reported the practical utilization of hybrid vigour in rice under field conditions for increasing yield. Commercial hybrid seed production was difficult in this strictly self pollinated crop initially. However, with the development of cytoplasmic male sterile lines it became easier to produce hybrid seeds in bulk, which promoted large-scale adoption of hybrid rice in and outside China.

Yield is an intricate result of plant growth, which is a function of the genotype and environment. F<sub>1</sub> hybrids in rice were reported to be superior to their parents in various agronomic characters such as wider adaptability<sup>10</sup>, higher tillering ability<sup>9</sup>, larger

leaf area and higher dry matter accumulation<sup>9</sup>. However, the enhanced vegetative growth did not always lead to a higher yield in the F<sub>1</sub> hybrids<sup>6, 9</sup>. In a previous study by the present authors<sup>9</sup>, heterosis values for the number of tillers, leaf area and total dry matter accumulation at the pre-heading growth stages were recorded. In cereal crops the carbohydrates that are stored during the vegetative growth stages can later be translocated to grain. Published literature regarding apparent translocation in the F<sub>1</sub> hybrids of rice is very limited. Higher translocation along with larger pre-heading dry matter accumulation may contribute to the production of a higher yield in the F<sub>1</sub> hybrids of rice. The implication of heterosis in the growth parameters for yield should be studied carefully for a better understanding of the yielding ability in the F<sub>1</sub> hybrids of rice. Therefore, it was planned to investigate some of the growth parameters of the F<sub>1</sub> hy-

Received Dec. 11, 1997

Accepted Aug. 19, 1998

brids including apparent translocation and their effect on yield and yield components. The present study was undertaken to examine important growth components of two  $F_1$  hybrids throughout the growth period along with the yield and yield components and apparent translocation.

### Materials and Methods

The experiment was conducted in a glasshouse of the Experimental Farm of the Faculty of Agriculture, University of the Ryukyus, Okinawa, Japan (26° 10' N and 127° 45' E).  $F_1$  seeds were produced during the second growing season of 1995 by crossing two semi-dwarf Japonica varieties, Akebono and Chiyonishiki and an Indica-Japonica semi-dwarf hybrid variety, Milyang 25. Chiyonishiki is commercially cultivated in Okinawa prefecture and Akebono showed a high tillering ability in the previous observations at the Faculty of Agriculture, University of the Ryukyus.  $F_1$  cross combinations of Milyang 25 x Akebono and Chiyonishiki x Milyang 25 were used for the present study.

Seeds of parent cultivars and  $F_1$  hybrids were treated with systemic fungicide "Benlate T" and were incubated for twenty four hours at 30°C. Pregerminated seeds were sown in nursery boxes (60×35×8 cm) on a soil medium on 1 March, 1996. Three weeks old seedlings of each parental cultivar and  $F_1$  hybrids were transplanted individually to 0.02 m<sup>2</sup> Wagner pots containing Shimajiri Mahji (Dark Reddish) soil distributed in the Okinawa region. Soils in the pots, were mixed with organic matter at the rate of 3 kg per m<sup>2</sup> and puddled in order to simulate natural wetland paddy field conditions. Inorganic fertilizers were supplied at the following rates as basal application: N 6.5 g/m<sup>2</sup>; P<sub>2</sub>O<sub>5</sub> 5 g/m<sup>2</sup>; K<sub>2</sub>O 6.0 g/m<sup>2</sup>. First top dressing of NPK fertilizers was applied at fifty days after sowing around the panicle initiation stage at the following rates: N, 3.5 g/m<sup>2</sup>; P<sub>2</sub>O<sub>5</sub>, 2.5 g/m<sup>2</sup>; and K<sub>2</sub>O, 3.0 g/m<sup>2</sup>. Second top dressing of inorganic fertilizers was done eighty five days after sowing at the following rates: N, 3.0 g/m<sup>2</sup>; P<sub>2</sub>O<sub>5</sub>, 2.5 g/m<sup>2</sup>; K<sub>2</sub>O, 3.0 g/m<sup>2</sup>. Plants were watered everyday so that at least five cm of standing water remained throughout the trial. The glasshouse

was well ventilated to maintain natural temperature and light conditions inside the glass house. To avoid border effect, guard rows were used with the variety Akebono. The crop was free from insect and disease infestation, except for a minor leaf hopper infestation. As a precautionary measure, Diazinon (granular form) was applied to the forty five days old crop.

