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Evaluation of Circulant Partial Diallel Crosses in Maize

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Summary. The present study was conducted in maize (*Zea mays* L.) on crosses among 20 diverse parents. The materials were evaluated in four different environments for eight characters. Combining ability analysis was carried out following diallel and partial diallel crosses. The number of crosses per parent (s) varied from 3 to 19 and the results were studied to identify the critical value of s that would provide an adequate information with minimum resources. The S_5 partial diallel was as good as the S_{19} for the detection of differences among general combining ability (GCA) effects. Even the S_3 gave adequate information in the case of characters with high heritability. However, partial diallel analysis was less efficient in detecting the differences due to specific combining ability (SCA) effects. These results varied with environments, and characters with low heritability were more prone to misinterpretation. GCA effects showed fluctuations in partial diallel analysis which were more pronounced in S_5 and S_3, particularly for characters with low heritability. The average standard error of difference between GCA effects increased with a decrease in s, with a steep slope for $s < 7$. The partial diallel analysis was more efficient for the estimation of the variance component of GCA than for SCA, as the estimate of SCA was biased upwards. Estimates of broad sense heritability obtained from the partial diallels agreed with the full diallel analysis better than the narrow sense estimates. Smaller partial diallels gave erratic estimates of heritability, particularly for the characters with low heritability.

Key words: Partial diallel analysis – Combining ability – Heritability – Maize

Introduction

For identifying the superior combinations, a diallel mating system is frequently used by the plant breeders and geneticists. This system has several advantages but its practical use is limited to studies involving a relatively small number of parents. With an increase in the number of parents (n), the number of cross combinations increases dramatically. It then becomes difficult to make convenient evaluations in the field with a desired level of precision. One alternative is the partial diallel cross where only a sample of all possible crosses is studied. The information available from the partial diallel analysis is expected to be less precise than that from the full diallel. This level of precision depends, to a considerable extent, upon the number of crosses per parent (s) studied.

From a study of a ten parents' diallel, and samples thereof, Murty et al. (1967) and Anand and Murty (1969) reported that $s = n/2$ may be adequate to obtain a meaningful combining ability analysis. However, Bray (1971) pointed out some errors in the computer programme (Arunachalam 1967, 1972). From his studies, Bray (1971) concluded that the bias in the estimates obtained by partial diallel analysis depended on the character studied and the number of crosses sampled. He recommended that not more than eight to ten crosses per parent be evaluated, but his study involved a relatively small number of parents (12) and was conducted in only one environment. Moreover, Kearsey (1965) observed that the heavy computations involved in the partial diallel analysis were not commensurate with either the number or the precision of the estimable genetic parameters in comparison to the full diallel.

Thus, the available information about the ideal size of s is not conclusive and needs to be clarified in order to exploit the genetical, statistical, and economical advantages offered by the partial diallel cross (Kempthorne and Curnow 1961). The present investigation was planned keeping in view the desirability of involving a large number of parents, the situation where the partial diallel design is likely to prove most useful, and a number of differ-

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ent environments in order to evaluate the fluctuations in the estimates of genetic parameters due to environmental influences.

Materials and Methods

One hundred and ninety F_1 hybrids of maize from 20 diverse parents were raised from bulked seed of reciprocal and direct crosses for two years, at two locations representing the diverse agro-climatic regions of the country. Data were recorded on grain yield, plant height, ear height, days to silk, grain moisture at harvest, ear length, ear diameter and number of kernel rows per ear. The experimental details are on record (Dhillon 1974).

Circulant partial diallel crosses of varying sizes (s = 15, 11, 7, 5, 3) were sampled and analysed following the method of Kempthorne and Curnow (1961). These partial diallels were designated as S_{15}, S_{11}, etc. Diallel cross (S_{19}) was analysed using method 4 of Griffing (1956). Model I (fixed effects) as well as model II (random effects) were used to analyse the results in various situations. Heritability estimates were obtained following Bray (1971) but are presented in percent. The diallel cross is written as full diallel to distinguish it clearly from the partial diallel cross, and the results obtained from it are referred to as true estimates, as these were the best possible estimations.

