MANIFESTATION OF HYBRID VIGOR IN RICE[1]

W. L. Chang, E. H. Lin and C. N. Yang[2]

INTRODUCTION

Over the years, much of varietal improvement in rice has centered around the development of purelines. The improved varieties were generally high yielding and had contributed greatly to the increase of unit yield production of rice in the past years. However, the efficiency of varietal improvement in rice in terms of the percent of newly developed varieties outyielding the standard commercial varieties has been steadily decreasing. For instance, Kariya (1966) has reported that average yield increase of the Norin Number varieties has decreased from 6.8% for those developed during 1931–1941 to only 2.1% for those registered during 1962–1965. Thus, a remarkable improvement in the yielding ability of rice appears unlikely unless more efficient breeding techniques become available. The successful utilization of heterosis may set up a new level of varietal productivity in rice.

Heterosis is but one requisite for commercial production of hybrid rice. Research results indicated that the amount of heterosis exhibited in crosses among varieties and strains of rice varied greatly. Jones (1926) found a distinct vigor in the number of tillers and the yield per plant among four crosses of American varieties. Hsu *et al.* (1969) also reported that F_1 plants produced more grain yield than their respective high yielding parents in 44 out of 90 crosses evaluated. However, Jennings(1967)and Kawano *et al.*(1969) indicated that heterosis in grain yield may not be generally expected under commercial planting of rice where close spacing and heavy application of nitrogen are usually recommended. Before commercial hybrid rice becomes a reality, it is imperative that sufficient hybrid vigor be available through specific parental combinations so that hybrids will produce signif icantly more grain than their conventional varieties. This paper presents results from three-year study of heterosis displayed for several agronomic characters by a group of 265 rice hybrids studied at Chiayi, Taiwan.

MATERIALS AND METHODS

Heterosis in F_1 hybrids of rice was evaluated at the Chiayi Agricultural Experiment Station for six crops from the second crop of 1967 to the first crop of 1970. Various cross

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2. Agronomist and Research Assistants, respectively, Chiayi Agricultural Experiment Station, TARI. The writers wish to express their sincere thanks to Mr. C. H. Huang, Senior Rice Specialist, JCRR for his valuable advice during the course of this experiment.

combinations were made either between local varieties or between local varieties and foreign introductions. The number of crosses evaluated in this experiment is shown in Table 1. Inter-type crosses were excluded from the tests after the first crop of 1969 because seed sterility associated with these hybrids prohibited accurate measurement of hybrid vigor. F_1 hybrids between early and late maturing varieties or between short and tall varieties were also not included in the tests after 1969 to prevent excessive segregation for these traits in the F_2 population since the possiblity of utilizing hybrid vigor in advanced generations of rice is also considered.

Table 1. Number of crosses evaluated.

Crosses between	Second crop 1967	First crop 1968	Second crop 1968	First crop 1969	Second crop 1969	First crop 1970	Total
Early maturing japonica varieties	—	—	—	27	24	13	—
Late maturing japonica varieties	—	—	—	18	28	25	—
Indica varieties	—	—	—	15	29	27	—
Total	22	17	20	60	81	65	265

Field test was conducted separately for early maturing japonica, late maturing japonica, and indica crosses. The F_1 hybrids, parental and check varieties of each group were arranged in either randomized or lattice design with two to three replications. Plot size was 0.5×2.0 m and consisted of 2 rows. The plants were grown at the spacing of 25 $\times 20$ cm with single seedling being transplanted at each hill.

Fertilization was made at the rate of 100, 50, and 50 kg per ha for N, P_2O_5, K_2o respectively. Data for grain yield, yield components, and several important agronomic characters were recorded and their heterosis estimated. Analysis of variance was made for grain yield per plant only in 1969 tests. Correlations between F_1 hybrid and midparental values were calculated for grain yield and heterosis of grain yield. Correlation coefficients for the heterosis of grain yield and its components were also calculated to indicate the association of grain yield and four components of grain yield in F_1 hybrids.

In this experiment, heterosis of F_1 hybrids was expressed in the percentage of (a) the high or more favorable parent, i.e., more productive, earliness, etc., (b) the midparental value, and (c) the standard check varieties. Rice varieties Taichung 180, Tainan 5, and Taichung native 1 were selected to represent standard check varieties for early maturing japonica, late maturing japonica, and indica crosses. Special emphasis was, however, given to the heterosis expressed in the percentage of standard check varieties since the hybrid population will need to exceed the leading commercial varieties in one or more characteristics if hybrid rice is to be very appealing.

