INTERACTION BETWEEN RICE VARIETIES

By SUBODH KUMAR ROY
Indian Statistical Institute, Calcutta-35

INTRODUCTION

This is a preliminary account of a biological fact which will require a great deal of further research to explain, but may prove of considerable economic value before it is explained. Gustafsson (1953) sowed mixtures of pure lines of barley, and determined the yields of the mixtures. His best result (with Maja and Bonus) was a gain of 5·5% over the mean yield of the two varieties which were mixed, and of 2·4% over that of the better of the two. He obtained more striking gains with heterozygotes, but these would not be of much practical value. Sakai (1957), Sakai and Utyamada (1957) and Oka and Sakai (1956) have published results on rice, but these have demonstrated competition rather than cooperation.

Rice is particularly well adapted for experiments of this type owing to its peculiar ecology. In India the rice cultivated is *Oryza sativa*, var. *indica*. The variety or subspecies *japonica*, which gives higher yields per acre in temperate climates than var. *indica* in India, is not successful in India. The usual procedure in India, which was followed in the experiments described, is as follows. The seed is sown in a seed bed at densities about 1·5 lbs per 100 sq. ft. The seedlings of *aus* paddy are transplanted at the age of about 21 to 28 days, and those of *aman* at about 28 to 35 days. It is thus easy to plant them alternately in rows, in alternate rows, and so on. The rice fields are flooded, the water being retained by earth dams or bunds. The depth in these experiments varied from about 30 to 45 cm. The bunds may be cut and the field drained, or the water may be allowed to dry up shortly before harvesting.

Some 400 more or less pure lines are recommended by different rice research stations in India, adapted to different soils, climates, and times of year. Those used by me can be divided into autumn rices not requiring a long night for flowering, called *aus* in Bengali, and winter rices requiring a long night, called *aman*. The latter are more important.

Preliminary pilot experiments were carried out at Giridih in south Bihar in 1958. As they gave a hopeful result they were continued in 1959 on a much larger scale at Giridih, at two localities in West Bengal, and at Model Agronomic Farm, Karamana, near Trivandrum, in Kerala. Unfortunately there was very heavy rain at the end of September causing disastrous floods in West Bengal, and somewhat less serious ones in Bihar. Thus the results obtained over most of the area were of little value.

I shall first describe the experiment of 1958 at Giridih in some detail. Three winter (*aman*) varieties, 36 BK BR7, 498-2A BR8, and Bank-35 Randhani Pagal were chosen because they can readily be distinguished when ripe. For the sake of convenience these varieties will be described as BK, 2A and RP respectively. The results are given in Table 1, and condensed in table 2. In this Table yields* per unit area are given. Thus 574·0, the yield of 2A in the presence of BK, is twice the observed yield of 287·0 given in Table 1. The monsoon was delayed, and this may account for the poor performance of RP in pure stand. It is worth pointing out that it sells at a higher

Table 1. *Summary of experiments of 1958*

Treatment No.	Treatment Description	Yield (Dry wt. in tola for blocks) I	II	III	Total	Total yield for two varieties combined
1	BK	175·4	184·5	193·1	553·0	
2	2A	193·2	166·3	210·8	570·3	
3	RP	115·0	133·3	72·5	320·8	
4	BK	122·5	133·9	102·3	358·7	645·7
	2A	89·1	80·9	117·0	287·0	
5	BK	132·9	84·9	193·0	410·8	484·7
	RP	24·3	26·6	23·0	73·9	
6	2A	145·7	97·0	129·0	371·7	409·5
	RP	6·5	15·1	16·2	37·8	

Table 2. *Yields per unit area, 1958*

		Variety competing or cooperating 2A	BK	RP
Variety yielding grains	2A	570·3	574·0	743·4
	BK	717·4	553·0	821·6
	RP	75·6	147·8	320·8

price per unit weight than the others. It is also clear that it suffered severely when planted along with the other varieties. Let us first determine the significance of the increased yields of the BK and 2A mixtures. They were grown in separate seed beds. Each was planted out in pure stand, and in the mixed plots four plants, two of each variety, were planted together in a small "hill" as close as practicable. They were harvested separately.