Table 1. Analysis of Variance (mean squares) for Combining Ability

	General combining ability				Specific combining ability			
Character	Env. I	Env. II	Env. III	Env. IV	Env. I	Env. II	Env. III	Env. IV
Grain yield								
s = 19	2092**	2849**	955**	2058**	727**	709**	287**	351*
s = 15	1980**	2332**	712**	1647**	737**	700**	281*	380**
s = 11	1553**	1729**	729**	1211**	753**	746**	251	346
s = 7	1285**	1068**	439**	1084**	828**	818**	281	419*
s = 5	974**	815**	447**	1074**	822**	772**	272	449*
s = 3	1061**	1049**	596**	637**	213	796*	210	651*
Plant height								
s = 19	3794**	3240**	4129**	3778**	413*	216**	180**	201**
s = 15	2887**	2623**	3446**	2905**	378	213**	163*	214**
s = 11	2259**	1885**	2919**	2231**	400	208**	173*	198*
s = 7	1721**	1116**	1895**	1556**	342	249**	185	206**
s = 5	1607**	1079**	1361**	1202**	364	223*	141	245*
s = 3	879**	484**	804**	705**	346	264	203	200
Days to silk (X 10^2)								
s = 19	5200**	3228**	5359**	9768**	1188*	462*	504**	1171*
s = 15	5526**	2942**	4298**	7479**	1239**	468*	503**	1214**
s = 11	4827**	2372**	3233**	6025**	1096	514**	526**	1410**
s = 7	2746**	1995**	1910**	4782**	1118	620**	527**	1736**
s = 5	2313**	1995**	1509**	3638**	922	641	498*	2072**
s = 3	1815**	886**	948**	2493**	907	654*	451	2052**
Grain moisture (X 10^2)								
s = 19	744**	860**	3136**	7620**	187	635	544	857
s = 15	821**	511	2544**	5724**	184	674*	577*	892
s = 11	594**	589	2168**	3115**	158	816**	510	902
s = 7	450**	510	1439**	2215**	162	812*	441	1154*
s = 5	382*	786	1011**	1444**	171	670	380	1428**
s = 3	157	690	790	1740**	141	742	345	477
Ear length (X 10^2)								
s = 19	764**	857**	806**	902**	202*	244*	199	166*
s = 15	642**	729**	607**	776**	203*	269*	193	153
s = 11	628**	471**	562**	594**	194	263*	190	130
s = 7	402**	332**	397**	293**	186	205*	202	128
s = 5	272*	433**	387**	312**	231*	178	236	138
s = 3	321**	450**	306*	204	347**	191	272	146

*, ** Significant at 5 percent and 1 percent levels, respectively

Results and Discussion

The results obtained for plant height, ear height, ear diameter and kernel rows agreed very closely with each other. Thus, only one of these traits is generally discussed.

Combining Ability Effects

Detection of Differences Due to Combing Ability Effects

There was complete agreement between the full diallel (S_{19}) and partial diallel (S_{15} to S_3) analyses for the detection of differences due to general combining ability (GCA) for all traits except ear length and grain moisture (Table 1). With the exclusion of S_3, there was agreement for all traits except grain moisture in one environment.

For differences due to specific combining ability (SCA), the significance of the F ratio varied from character to character and environment to environment, showing that the sampling of crosses had a pronounced effect, but with a conspicuous absence of any worthwhile trend. Ear length in one environment showed non-significant mean squares in all the partial diallel samples, even though true mean squares were significant.

An interesting case was the expression of days to silk in environment IV. SCA effects accounted for relatively higher mean squares in the partial diallels, resulting in highly significant differences even though the differences were only significant in the full diallel. Results obtained for grain moisture were also worth consideration. Even though differences were non-significant for S_{19}, significant mean squares were observed in some partial diallels. In environment II, full diallel analysis showed significance for GCA and non-significance for SCA mean squares, but in partial diallel samples, non-significance was observed for GCA while in some cases SCA was significant. This indicated more chances of misinterpretation when differences are marginal.

