Indian J. Genet., **56** (3): 341–349 (1996)

COMPARISON OF AUGMENTED PARTIAL DIALLEL CROSS TO COMPLETE DIALLEL CROSS

SEEMA JAGGI AND R. K. SHUKLA

Indian Agricultural Statistics Research Institute, Library Avenue
New Delhi 110012

(Received: July 29, 1995; accepted: November 2, 1995)

ABSTRACT

The augmented partial diallel cross (APDC) is a combination of the complete diallel cross (CDC) and partial diallel cross (PDC) wherein one or more primary lines are crossed with all other lines but the lines of secondary interest form a PDC system. The method of sampling adopted for crosses of secondary lines is of circular type. Using the principle of least squares, the analysis of APDC is developed and is applied to the data collected on various traits of maize. The data collected is analysed for CDC using the same number of lines following Griffing's method. The efficiency of estimates of general combining ability (gca) effects obtained from APDC has been compared with that of CDC.

Key words: Complete diallel cross, partial diallel cross, combining ability.

In a complete diallel cross (CDC) technique, the number of possible crosses increases rapidly with increase in the number of inbred lines (N). It results in less precise estimates and many of the lines with high potentials for production traits may likely to be left out completely untested. This led to the development of the concept of partial diallel cross (PDC) [1–7].

There are instances like in breeding trials, where among parental lines some are believed to be superior (primary lines), therefore it would be reasonable to obtain more information about these lines than the other lines (secondary lines) in the experiment. For such situation, Pederson [8] designed a mating system called as augmented partial diallel cross (APDC) for estimating general combining ability (gca) and specific combining ability (sca) effects in which one or more primary lines are crossed with all other lines, but the secondary lines form a PDC system.

In the present article, an APDC mating system with two primary lines and seven secondary lines has been considered. The method of sampling adopted for crosses of

secondary lines is from arrangement of secondary lines on the circumference of a circle. The method of analysis of APDC has been given which is applied to the data collected on various traits of maize from a designed experiment, i.e. randomized block design (RBD). Further a CDC using the above nine lines with 36 single crosses was also laid out in RBD. The data collected on various traits of maize has been analysed following the Griffing's method [9]. The efficiency of estimates of gca effects obtained from APDC has been compared with that of CDC experimentally.

ANALYSIS OF APDC

The mean yield in an experiment of the cross between lines i and j can be written as

$$Y_{ij} = \mu + g_i + g_j + S_{ij} + \bar{e}_{ij},$$

$$(i.j = 1, \ldots, N; i \neq j) \qquad (1.1)$$

where μ—the general mean effect, g_i and g_j—the gca of line i and j, s_{ij}—the sca of cross of two lines i and j and $\bar{e}_{ij}$ is the average of the genetic deviations from the model, the plot errors and the effect of the genotype–environment interactions.

$$\text{Let } \bar{Y}_{i.} = \sum_{j=1}^{N} \bar{Y}_{ij}, \qquad \bar{Y}_{.j} = \sum_{i=1}^{N} \bar{Y}_{ij}, \quad \text{and} \quad \bar{Y}_{..} = \sum_{j<1}^{N} \bar{Y}_{ij}.$$

Also $\gamma_{i.} = \sum_{j=1}^{N} \gamma_{ij}$, the number of times i^{th} line is involved in crossing with other lines.

$\gamma_{.j} = \sum_{j=1}^{N} \gamma_{ij}$, the number of times j^{th} line is involved in crossing with other lines.

$\gamma_{..} = \sum_{i<j=1}^{N} \gamma_{ij}$, total number of crosses.

γ_{ij} = 1, if i^{th} line is crossed with j^{th} line

= ∅, otherwise.

Applying the least square procedure in the model (1.1), the normal equation for the *parameters reduces to*

$$C\,G = Q \tag{1.2}$$

where C—the square symmetric matrix of order N with diagonal elements as $\gamma_{i.} - \frac{\gamma_{i.}^2}{\gamma_{..}}$ and off diagonal elements as $\gamma_{ik} - \frac{\gamma_{i.}\,\gamma_{k.}}{\gamma_{..}}$ $(i, k=1, \ldots, N, i \neq k)$, G is the N x 1 vector of parameters and Q is the adjusted vector of observations i.e. $Q = Y_{i.} - \frac{\gamma_{i.}\,Y_{..}}{\gamma_{..}}$.