In the three replications the sums of the yields of BK and 2A were 368·6, 350·8 and 403·9. Twice the total yields of the mixed plots in the same blocks were 423·2, 429·6, and 438·6. These are the yields for an area equal to two plots. The gains were 54·6, 78·8, and 34·7. The mean gain is 56·0. Applying Student's test we find $t = 4{\cdot}40$

* 1 tola = 11·664 gm

for 2 degrees of freedom. This gives P=·024. However this value may be deceptively low, since it is based on the assumption that the gains are sampled from a normal distribution. It will be seen that the gain over the mean of the two varieties was 15·0%, over the better yielding of them 13·2%. Here and throughout I have based tests of significance on the mean of the differences within blocks, divided by the variance of these differences, not on the difference of means divided by the variance of the plot yields. This is because the blocks were chosen so as to minimize the differences of soil within each block, this causing considerable differences between blocks. This is very clear in Table 4. A test of significance based on the variance of the two sets of three blocks compared gives $t_4=3{\cdot}41$, P=·014. In this particular case the significance is increased. But for the reason given I think the higher value of P is more reliable.

In order to get an idea of the nature of the interaction the ears were counted. The results are given in Tables 3 and 3a. In Table 3a the figures for numbers of ears and grain have been doubled in the mixed plots, so as to make them comparable with those in the unmixed plots. We see that the yield of BK per ear varied little. The increased yields of this variety were due to its producing more ears. On the other hand 2A in presence of BK produced fewer ears, but a much higher yield per ear, while in presence of RP it merely produced more ears. The effect of competition on RP was to reduce the number of ears and the yield per ear about equally. It has been suggested that the cooperative effect is due to cross-pollination. This could conceivably account for the higher yield of 2A (though the results of 1959 make this impossible). It could not account for the higher yield of BK.

As a result of this experiment, it was decided to repeat it next year in West Bengal and Kerala as well as Bihar, and to try comparable experiments on a number of other varieties. However the actual methods of mixture were rather different.

Table 3. *Yields in ears, 1958*

Treatment No.	Treatment Description	Yield (no. of ears) for blocks I	II	III	Total	Total yield mixed plots
1	BK alone	1147	1144	1197	3488	
2	2A alone	1088	979	1152	3219	
3	RP alone	1088	1133	889	3110	
4	BK mixed	753	761	613	2127	3531
	2A mixed	456	417	531	1404	
5	BK mixed	892	681	1011	2584	3568
	RP mixed	322	377	285	984	
6	2A mixed	771	679	765	2215	2934
	RP mixed	160	276	283	719	

Table 3a *Comparison ear and grain yield, 1958*

Variety	Mixed with	Ears/Plot	Grain/Plot	Grain/Ear
BK	BK	3488	553·0	·159
BK	2A	4254	717·4	·169
BK	RP	5168	821·6	·159
2A	2A	3219	570·3	·177
2A	BK	2808	574·0	·204
2A	RP	4430	743·4	·168
RP	RP	3110	320·8	·103
RP	BK	1968	147·8	·075
RP	2A	1438	75·6	·053

The Experiment of 1959 at Giridih with 36BK BR7 and 498 2A-BR8

The experiment was originally planned as follows. Three "fields", 27, 28, and 85, were used. Each was divided into four blocks. The blocks were chosen so as to have as homogeneous soil conditions as possible within each. Each block was divided into 6 plots, each plot being of ·01 acre (1 cent, 0·4 are). The plots were separated by dams (bunds) of earth. The six plots in a block were treated as follows:

(1) Planted with BK.
(2) Planted with 2A.
(3) Planted with a mixture of equal numbers of plants of these varieties, transferred from separate seed beds.
(4) Planted with a mixture, derived from approximately equal numbers of seeds of the two varieties mixed in the seed bed.
(5) Planted with equal numbers of plants of the two varieties in alternate rows.
(6) One half planted with 10 rows of BK, the other with 10 rows of 2A.

In (5) and (6) the two varieties were harvested separately.

It will be seen that plots 3 to 6 can be graded in order of increasing association of the plants in space and time, as 6, 5, 3, 4. The order of the plots in the blocks was a random one. In plots 5 and 6 the rows were harvested separately.