Six destructive samplings were performed starting from sixty days after sowing (DAS). At each sampling, the number of tillers, plant height, leaf area and dry matter accumulation were recorded. Leaf area measurement was carried out using an automatic area meter (AAM Hayashi Denko, Japan) immediately after leaf removal to avoid shrinkage and leaf rolling. Dry matter accumulation measurement was carried out after drying the plants at 80°C for 48 hours in an oven. At the final harvest, data on yield and yield components were collected. Grain yield was measured at maturity after threshing, cleaning, and drying. Number of panicles were counted from four plants and three panicles from each plant were randomly selected for determining the number of spikelets per panicle, fraction of unfilled spikelets and hundredseed weight. An additional sampling was performed immediately after flowering from each  $F_1$  hybrid and parent cultivars for apparent translocation (AT) determination. Apparent translocation was computed by the formula (REYNIERS *et al.*<sup>14)</sup> as

$$AT = \frac{(WSF - WSM)}{(WPM - WPF)} \times 100$$

Where

WSF = Dry weight of stem at flowering

WSM = Dry weight of stem at maturity

WPM = Dry weight of panicles at maturity

WPF = Dry weight of panicles at flowering.

Heterosis was expressed as the ratio between the performance of the  $F_1$  hybrid and the mid-parent. (heterosis =  $F_1$ /Mid-parental value). Mid-parental value was calculated as the average performance of the female parent and the male parent [mid-parental value = (female parent + male parent)/2]. Data were analyzed by the Analysis of Variance (ANOVA) technique and means were tested

with least significance difference (LSD) test. Statistical analyses were carried out following the procedure laid out in GOMEZ and GOMEZ<sup>4)</sup> and CLEWER and SCARISBRICK<sup>1)</sup>

### Results and Discussion

No particular differences in disease or insect infestation were noticed in the F<sub>1</sub> hybrids compared with the inbred parent cultivars throughout the growing season.

Number of tillers per plant in both F<sub>1</sub> cross-combinations differed between F<sub>1</sub> hybrids and parent cultivars (Fig. 1a and 1b). In the parental combination Milyang 25 × Akebono (Fig. 1a) the inbred cultivars were found to display a similar tillering ability. However, the F<sub>1</sub> hybrids in this parental combination showed a higher number of tillers per plant than the higher parent throughout the growing season. A similar trend was also observed in the parental combination Chiyonishiki × Milyang 25 (Fig. 1b), although the differences between the F<sub>1</sub> hybrid and parental cultivars were less appreciable in this

case. Number of tillers per plant continued to increase in both the F<sub>1</sub> hybrids and inbred parent cultivars up to the fourth sampling (105 DAS) and thereafter no further increase was noticed. No particular differences in tiller mortality were observed in the F<sub>1</sub> hybrids compared with the parent cultivars. Higher tillering ability of the F<sub>1</sub> hybrids in the present experiment was consistent with the report of GOVINDARAJ and SIDDIQ<sup>5)</sup>. However, VIRMANI *et al.*<sup>18)</sup> reported a lower number of tillers per plant in the F<sub>1</sub> hybrids compared with the mid-parent.

Plant height among parent cultivars and between F<sub>1</sub> hybrid and parent cultivars was found to be different in both F<sub>1</sub> cross-combinations (Fig. 2a and 2b). In the F<sub>1</sub> cross-combination of Milyang 25 × Akebono (Fig. 2a) the difference was highly significant at later samplings and the F<sub>1</sub> hybrids showed the highest plant height. In the F<sub>1</sub> cross-combination of Chiyonishiki × Milyang 25 (Fig. 2b) the F<sub>1</sub> plants showed a plant height almost similar to the female parent Chiyonishiki which was

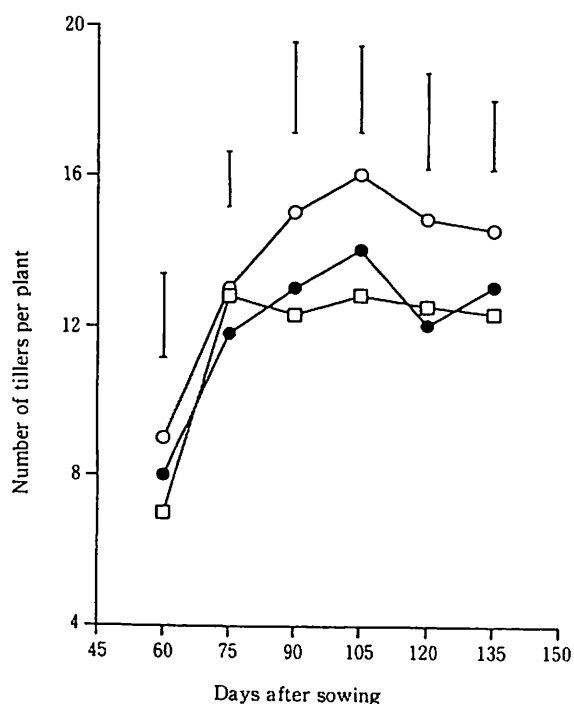


Fig. 1a. Time course of tiller production in the F<sub>1</sub> hybrid and parent cultivars (Milyang 25 × Akebono).

—□— Milyang 25; —●— Akebono; —○— Milyang 25 × Akebono. Bars represent LSD at the 5% level of significance.