When true mean squares were significant, non-significant differences were more frequent in environment I, indicating the effects of environmental forces on the phenotypic expression of various traits.

Evidently, the partial diallel analysis is sensitive enough to detect differences due to GCA, but it may result in serious mistakes in making conclusions concerning SCA. Kempthorne and Curnow (1961) pointed out that in the partial diallel cross, the partitioning of the degrees of freedom between GCA and SCA are to the advantage of the former, resulting in more precision for GCA. This was also evident from the present study. Bray (1971) also observed that correct decisions concerning SCA appeared more difficult to reach than those concerning GCA. Bray (1971) encountered both types of errors: Acceptance of the wrong hypothesis and rejection of the right hypothesis (both observed in the present study for mean squares due to SCA).

Mean squares due to GCA decreased as s decreased while SCA mean squares remained almost the same. This is due to the fact that expected mean squares of GCA contain the factor s while expectations of SCA mean squares are independent of it (Kempthorne and Curnow 1961). Except for days to silk in environment IV, there was no overestimation of SCA mean squares, which had been reported by Murty et al. (1967) and Anand and Murty (1969).

Estimation of GCA effects

One of the foremost objectives of the partial diallel analysis is to order a large number of parents for their GCA effects. From our earlier discussion, it emerges that even small partials are adequate to detect differences among the parents due to their GCA effects. However, the actual estimates which are indicative of the potence of the parents are of greater importance. Murty et al. (1967) concluded that the smaller partial diallels overestimated the GCA effects ($\hat{g}_i$), but Bray (1971) argued that since by definition $\Sigma\, \hat{g}_i = 0$, the contention of Murty et al. (1967) cannot be true. Even though $\Sigma\, \hat{g}_i = 0$, overestimation is possible towards both the negative and positive extremes. The range of GCA effects was studied in relation to the value of s (Fig. 1). Obviously the range increased as the

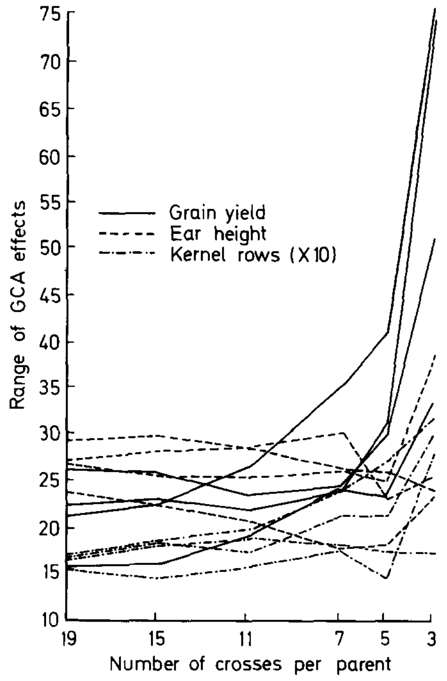

Fig. 1. Relationship between Number of Crosses per Parent and Range of GCA Effects in Four Environments

value of s decreased. This was observed for all the traits except for ear height (Dhillon 1974) where the range remained almost static. The rate of increase, however, varied with the characters, as shown for grain yield and kernel rows.

The GCA effects of various parents are represented in Fig. 2 for grain yield and kernel rows, each in a different environment. These two characters were selected for consideration because they widely differed in their behaviour. The GCA effects obtained from partial diallel analysis showed a much greater correlation with the true GCA effects in the case of kernel rows than those of the grain yield. To make the graph explicit, some of the parents with similar behaviour to those included in the figure are not presented. There were fluctuations in the estimates of GCA effects as s decreased, and these were more conspicuous for S_5 and S_3. This was true for both the traits but yield was apparently more susceptible. Bray (1971) also concluded that little faith can be placed in estimates from small sized partial diallel crosses as predictors of the true values.