Unfortunately field 28, containing blocks V, VI, VII, and VIII, was severely damaged by floods. The yields are given in Table 4, but I believe that the values obtained in the other eight blocks are much more reliable, and most of the analysis which follows is based on them. These results are summarized in Table 5. It will be seen that all the mixtures gave an increased yield, both in the total for the unflooded areas, and in the grand total, and that in each of these totals the method of planting in alternate rows was the most successful. Let us analyse its results in more detail. Table 6 shows the figures obtained for the two varieties of rice separately and jointly. The column for increased yield of BK is twice column 4 minus column 2, and so on. Let us consider the significance of these gains. It is certainly justifiable to consider the gains in each plot separately, for there were considerable differences between plots. For example Block XII, which was comparatively newly reclaimed, gave uniformly poor yields. Student's test of significance involves the supposition that the increases in the last three columns are samples from normal distributions. We can use a test which is sometimes

Table 4. *Total yields of plots in 1959 at Giridih*

Block	BK alone	2A along	Mixed in field	Mixed in seed bed	Alternate rows	Half plots	Mean BK & 2A
I	515·0	792·0	705·5	728·0	738·5	714·4	653·5
II	749·0	709·5	764·0	827·5	791·5	788·4	729·2
III	734·0	596·5	866·0	767·0	777·5	784·1	665·2
IV	757·0	671·0	500·5	723·0	768·0	644·1	714·0
IX	718·0	603·5	793·0	718·0	771·5	709·0	660·8
X	438·5	493·0	659·5	698·0	733·0	738·4	465·8
XI	543·5	387·0	344·0	337·5	613·0	529·8	465·2
XII	383·0	112·5	418·0	484·0	598·2	153·4	247·8
Total	4838·0	4365·0	5050·5	5283·0	5791·2	5061·6	4601·5
V	630·5	869·5	745·2	796·7	634·5	796·5	750·0
VI	699·0	787·1	805·5	789·0	808·5	789·5	743·0
VII	649·8	698·2	769·3	720·4	774·5	812·9	674·0
VIII	659·1	628·2	673·4	303·0	510·6	463·1	643·7
Grand Total ..	7476·4	7348·0	8043·9	7892·1	8519·3	7923·6	7412·2

Table 5. *Summary of results at Giridih in 1959*

a. *Unflooded areas*

Treatment	Total grain yield tolas/·08 acre	% Gain over mean	% Gain over BK
1. BK alone	4838·0		
2. 2A alone :	4365·0		
3. Mixed during transplantation ..	5050·5	9·8	4·4
4. Mixed in seed bed	5283·5	14·8	9·2
5. In alternate rows	5791·2	25·9	19·7
6. In half-plots	5061·6	10·0	4·6

b. *Sum of unflooded and flooded areas*

Treatment	Total grain yield tolas/·12 acre	% Gain over mean	% Gain over BK
1. BK alone	7476·4		
2. 2A alone	7348·0		
3. Mixed during transplantation ..	8043·9	8·5	7·6
4. Mixed in seed bed	7892·1	6·5	5·6
5. In alternate rows	8519·3	14·9	11·5
6. In half plots	7923·6	6·9	6·0

c. *Yields of the two varieties in the unflooded areas*

		% Gain over same variety
BK in alternate rows (×2)	5617·0	16·1
2A in alternate rows (×2)	5965·4	36·7
BK in half plots (×2)	5174·8	7·0
2A in half plots (×2)	4948·4	13·4

d. *Significance of differences in unflooded areas*

Comparison	t_7	P
Mixture at transplantation vs. mean ..	1·02	·17
Mixture in seed bed vs. mean	2·00	·043
Alternate rows vs. mean	3·98	·0029
Half-plots vs. mean	1·41	·10
Alternate rows vs. mixture at transplantation	2·69	·016
Alternate rows vs. mixture in seed bed ..	1·86	·053
Alternate rows vs. half-plots	1·72	·058
BK vs. 2A	1·06	·16
BK pure vs. BK in alternate rows ..	2·24	·030
BK pure vs. BK in half plots	0·74	·24
2A pure vs. 2A in alternate rows ..	3·00	·010
2A pure vs. 2A in half plots	1·81	·057

less powerful, but which involves no assumption. All the unflooded plots gave increased total yields. The probability that this should be due to chance is 2^{-8}, or ·00387. Only 6 of the 8 unflooded plots gave increases of BK, and only 7 out of 8 gave increases