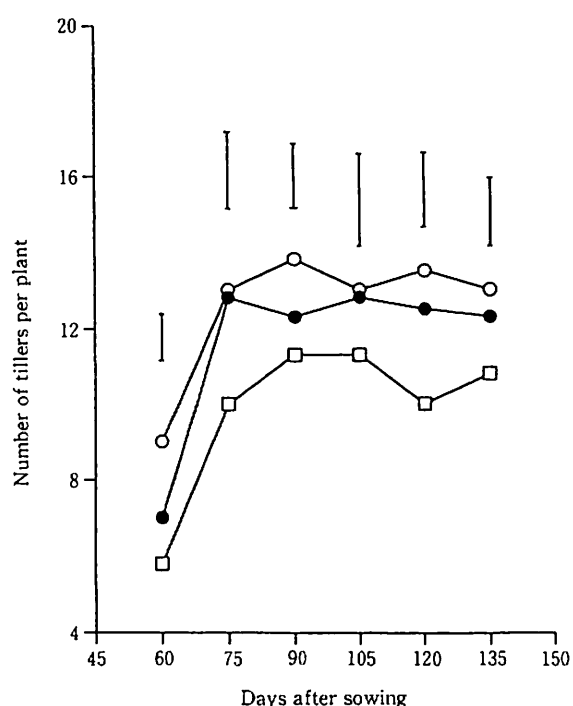


Fig. 1b. Time course of tiller production in the F<sub>1</sub> hybrid and parent cultivars (Chiyonishiki × Milyang 25).

—□— Chiyonishiki; —●— Milyang 25; —○— Chiyonishiki × Mitsuyo 25. Bars represent LSD at the 5% level of significance.

the higher parent in this cross-combination. Plant height increased gradually up to the fourth sampling (105 DAS) and it remained static thereafter for both the  $F_1$  hybrids and parental cultivars. The higher plant height of the  $F_1$  hybrids in the present experiment is in agreement with the findings of other authors, such as SINGH *et al.*<sup>16)</sup> who reported a significant positive heterosis for this trait. VIRMANI<sup>17)</sup> concluded that positive heterosis for plant height in rice is common, although there were a few cases of negative heterosis<sup>15)</sup>.

Leaf area per plant differed among the parent cultivars and between  $F_1$  hybrids and parent cultivars in both  $F_1$  cross-combinations (Fig. 3a and 3b). During the pre-anthesis growth stages, the  $F_1$  hybrids showed a significantly larger leaf area than the parent cultivars. Flowering took place almost at the same time in the  $F_1$  hybrids and parent cultivars (Akebono and Chiyonishiki required ninety eight days for flowering, Milyang 25 hundred two days, Akebono  $\times$  Chiyonishiki ninety eight days and Chiyonishiki  $\times$  Milyang

25 hundred days). After the onset of flowering,  $F_1$  plants of the cross-combination Milyang 25  $\times$  Akebono had a depression in leaf area compared with the parental cultivars (Fig. 3a). In Chiyonishiki  $\times$  Milyang 25, although a fast decline was also evident, the  $F_1$  plants in this case maintained a higher leaf area throughout the growing season. Leaf area increased with the plant age, reached a maximum value around anthesis and then declined in both the  $F_1$  hybrids and inbred parent cultivars. Leaf aerial development in the  $F_1$  plants was vigorous at early growth stages. In rice, leaf and tiller emerge from the same node<sup>20)</sup>. Thus the higher number of tillers in the  $F_1$  hybrids led to a more active leaf aerial development early in the growth stages of the  $F_1$  hybrids. Larger leaf area in the  $F_1$  plants were also reported in other studies<sup>9)</sup>. Rice is a determinate crop and with the onset of flowering, leaf senescence starts and the inflorescence prevents a considerable amount of photosynthetically active radiation from penetrating into the

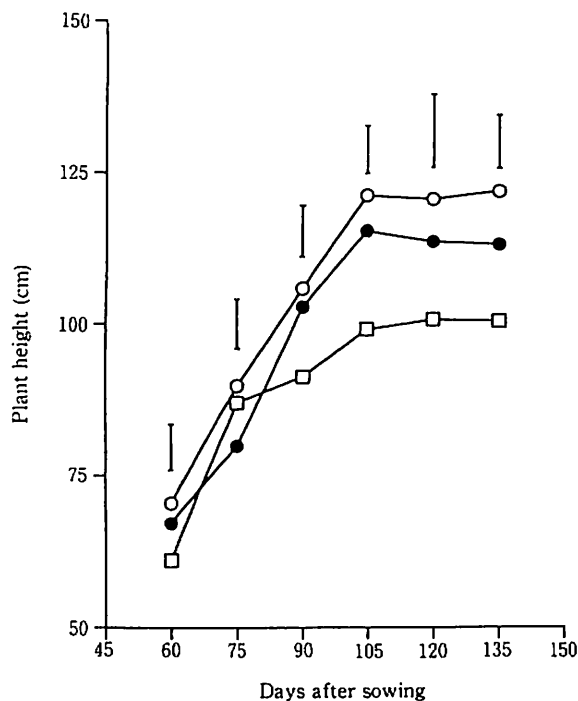


Fig. 2a. Time course of plant height in the  $F_1$  hybrid and parent cultivars (Milyang 25  $\times$  Akebono).

