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COMPUTER PROGRAMMES FOR SOME PROBLEMS IN BIOMETRICAL GENETICS—IV. ANALYSIS OF COMBINING ABILITY BY PARTIAL DIALLEL CROSSES

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Analysis of the nature of gene action in crop plants by means of diallel crosses is of practical utility in plant breeding. Methods have been developed based on random and fixed effect models to estimate the components of genetic variation in the case of full and partial diallel crosses (Griffing, 1956; Kempthorne and Curnow, 1961; Curnow, 1963; Fyfe and Gilbert, 1963). However, Kempthorne's circulant design for making partial diallel crosses is frequently used by plant breeders. On account of the complex computations involved in the analysis of partial diallels, it was felt essential to make a computer programme available to biologists to suit their needs. Such a programme prepared at the Biometrics Unit of the Division of Genetics, Indian Agricultural Research Institute, is presented is this paper as Appendix I along with an example from the published data on linseed (Murty, Arunachalam and Anand, 1967).

Method of Analysis.—The programme presented below is based on the method outlined by Kempthorne and Curnow (1961). It is assumed that the partial diallel set is grown in a randomised block design and mean values per plant for each replication for several characters are available for further computation.

Language of the Programme.—FORTRAN II suitable for working on an IBM 1620 Model II computer.

Computational Steps

(i) For a given number of parents (=n), s (as explained by Kempthorne and Curnow, 1961) and number of replications (=r), the A-matrix is computed and printed, if required.

(ii) After the mean values of sampled crosses for each replication are fed to the computer, the mean values of sampled crosses per replication are printed out to enable comparisons among them.

(iii) Using the method given by Kempthorne and Curnow for inverting a circulant matrix, the inverse of the A-matrix is computed and printed, if required.

(iv) The estimates of the general combining ability effects of the parents are computed and the analysis of variance of the partial diallel cross is done.

(v) Utilizing the expectations of the various mean sum of squares, the estimates of environmental, s.c.a. and g.c.a. variances, namely, σe^2, σs^2 and σg^2 are computed, if estimable, along with the estimates of $\log_e (\sigma g^2/\sigma e^2)$ and $\log_e (\sigma s^2/\sigma e^2)$ and Av. var. $(g_i\text{-}g_j)$ and Av. S.E. $(g_i\text{-}g_j)$. The utility of these estimates in interpretation of results in the light of their biological significance is illustrated in the publication by Murty *et al.*, (1967).

ABOUT THE PROGRAMME. The programme that can be run with the control card≠≠FORX53 only given in Appendix I needs no alteration for parents up to a maximum of 20 in number, for values of ' s ' such that ns/2 is less than or equal to 50 and for three replications. The number of parents can be increased with a reduced number of replications and crosses in which case the ' Dimension ' statement is to be altered accordingly. In other cases, the programme may easily be split into a main and a link programme to suit the individual needs. Before utilizing this programme, it is desirable to ascertain whether the output Format statements would be adequate or need alteration to suit the particular problem.

Input.—The following is required as input data in this order.

(i) The title of the experiment and other coded details which can occupy a maximum of 80 letters and punched in one card starting from column 1.

(ii) The number of parents used (=N), the chosen S value (=S) and the number of replications used (=R) punched in one card in this order starting from column 1, each quantity occupying 4 columns. Thus, N=10, S=3, R=3 would be punched in one card starting from column 1 to column 12 as 001000030003

(iii) It is known that the partial diallel programme of making crosses when n=6 and s=3, for example, is as follows: 1×3, 1×4, 1×5, 2×4, 2×5, 2×6, 3×5, 3×6, 4×6. The data on mean values per plant for the crosses are to be arranged in this order for each replication. The arranged data are to be punched in cards replicationwise each quantity occupying 4 columns with one decimal digit. Each card contains 18 quantities and hence occupies columns 1 to 72. In the above example, the values for crosses 1×3, ..., 4×6 for I replication and 1×3, ..., 4×6 for II replication would be punched in one card. Thus, if the respective values were 0·1, 10·3, 1·2, 11·3, 8·0, 10·0, 9·0, 10·1, 111·8, 112·3, 0·2, 0·7, 1·7, 16·7, 187·4, 18·6, 111·1, 100·7, they would be punched in one card from column 1 to column 72 as 00010103 0012011300800100009001011118112300020007001701671874018611111007. The decimal point should not be punched. The values for crosses 1×3, ..., 4×6 for III replication would therefore occupy another card from columns 1 to 36 (for 9 quantities) as illustrated above.

The input data from (i) to (iii) form one set for a particular character for a particular N and S. Similarly other sets for different values of ' N ' or ' S ' or both and for different characters may be prepared and stacked together as input data so that the results would be obtained set by set.