Table 6. *Analysis of yields in alternate row experiment, Giridih 1959*

Block	BK alone	2A alone	BK (½)	2A (½)	Increase of BK	Increase of 2A	Joint increase
I ..	515·0	792·0	356·5	382·0	+ 198·0	− 28·0	+ 170·0
II ..	749·5	709·0	433·5	358·0	+ 118·0	+ 7·0	+ 125·0
III ..	734·0	596·5	375·0	402·5	+ 16·0	+ 208·5	+ 224·5
IV ..	757·0	671·0	421·0	347·0	+ 85·0	+ 23·0	+ 108·0
IX ..	718·0	603·5	358·5	413·0	− 1·0	+ 222·5	+ 221·5
X ..	438·5	493·0	346·0	387·0	+ 253·5	+ 281·0	+ 534·5
XI ..	543·5	387·0	217·0	396·0	− 109·5	+ 405·0	+ 295·5
XII ..	383·0	112·5	301·0	297·2	+ 219·0	+ 481·9	+ 700·9
Total ..	4838·0	4365·0	2808·5	2982·7	+ 779·0	+1600·9	+2379·9
V ..	630·5	869·5	366·5	268·0	+ 102·5	− 333·5	− 231·0
VI ..	699·0	787·1	450·0	358·5	+ 201·0	− 70·1	+ 130·9
VII ..	649·8	698·2	395·1	379·0	+ 140·4	+ 59·8	+ 200·2
VIII ..	659·1	628·2	310·0	200·6	− 39·1	− 227·0	− 266·1
Grand Total	7476·4	7348·0	4330·1	4188·8	+1183·8	+1030·1	+2213·9

of 2A. The corresponding probabilities are ·145 and ·035, the latter but not the former being significant by the usual criteria. If we include the flooded plots, the probability that the joint yield is not significantly increased becomes ·019, while those for BK and 2A are ·073 and ·19. While I have little doubt that the flooded plots should be excluded, or at least given less weight than the unflooded, it is desirable to point out that even if they are included and given equal weight with the rest, the gain is highly significant. On applying the t test to the data from the unflooded plots we find $t_7=3{\cdot}940$, whence $P=\cdot 00382$. This happens to be the same as that given by the simpler non-parametric test. The t test is usually more sensitive. In this case the very high increase in block XII makes it improbable that the distribution of increases should be normal, and hence the t test is not very sensitive. Applying the t test to the grand total we have $t_{11}=2{\cdot}37$ whence $P=\cdot 019$. There can, in fact, be no doubt that, even if we include the flooded areas, and even if we neglect all other results, the gain from planting in alternate rows is significant.

Figure 1 shows that the gain from mixture has a strong negative regression on the yields of the unmixed varieties in any block. This suggests that further work may show that this mixture, at any rate, is of most value when soil conditions are fairly bad, as in blocks X and XII.

Let us now consider the results of the plots in the unflooded fields of which one half was planted with each variety. The overall gain shown in Table 7 is not significant, $t_7=1{\cdot}44$, $P=\cdot101$, though the gain of 2A, $t_7=1{\cdot}81$, $P=\cdot057$, is more nearly so. However in this case I have a good deal more information, since the rows were harvested

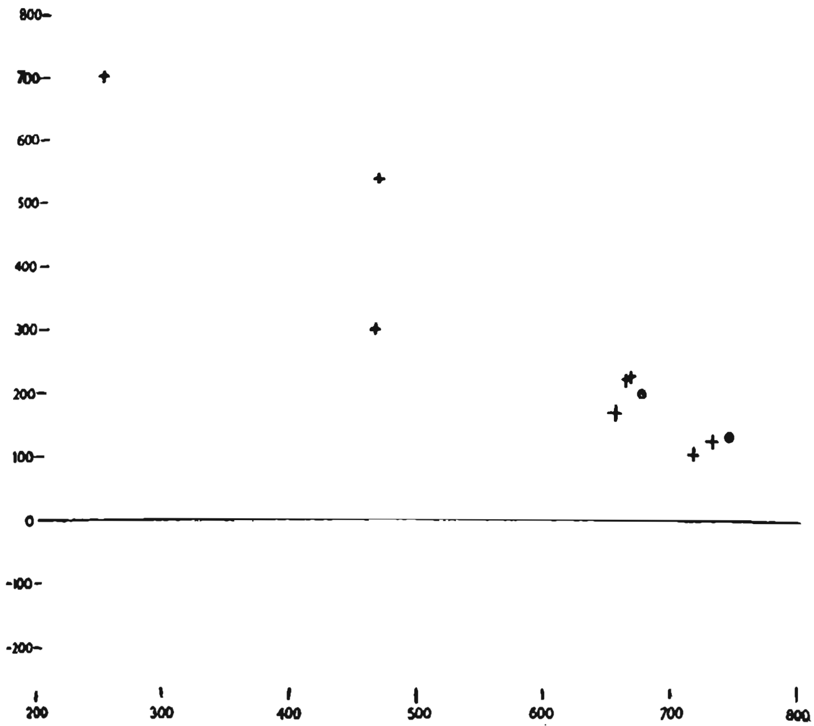

Fig. 1. Relation between yield of unmixed varieties and gain from planting in alternate rows.
Abscissa. Mean yield unmixed.
Ordinate. Gain from planting in alternate rows.
X Unflooded plots.
O Flooded plots.