—□— Milyang 25 ; —●— Akebono ; —○— Milyang 25  $\times$  Akebono. Bars represent LSD at the 5% level of significance.

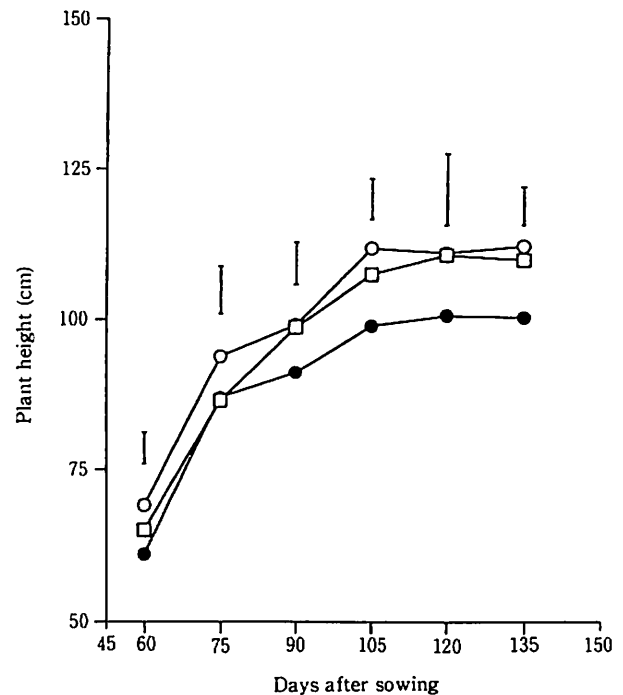


Fig. 2b. Time course of plant height in the  $F_1$  hybrid and parent cultivars (Chiyonishiki  $\times$  Milyang 25).

—□— Chiyonishiki ; —●— Milyang 25 ; —○— Chiyonishiki  $\times$  Milyang 25. Bars represent LSD at the 5% level of significance.

canopy. MURATA *et al.*<sup>10</sup> suggested that the inflorescence could cause a reduction of about 13-20 % of irradiance to penetrate into the canopy. In addition, the nitrogen content in the leaves of the F<sub>1</sub> plants may have decreased due to the high heterosis value for the leaf area in the F<sub>1</sub> plants. KABAHI *et al.*<sup>7</sup> stated that the nitrogen content in the leaves of the F<sub>1</sub> plants was lower than in the parental inbred cultivars due to the larger leaf area in the F<sub>1</sub> hybrid plants. These factors may have contributed to the faster leaf senescence in the F<sub>1</sub> hybrid plants.

Initial shoot dry matter accumulation was low, but from the second sampling (75 DAS), it increased exponentially during vegetative growth followed by a linear phase in both the F<sub>1</sub> hybrids and parent cultivars (Fig. 4a and 4b). The shoot dry weight in the F<sub>1</sub> plants in both hybrid combinations was higher than that of the parent cultivars in all the sampling occasions except at the last

sampling when a depression was observed in the F<sub>1</sub> hybrids of the parental combination Milyang 25 × Akebono (Fig. 4a). Dry matter accumulation in the F<sub>1</sub> hybrids were much larger from the early growth stages. GALLAGHER and BISCOE<sup>2</sup> mentioned that under non-limiting conditions dry matter accumulation in cereals was proportional to the amount of radiation they intercepted. In the present study it is likely that at the pre-heading growth stages there was no limitation in radiation interception. However, with the onset of flowering the situation changed and a faster leaf senescence occurred in the F<sub>1</sub> plants. Larger dry matter accumulation during the pre-anthesis growth stages along with the higher number of tillers per plant in the F<sub>1</sub> plants led to a high potential yielding ability in the form of a large number of spikelets per plant. At the post-anthesis growth stages, due to the reduced photosynthetic ability in terms of higher leaf senes-