EXPERIMENTAL RESULTS

Heterosis for Grain Yield

Average performance of the hybrids, parental and check varieties for grain yield and its four components is presented in Table 2. The 6-crop average grain yield of all F_1 hybrids was equal to the higher yielding parent but the hybrids exhibited advantages of 10.6 and 6.3 % over their mid-parent and standard check varieties, respectively. A summary of the number of hybrids with means above those of their respective higher parents, mid-parent, and check varieties in Table 3 shows that 54.7% of the hybrids had yield higher than better parents while 72.5% of the hybrids outyielded both mid-parent and check varieties. The average heterosis for these outstanding hybrids was 18.6, 20.3 and 19.1% based on the better parent, mid-parent, and check varieties, respectively. Tabulations of the levels of heterosis on an individual cross basis are too voluminous for presentation herein and only several instances of high percentage heterosis in both crops of 1969 and the first crop of 1970 are given in Table 4. It can be seen that each of the hybrids exhibited considerably large amount of heterosis in relation to its mid-parent. Heterotic effects (F_1 minus mid-parent values) of these crosses all reached the 1% level of significance. The heterosis based on higher yielding parent was also substantially high for each cross combination, although the amount of heterosis was somewhat smaller than that based

Table 2. Mean performance of grain yield and its components of F_1 hybrids, parental and check varieties, 1967-70.

	Grain yield (g/plant)	Number of panicle per plant	Number of grains per panicle	Weight of 1,000 grains (g)	Percentage of fertility (%)
Mean of					
High-parent (HP)	30.2	15.8	128.2	22.6	87.5
Mid-parent values (MP)	27.3	14.3	114.8	21.9	84.2
Check varieties (CK)	28.4	14.2	114.7	21.9	83.8
F_1 hybrids	30.2	15.0	117.6	22.3	81.5
F_1 hybrids as					
% of HP	100.0	94.9	91.7	98.7	93.1
% of MP	110.6	104.9	102.4	101.8	96.8
% of CK	106.3	105.6	102.5	101.8	97.3

on mid-parent value. The greatest heterosis was manifested by the cross of IR8 × Liu-tou-tze in the first crop of 1970 which outyielded mid-parent and high parent by as much as 79.1%, respectively. This hybrid also yielded 46.7% more than the commercial variety, Taichung native 1 but the highest percentage increase of 80.4% over the standard check variety was recorded for the cross of Ti-chueh-min-tan × IR 9-60 in the second crop of 1969.

Table 3. Number of F_1 hybrids with heterosis for grain yield and average heterosis shown by these hybrids, 1967–70.

Crop	Number of hybrids tested	Number of hybrids with mean			Mean yield of these hybrids as		
		Above high parent	Above mid-parent	Above check variety	% of HP	% of MP	% of CK
Second crop, 1967	22	6 (27.3)*	15 (68.2)	11 (73.3)	119.5	121.9	106.3
First crop, 1968	17	4 (23.6)	8 (47.1)	10 (58.8)	161.7	131.7	132.2
Second crop, 1968	20	3 (15.0)	8 (40.1)	3 (15.0)	117.1	121.8	123.6
First crop, 1969	60	39 (65.0)	51 (85.0)	55 (91.7)	113.6	116.9	116.6
Second crop, 1969	81	51 (63.0)	61 (75.3)	60 (74.1)	115.8	120.0	122.0
First crop, 1970	65	39 (60.0)	42 (64.6)	40 (61.5)	112.4	119.1	117.2
Total	265	145 (54.7)	192 (72.5)	192 (72.5)	118.6	120.3	119.1

* Number in the parenthesis represents % of the total number of hybrids tested.

Heterosis for Components of Grain Yield

Comparisons of average parent and F_1 hybrid performance for four components of grain yield i. e. number of panicles per plant, number of grains per panicle, weight of 1,000 grains, and percentage of fertility are also shown in Table 2.The average performance of the hybrids for these traits was generally inferior to that of their corresponding better parents but was superior to those of mid-parents and check varieties in 3 out of 4 yield components. The average heterosis expressed by the hybrids for these three components was 4.9, 2.4, and 1.8% in relation to mid-parents and 5.6, 2.5, and 1.8% in relation to standard check varieties for the number of panicles per plant, number of grains per panicle, and weight of 1,000 grains, respectively. The percentage of fertility was the only component of yield that did not show hybrid vigor. Correlation coefficients between heterosis for grain yield and its components all reached a significant level when F_1 hybrids of all six crops were pooled(Table 5). The"r"values obtained between grain yield and the number of grains per panicle, number of panicles per plant, and percentage of fertility were +.4980, +.4206,and +.3714 respectively, whereas correlation coefficient between grain yield and the weight of 1,000 grains was only +.1569. The former three correlation coefficients were significant at the 1% level while the latter one was significant only at the 5% level of probability.