separately. Each half-plot had ten rows of each variety. In Table 8, I give the total yields of each of the first five rows, and of the sum of the last five, multiplied by numbers which give the yield per plot. The gains are highly significant. For BK, $t_5=2{\cdot}57$, $P=\cdot021$, for 2A, $t_5=5{\cdot}56$, $P=\cdot001$. It is clear that the favourable effect of one variety on the other is not confined to the nearest row, though in the case of 2A it is much stronger (gains of 26% and 24%) in the first two rows. But it seems to extend to the farther quarter of the plot. BK gives a much more surprising result. The nearest row is practically unaffected. The farthest rows gain more than any of the five nearest.

It is very difficult to suppose that an effect of such long range (up to 10 feet) is transmitted through the soil. It is much more likely that, especially in the case of the effect of 2A on BK, it is transmitted through the water. Indeed the nearest row is insignificantly inhibited, which suggests that the effect of 2A plants on BK in their immediate neighbourhood is unfavourable, while distant BK plants are encouraged by a substance added to the water. If the mutual influence is largely through water, the adverse effect of flooding on cooperation is explained.

Table 7. *Analysis of the half-plot experiment by blocks*

Block	BK alone	2A alone	BK (½)	2A (½)	Increase of BK	Increase of 2A	Total increase
I ..	515·0	792·0	365·3	349·1	+215·6	− 93·8	+121·8
II ..	749·0	709·5	390·1	398·3	+ 31·2	+ 87·1	+118·3
III ..	734·0	596·5	404·6	379·5	+ 75·2	+162·5	+237·7
IV ..	757·0	671·0	321·7	322·4	−113·6	− 26·2	−139·8
IX ..	718·0	603·5	371·2	337·8	+ 24·4	+ 72·1	+ 96·5
X ..	438·5	493·0	349·4	389·0	+260·3	+285·0	+545·3
XI ..	543·5	387·0	309·1	220·7	+ 74·7	+ 54·4	+129·1
XII ..	383·0	112·5	76·0	77·4	−231·0	+ 42·3	−188·7
Total ..	4838·0	4365·0	2587·4	2474·2	+336·8	+583·4	+920·2

Table 8. *Analysis of the half-plot experiment by rows*

	BK	2A	Gain of BK	Gain of 2A
Pure culture ..	4838	4365		
Row 1 ×20 ..	4822	5534	− 16	+1169
Row 2 ×20 ..	5066	5432	+228	+1067
Row 3 ×20 ..	5054	5038	+216	+ 673
Row 4 ×20 ..	4946	5010	+108	+ 645
Row 5 ×20 ..	4944	5078	+106	+ 713
Rows 6-10× 4 ..	5383	4678	+545	+ 313

The yields of straw were also weighed. The results are summarized in Table 9. All the mixtures give a slightly lower total yield than the mean of the two pure varieties, the fall in yield ranging from 1·9% to 8·0%. An analysis by blocks shows that the losses were not significant. They are however of interest in making it clear that we are not dealing with an overall growth stimulation. Thus the analysis of Table 3a is confirmed.

Table 9. *Yields of straw at Giridih in 1959, in the 8 unflooded blocks. Weight in tolas.*

Variety and treatment		Total weight
BK alone	..	9,865·0
2A alone	..	10,843·0
Mean of BK and 2A	..	10,354·0
Mixed on transplantation	..	9,522·5
Mixed in seed bed	..	10,153·5
Alternate rows	..	10,088·0
Half plots	..	9,909·0

The Experiments of 1959 at Trivandrum and Udayrajpur with 36BK BR7 and 498-2A BR8

Six blocks of three plots each were planted with BK, 2A, and a mixture (at planting) at Trivandrum. The plot size was 1 cent, and dry weights of grain are given in units of two ounces. BK appears to be well suited to the conditions at Trivandrum, which is in the extreme south of India. Its yield was better than that of some varieties, for example P.T.B. 27, selected for growing in Kerala. Variety 2A did much better in the second field than the first, but is not well adapted to Kerala. Table 10 shows the results.