Output.—The following is rendered as printed output in the order presented with underlined subtitles in a neat form as in the example appended at the end of this paper.

(i) If the A-matrix is desired to be printed, Sense Switch 1 should be put on, before the data are fed into the computer; otherwise, the sense switch 1 should be left on the 'off' position.

(ii) The mean values of the sampled crosses to one decimal along with the identity of the crosses are printed.

(iii) The inverse of A-matrix will be printed, if sense switch 2 is put on before the data are fed.

(iv) The identifying number and the estimated g.c.a. effects of the parents are printed.

(v) The partial diallel analysis of variance table is printed out.

(vi) All the estimable parameters enumerated in "computational steps" are printed out as illustrated in the example.

Acknowledgements

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References

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Fyfe, J. L. and Gilbert N. (1963). Partial diallel crosses. *Biometrics*, **19**: 278–86.

Griffiing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Aust. J Biol. Sci.*, **9**: 463–93.

Kempthorne, O. and Curnow R. N. (1961). The partial diallel cross. *Biometrics*, **17**: 229–50.

Murty, B. R., Arunachalam V. and Anand I. J. (1967). Diallel and partial diallel analysis of some yield factors in *Linum usitatissimum* L. *Heredity*, **22**.

APPENDIX

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≠≠JOB 5
≠≠FORX 53
COMBING ABILITY ANALYSIS BY PARTIAL DIALLEL CROSSES
C PROGRAMMED BY V. ARUNACHALAM, DIVISION OF GENETICS, I.A.R.I., DELHI-12.
C FOR THE METHOD USED, REFER TO THE PARTIAL DIALLEL CROSS BY KEMPTHORNE, O
C AND CURNOW, R. N. (1961) BIOMETRICS, 17, PP...229-250
      DIMENSION A(20,20), X (50,3), RSUM (3), V (50), Y (20, 20), Q (20), P (20),
    1 JZ (20)
  320 READ 321, (Q (I), I=1, 20)
  321 FORMAT (20 A 4)
      PRINT 322, (Q (I), I=1, 20)
  322 FORMAT (1X, 20A4/1X, 80 (1H-)/)
C THE ABOVE CAUSES THE PRINTING OF THE TITLE OF THE EXPERIMENT.
      READ 1, N, IS, IR
    1 FORMAT (3I4)
      S=IS
      KDF=N(N-IS-1)/2
      NOFX=N* IS/2
      FNOFX=NOFX
      RDF=IR-1
      IN=N-1
      FIN=IN
      IRDF=RDF
      IDF1=NOFX-N
      IDF2=(NOFX-1)* IRDF
      IDF3=NOFX * IR - 1
C N-NUMBER OF PARENTS, IS-VALUE OF S, IR-NUMBER OF REPLICATIONS,
C NOFX-NUMBER OF CROSSES SAMPLED PER REPLICATION.
      READ 9, ((X(I, J), I=1, NOFX), J=1, IR)
    9 FORMAT (18 F 4.1)
      SUM=0.
      SUMSQ=0.
      DO 10 I=1, NOFX
      DO 10 J=1, IR
      Z=X (I, J)
      SUM=SUM+Z
   10 SUMSQ=SUMXQ+Z* Z
      AVRGE=SUM/(FNOFX* (RDF+1.))
      CF=SUM* SUM/ (FNOFX* (RDF+1.))
      TOTSS=SUMXQ-CF
      DO 11 J=1, IR
   11 RSUM (J)=0.
      DO 12 J=1, IR
      DO 12 I=1, NOFX
```

```
 12 RSUM (J)=RSUM (J)+X (I, J)
    RSS=0.
    DO 13 J=1, IR
    W=RSUM (J)
 13 RSS=RSS+W* W
    RSS=RSS/FNOFX-CF
    DO 14 I=1, NOFX
 14 V(I)=0.
    DO 15 I=1, NOFX
    DO 15 J=1, IR
 15 V(I)=V(I)+X(I, J)
    CROSS=0.
    DO 16 I=1, NOFX
    U=V(I)
 16 CROSS=CROSS+U* U
    CROSS=CROSS/(RDF+1.)-CF
    DO 17 I=1, NOFX
 17 V(I)=V(I)/(RDF+1.)
    DO 2 I=1, N
    DO 2 J=1, N
  2 A(I, J)=1.
    DO 8 I=1, N
    A(I, I)=A(I, I)-1.+S
    IF (KDF) 8, 8, 200
200 DO 5 L=1, KDF
    IF (I+L-N) 3, 3, 4
  3 J=I+L
    GO TO 5
  4 J=I+L-N
  5 A(I, J)=A(I, J)-1.
    DO 8 L=1, KDF
    IF (I-L) 6, 6, 7
  6 J=N+I-L
    GO TO 70
  7 J=I-L
 70 A(I, J)=A(I, J)-1.
  8 CONTINUE
    IF (SENSE SWITCH 1) 102, 103
102 PRINT 100
100 FORMAT (1X, 8HA-MATRIX/1X, 8 (1H-)/)
    DO 82 I=1, N
    DO 80 J=1, N
 80 JZ (J)=A (I, J)
    PRINT 81, (JZ(J), J=1, N)
```

