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On The Diallel Crosses Designs

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Abstract: The Diallel Cross designs have applications in various areas such as biology and plant breeding. Specifically, these designs are used in the study of genetic properties of plants and animals, where they estimate the variations of genetic components as fixed and random effects models. This paper aims to provide a comprehensive review of the Diallel Cross designs. Particularly, it synthesizes various definitions of the Diallel Cross designs, summarizes some well-known designs, and shows how to constructs them. This review would guide future researchers.

keywords: Diallel Crosses; Efficienct; Repeated Measurements;

1. Introduction

A design in which all expected crossbreeds among the breeding system of plants are used to study the genetic properties of inbred lines, and exposing them to a sequence of the different or identical cross is called a Diallel Cross design. The Diallel design has widely been used in plant breeding systems for the past five decades. The application of this design was extended to study the genetic combinations in animals. Schmidt was the first to introduce the Diallel design in 1919. Haymann (1954, 1958) developed diallel analysis which is the expected crosses acknowledge notice in respective breeding of plant progeny and for that causes the examination of diallel crosses to satisfy certain particular demands of plant breeders. The estimation of diallel cross design is useful to reduce the combining ability of inbred lines. Sprague and Tatum (1942) proposed two types of estimation of combining abilities for testing paternal and maternal effects for diallel designs, named as general combining ability (GCA) and the second one is specific combining ability (SCA). Both are used to measure and calculate different properties of breeding lines. Whereas GCA is widely used for the effects of parents, the SCA is used for the effects of crosses which are very useful in crops. These combining abilities are used in two different models which were presented by Griffing (1956). These models are named as random and fixed effect models for diallel analysis. These models are used for different assumptions. For example, when the effects are fixed, the reason is to measure the GCA effects for every parent and SCA effects for every pair of parents. Griffing (1956) presented a numerical approach for diallel analysis which is very popular and useful. This approach consists of four methods:

- Parents and reciprocals, (n_2) (full diallel)

- Parents without reciprocals, n (n+1)/2 (half diallel)
- Reciprocals without parents, n (n-1)
- Without parents and reciprocals, n (n-1)/2

These four diallel methods of Griffing (1956) are handed down for one year or one location attribute and are helpful to study the model of genetics to distinguish traits in plant and animal. Haymann (1954) proposed a graphical approach for the analysis of diallel design. The plant breeders and geneticists extensively used Diallel designs applications to obtain genetic information for qualitative and quantitative features. The diallel analysis is applicable in both crop and genetic improvement.

2. Literature Review

Schmidt (1919) first proposed diallel mating designs. In diallel mating designs, a set of 'f' is crossed with a set of 'm', where 'f' and 'm' denote female-male, respectively. Then pairs are obtained in all possible combinations to rank breeding lines for prospective as the breeding program. Sprague and Tatum (1942) developed combining ability effects. That is, they developed general combining ability (GCA) effects and specific combining ability (SCA) effects. GCA "measures the average performance of a line in hybrid combinations", whereas SCA "based on average performance take the deviations from expectation and it is due to dominance and epitasis or non-additive genetic. Rojas and Sprague (1952) compared estimates of the variance of GCA and SCA. They also highlighted that the variance of SCA includes a considerable portion of the genotype "X" environmental interaction with non-additive deviations due to epitasis. Torrie et al. (1952, 1957) studied the effects of sibbing on forage by making the use of poly cross test and combining ability in red clover and distinguished the general combining ability (GCA) among the sib lines. Torrie (1957) calculated GCA and specific combining ability (SCA) effects from diallel crosses, as it includes the set of all expected number ofcrosses within a group of plants and the uses are slightly restricted for the minimum number of plants. Jinks and Haymann (1953) presented certain conditions on the lines. These lines depend on the test significantly and should be a self-realization by Jinks and Haymann (1953). These four conditions are

- The inheritance process/mechanism must be dual.
- Maternal effects should not be present.
- The parents are to be used in the crosses having two identical alleles of the same gene.
- They should not have any interconnection between genes and different loci.

Two further conditions for diallel crosses must be satisfied

- Multiple alleles should not be present.
- The distribution of genes among the parents should be random.