Table 4. F_1 hybrids showing high heterosis for grain yield.

Crop	F_1 cross	Hybrid yield (g/plant)	Mid-parent yield (g/plant)	Hybrid minus mid-parent (g/plant)	Heterosis, % increase over mid-parent	Heterosis, % increase over high parent	Heterosis, % increase over check variety
First	Tainan 5x Line 561111	50.6	34.6	16.0**	46.2	45.8	45.8
crop,	Taichung (N) 1 x CP 231	46.0	27.4	18.6**	67.9	40.2	40.2
1969	CP 231 x Taichung (N) 1	40.4	27.4	13.0**	47.5	23.2	23.2
	IR8 x Taichung (N) 1	39.9	29.5	10.4**	35.3	21.7	21.7
	IR8 x Hsinchu-ai-chueh-chien	39.1	29.9	9.2**	30.8	16.4	19.2
	Taichung 180 x Fukunishiki	38.0	31.6	6.4**	20.3	19.5	19.5
	Taitung 138 x Taichung 180	36.5	32.7	3.8**	11.6	8.6	14.8
Second	Ti-chueh-min-tan x IR 9-60	42.4	27.3	15.1**	55.3	36.3	0.4
crop,	IR 8 x Ti-chueh-min-tan	41.7	30.9	10.8**	35.0	34.1	77.5
1969	IR 8 x IR 9-60	37.4	27.1	10.3**	38.0	22.2	59.2
	IR 9-60 x Saturn	26.7	17.3	9.4**	54.3	13.6	13.6
	C 236 x Tainan 5	25.2	20.1	5.1**	25.4	21.7	29.9
	C 223 x Taichung 65	25.1	18.5	6.6**	35.7	19.5	29.4
	C 236 x Hsinchu 61	24.3	19.1	5.2**	35.9	28.0	36.6
	Taichung 186 x Yachikogane	18.1	12.2	5.9**	48.3	44.4	29.2
	Taichung 186 x BC-68	17.8	11.6	6.2**	53.4	41.7	26.8
First	IR8 x Liu-tou-tze	58.4	32.6	25.8**	79.1	75.9	46.7
crop,	Taichung (N) 1 x IR8	47.4	35.9	11.5**	32.0	19.1	19.1
1970	Taichung 122 x C-early-1	45.4	37.6	7.8**	20.7	16.4	28.3
	Tainan 1 x Tainan 3	45.3	37.5	7.8**	20.8	12.1	28.0
	Taichung 122 x Hsinchu 61	44.0	35.6	8.4**	23.6	21.9	24.3
	Ti-chueh-min-tan x C230	41.5	30.5	11.0**	36.1	8.1	4.3
	Line 54233 x Taichung 180	40.7	31.9	8.9**	27.6	18.0	38.9
	Taichung 180 x Line 54233	40.2	31.9	8.3**	26.0	16.5	37.2

**Significant at 1% level.

Table 5. Simple correlation coefficients of heterosis between grain yield and its components of F_1 hybrids, 1967–70.

Crop	D.F.	Grain yield and panicles per plant	Grain yield and grains per panicle	Grain yield and 1,000-grain weight	Grain yield and fertility percentage
Second crop, 1967	26	0.6355**	0.3591	0.0554	0.0271
First crop, 1968	15	0.2269	0.8210**	0.0775	0.7112**
Second crop, 1968	18	0.7119**	0.7531**	0.6338**	−0.1464
First crop, 1969	58	0.6178**	0.1562	0.3119*	−0.1253
Second crop, 1969	79	0.5901**	0.5796**	0.0336	0.4918**
First crop, 1970	63	0.3925**	0.4707**	0.3659**	0.0956
All six crops	263	0.4206**	0.4980**	0.1569*	0.3714**

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

Relationship Between Parental Performance and Hybrid Performance

Correlation coefficients between the grain yields of mid-parent and the hybrid, between the grain yield of mid-parent and heterosis for grain yield of the hybrid, and between the hybrid yield and its heterosis are shown in Table 6. Heterosis is expressed as a percentage of the mid-parent value. Correlation coefficients between the grain yields of mid-parent and the hybrid were significant in 3 out of 6 crop seasons. However, when pooled data of 6 crop seasons were considered, the correlation coefficient was significant at the 1% level, indicating that a close relationship exists between the parental performance *per se* and the performance of their hybrids. Correlation coefficients between the grain yield of mid-parent and heterosis for grain yield of the hybrid were mostly negative and attained significance in 3 out of 6 crops, suggesting that the percent increase in yield over the mid-parent of the hybrids tends to decrease as average yield of the mid-parent increases. This, of course, is expected if the actual amount of heter osis on a gram of grain per plant basis for the hybrid remains fairly constantrover a range of yield levels for the mid-parent. A close relationship was also observed between the hybrid yield and its heterosis as indicated by highly significant correlation coefficients. It appears, therefore, that high level of grain yield of F_1 hybrids is likely to accompany relatively large amount of heterosis.