Table 10. *Interaction of BK and 2A at Trivandrum, 1959. Weights in two ounce units.*

BK alone	2A alone	BK+2A	BK (½)	2A (½)	Gain over mean	Gain over BK
155	92	183	..	..	+59·5	+28
140	66	138	..	..	+35	− 2
136	75	147	..	..	+41·5	+11
123	112	136	96	40	+18·5	+13
147	105	157	111	46	+31	+10
145	122	140	100	40	+ 6·5	− 5
846	572	901	307	126	+192	+55

Only in the second field were the two varieties harvested separately in the mixed crop. There was a heavy and clearly significant gain of 27·1% over the mean. The gain over BK was only 6·5%, with $t_5=2{\cdot}21$, P=·052. In the three plots which were harvested separately the yield of BK rose by 48·0%, that of 2A fell by 55·9%. The result of is biological interest, but it is unlikely that this mixture would be of economic value in Kerala unless a small fraction of 2A plants have a stimulating effect on BK. I think, however, that the intense interaction observed strengthens the evidence that the interactions observed elsewhere were a reality.

At Udayrajpur, in West Bengal, the experiment was replicated 11 times, each block consisting of a plot of BK, a plot of 2A, a plot mixed at transplantation, and a plot of

Table 11. *Interaction of BK and 2A at Udayrajpur in 1959. Total yields of 11 Blocks.*

Variety and treatment	Yields of dry grain		Gain %
BK alone	3903·0	4109·6*	
2A "	4316·2		
BK mixed on transplantation	2294·6	4134·9	+0·6
2A " " "	1840·3		
BK in half plots	1962·1	4150·1	+1·0
2A " " "	2188·0		

* Mean of BK and 2A alone.

which one half was planted with BK, the other half with 2A. Plot sizes were as at Giridih. Dry weights are in tolas. The whole area was severely flooded, and no cooperation was found. The total yields of dry grain in tolas are given in Table 11. The gains are small and insignificant. It can be seen that in the half plots there was a negligible interaction. In the mixed culture the yield of BK rose by 17·6%, that of 2A falling by almost the same amount. The gain of BK is quite significant, $t_{10}=2{\cdot}93$, P=·008.

The interpretation of these results is not certain. Clearly it will be necessary to test the interaction of BK and 2A in West Bengal in the absence of flooding. However, since in the absence of flooding they give an increased joint yield in Bihar and in Kerala, it seems likely that they will also do so in West Bengal.

A number of other plots in West Bengal where these varieties were being grown together were more or less completely ruined by floods, and no attempt was made to record the yield.

Experiments with other varieties in 1959

Table 12 gives a summary of the results obtained on "pilot" experiments with other pairs of varieties in 1959. Udayrajpur and Gocharan are both in West Bengal. Both were severely flooded, so one cannot conclude from a negative result that there would not have been gains in the absence of flooding. In column 3, A means autumn, W winter. In column 5 T means mixture on transplantation, H culture in half-plots.

Table 12. *Results of 1959 harvest* (*except BK and 2A*)