Haymann (1954) worked on diallel crosses data by applying the "genetic algebra" also presented some statistics for estimating deviations for diallel mating designs. The genetic system of the study uses statistics according to the hypothesis. In the ANOVA table, the expected values of various "SS" are also demonstrated in form of statistics. They settled under the criteria of homozygous parents, independent distributions of genes in parents, and without the presence of numerous alleles. The Diallel mating designs (Rawlings and Cockerham, 1954a, b) were useful in evaluating the additive and dominance genetic variances. However, they can only be used when the epitasis effect is not present. In the presence of the epitasis effect, the variance components of account of interconnections in additive and dominance effects could be measured by increasing trailed crosses three ways, two-way crosses and tetra crosses. Another remarkable contribution to Diallel mating designs was made by Griffing (1956). He presented four designs called "methods" which are used for bringing the crosses among a set of "P" inbred lines and analysis for the comparative and explanatory experiment. He also developed two models in which the genetic effects can be taken as fixed or random. The mating designs are:

- Method 1: Total number of expected P^2 crosses (F_1) with reciprocals and itself.
- Method 2: An expected cross includes itself without reciprocals.
- Method 3: (F_1) includes reciprocals but not itself.
- Method 4: All crosses only.

Among these four methods, Method 3 and Method 4 are used mostly.

Haymann (1953, 1954b, 1958) applied the concept of genetic algebra to the theory of Diallel crosses and developed basic statistics for estimating and detecting various deviations such as additive deviation and dominance deviation. Haymann (1954b) presented these statistics according to the hypothesis of the genetic system of study. In this ANOVA table the expected values of various "SS" are also calculated in form of statistics. These basic components for mean and variance are for interacting gene effect and some non-interacting gene allelic frequencies. Haymann thoroughly studied the formulae of Jinks and re-established them. Additionally, he reported the properties of relative dominance of the parental lines and showed how to detect non-allelic gene interaction. Gilbert (1958) presented some assumptions for lines "P". For comparatively large P values, the number of crosses is obtained by using following formula: n = P (P-1)/2 (Griffing, 1958). This formula is, however, is not suitable as well as hard to manage. Alternatively, Gilbert (1958) provided a formula n=p(p-1)/2, a fractional Diallel design when smaller values of "P" are required n_c (<n = p (p-1)/2). Gilbert (1958) compared (PDC) and (IBD) size of block will be two. Pearce (1960) significantly added to literature on "S" designs. Particularly, he derived least square estimation of treatment parameters along with their variations and co-variances. Furthermore, he presented general expressions of adjusted treatment sum of squares for type "S" designs. Pearce used some techniques that type "S" designs are in supplemented treatments. Lastly, he contemplated type "S" designs with different block size in row and columns designs situation. Kemthrone and Curnow (1961) performed experiment to assess the performance of crosses in (CRD) and (RCD) as environmental design. Cockerham (1963) presented Diallel mating designs for estimation of the variance elements. These mating designs are in main factorials, such as diallel and higher way crosses. The main experimental design include complete block design (CBD), incomplete block design (IBD) and simply complete randomized designs (CRD) when no experimental factors present. Curnow, Hinkelmann and Kemthrone (1963) examined similarity between partial diallel crosses (PDC) and partially balanced incomplete blocks (PBIB) with "m" associate classes and gave general method for analyzing these designs. Flexible designs obtained from (PBIB) with two associate classes. The observed general classes are follows:

- New class from generalization of group divisible (PBIB) with two associate classes (Ray 1953-1954).
- Representing extension of designs with three associate classes given by Vartak (1959).
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Curnow (1963) analyzed the variances of general combining ability (GCA) effects yielding two or more variances. Fyfe and Gilbert (1963) constructed PDCs by using triangular and rectangular arrangement of integers. These are balanced for estimation of general combining ability (GCA). Fyfe and Gilbert (1963) have derived PDCs form partially balanced incomplete block designs with three associate classes. Federer (1967) thoroughly perceive the methods of Griffing (1956). As a fractional replicate of the 'p^2' factorial design. For constructing partial diallel crosses (PDC) Federer (1967) used one of interaction component of two factor at 'P' levels. Hallauer and Eberhart (1970) developed biaular method and developed single crosses for improvement of population. They named this method as reciprocal full-sib. S.N.Muthar and Prem Narain (1976) sampling the diallel crosses approach and presented in different angels. They derived some criterion for optimal plans worked for different circumstances. Arya and Narain (1977) extend the work for constructing partial diallel crosses. They employed PBIB designs with three or four associate classes and established group divisible designs with three associate classes and they are more efficient for constructing PDCs based on generalized right angular designs with four associate classes. Singh and Chaudhary (1979) formulate step by step computations for analysis of commonly used inherited experiments. They includes formulae for co-variances among relative diallel analysis. Pederson (1980) constructed augmented partial Diallel crosses. Some situations have applied for lines in augmented partial diallel crosses. The lines name as primary lines and secondary lines. Primary lines well adopted and will have better significance and represented in excessive proportion. Secondary line may be of secondary importance. Primary lines denoted as 'p' and secondary line denoted as 'q'. In short, he worked for interline comparisons and presented approximate expressions for the variances of inner line comparisons. Some expression is as follows:

- Crossing each primary line ensuring crosses for every primary line.
- PDC designs with (p+s) consistent with secondary line.
- Variety of crosses in augmented PDC will be measured as $\frac{1}{2}$[p (p+q-1)+q (p+s)], when reciprocal are excluded.