Table 6. Simple correlation coefficients between yield performance of mid-parents and their hybrids, 1967-70.

Crop	D.F.	Mid-parent yield and yield of F_1 hybrids	Mid-parent yield and heterosis for yield of F_1 hybrids	Yield of F_1 hybrids and heterosis for yield of F_1 hybrids
Second crop, 1967	20	0.4366*	− 0.4173	0.6180**
First crop, 1968	15	− 0.0115	− 0.5066*	0.8409**
Second crop, 1968	18	0.6176**	− 0.2363	0.6080**
First crop, 1969	58	0.2457	− 0.5750**	0.6445**
Second crop, 1969	79	0.8496**	0.2247*	0.6931**
First crop, 1970	63	0.1000	− 0.3505**	0.7857**
All six crops	263	0.8326**	− 0.0735	0.4662**

*Significant at the 5% level. **Significant at the 1% level.

Comparison of F_1 Hybrids and Parents for Grain Yield

In this experiment, yield comparison of F_1 hybrids and parents was based on the yield data obtained in the first and second crops of 1969. A part of the analyses of variance pertinent to the heterosis is given in Table 7. It was observed that differences in grain yield of various F_1 hybrids and parents were highly significant. In order to find out

Table 7. Analysis of variance for grain yield of F_1 hybrids and their parents, 1969.

Crop	Source of variation	Early maturing japonica		Late maturing japonica		Indica		Pooled	
		D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
First	Entries	40	53.84**	28	60.98**	23	80.59**	93	72.00**
	F_1 vs. P	(1)	474.68**	(1)	169.19**	(1)	841.41**	(1)	1,252.39**
	F_1 vs. HP	(1)	1.43	(1)	26.53	(1)	257.52**	(1)	135.63**
	F_1 vs. CK	(1)	49.31*	(1)	78.39	(1)	78.34*	(1)	179.14**
	Residuals	(37)	44.01	(25)	57.34	(20)	33.81*	(90)	56.99**
	Error	80	11.71	56	35.59	46	17.35	186	21.48
Second	Entries	44	20.60**	50	32.01**	52	210.09**	148	134.03**
	F_1 vs. P	(1)	1.23	(1)	427.74**	(1)	1,274.89**	(1)	1,200.77**
	F_1 vs. HP	(1)	7.61	(1)	27.09	(1)	31.74	(1)	24.06
	F_1 vs. CK	(1)	2.83	(1)	17.67	(1)	32.91	(1)	60.94*
	Residuals	(41)	21.82**	(47)	24.13**	(49)	195.61**	(145)	127.94**
	Error	88	3.50	100	8.37	104	15.79	296	9.58

*Signficant at 5% level. **Signficant at 1% level.

whether grain yield of the hybrids was significantly different from those of parents and standard check varieties, single degrees of freedom associated with F_1 hybrids vs. parents,

F_1 hybrids vs. high parents, and F_1 hybrids vs. check varieties were partitioned from the variation among entries. The yield difference of F_1 hybrids vs. parents attained significance except for early maturing japonica group in the second crop of 1969 while that of F_1 hybrids vs. high parents was significant only for indica group in the first crop of 1969. The differences in grain yield of F_1 hybrids vs. check varieties were significant in the early maturing japonica and indica groups in the first crop of 1969. However, when three varietal groups were pooled together, all comparisons were significant except that of F_1 hybrids vs. high parents in the second crop of 1969.

Comparison of reciprocal crosses for grain yield was also made in the first crop of 1969 for the purpose of finding out whether there was a significant difference between each of F_1 hybrids and its reciprocal cross. The results are presented in Table 8. It was found that mean squares associated with reciprocal crosses all failed to reach a significant level, indicating that there was no evidence of maternal effect on the expression for the grain yield of F_1 hybrids. Thus, a given variety may serve equally well either as male or as female parent.

Table 8. Analysis of variance for reciprocal effect of grain yield of F_1 hybrids, first crop, 1969.