Place	Varieties mixed: Name	Varieties mixed: Agricultural group	Replications	Mixture	% gain over mean	% gain over better	P for gain over mean
GIRIDIH	Chin-2 Kele, Laksmiparijat ..	A	3	T	+15·7	+ 2·7	0·14
	BR1 Kolaba, BR2 Sarguja ..	A	3	T	−20·3	−34·1	
	Bank-6 Ashkata, Bank-2 Jhanji-34 ..	A	3	T	− 2·7	−25·5	
	Chin-3 Bhasamanik, Chin-7 Patnai-23	W	3	T	− 0·2	− 4·2	
	Chin-25 Latisail, Chin-27 Jhingasail	W	3	T	+ 6·9	−11·3	
	Chin-39 Kataribhog, Bank-29 Sindurmukhi ..	W	3	T	+47·7	+30·6	0·18
TRIVANDRUM	P.T.B.7, P.T.B.26 ..	A	3	T	− 8·8	−12·1	
	P.T.B.7, P.T.B.32 ..	A	3	T	− 2·0	− 3·3	
	P.T.B.26, P.T.B.32 ..	A	3	T	+ 3·8	− 1·2	
	P.T.B.8, P.T.B.9 ..	A	3	T	+ 1·5	+ 1·5	
	P.T.B.2, P.T.B.5 ..	A	3	T	+10·7	+ 7·0	0·044
	P.T.B.10, CH.10 ..	A	3	T	+10·8	+ 9·6	0·18
UDAYRAJPUR	Chin-2 Kele, Chin-4 Bhutmuri ..	A	3	T	+ 5·0	+ 4·8	
			3	H	+ 9·2	+ 2·5	
	Bank-6 Ashkata, Bank-2 Jhanji-34 ..	A	3	T	− 5·6	− 9·7	
			3	H	− 8·0	−12·0	
	BR1 Kolaba, BR2 Sarguja ..	A	3	T	0·0	− 1·8	
			3	H	− 3·4	− 4·4	
	Chin-4, Dular, Chin-12 Satika ..	A	3	T	+ 5·1	+ 0·3	
			3	H	+11·0	+ 5·9	0·026
	Chin-3 Bhasamanik, Chin-7 Patnai-23	W	3	T	− 3·7	− 5·4	
	Chin-25 Latisail, Chin-27 Jhingasail	W	3	T	+ 0·7	− 8·6	
	Chin-3 Bhasamanik, Chin-23 Dudshar	W	2	T	+ 4·2	− 0·7	
GOCHARAN	Chin-2 Kele, Chin-4 Bhutmuri ..	A	3	T	−39·5	−40·5	
			3	H	−69·9	−71·8	
	Bank-6 Ashkata, Bank-2 Jhanji-34 ..	A	2	T	+ 4·9	− 1·3	
			2	H	+ 9·8	+ 3·3	
	Chin-4 Dular, Chin-12 Satika ..	A	3	T	− 5·6	−10·7	
			3	H	− 3·0	− 8·4	
	Kalare, CH-10 ..	A	3	T	+ 1·4	− 3·5	
			3	H	− 9·6	−14·0	

In the last column I have calculated P from Student's test wherever the gain over the mean of the pure varieties exceeded 10%. The area was one cent.

It will be seen that 16 mixtures yielded more than the mean of the varieties, 14 less, dna one the same. The mean of the gains was—1·1%. There is thus no reason to suppose that mixture of varieties leads to cooperation (or to lower joint yield) as a general rule. Of the 31 experiments 5 showed a gain of more than 10% over the mean of the two varieties, and all these showed some gain over the better yielding of the two. However only two of these five gains, both in autumn varieties, showed a gain significant at the 5% level. It will however be noted that four out of the five gains of 10% or more occurred in the 12 unflooded experiments in Bihar and Kerala, and only one in the 19 flooded experiments in West Bengal. Perhaps we may hope for more favourable results in a normal year in West Bengal. It must also be added that in none of these experiments were the two varieties planted in alternate rows, which gives the most favourable result with "BK" and "2A" though it may not do so in other cases. The mixture of P.T.B. 2 and P.T.B. 5 may prove of value in Kerala. It is unlikely that that of P.T.B. 10 and CH. 10 will do so. The latter is of Chinese origin, and both gave low and irregular yields.

The most sensational gain, recorded in the last experiment at Giridih, is not statistically significant, the results in the three replications being very different. If it proves possible to discover the reason for this heterogeneity, it may be possible to exploit this mixture. It is interesting that in seven out of the eight experiments where the effect of mixture on transplantation (T) and compresence in half plots (H) were compared, the effects, whether favourable or unfavourable, of the latter treatment, were the larger. That is to say, the sums of the two half-plots differed more from the mean of the varieties than did the yield of the mixed plots. This supports the view that interaction at a distance due to substances dissolved in the water is important. To sum up, these results give good ground for hoping that other pairs of varieties interacting as favourably as "BK" and "2A" may be found.

DISCUSSION

The results here reported, incomplete as they are, are of biological and economic interest. The most obvious biological interpretations of such results are that the two varieties which cooperate in a mixture make different demands on the soil, and in rice, the water; and that one or both produces substances which stimulate seed production by the other. Thus Chakraborti and Sen Gupta (1959) find that rice plants of an unstated variety can fix atmospheric nitrogen. However other organisms may be concerned, particularly Cyanophyceae, such as *Anabaena* and *Phormidium* which De (1939) Uppal, Patel, and Daji (1939) and others found to fix nitrogen in the water above the soil. Again the most obvious biological analogy is with heterosis. If two genotypes of the same fungus cause mutual stimulation of growth when cultured in the same Petri dish, this is often because they have complementary metabolic insufficiencies, and each can supply the other's need. If so they generally produce a heterokaryon or heterozygote fitter than either. It would be of great interest to discover whether homozygous strains of *Zea mays* which produce very vigorous hybrids, influence one another favourably when planted alternately. However further research may well show that these explanations and analogies are much too simple.