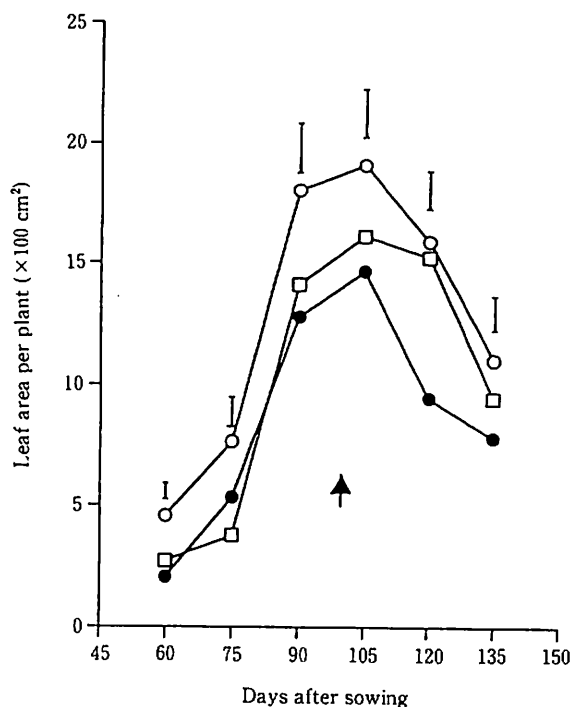
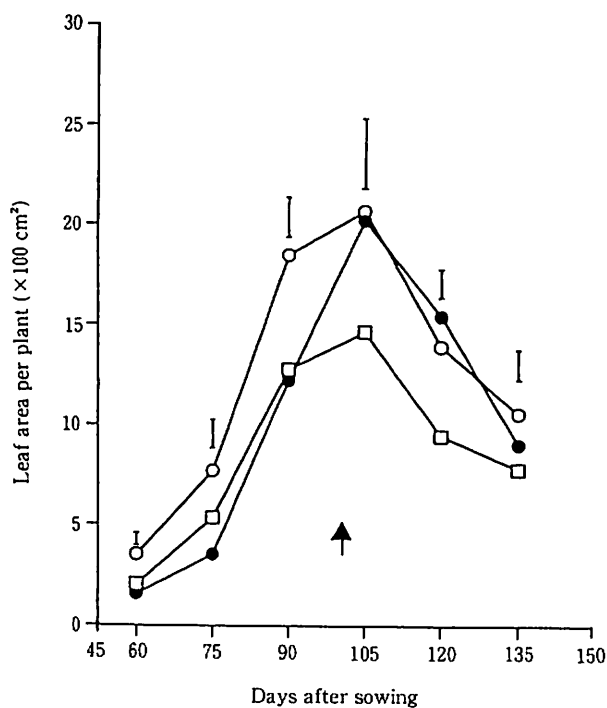


Fig. 3a. Time course of leaf area per plant in the F<sub>1</sub> hybrid and parent cultivars (Milyang 25 × Akebono).

□ - Milyang 25; ● - Akebono; ○ - Milyang 25 × Akebono. Bars represent LSD at the 5% level of significance. Arrow indicates heading time for parents and the F<sub>1</sub> hybrid.

Fig. 3b. Time course of leaf area per plant in the F<sub>1</sub> hybrid and parent cultivars (Chiyonishiki × Milyang 25).

□ - Chiyonishiki; ● - Milyang 25; ○ - Chiyonishiki × Milyang 25. Bars represent LSD at the 5% level of significance. Arrow indicates heading time for parents and the F<sub>1</sub> hybrid.

cence, dry matter accumulation in the F<sub>1</sub> plants of the parental combination Milyang 25 × Akebono may have declined.

Comparison of yield components is shown in Table 1. In both parental combinations, the number of panicles per plant in the F<sub>1</sub> hybrids, although not significantly, exceeded that of the higher parent and the average heterosis value was 1.14. Number of spikelets per panicle differed significantly among parent cultivars and between F<sub>1</sub> hybrids and parent cultivars. The number in the F<sub>1</sub> plants exceeded that of the higher parent in both cross combinations. Heterosis values of 1.15 and 1.21 were recorded for the Milyang 25 × Akebono and Chiyonishiki × Milyang 25 cross-combinations respectively. The proportion of unfilled grains was larger in the F<sub>1</sub> plants than in the parental cultivars in both cross-combinations and the difference was significant in Milyang 25 × Akebono (Table 1). Although the F<sub>1</sub> plants in this F<sub>1</sub>

cross-combination showed a significantly higher percentage of unfilled spikelets than both parents, the difference between the F<sub>1</sub> hybrids and parent cultivars was not significant in the case of Chiyonishiki × Milyang 25. One hundred-seed weight differed significantly among the inbred parent cultivars and between F<sub>1</sub> hybrids and parent cultivars. F<sub>1</sub> plants of Milyang 25 × Akebono showed the same one hundred seed weight as the mean parent, while in case of Chiyonishiki × Milyang 25 the value was slightly lower than that of the mid-parent. An average heterosis value of 0.99 for 100-seed weight was recorded in the two F<sub>1</sub> cross-combinations. There were significant differences in grain yield among the parent cultivars and between F<sub>1</sub> hybrids and parent cultivars (Table 2) in both F<sub>1</sub> cross-combinations. Grain yield per plant in the F<sub>1</sub> plants was higher than in the mid-parents in both F<sub>1</sub> cross-combinations. However, the degree of heterosis was much