Ranking of the Parents Based on their GCA Effects

There was apparently a lack of any stable ranking for grain yield (Fig. 3). However, the true best general combiner, which had a distinctly higher true GCA effect, (Fig. 2) managed to keep position 1 upto S_7. But in the S_5 partial, it drifted into second place, and its rank was as low as 14 in the S_3 sample (Fig. 3). On the poorer side, three parents can be differentiated from the rest and they recorded a relatively stable performance. For kernel rows, the parents on the extremes exhibited a good degree of stable ranking. The parents with 1st, 2nd, 17th, 18th, 19th and 20th true ranks maintained that in the partial diallels of the size of $s \geq 7$. There were only slight disturbances for the parents with 3rd, 4th, 14th, 15th and 16th true ranks. Considering S_5, results for this character were much more encouraging than for grain yield.

Apparently selection of the parents on the basis of their GCA will be quite reliable if based on partials of $s \geq 7$. With lower values of s, misleading results can be obtained; e.g. a distinctly good combiner like the best one for grain yield was rated as a poorer combiner. However, a comparison of various traits clearly indicated that there are differences among them: The ranking of the parents was more stable for kernel rows than for grain yield. For kernel rows, partials of s = 7 and above showed an ordering of the parents similar to S_{19}. The ranking was fairly reliable even in the S_5 partial, but it changed very much with a further reduction in the size of sample. Bray (1971) observed that small partial diallels frequently lead