Most of the work which has been done on interaction relates to interactions which are unfavourable for at least one of the species or varieties concerned. In some cases there may merely be competition between the root systems. In others the roots produce substances inhibiting growth of other species, or even of seedlings of the same species. These have been described by Bonner and Galston (1944), Bonner (1946), and Gray and Bonner (1948). It is quite possible that such substances are responsible for the suppression of some varieties in competition with others in my experiments.

One immediate conclusion may be drawn. I have frequently seen several varieties of rice being experimentally grown side by side in a plot surrounded by a single bund. In such cases interactions may be expected, and may lead to quite false conclusions as to the yields of the varieties in question in pure stand. It is possible that varieties which do well in the absence of competition have been discarded. Even if the preliminary conclusions are later disproved by large scale trials, time and effort are wasted. In general a plot should contain only a single variety. If one plot drains into another, similar effects may occur. It is too early to lay down principles for the design of experiments on rice and other crops, such as jute, which are grown in water. But I think it is clear that a new set of principles will have to be worked out.

In a more general way these experiments indicate the need for thought and investigation concerning tropical agriculture not based on the experience of cooler climates. Their general plan, though not their details, was suggested by Professor J. B. S. Haldane. It is based on considerations which were partly given by Haldane (1958a, 1958b) but are more clearly expressed in the following paragraph which he has kindly written.

"One of the greatest differences between a tropical flora and a temperate one is the far greater number of species in the former (apart from very arid regions). Thus India has over 20,000 species of flowering plants, a number far surpassing states of much larger area such as the U.S.S.R., and only surpassed by Brazil. One would expect symbiotic relations between flowering plants to be much commoner in regions with a diverse flora than in those where a natural plant community often consists of few members. Further, where harvesting is not mechanized, there is often no difficulty in growing mixed crops; and they are in fact grown largely in India. While the most obvious symbiosis to look for and to exploit, if discovered, to increase agricultural production, is between different species, particularly cereals and legumes; nevertheless if such symbiotic relations are common, they should be looked for between different genotypes of the same species. It is possible that some of the advantage of outbreeding in such a crop as cotton may be due to the compresence in a field of diverse genotypes, that is to say to heterogeneity between plants as well as within them."

It is not yet possible to assess the economic value of the discovery of which this is a preliminary report. In the first place it appears that the way in which the mixture is made is of considerable importance. In the alternate row experiments at Giridih 2A was much more stimulated than BK in the unflooded areas. If this is still so when (say) two rows of 2A are planted between each pair of single rows of BK, we might perhaps hope for gains of 30%. Further BK and 2A is the only symbiotic pair which has been tested with adequate replications. But my preliminary results suggest that

10 to 20% of all suitable pairs tested may give cooperative interaction. If so, some of these should do better than the first pair tested. It does not seem unduly optimistic to hope for gains of 20% in many areas. Fig. 1 suggests that the gain may be highest on poor soil. Such a result is of course not comparable with the effect of fertilizers on many crops, but it involves little additional effort and no additional expenditure.

Mangelsdorf (1957) writes concerning maize:

"Whereas hybrid corn in controlled experiments usually yields about 20 to 30 per cent more than the original open pollinated corn from which it derives, the average farm yield of corn per acre in the United States has increased by about 50%. ......This substantial increase can be attributed to the use of fertilizers and other soil improvement practices as well as hybrid corn". It therefore seems possible that mixed cropping in rice may produce results comparable to those of hybridization in maize.

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SUMMARY

When two varieties of rice are planted together, either fully mixed, in alternate rows, or in separate halves of the same small plot surrounded by a dam, each may influence the yield of the other. The effect is as often unfavourable as favourable. However cooperation occurs, and in the case most fully investigated the yield from alternate rows was 126% of the mean yield when the varieties were grown separately. In this case at least the favourable interaction takes place mainly through water, and disappears if the area is flooded.

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