Source of variation	Early maturing japonica		Late maturing japonica		Indica		Pooled	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Hybrids	19	41.44**	11	51.02	11	31.88	43	44.32**
Reciprocals	(1)	1.74	(1)	7.94	(1)	6.77	(1)	3.74
Residuals	(18)	43.64**	(10)	55.33	(10)	34.41	(42)	45.28*
Error	38	16.98	22	49.43	22	20.30	86	27.42

* Significant at 5% level.

** Significant at 1% level.

Heterosis for Grain Yield Under Different Crop Seasons

Data on the amount of heterosis averaged over all entries at the different crop seasons are presented in Table 9. Heterosis is expressed both as the difference between yields of the hybrid and the mid-parent value on a gram of grain per plant basis and as percentage of the mid-parent value. Examination of heterosis expressed on a gram per plant basis revealed that larger heterosis occurred in the first rather than in the second crop. The average actual increase of the hybrids over the mid-parent was 3.7and 2.0 grams per plant respectively for the first and second crops, indicating that average heterosis in the first crop was 85% higher than that of the second crop. When heterosis is expressed on a percentage basis, however, there was a marked tendency for the hybrids to have similar level of heterosis in different crop seasons. The average percentage increase for the first and second crops was 11.1 and 9.7% respectively with a difference of only 1.4%

in the magnitude of heterosis between the two crop seasons. In other words, average heterosis in the first crop was only 14% higher than that of the second crop.

Table 9. Average heterosis for grain yield at different crop seasons, 1967–70.

Crop	Hybrid yield (g/plant)	Mid-parent yield (g/plant)	Hybrid minus mid-parent (g/plant)	Heterosis, %increase over mid-parent
Second crop, 1967	25.8	23.1	2.7	11.7
First crop, 1968	24.2	24.1	0.1	0.4
Second crop, 1968	23.0	23.2	− 0.2	− 0.9
First crop, 1969	37.6	33.7	3.9	11.6
Second crop, 1969	21.6	19.2	2.4	12.5
First crop, 1970	40.6	35.9	4.7	13.1
Mean of first crop	36.9	33.2	3.7	11.1
Mean of second crop	22.6	20.6	2.0	9.7

Heterosis for Major Agronomic Traits

The heterosis of five important agronomic characters is shown in Table 10. It can be seen that the greatest heterosis was exhibited by the leaf area index (LAI) measured at heading stage. The average heterosis for LAI was 1.4, 14.5, and 22.0% in relation to the high-parent, mid-parent, and standard check varieties, respectively. The manifestation of heterosis for LAI was more pronounced in the first than in the second crop. The average increase of the hybrids over the mid-parent for LAI was 18.1 and 11.5%, respectively for the first and second crops (Table 11) . However, the correlation coefficients given in Table 11 indicated that the LAI value was more closely associated with grain yield of the hybrids in the second than in the first crop. Correlation between LAI and grain yield gave"r" values of +.1902 and +.7467 for the first and second crops, respectively. The coefficient for the first crop failed to reach a significant level but that for the second crop was significant at the 1% level. When data of all five crops were pooled, a highly significant correlation coefficient was also obtained.

Table 10. Mean performance for major agronomic traits of F_1 hybrids, parental and check varieties, 1967–70.

	LAI*	Days to heading	Plant height (cm)	Panicle length (cm)	Panicle weight (g)
Mean of					
High-parents (HP)	4.44	74.1	108.0	21.6	2.80
Mid-parent values (MP)	3.93	76.7	100.7	20.5	2.50
Check varieties (CK)	3.69	79.7	102.3	20.3	2.50
F_1 hybrids	4.50	74.6	104.4	20.8	2.56
F_1 hybrids as					
% of HP	101.4	100.7	96.7	96.3	91.4
% of MP	114.5	97.3	103.7	101.5	102.4
% of CK	122.0	93.6	102.1	102.5	102.4

*Average of five crops, 1967–69.

The heterosis for days to heading is expressed by an earlier heading date in comparison with mid-parent and check varieties. On the average, heading date of the hybrids was very similar to that of the earlier parents but it was 2 and 5 days earlier than the mid-parent and standard check varieties, respectively. For mature plant height, panicle length and panicle weight, the hybrids had no advantage over the high parental values but they expressed heterosis for these three characters in relation to mid-parent and check varieties, although the advantage for these characters was less significant than that for the LAI.

Table 11. Average heterosis for LAI and correlation between LAI and grain yield, 1967–69.