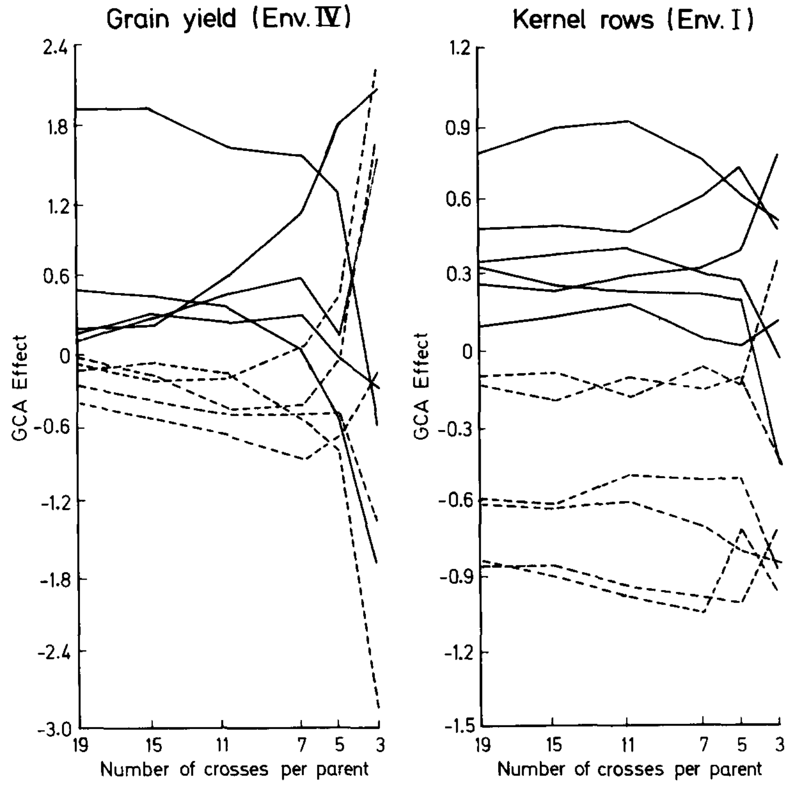

Fig. 2. Relationship between Number of Crosses per Parent and GCA Effects

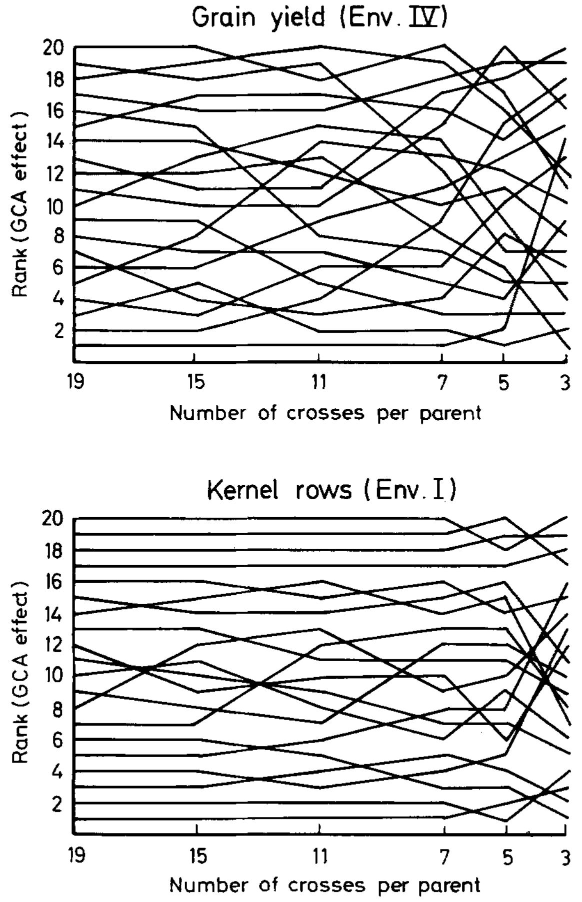

Fig. 3. Relationship between Number of Crosses per Parent and Ranking of Parents

to wrong selections and that this lack of efficiency was more marked for characters of low heritability.

Degree of Association between GCA Effects Obtained from full and Partial Diallel Analyses

Simple and rank correlations were estimated, and both showed a similar trend. Fig. 4 depicts the relationship between r^2 and s. There was a gradual decrease in r^2 up to S_7, but the curve became steep at the low levels of s. The decrease from S_5 to S_3 was most critical.

Two groups of characters emerged from the data in this figure. Plant height, ear height, kernel rows, and ear diameter showed, in the S_3 sample, r^2 greater than 33 percent, whereas for grain yield, days to silk, ear length, and grain moisture, the corresponding r^2 was less than 16 percent. If a r^2 value accounting for 66 percent variation is taken as a reasonable limit (in terms of resources and gains), then S_5 qualifies for all characters except for grain yield, ear length and grain moisture, for which S_7 was nearly in the acceptable range.

Detection of Differences among GCA Effects

Previous workers (Murty et al. 1967; Anand and Murty 1969; Bray 1971) observed an increase in the average standard error of difference between GCA effects (S.E.$(\hat{g}_i$-$\hat{g}_j)$) as s decreased. The change was more pronounced at lower

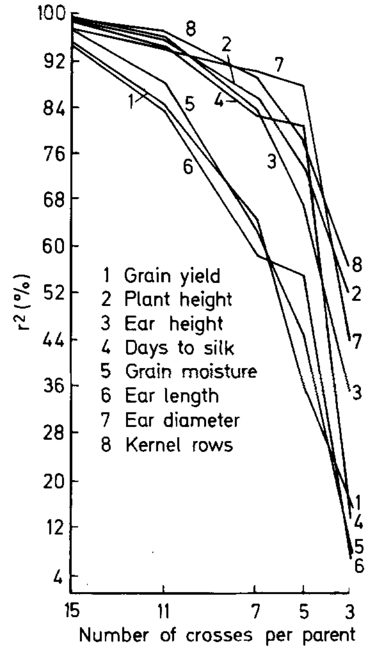

Fig. 4. Relationship between Number of Crosses per Parent and Percent r^2

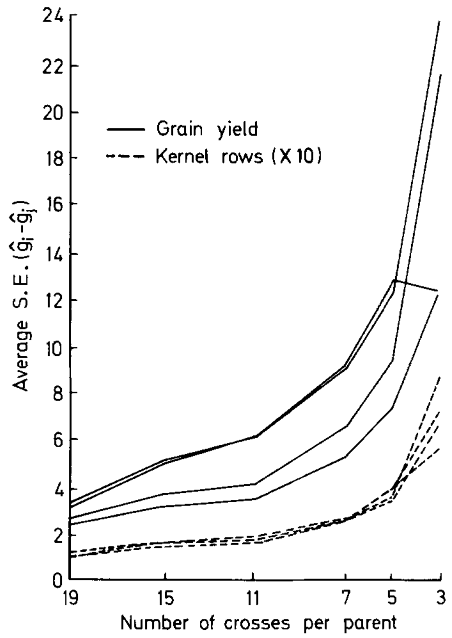

Fig. 5. Relationship between Number of Crosses per Parent and Average S.E. $(\hat{g}_i - \hat{g}_j)$ in Four Environments