C can be written as

$$C = X'X - \frac{\gamma\,\gamma'}{\gamma_{..}} \tag{1.3}$$

where γ—a column vector having $\gamma_{i.}$ its i^{th} element, X is the design matrix of order $\gamma_{..}$ x N. Here C is a singular matrix and let the inverse of C be

$$D = (d^{ij}) = \begin{bmatrix} d^{11} & d^{12} & \ldots & d^{1N} \\ d^{21} & d^{22} & \ldots & d^{2N} \\ . & . & . & . \\ . & . & . & . \\ d^{N1} & d^{N2} & \ldots & d^{NN} \end{bmatrix} \tag{1.4}$$

Then, $\hat{G} = D\,Q$ (1.5)

The sum of squares due to G is given by $Q'DQ$ where Q' is the transpose of Q. The resulted analysis of variance for combining ability effects for APDC is given in Tables 1 and 2.

Table 1. RBD analysis of variance for APDC

Source	d.f.	MSS
Replications	r–1	MSS_r
Crosses	$\gamma_{..} - 1$	MSS_c
Error	$(r-1)(\gamma_{..} - 1)$	MSS_e

VARIANCES OF EFFECTS

In APDC there are four variance groups of interline comparisons depending on whether

(i) i and j are primary lines,

$$V_1 = V[(\hat{g}_i - \hat{g}_j) / i, j = \text{primary lines}] = \frac{d^{11} + d^{22} - 2d^{12}}{r}\,\hat{\sigma}_e^2$$

Table 2. Analysis of variance for combining ability effects (based on mean value)

Source	d.f.	MSS	Expected mean square
Gca	N - 1	$MSS_g = a$	$\hat{\sigma}^2_s + m\hat{\sigma}^2_g + \hat{\sigma}^2_e/r$
Sca	$\gamma_{..} - N$	$MSS_g = b$	$\hat{\sigma}^2_g + \hat{\sigma}^2_e/r$
Error	$(r-1)(\gamma_{..}-1)$	$MSS_e = c$	$\hat{\sigma}^2_e/r$

Where r--the number of replications, and m = h(N-2)/(N-1); and h—the harmonic mean of $\gamma_{i.}$. Also MSS_g = $Q'DQ/r(N-1)$, $MSS_s = MSS_c - MSS_g$. From Table 2, $\hat{\sigma}^2_s = (b-c)$; $\hat{\sigma}^2_g = (a-b)(N-1)/h(N-2)$; and $\hat{\sigma}^2_e/r = c$.

(ii) i primary and j secondary line,

$$V_2 = V[(\hat{g}_{i.} - \hat{g}_j) / i = \text{primary line, } j = \text{secondary line}], = \frac{d^{11} + d^{99} - 2d^{19}}{r} \hat{\sigma}^2_e$$

(iii) i and j secondary lines that are crossed

$$V_9 = V[(\hat{g}_{i.} - \hat{g}_j) / i, j = \text{secondary lines crossed}] = \frac{d^{33} + d^{44} - 2d^{34}}{r} \hat{\sigma}^2_e$$

(iv) i and j are secondary lines that are not crossed

$$V_4 = V[(\hat{g}_{i.} - \hat{g}_j) / i, j = \text{secondary lines not crossed}] = \frac{d^{99} + d^{66} - 2d^{36}}{r} \hat{\sigma}^2_e$$

Therefore, variance of two gca effects is given by

$$V(\hat{g}_i - \hat{g}_j) = \frac{d^{ii} + d^{jj} - 2d^{ij}}{r} \sigma^2_e \qquad (1.6)$$

where σ^2_e is the error variance and r is the number of replications. dii, djj and dij are the elements of the inverse matrix.

Average variance of the difference between two gca effects =

$(2\sigma^2_e/r)$ [Average diagonal term — Average nondiagonal term of the inverse matrix]

MATERIALS AND METHODS

An experiment for the estimation of combining ability effects following APDC and CDC separately was conducted at Indian Agricultural Research Institute New Delhi, with nine varieties of maize (*Zea mays*) used as parents, viz. 1) PR Gr E 116 x J 54 CTC 3, 2) J 115,

3) J 2006, 4) AB (Y) Pool Male Balanced Composite, 5) Suwan I (C7), 6) MCU 784-2034, 7) J1 (Arr-2), 8) Kisan, and 9) Comp. A 53-54.

Out of these nine parents, first two lines were of primary interest and the remaining seven were of secondary interest. Hence, $p = 2$, $q = 7$, $n = p+q = 9$. The various characters on which the data were recorded from experiment are:

1. Fresh ear weight in kg/plot of size 7.5 sq.m. 2. Stand at thinning. 3. 50% silking. 4. Stand at harvest. 5. Adjusted yield/plot. 6. Ear aspect.