Crop	Heterosis			Correlation	
	Hybrid LAI	Mid-parent LAI	Heterosis, % of MP	D.F.	r
Second crop, 1967	3.19	3.05	104.6	20	0.4837*
First crop, 1968	6.32	4.82	131.1	15	0.1381
Second crop, 1968	3.72	3.73	99.7	18	0.8100**
First crop, 1969	5.53	4.86	113.8	58	0.4453**
Second crop, 1969	3.83	3.30	116.1	79	0.7271**
First crops pooled	5.73	4.85	118.1	75	0.1902
Second crops pooled	3.70	3.32	111.5	121	0.7467**
All 5 crops	4.50	3.93	114.5	198	0.4810**

*Significant at the 1% level. **Significant at the 5% level.

Heterosis Expressed at Different Stages of Growth

The performance of the hybrids was compared with their respective mid-parents at three stages of rice growth i.e. late tillering stage (50 and 40 days after transplanting in the first and second crops respectively) , heading stage, and maturity stage. A summary of the number of hybrids showing heterosis for plant height and number of tillers per plant based on mid-parent values is presented in Table 12. The hybrid advantage was equally evident at three growth stages for plant height and number of tillers per plant. The average percentages of F_1 hybrids showing heterosis for plant height and tiller number were 73.6, 72.8, 66.4 and 67.6, 62.3, 67.6% at late tillering, heading, and maturing stages respectively, indicating that the manifestation of heterosis was not greatly affected by the stage of rice development.

Table 12. Number of F_1 hybrids with heterosis for plant height and number of tillers per plant based on mid-parent at different growth stages, 1967-70.

Crop	Number of hybrids tested	Plant height			Number of tillers per plant		
		Late tillering	Heading	Maturity	Late tillering	Heading	Maturity
Second crop, 1967	22	17 (77.3)*	15 (68.2)	10 (45.5)	14 (63.6)	12 (54.6)	12 (54.6)
First crop, 1968	17	15 (88.2)	9 (52.9)	8 (47.1)	13 (76.5)	13 (76.5)	15 (88.2)
Second crop, 1968	20	18 (90.0)	8 (40.0)	11 (55.0)	7 (35.0)	5 (25.0)	5 (25.0)
First crop, 1969	60	42 (70.0)	45 (75.0)	33 (55.0)	37 (61.7)	39 (65.0)	43 (71.7)
Second crop, 1969	81	59 (72.8)	67 (82.7)	66 (81.5)	58 (71.6)	58 (71.6)	57 (70.4)
First crop, 1970	65	44 (67.7)	49 (75.4)	48 (73.9)	50 (76.9)	38 (58.5)	47 (72.3)
Total	265	195 (73.6)	193 (72.8)	176 (66.4)	179 (67.6)	165 (62.3)	179 (67.6)

* Number in the parenthesis represents % of the total number of hybrids tested.

DISCUSSION

The data obtained in this experiment indicate that certain hybrids are clearly superior in grain yield to both the higher yielding parents and the standard checks represented by leading commercial varieties. Although average heterosis exhibited by the hybrids may vary with cross combinations, a conservative estimate of the magnitude of this superiority might range from 10 to 20%. Since comparisons between hybrids and their respective parents as well as check varieties were carried out under growing conditions of close spacing (20 hills per m^2) and heavy fertilization (100, 50, and 50 kg per ha of N, P_2O_5 and K_2O, respectively) , the results of this experiment also demonstrate that substantial amount of heterosis could be obtained under intensive cultural practices used for growing rice commercially in Taiwan. These results are generally in agreement with those reported by

Hsu *et al.* (1969) but contrast with the findings of Jennings (1967) and Kawano *et al.* (1969). However, it should be pointed out that yield data were based on individual plants rather than whole plots as in the case of ordinary yield trials and the number of plants sampled for each cross combinations were also relatively small. It appears likely, therefore, that the performance of the hybrids could have been either over- or under-estimated in this experiment.

For a highly self-fertilized species such as rice (*Oryza sativa L.*), two requirements are generally considered necessary for a successful commercial production of F_1 hybrid. The first requirement is that significant heterosis in grain yield must have been demonstrated to occur in F_1 hybrid populations and the second requirement is that techniques must be available for economically producing large quantities of hybrid seeds. It has been shown in Table 4 that certain hybrids significantly outyielded their parents and heterosis expressed in the percent increase over their parents and check varieties was substantially high, suggesting that the first requirement for commercial production of hybrid rice could be fully satisfied. As for the second requirement, no techniques is currently available for economically producing large quantities of F_1 seed for rice. However, it is fortunate that materials for cytoplasmic male sterility and genetic restoration of fertility have already been found in rice. It appears, therefore, that hybrid rice will sooner or later become practical on a commercial scale. Before hybrid rice being actually developed, the use of heterosis in F_2 populations of rice seems to be another promising way. Preliminary results so far obtained at this Station on the performance of F_2 populations are generally encouraging. Furthermore, F_2 seeds can also be rapidly increased by the vegetative propagation of F_1 plants (Chang *et al.*, 1971) which may considerably reduce the cost of seed production.