levels of s. Murty et al. (1967) suggested $s = n/2$, while Bray (1971) observed that it would not be worthwhile to have a partial diallel cross larger than $s = 8$ or 10. Average S.E.$(\hat{g}_i-\hat{g}_j)$ is plotted against s in Fig. 5 for two characters. The S.E.$(\hat{g}_i-\hat{g}_j)$ increased at a very slow rate as s decreased from 19 to 7. This rate increased with a further reduction in s, and the curve was steep when s changed from 5 to 3. The magnitude of this change varied with the environments as well as the characters, but in general, results for all the traits followed a similar trend (Dhillon 1974).

Variance Components of Combining Ability

Significance of Variance Components

As discussed earlier, an advantage of the partial diallel cross is the rational distribution of degrees of freedom between GCA and SCA in comparison to the full diallel. Kempthorne and Curnow (1961), therefore, expected that the partial diallel cross should estimate the variance component of GCA $(\hat{\sigma}_g^2)$ more efficiently.

Table 2. Estimates of Variance Components of General $(\hat{\sigma}_g^2)$ and Specific Combining Ability $(\hat{\sigma}_s^2)$, and their Ratio $(\hat{\sigma}_s^2/\hat{\sigma}_g^2)$

	General combining ability				Specific combining ability				Ratio			
Character	Env. I	Env. II	Env. III	Env. IV	Env. I	Env. II	Env. III	Env. IV	Env. I	Env. II	Env. III	Env. IV
Grain yield (X 10)												
s = 19	190**	297**	93**	237**	774**	870**	183**	209*	4.1	2.9	2.0	0.9
s = 15	219**	287**	76**	223**	813**	904**	187*	280**	3.7	3.2	2.5	1.2
s = 11	192**	236**	115**	208**	821**	1020**	115	158	4.3	4.3		
s = 7	172	94	59	251**	1060**	1103**	204	365*				1.5
s = 5	80	23	92	330*	1017**	1019**	204	473*				1.4
s = 3	746**	222	240*	§	§	1202*	51	884*				
Plant height (X 10)												
s = 19	470**	420**	548**	497**	238*	200**	155**	187**	0.5	0.5	0.3	0.4
s = 15	441**	424**	577**	473**	149	191**	110*	218**		0.4	0.2	0.5
s = 11	446**	402**	659**	488*	164	205**	116*	155*		0.5	0.2	0.3
s = 7	520**	327**	645*	509**	32	332**	110	202**		1.0		0.4
s = 5	656**	451**	644**	569**	103	230*	§	224*		0.5		0.4
s = 3	469	194	529*	444*	60	334	68	189				
Days to silk (X 10^2)												
s = 19	55**	38**	67**	119**	73*	28*	46**	117*	1.3	0.7	0.7	1.0
s = 15	75**	44**	67**	110**	95**	28*	48**	130**	1.3	0.6	0.7	1.2
s = 11	90**	45**	65**	111**	58	43**	56**	173**		1.0	0.9	1.6
s = 7	61**	52**	52**	115**	56	70**	59**	261**		1.4	1.1	2.3
s = 5	73*	72**	53**	83	§	81	44*	358**			0.8	
s = 3	80	20	44	39	§	83*	43	378**				
Grain moisture (X 10^2)												
s = 19	8**	3	36**	94**	2	27	18	13				
s = 15	11**	§	35**	85**	0	36*	34*	37			1.0	
s = 11	10**	§	40**	53**	§	73**	23	42				
s = 7	11**	§	38**	40**	§	67*	3	109*				2.7
s = 5	11*	6	33**	1	§	38	§	176**				
s = 3	1	§	39	111*	§	35	§	§				
Ear length (X 10^3)												
s = 19	78**	85**	84**	102**	113*	143*	47	88*	1.4	1.7		0.9
s = 15	77**	80**	73**	110**	123*	188*	12	69	1.6	2.3		
s = 11	104**	50*	89**	111**	96	182*	§	§		3.6		
s = 7	81*	48	74*	62*	106	153*	§	§				
s = 5	22	134*	79	92*	211*	61	125	11				
s = 3	§	227	30	51	542**	96	252	8				