METHOD OF SAMPLING OF PDC IN SECONDARY LINES

Each of the two parents of primary interest were crossed with eight other lines thus giving 16 crosses. In the remaining seven lines of secondary interest, circular method of sampling the crosses was adopted in such a way that each secondary line was involved in $s = 4$ crosses. The seven secondary lines were numbered at random from 2 to 9 and the following crosses were sampled.

line 3 x line 4,	line 5,	line 9,	line 8
line 4 x line 5,	line 6,	line 3,	line 9
line 5 x line 6,	line 7,	line 4,	line 3
line 6 x line 7,	line 8,	line 5,	line 4
line 7 x line 8,	line 9,	line 6,	line 5
line 8 x line 9,	line 3,	line 7,	line 6
line 9 x line 3,	line 4,	line 8,	line 7

Thus, there are $7 \times 4 = 28$ crosses of secondary lines. But each secondary line can be crossed with two primary lines, thus number of crosses of secondary lines with primary lines are $7 \times 2 = 14$. Hence total number of crosses (including reciprocals) are 58. If maternal effect is assumed to be absent then 29 crosses are sampled for the experiment. These 29 crosses were randomized and sown in RBD with four replications.

To compare the efficiency of combining ability effects obtained from APDC, a CDC trial of above nine parents consisting of 36 crosses was also laid out in RBD with four replications and similar operations as for the APDC trial.

Using the data, the estimates of combining ability of each line and standard errors of comparisons of primary and secondary lines are worked out following the least square procedure.

The incidence matrix ($X'X$) of the APDC experiment is given as

$$X'X = \begin{bmatrix} 8 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ & 8 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ & & 6 & 1 & 1 & \varnothing & \varnothing & 1 & 1 \\ & & & 6 & 1 & 1 & \varnothing & \varnothing & 1 \\ & & & & 6 & 1 & 1 & \varnothing & \varnothing \\ & & & & & 6 & 1 & 1 & \varnothing \\ & & & & & & 6 & 1 & 1 \\ & & & & & & & 6 & 1 \\ & & & & & & & & 6 \end{bmatrix}$$

$\gamma = (8, 8, 6, 6, 6, 6, 6, 6, 6), \gamma = 29.$

Therefore, $C = X'X - \frac{\gamma\,\gamma'}{\gamma..}$ can be obtained which is obviously a singular matrix.

RESULTS AND DISCUSSION

Here we give the analysis of APDC and CDC for combining ability for all the characters. The data is analysed for CDC following Griffing's method [9].

From Table 3 it is observed that the gca is significant for all the characters except for stand at thining and stand at harvest in both the cases, i.e. APDC and CDC indicating that

Table 3. Combining ability analysis (MSS) based on mean over replicate

Source	d.f.	Fresh ear wt.	Stand at thinning	50% silk	Stand at harvest	Ear aspect	Yield per plot
a) APDC Analysis:							
Gca	8	0.48*	18.61	6.93*	29.90	0.15*	0.08*
Sca	20	0.13	20.22	3.72*	13.11	0.06	0.03*
Error	84	0.10	11.36	0.86	12.73	0.04	0.01
b) CDC Analysis:							
Gca	8	0.36*	21.75	9.10*	09.72	0.10*	0.11*
Sca	27	0.19*	24.30**	1.33**	25.78*	0.04**	0.05*
Error	105	0.11	18.87	0.98	15.64	0.03	0.02

*,** Significant at 5% and 1% levels, respectively.

parents differed in their comparative ability to combine with a group of lines for these two characters. Further, sca is also significant for 50% silk and yield per plot from APDC analysis showing that design is unbalanced for comparison of two sca effects while in case of CDC analysis the sca for all the characters is significant indicating more prominent role of nonadditive gene action for all the characters under study. Significance of mean squares due to sca showed that the performance of cross-combination differed significantly from their expected performance on the basis of gca of the parents used in a particular cross. Also the magnitude of gca variances were higher than sca variances exhibiting the predominant role of additive gene effects in the genetic control of the traits in both the cases i.e. APDC and CDC.