It was observed that among four components of grain yield, the hybrids seem to have the advantage of producing more number of panicles per plant and more number of grains per panicle, but there was no pronounced effect on the weight of 1,000 grains and the percentage of fertility. Correlation coefficients of heterosis between grain yield and each of its components also indicated that the number of grains per panicle and the number of panicles per plant were the components most highly associated with grain yield. This suggests that heterosis for grain yield in F_1 hybrids of rice depends largely on the hybrid vigor manifested for number of panicles per plant and number of grains per panicle. As most ponlai rice varieties are rather weak in their tillering ability, any increase in the number of panicles per plant (or hill) will undoubtly result in the increase of grain yield in rice. From this standpoint, hybrid advantage shown for number of panicles per plant is highly encouraging. The degree of heterosis exhibited by the number of grains per panicle appeared slightly lower than that expressed by the number of panicles per plant. This may be due largely to the fact that most ponlai rice varieties are associated with relatively large panicles. Kawano *et al.*(1969) also reported that majority of the F_1 hybrids had larger number of panicles per plant than mid-parent. The highly significant correlation coefficients between grain yield and number of panicles per plant as well as number of grains per panicle may also be of value in determining useful avenues for indirect

selection of grain yield for the hybrids.

The correlation coefficient between yields of mid-parent and the hybrids (+.8326) was highly significant as the data of all six crops were pooled. This coefficient was of a high value and would transpose to a high coefficient of determination accordingly. This suggests that parental values could be effectively used as a criterion for the prediction of hybrid performance for grain yield. It appears likely that little is to be gained from testing hybrids in which one or more of the parents are clearly inferior in yield to the standard check varieties with which they would be compared. Preliminary screening of materials for potential hybrids might depend entirely on the basis of the performance of the varieties or strains. Of course, potential parents must perform at acceptable levels for other important economic traits if the hybrids can be commercially accepted. This procedure would permit the elimination of a large amount of undesirable parental materials and thus avoid the necessity of testing numerous cross combinations. It should be pointed out, however, that the correlation between mid-parent values and the hybrid performance is obviously less than unity. It has been suggested that average heterosis and the mean square for parents vs. hybrids may serve as measures of nonadditive gene effects (Kirby and Atkins, 1968) . Thus, significant mean squares for the parents vs. hybrids component in Table 7 plus sizable heterosis value for the grain yield may indicate that nonadditive gene effects also played an important role in the expression for grain yield. Obviously, the performance of the parental varieties or strains themselves might not be sufficient to insure the production of superior yielding hybrids. This should be supplemented by thorough evaluation of individual cross combinations for specific combining ability. Frequently, two cultivars of a specific combination may nick especially well to result in an exceptionally high yielding F_1 hybrid.

The finding that the hybrids exhibited less heterosis for grain yield in the second crop was somewhat surprising. The hybrids are generally considered to have greater adaptability than their homogeneous parental varieties. Thus, the hybrids are likely to perform better than their parents under less optimum environments. Present data indicate, however, that greater heterotic effect was observed in the first rather than in the second crop season. In Chianan district of Taiwan where this Station is located, environmental conditions in the first crop season are usually more favorable for rice production than in the second crop season. It appears, therefore, that greater heterosis for grain yield may occur when the hybrids are grown under conditions approaching a more optimum environment for high yield. It should be noted, however, that when heterosis is expressed as a percentage of mid-parent value instead of actual increase in grams per plant, the difference in advantage for the hybrids between the two crop seasons tended to become smaller. For instance, average heterosis in the first crop was 85% higher than that in the second crop when heterosis is expressed on a gram per plant basis, but it was only 14% higher in the first than in the second crop if expressed on a percentage basis. This emphasizes the need for careful interpretation of heterosis data expressed on a percentage basis.