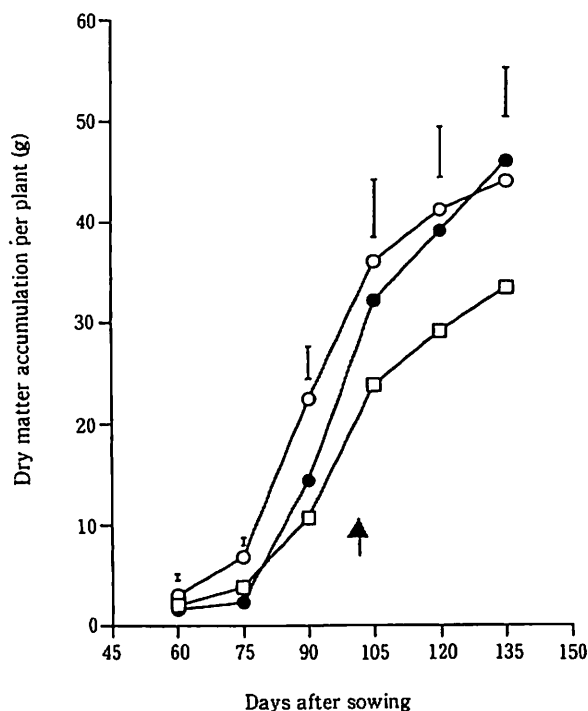


Fig. 4a. Time course of dry matter accumulation per plant in the F<sub>1</sub> hybrid and parent cultivars (Milyang 25 × Akebono).

—□— Milyang 25; —●— Akebono; —○— Milyang 25 × Akebono. Bars represent LSD at the 5% level of significance. Arrow indicates heading time for parents and the F<sub>1</sub> hybrid.

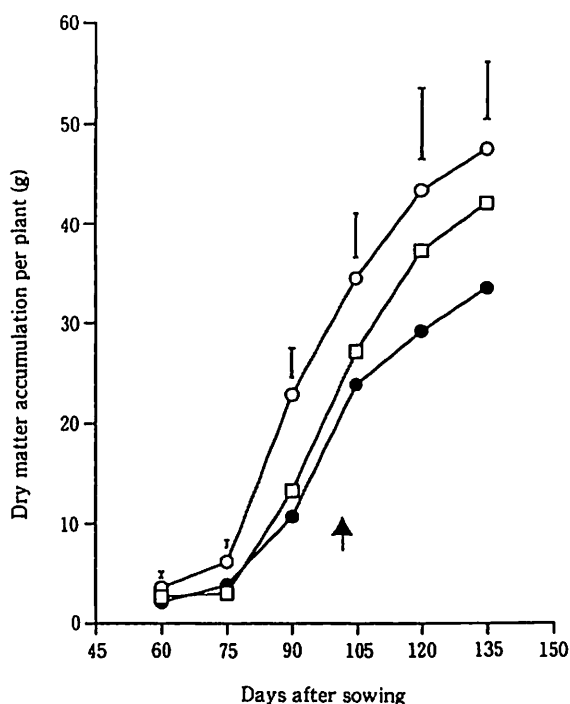


Fig. 4b. Time course of dry matter accumulation per plant in the F<sub>1</sub> hybrid and parent cultivars (Chiyonishiki × Milyang 25).

—□— Chiyonishiki; —●— Milyang 25; —○— Chiyonishiki × Milyang 25. Bars represent LSD at the 5% level of significance. Arrow indicates heading time for parents and the F<sub>1</sub> hybrid.

Table 1. Comparison of yield components among the F<sub>1</sub> hybrids and parent cultivars.

Parental combinations	Yield components	Female parent (P <sub>1</sub> )	F <sub>1</sub> hybrid (F <sub>1</sub> )	Male parent (P <sub>2</sub> )	Sig.	LSD (5% level)	Heterosis
Milyang 25 x Akebono	Number of panicles per plant	11.5	13.0	12.0	ns	2.66	1.11
	Number of spikelets per panicle	98.9	122.6	114.3	**	11.89	1.15
	Proportion of unfilled spikelets (%)	12.7	17.9	13.2	*	4.50	—
	100-seed weight (g)	2.01	2.13	2.24	**	0.11	1.00
Chiyonishiki x Milyang 25	Number of panicles per plant	10.0	12.5	11.5	ns	2.61	1.16
	Number of spikelets per panicle	125.0	135.9	98.9	**	15.73	1.21
	Proportion of unfilled spikelets (%)	10.3	14.7	12.7	ns	3.81	—
	100-seed weight (g)	2.23	2.08	2.01	**	0.10	0.98
Average heterosis				Number of panicles per plant			1.14
				Number of spikelets per panicle			1.18
				100-seed weight			0.99

ns, \* and \*\* indicate statistically nonsignificant and significant at the 5% and 1% levels, respectively; Heterosis =  $F_1 / \text{mid-parental value}$ . Mid-parental value =  $(P_1 + P_2) / 2$ ; Heterosis for unfilled spikelets was not calculated.