```
  81 FORMAT (3 0 I 4)
  82 CONTINUE
C SENSE SWITCH 1 SHOULD BE PUT ON FOR GETTING A-MATRIX PRINTED.
 103 PRINT 90
  90 FORMAT (//1X, 22 HMEAN VALUES OF CROSSES/1X, 22 (1H-)/3X, 5 HCROSS, 8X, 4 HM
    1 EAN/3X, 17 (1H-)/)
     M=0
     DO 19 I=1, IN
     DO 19 J=I, N
     IF (A (I, J)-1.) 19, 18 19
  18 M=M+1
     Y (I, J)=V (M)
     Y(J, I)=V (M)
     PRINT 91, I, J, Y (I, J)
  91 FORMAT (3X, I2, 1H-, I2, 5X, F7.1)
  19 CONTINUE
     PIE=3.141592654
     DO 83 I=1, N
     DO 83 J=1, N
  83 A(I, J)=0.
     DO 84 J=1, IN
     FJ=J
  84 P (J)=S-SIN ((FIN+1.-S)* FJ* PIE/(FIN+1.))/SIN (FJ* PIE/(FIN+1.))
     P (N)=2. * S
     Q(1)=0.
     DO 85 J=1, N
  85 Q(1)=Q(1)+1./P(J)
     Q(1)=Q(1)/(FIN+1.)
     DO 87 J=2, N
     FJ=J-1
     Q(J)=0.
     DO 86 L=1, N
     FL=L
  86 Q(J)=Q(J)+(1./P(L))* COS (FJ* (FIN+1.-FL)* 2. *PIE/(FIN+1.))
  87 Q(J)=Q(J)/(FIN+1.)
     DO 88 J=1, N
  88 A(1, J)=Q(J)
     DO 812 I=2, N
     A(I, I)=Q(1)
     IF (I-N) 89, 811, 811
  89 IONE=I+1
     DO 810 J=IONE, N
     JAI=J-I
 810 A(I,J)=Q(JAI+1)
```

```
  811 IONEI=I-1
      DO 812 J=1, IONEI
      JOY=J-I+N
  812 A(I, J)=Q(JOY+1)
      IF (SENSE SWITCH 2) 92, 93
   92 PRINT 821
  821 FORMAT (//1X, 9HA-INVERSE/1X, 9 (1H-)/)
      DO 814 I=1, N
      PRINT 813, (A (I, J), J=1, N)
  813 FORMAT (12 F 10.6)
  814 CONTINUE
C SENSE SWITCH 2 SHOULD BE PUT ON FOR GETTING THE INVERSE OF A-MATRIX
C PRINTED.
   93 DO 20 I=1, N
   20 Q(I)=0.
      DO 23 I=1, N
      DO 23 M=1, IS
      IF (I+KDF+M-N) 21, 21, 22
   21 J=I+KDF+M
      GO TO 23
   22 J=I+KDF+M-N
   23 Q(I)=Q(I)+Y(I, J)-AVRGE
      DO 24 I=1, N
   24 P(I)=0.
      DO 25 I=1, N
      DO 25 J=1, N
   25 P(I)=P(I)+Q(J)* A(J, I)
      PRINTED 250
  250 FORMAT (/1X, 23 HPARENT        G.C.A. EFFECT/1X, 6(1H-), 4X, 13 (1H-)/)
      DO 251 I=1, N
  251 PRINT 252, I, P(I)
  252 FORMAT (1X, I4, 6X, F10.4)
      GCA=0.
      DO 26 I=1, N
   26 GCA=GCA+P(I)* Q(I)
      GCAMS=GCA/FIN
      ERRSS=TOTSS-RSS-GCA
      ERRMS=ERRSS/((FNOEX-1.)* RDF)
      GCAF=GCAMS/ERRMS
      SCA=CROSS-GCA
      SCAMS=SCA/(FNOFX-FIN-1.)
      SCAF=SCAMS/ERRMS
      PRINT 261
  261 FORMAT (//22X, 20 HANALYSIS OF VARIANCE/22X, 20 (1H-)/)
```