The gca for all the varieties along with their standard error for APDC analysis is given in Table 4. It can be seen that the variety 9, i.e. Comp A 53-54 was the best general combiner

Table 4. General combining ability effects for different characters

Parent	Fresh ear wt.	Stand at thinning	50% silk	Stand at harvest	Ear aspect	Yield per plot
PRGrE116 x J54	- 0.84	- 2.27	0.77	- 1.18	0.08	0.30
J 115	- 1.84	- 0.34	1.38	- 4.14	0.98	0.58
J 2006	5.73	1.09	- 2.02	4.41	- 3.08	1.57
AB(Y) Pool Male	1.44	- 1.37	1.05	- 0.65	- 0.93	1.19
Suwan I(C7)	- 1.83	2.79	0.44	0.25	1.12	- 1.27
MCU 784-2034	- 3.50	- 0.78	- 1.15	- 0.26	2.38	- 2.06
J1 (Arr-2)	- 0.95	1.70	- 0.44	- 0.07	0.54	- 0.57
Kisan	- 0.41	- 2.31	- 0.80	0.20	- 0.62	- 0.19
Comp. A 53-54	2.20	1.50	0.76	1.43	- 0.46	0.46
a) S.E. (i)	0.170	1.801	0.496	1.907	0.111	0.060
b) S.E. (ii)	0.188	1.997	0.549	2.115	0.123	0.067
c) S.E. (iii)	0.205	2.177	0.599	2.305	0.134	0.073
d) S.E. (iv)	0.186	1.981	0.545	2.097	0.122	0.066
C.D. (a)	0.333	3.530	0.972	3.738	0.217	0.118
C.D. (b)	0.368	3.914	1.076	4.145	0.241	0.131
C.D. (c)	0.402	4.267	1.174	4.518	0.263	0.143
C.D. (d)	0.365	3.883	1.068	4.110	0.239	0.129

$V_1 = 0.0714\,\sigma^2_c$, $V_2 = 0.0878\,\sigma^2_e$, $V_3 = 0.1043\,\sigma^2_e$, $V_4 = 0.0863\,\sigma^2_e$.

for all the characters except for the Ear aspect. Variety 3 was the best combiner for fresh ear weight, Stand at harvest and yield/plot. A similar type of result was observed when obtained through CDC.

Table 5 gives the efficiency of APDC for gca effects in different characters. It is seen that except for the character ear aspect, the efficiency of all the characters is high, i.e. more than 70%. For stand at thinning and yield per plot, the efficiency is more than 100% indicating that these are more efficient as compared to CDC.

Table 5. Efficiency of APDC for gca effects in comparison to CDC

Character	Efficiency of APDC
Fresh ear wt.	0.7142
Stand at thinning	1.1341
50% silking	0.7756
Stand at harvest	0.8386
Ear aspect	0.4650
Yield/plot	1.1023

The comparison of the results obtained from two designs for various traits indicate that APDC can replace CDC without much loss in efficiency in the estimates of gca effects with the additional advantage that large number of lines can be evaluated through APDC.

Table 6. Heritability (%) for different characters

Character	APDC	CDC
Fresh ear wt.	61.21	55.89
Stand at thinning	42.17	19.94
50% silking	82.35	72.48
Stand at harvest	33.51	26.20
Ear aspect	53.83	47.53
Yield/plot	73.58	68.97

Table 6 gives the heritability for different characters obtained from APDC and CDC. It can be seen that heritability for fresh ear weight, 50% silking, yield/plot and ear aspect is more than 50% for both APDC and CDC, indicating that the direct selection can be made for these characters.

REFERENCES

1. O. Kempthorne and R. N. Curnow. 1961. The partial diallel cross. Biometrics, **17**: 229–280.

2. R. N. Curnow. 1963. Sampling the diallel crosses. Biometrics, **19**: 287–306.

3. J. L. Fyfe and N. Gilbert. 1963. Partial diallel crosses. Biometrics, **19**: 278–286.

4. P. Narain. 1979. The use of partial diallel crosses in plant improvement. ICAR Golden Jubilee (1929–79). IASRI Souvenir, 183–193.

5. A. S. Arya. 1983. Circulant plans for partial diallel crosses. Biometrics, **39**: 43–52.

6. L. S. Kaushik and P. D. Puri. 1989. Partial diallel crosses based on generalized right angular association scheme. Commun. Statist. Theory Met., **18**(7): 2501–2510.

7. S. C. Agarwal and M. N. Das. 1990. Incomplete block designs for partial diallel cross. Sankhya, B, **52**: 75–81.

8. D. G. Pederson. 1980. The augmented partial diallel cross. Heredity, **44**: 327–331.

9. B. Griffing. 1956. A concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sciences, **9**: 463–493.