higher in the case of Chiyonishiki × Milyang 25 than in Milyang 25 × Akebono. Although the harvest indices did not differ significantly, a slight decline was noticed in the F<sub>1</sub> plants compared with the parent cultivars (Table 2) in both F<sub>1</sub> cross-combinations. A slightly negative heterosis in both the F<sub>1</sub> cross-combinations was recorded and an average heterosis value of 0.95 was recorded for this trait. It seems that the number of panicles per plant as well as spikelets per panicle both contributed to the development of a positive heterosis value for grain yield. However, the significant difference in the number of spikelets per plant between F<sub>1</sub> hybrids and parent cultivars suggests that this character had contributed more to the development of a positive heterosis value for grain yield per plant. MURAYAMA *et al.*<sup>12)</sup> and SINGH and SINGH<sup>15)</sup> stated that a positive heterosis value for the number of panicles per plant and spikelets per panicle both contributed to higher grain yield in the F<sub>1</sub> rice

hybrids. On the other hand, PONNUTHURAI *et al.*<sup>13)</sup> stated that heterosis for grain yield of the F<sub>1</sub> rice hybrids was mainly due to the larger number of spikelets per panicle and heterosis for the number of panicles was not significant. The results of the present study suggest that both the number of panicles per plant and number of spikelets per panicle played an important role in the heterotic yield in the F<sub>1</sub> hybrid plants. Larger dry matter accumulation during the pre-anthesis growth stages along with the higher number of tillers in the F<sub>1</sub> plants induced a high potential yielding ability. Consequently, although a large number of spikelets per plant were induced, with the onset of flowering, the F<sub>1</sub> plants were unable to sustain the higher number of spikelets due to the reduced photosynthetic ability. As a result a larger proportion of unfilled grains occurred in the F<sub>1</sub> plants, particularly in the F<sub>1</sub> cross-combination Milyang 25 × Akebono where leaf senescence was more rapid. The slightly

Table 2. Grain yield and harvest index (HI) of F<sub>1</sub> hybrids and parent cultivars.

		Grain yield per plant and harvest index (HI)					
		Female parent (P <sub>1</sub> )	F <sub>1</sub> hybrid (F <sub>1</sub> )	Male parent (P <sub>2</sub> )	Sig.	LSD (5% level)	Heterosis
Milyang 25 × Akebono	Grain yield (g)	14.2	17.4	18.9	*	2.93	1.05
	Harvest index	0.43	0.39	0.41	ns	0.06	0.93
Chiyonishiki × Milyang 25	Grain yield (g)	18.2	19.8	14.2	**	2.08	1.22
	Harvest index	0.44	0.42	0.43	ns	0.05	0.97
Average heterosis				Grain yield			1.14
				Harvest index			0.95

ns, \* and \*\* indicate statistically nonsignificant and significant at the 5% and 1% levels, respectively; Heterosis =  $F_1$ /mid-parental value. Mid-parental value =  $(P_1 + P_2)/2$ .

lower harvest indices in the present experiment are not in agreement with the findings of PONNUTHURAI *et al.*<sup>13)</sup>, who observed a positive heterosis value for this parameter.

Apparent translocation differed among parent cultivars and between F<sub>1</sub> hybrids and parent cultivars. The F<sub>1</sub> plants in both cross-combinations showed a higher apparent translocation than the parent cultivars (Fig. 5). Although a high heterosis value for apparent translocation was recorded for both F<sub>1</sub> cross-combinations, the degree of heterosis was much higher for Milyang 25 × Akebono than for Chiyonishiki × Milyang 25. Higher apparent translocation (AT) in the F<sub>1</sub> plants was consistent with the faster leaf senescence. Higher AT suggests that assimilates that were produced during the vegetative growth stage were transported in a larger proportion to the grain at a time when a large number of seeds were growing. GALLAGHER *et al.*<sup>3)</sup> reported that stems can act as organs for pre-anthesis storage of carbohydrates in cereal crops which can be later remobilized for the development of seeds.

Thus, the larger dry matter accumulation in the F<sub>1</sub> hybrids at early growth stages appears to be an important factor for the stabilization of yield. This experiment indicated the presence of a slightly different type of growth, particularly in the post anthesis phases, in the F<sub>1</sub> plants compared with their parent cultivars. Further experiments with a