*, ** Significant at 5 percent and 1 percent levels, respectively

§ Negative estimate of variance component

For plant height, ear height, ear diameter, and kernel rows, there was complete agreement of S_{15} to S_5 with true $\hat{\sigma}_g^2$ estimates. At the S_3 level either it was not significant, or if significant, the probability level decreased (Table 2). The results were in agreement for S_{19} to S_7 for days to silk and grain moisture, and for S_{19} to S_{11} for grain yield and ear length. For SCA ($\hat{\sigma}_s^2$), the results are the same as those discussed earlier under the detection of differences due to combining ability effects. The test of significance is the same.

Estimation of Variance Components

As the variance components are independent of s, except in the precision of the estimates, it is expected that the estimates obtained from the partial diallel will approximate true values. Bray (1971) observed that the larger partial diallels showed less deviation from true estimates. But at the lower levels of s, the estimates sometimes considerably departed from the true values, showing a sudden downfall and non-significant estimates.

Table 3. Estimates of Heritability in Broad and Narrow Sense

	Broad sense heritability				Narrow sense heritability			
Character	Env. I	Env. II	Env. III	Env. IV	Env. I	Env. II	Env. III	Env. IV
Grain yield								
s = 19	79	83	67	73	15	21	23	39
s = 15	80	85	62	75	17	20	22	33
s = 11	79	86	64	67	16	16	32	38
s = 7	83	84	68	78	12	6	15	32
s = 5	81	82	71	83	6	2	22	34
s = 3	74	88	77	83	74	14	67	0
Plant height								
s = 19	78	88	91	90	52	60	71	65
s = 15	75	88	90	90	56	60	76	61
s = 11	74	88	91	88	54	59	77	67
s = 7	72	90	89	90	68	44	76	64
s = 5	79	89	87	92	68	59	87	66
s = 3	72	87	84	89	64	32	75	62
Days to silk								
s = 19	70	75	85	84	30	43	50	42
s = 15	76	76	86	85	34	46	50	39
s = 11	73	80	86	86	44	41	46	34
s = 7	68	85	86	89	35	36	40	27
s = 5	53	88	83	92	53	41	45	17
s = 3	58	84	83	92	58	17	42	9
Grain moisture								
s = 19	46	48	64	68	37	5	43	60
s = 15	51	52	71	72	49	0	36	50
s = 11	48	69	70	67	48	0	45	38
s = 7	49	66	58	77	49	0	57	20
s = 5	49	58	93	80	49	8	93	1
s = 3	10	48	56	74	10	0	56	74
Ear length								
s = 19	66	66	54	70	27	25	34	38
s = 15	68	69	42	70	26	21	36	42
s = 11	67	66	42	57	35	14	42	57
s = 7	67	69	36	41	29	16	36	41
s = 5	72	67	64	55	7	46	25	49
s = 3	87	77	73	40	0	54	8	34

Considering only the significant components, the $\hat{\sigma}_s^2/\hat{\sigma}_g^2$ ratio was almost consistent for plant height, but it showed an increase for grain yield, days to silk and ear length. These traits also showed a similar trend for $\hat{\sigma}_s^2$. On the other hand, $\hat{\sigma}_g^2$ was more stable with minor fluctuations.

Negative estimates of variance components were obtained, and these were more prevalent in the partial diallels of smaller sizes. For GCA, negative estimates were observed only for grain moisture, grain yield and ear length. For SCA, such estimates were present for all traits and were more common in case of grain moisture and ear length. High frequencies of occurrence of such spurious estimates for grain moisture indicated the shortcoming of the partial diallel cross in handling characters with a low genotypic variation.