It is of interest to note that substantial amount of heterosis for leaf area index(LAI) occurred at heading stage. Under recommended levels of spacing and fertilization for

commercial production of rice in Taiwan at the present time, grain yield usually increases with the increase in LAI value especially in the second crop season when LAI tends to become smaller (Chang, 1968) . This indicates that hybrid advantage for LAI at heading stage may have contributed greatly to the expression of heterosis for grain yield in this experiment. Jennings (1967) reported that the absence of heterosis for grain yield in the tropical environment was due largely to the extremely vigorus vegetative development of the hybrids during the early growth stage, resulting in excessive mutual shading which retarded net assimilation and also reduced the amount of storage products available for translocation to the grain after flowering. The situation in Taiwan is apparently different from that of the tropical countries. Mutual shading seldom constitutes a serious problem for the improved varieties provided that the recommended cultural practices are followed. On the contrary, low LAI has been identified as one of the main causes for low yield in the second crop season (Lian *et al.*, 1969) . It becomes apparent that heterosis for LAI could greatly enhance the yielding potential of the hybrids. The correlation between LAI and light transmission ratio (LTR) at heading stage gave "r" value of +.0049 for the hybrids in the first crop of 1969, showing that the transmission of light may not be affected by increased LAI of the hybrids.

In Taiwan, a farming practice of growing one or more upland crops between two rice crops on the same piece of land during a single year has been widely adopted by farmers. As successful operation of this multiple cropping system depends largely on the growing of early maturing rice varieties, the finding that the hybrids headed earlier than both the earlier parents and the commercial check varieties was highly encouraging. The successful utilization of the hybrids would make it possible to grow more upland crops which are otherwise difficult to fit into the multiple cropping system. It was also noted that the plant height of the hybrids was taller than shorter parents or check varieties. Heterosis for plant height may contribute to the yield increase for the hybrids between semi-dwarf cultivars. However, when parental varieties with plant height exceeding 110 cm are involved, hybrid advantage for plant height might bring in the problem of lodging because plant height is negatively correlated with lodging resistance factor (Chang, 1967) . Careful selection of parental materials based on plant height appears to be necessary.

SUMMARY

The manifestation of heterosis for grain yield, yield components and several important agronomic characters by a group of 265 F_1 hybrids of rice over a six-crop period from the second crop of 1967 to the first crop of 1970 are reported. Among 265 F_1 hybrids evaluated, a total of 192 or 72.5% of the total hybrids outyielded their mid-parent and check varieties while grain yield of 145 or 54.7% of the hybrids exceeded their respective high-parent. The average heterosis for these outstanding F_1 hybrids was 20.3, 19.1 and 18.3% in relation to mid-parent, check varieties and high-parent, respectively. However, the magnitude of hybrid advantage over the mid-parent and check varieties reduced to 10.6 and 6.3% respectively when the average data of the six crops were considered. The superiority of F_1 hybrids over high-parent was also reduced to nil when averaged over all

entries. The number of panicles per plant and the number of grains per panicle were found to be the most important components associated with the manifestation of heterosis for grain yield.

The correlation coefficient between mid-parent yield and yield of the hybrids was large enough to indicate that mid-parent value would be highly effective indicator of hybrid performance. However, mean square associated with F_1 hybrids vs. parents also attained significance in some cases. There was no evidence of maternal effect on the grain yield of the hybrids.

The heterosis expresses for grain yield in the first crop was generally larger than that in the second crop. F_1 hybrids also exhibited large leaf area index, earlier heading, taller plant, longer and heavier panicle in comparison with mid-parent and check varieties. The expression of heterosis for plant height and number of tillers per plant was not affected appreciably by the stages of rice growth.

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水稻雜種優勢之表現

張萬來、林恩輝、楊建南

摘　要

本文係報告自民國56年第2期作至民國59年第一期作觀察265個 F_1 雜種對稻谷產量，產量構成因素，及其他主要農藝性狀所表現雜種優勢之結果。在供試F_1中，有192個或 72.5%之F_1，其稻谷產量超過中間親本及標準對照品種，其平均雜種優勢分別爲20.3與19.1%。又有145個或 54.7% F_1，其稻谷產量超過高產量親本，其平均雜種優勢爲18.3%。惟全部供試F_1之平均雜種優勢只分別超過中間親本及對照品種 10.6與6.3%，而對高產量親本則未見呈現絲毫雜種優勢。在產量構成因素中，以每株穗數及每穗粒數兩性狀對稻谷產量雜種優勢之表現，貢獻最大。

中間親本產量與F_1產量之間，其相關係數數值頗大，顯示可以中間親本之數值作F_1產量表現之初步推測，惟若干親本對F_1之均方和亦達顯著水準。正反交對F_1產量似無太大之影響。

F_1稻谷產量之雜種優勢，第1期作者較第2期作爲優。F_1在葉面積指數，生育日數，株高，穗長與穗重等性狀，對中間親本及對照品種而言，亦均顯示不同程度之雜種優勢。不同生育時期對株高及每株分蘖數之雜種優勢表現，似無太大之影響。