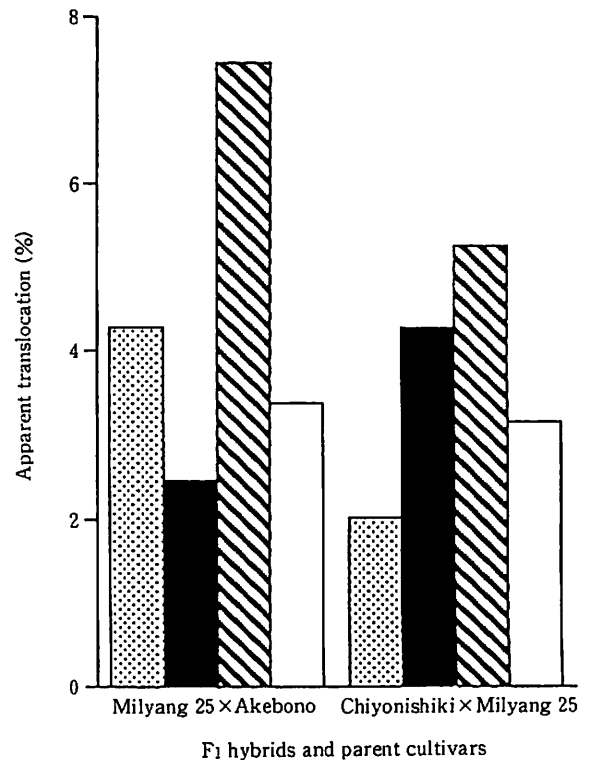


Fig. 5. Apparent translocation in F<sub>1</sub> hybrids and parent cultivars. ▨ female parent; ■ male parent; ▩ F<sub>1</sub> hybrid; □ mid-parent.

wide range of varieties and F<sub>1</sub> cross-combinations under different environmental and ecological conditions may provide more information in this regard.



## References

1. CLEWER, A. G. and D. H. SCARISBRICK 1990 An introduction to the principles of crop experimentation. Wye College (University of London). (London) pp. 93.
2. GALLAGHER, J. N. and P. V. BISCOE 1978 Radiation absorption, growth and yield of cereals. *J. Agric. Sci. Camb.* **91**: 47-60.
3. ———, ——— and R. K. SCOTT 1975 Barley and its environment V. Stability of grain weight. *J. Appl. Ecol.* **12**: 320-355.
4. GOMEZ, K. A and A. A. GOMEZ 1984 Statistical procedure for agricultural research. 2nd edition. John Wiley and Sons, Inc. (New York) pp. 680.
5. GOVINDARAJ, K. and E. A. SIDDIQ 1986. Hybrid vigour in rice with reference to morphophysiological components of yield and root density. *SABRAO J.* **18**: 1-7.
6. JENNINGS, P. R. 1967 Rice heterosis at different growth stages in the tropical environment. *Intl. Rice Comm. Newsl.* **16**: 24-26
7. KABAKI, N., S. AKITA, I. TANAKA and A. AMAMIYA 1976 Photosynthesis and photorespiration of cultivated rice and F<sub>1</sub> hybrid. *Proc. Crop Sci. Soc. Japan* **45** (Extra issue 2): 177-178.
8. KAWANO, K., K. KUROSAWA and M. TAKAHASHI 1969 Heterosis in vegetative growth of the rice plant. *Genetical studies on rice plants. Japan J. Breeding* **19**: 335-342.
9. KHAN, M. N. A., S. MURAYAMA, Y. ISHIMINE, E. TSUZUKI and I. NAKAMURA 1997 Physio-morphological studies of F<sub>1</sub> hybrids in rice (*Oryza sativa* L.) I. Heterosis in characters related to matter production. *Jpn. J. Crop Sci.* **66** (Extra issue 2): 66-67.
10. LIN, S. C. and L. P. YUAN 1980 Hybrid rice breeding in China. *In*: Innovative approaches to rice breeding. Selected papers from the 1979 Intl. Rice Res. Conf. Intl. Rice Res. Inst. (Los Banos) 35-51.
11. MURATA, Y., A. MIYASAKA, K. MUNAKATA and S. AKITA 1968 On the solar energy balance of rice population in relation to the growth stage. *Proc. Crop Sci. Soc. Japan* **37**: 685-691.
12. MURAYAMA, S., T. OMURA and K. MIYAZATO 1974 Basic studies on utilization of hybrid vigour in rice. Heterosis under different cultural conditions. *Japan. J. Breeding.* **24**: 287-290.
13. PONNUTHURAI, S., S. S. VIRMANI and B. S. VERGARA 1984 Comparative studies on the growth and grain yield of some F<sub>1</sub> rice (*Oryza sativa* L.) hybrids. *Philipp. J. Crop Sci.* **9**: 183-193.
14. REYNIERS, F. N., L. TROUNG-BINH, L. JACQUINOT and R. NICOV 1982 Breeding for drought resistance in dryland rice. *In*: Drought Resistance in Crops with Emphasis on Rice. Intl. Rice Res. Inst. (Los Banos) 273-292.
15. SINGH, S. P. and H. G. SINGH 1978 Heterosis in rice. *Oryza* **15**: 173-175.
16. ———, R. P. SINGH and R. V. SINGH 1980 Heterosis in rice. *Oryza* **17**: 109-113.
17. VIRMANI, S. S. 1994 Heterosis and hybrid rice breeding. Springer-Verlag. (London) pp. 189.
18. ———, R. C. CHAUDHARY and G.S. KHUSH 1981 Current outlook on hybrid rice. *Oryza* **18**: 67-84.
19. ——— and I. B. EDWARDS 1983 Current status and future prospects for breeding hybrid rice and wheat. *Adv. Agron.* **36**: 335-42.
20. YOSHIDA, S. 1981 Fundamentals of rice crop science. Intl. Rice Res. Inst. (Los Banos) pp. 269.