Estimation of Heritability

Narrow sense heritability was estimated by Bray (1971). He observed that little confidence can be placed on the estimates obtained from small samples, whereas large partial diallels gave quite reliable results. Pederson (1972), using simulation studies, concluded that for an efficient estimation of heritability, partial diallels should be preferred over full diallels. He suggested that the number of crosses per parent should be six or less, and that better estimates would result by increasing the number of parents.

There was practically no change in the heritability estimate in the broad sense for plant height, ear height, ear diameter, and kernel rows (Table 3). It is worthwhile to note that these traits had high true heritability. The partial diallel estimates, particularly S_3 to S_7, were not fully comparable with true estimates for grain moisture and ear length. The behaviour of days to silk and grain yield was intermediate between these two groups of traits. The narrow sense estimates, on the other hand, were more sensitive to a sampling of crosses. Partial diallels of S_3 to S_7 sizes showed appreciable sampling bias, resulting in erratic disturbances in the case of characters with low true heritability, like grain yield, days to silk, grain moisture, and ear length. Also, there were marked differences among environments in some of the cases, indicating the need of multi-environmental testing.

Conclusions

In addition to the size of sample, the magnitude and nature of the variability present also have a profound effect on the results obtained from the partial diallel analysis. To reduce the s substantially without jeopardizing the conclusions, the materials under evaluation should have a high total genotypic variability of which a greater proportion is due to additive gene action.

The traits evaluated in the present study can be placed into two groups on the basis of true estimates of heritability (Table 3). Plant height, ear height, kernel rows, and ear diameter had relatively higher estimates than the rest of the traits. By briefly reviewing the results, it appears that the partial diallel cross was, in general, less efficient for the other traits as enumerated below.

i. Mean squares due to GCA were not significant in some of the smaller partial diallels (model I).
ii. Estimates of GCA effects and their ranking in partial diallel analysis showed greater disturbances.
iii. The degree of association (r^2) of GCA effects obtained from partial diallel with full diallel cross was low.
iv. Average S.E.($\hat{g}_i$-$\hat{g}_j$) increased more rapidly for these traits in a partial diallel cross.
v. Significance of the variance component of GCA ($\hat{\sigma}_g^2$) in the partial diallel agreed less frequently with true estimates.
vi. Variance component of SCA ($\hat{\sigma}_s^2$) increased with a decrease in s.
vii. Negative estimates of variance components were more prevalent.
viii. Erratic estimates of heritability were obtained.
ix. More fluctuations due to environments were observed.

Thus, the extent of the sampling bias and it's likelihood depends upon the nature of the gene action controlling the inheritance of the traits under study, in addition to the sample size. Characters with low genotypic and/or additive genetic variations are particularly prone to misinterpretations in the partial diallel analysis and there is a need to study more crosses per parent in these cases. A consideration should also be given to the resources. The present study shows that reasonable genetic estimates can be obtained with a moderate loss in precision with $s = 7$ and, hence, crossing and testing programmes can be considerably reduced. The number of crosses per parent can be further reduced if interest lies in the evaluation of highly heritable traits. However, S_7 cannot be taken as an ideal size of partial diallels since the situations vary, depending upon the various factors outlined above. One example may be a study of a large number of parents where a few crosses per parent may suffice. This is a distinct possibility and needs to be examined experimentally.

Grain yield, in general, has low heritability and thereby is not suited to precise evaluation by smaller partial diallels. A way out is to study yield along with its components in partial diallel analysis. A combined study of yield and its components, most of which have high heritability, is likely to help in the proper selection of superior parents.

Another aspect worth discussion is an observation by Bray (1971). He doubted the reliability of only a single sampling from a large number of possibilities in a diallel cross, and sampled 20 partial diallels from a full diallel cross. Even though his contention is correct on theoretical grounds, it defeats the very basic advantage of partial diallel design and may need resources even greater than those required by the full diallel cross. While the study of only one sample may sometimes provide unreliable results, it is worthwhile to undergo this risk in view of the advantages offered by the partial diallel cross. Bray's suggestion may be used in multi-environmental testing by evaluating different samples in various environments, instead of repeating the same set of crosses in all the environments.

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