```
      PRINT 27
   27 FORMAT (4X, 6 HSOURCE, 7X, 4 HD. F., 7X, 4HS. S., 12X, 4HM, S., 12X, 4HV, R./)
      PRINT 28, IRDF, RSS
   23 FORMAT (1X, 12 HEREPLICATIONS, 4X, I4, 2X, F 14.4)
      PRINT 29, IN, GCA, GCAMS, GCAF
   29 FORMAT (4X, 6 HG. C.A., 7X, I4, 3 (2X, F14.4))
      PRINT 30, IDF1, SCA, SCAMS, SCAF
   30 FORMAT (4X, 6HS. C.A., 7X, I4, 3 (2X, F14.4))
      PRINT 31, IDF2, ERRSS, ERRMS
   31 FORMAT (4X, 5 HERROR, 8X, I4, 2 (2X,F14.4)/1X, 68 (1H-))
      PRINT 32, IDF3, TOTSS
   32 FORMAT (4X, 5 HITOTAL, 8X, I4, 2X, F14.4/1X, 68 (1H-)//)
      ZESQ=ERRMS
      ZSSQ=(SCAMS-ERRMS)/(RDF+1.)
      DE=(RDF+1.)* S* (FIN-1.)/FIN
      ZGSQ=(GCAMS-SCAMS)/DE
      QU=(FIN+1.)* A(1, 1)/FIN
      QT=1./(2.* S* FIN)
      QUO=QU-QT
      QUO=2.* QUO
      AVVAR=QUO* (ZSSQ+(ZESQ/(RDF+1.)))
      AVSE=SQRTF (AVVAR)
      RASE=LOGF (ZSSQ/ZESQ)
      IF (ZGSQ) 350, 351, 351
  351 RAGE=LOFG (ZGSQ/ZESQ)
      PRINT 352, ZGSQ, RAGE
  352 FORMAT (5X, 11 HSIGMA (GSQ)=, F8.2, 5X, 27 HILOG (SIGMA (GSQ)/SIGMA (ESQ))=, F8
     C. 2/)
  350 PRINT 353, ZESQ, ZSSQ, RASE, AVVAR, AVSE
  353 FORMAT (5X, 11 HSIGMA (ESQ)=, F8, 2, 5X, 11 HSIGMA (SSQ)=,F8. 2, 5X, 27 HLOG (SIG
     1 MA (SSQ)/SIGMA (SEQ))=, F8. 2//5X, 14 HAV. VAR (GI-GJ)=, F8. 2, 5X, 14 HAV. S.E.(
     2 GI-GJ)=, F8.2////)
      GO TO 320
C ALL THE RELEVANT FORMAT AND DIMENSION STATEMENTS SHOULD BE CHANGED
C WHERE NECESSARY.
C FOR MORE THAN 20 PARENTS, THE PROGRAM SHOULD BE SPLIT INTO PORTIONS AND
C ONE OR MORE OF THEM BE TREATED AS LINK PROGRAMS.
      END
```

INPUT DATA

```
PARTIAL DIALLEL ANALYSIS FLOWERING TIME   S=3-YEAR 1964-65
  10   3   3
862 776 948 798 986 8381036 718 774 748 716 866 764 930 814 828 830 938 PDFT 231
814 860 732 996 766 728 764 760 794 844 902 752 866 922 958 676 886 752 PDFT 232
968 814 822 900 830 870 876 844 818                                     PDFT 233
```

OUT PUT

PARTIAL DIALLEL ANALYSIS FLOWERING TIME S=3-YEAR 1964-65

MEAN VALUES OF CROSSES

CROSS	MEAN
1- 5	85.2
1- 6	84.2
1- 7	94.8
2- 6	76.2
2- 7	91.0
2- 8	77.4
3- 7	100.0
3- 8	76.6
3- 9	77.4
4-- 8	80.4
4- 9	76.8
4-10	84.3
5- 9	82.8
5-10	89.2
6-10	79.4

PARENT	G.C.A. EFFECT
1	-1.3175
2	-4.8084
3	-.0084
4	.6157
5	4.8521
6	-1.4509
7	13.5915
8	-4.2084
9	-6.5176
10	-.7478

ANALYSIS OF VARIANCE

SOURCE	D.F.	S.S.	M.S.	V.R.
REPLICATIONS	2	81.5100		
G.C.A.	9	685.5148	76.1683	.9202
S.C.A.	5	1525.1652	305.0330	3.6853
ERROR	28	2317.5252	82.7687	
TOTAL	44	3084.5500		

SIGMA (ESQ)= 82.76 SIGMA (SSQ)= 74.08 LOG (SIGMA(SSQ)/SIGMA (ESQ))= -.11

A.V. VAR (GI-GJ)= 169.97 A.V.S. E(GI-GJ)= 13.03