Patel, Christie and Kannenberg (1984) generalized the Haymann diallel approach constructed by Patel, Christie and kennenberrg (1984).Singh and Hinkelmann (1998) proposed algorithm for Partial Diallel Design (PDC) plans.Agarwal and Das (1990) worked on Diallel designs. They constructed number of partial diallel crosses (PDC). They used incomplete block (IB), Partial balance incomplete block (PBIB) designs and balance incomplete block (BIB) designs for constructing Diallel Designs. Additionally provided a few expressions for estimating a missing observation for "V" treatments. Singh and Hinkelmann (1990) calculated the efficiency factors and write down 112 designs. These designs developed from PDC in terms of balanced partial Diallel Crosses (BPDC) and their expressions derived from Eigen values. These designs developed in the given range 30 ≥ P ≥10 and 4 ≤ s ≤ min [p/2 or (P-1)/2]. The BPDCs developed for odd and even 'p' respectively. Singh and Hinkelmann (1990) developed a PDC designs with's' replication by combining $(s/2)$, of the BPDCs. Sudhir Gupta and Sanpei Kageyama (1994) presented optimal complete Diallel crosses (CDC) mating design in incomplete block (IB). The optimal designs in new context estimate all pair wise distinction among general combining ability with consistent variance and maximum efficiency. The number of lines starts with "P" instead of n_c, the overall number of different crosses in experiment. This new approach followed optimal designs just for one replication of the (CDC). The efficiency factor of optimal mating design is compared to randomized complete block design (RCBD). M. Singh and Hinkelmann (1995) presented the brief relationship among diallel crosses (DC) and incomplete block design (IBD).They formulate how the (PBIBD) can be used both for constructing the mating design and the environmental designs for crosses of partial diallel crosses(PDC). They presented the analysis of such combined mating design their properties and efficiency factor are discussed. They also write down other environment designs and compare them with new methods. Generally applicable method of partial diallel crosses in existing incomplete block design (IBD) as environmental design. Gupta et al., (1995) introduced the procedure for developing single replicate incomplete block design (IBD) for partial Diallel crosses (PDC) by Singh and Hinkelmann (1990). Dey and Midha (1996) expanded the work on optimal block design for complete diallel cross (CDC) design. They used triangular partially balanced incomplete block design (BIBD) for developing some optimal designs for Diallel crosses (DC). Dey and Midha (1996) presented optimal balanced design (BD) for obtaining these designs within the range $3\leq r \geq 10$. Aloke Dey and Chand K.Midha (1996) provide some new incomplete block design (IBD). They used triangular partially incomplete block designs (PIBD) for obtaining new additional incomplete block design (IBD) for some mating designs (type IV by Griffing (1956)). The considered modal includes general combining ability (GCA) effects and specific combining ability (SCA) effects cannot be involved in this modal. Further derived designs obtained from triangular designs with special parameters with strong optimality properties. Additionally offered several efficient (IBD) for diallel crosses and their stated modal involves (GCA) effects and derived designs are all variances balance. The variance of the best linear unbiased estimate among (GCA) effects are all same. Mukerjee (1997) was first who checked the optimality of partial diallel crosses and write down D-optimality and A- optimality designs for some saturated cases. Also measures E- optimality for unblocked partial diallel crosses (PDC) under certain class of group divisible designs. Das, Dey and Dean (1998) secure families of optimal designs from nested (BIBD) with sub block size two for diallel crosses and shows that triangular partially (BIBD) when positive situations are satisfied for optimal. When the variety of parental lines increase the quantity of crosses also increases. So for this situations use optimal partial diallel crosses. Chai and Mukerjee (1999) introduced the optimal designs for diallel crosses when specific combining ability presented in the modal and show that partially balanced incomplete block designs with the triangular association scheme can be used to obtain optimality. Gosh and Desai (1998, 1999) constructed complete diallel crosses with unequal replication for the setting of complete replications. Examine the setting of diallel crosses by [p(p-1)/2] crosses, and (integer $\{n<p\}$), crosses are constant λ_1 time, the remaining [p(p-1)/2], crosses are repeated λ_2 time. Gosh and Desai (1998) studied to determine the significance of complete diallel cross (CDC) plan produced by balanced incomplete block (BIB) designs which assist in loss of block consider the variable of balanced incomplete block design (BIBD) are v=P, b, r, (k>2) and r, where $2\leq k \leq 15$ and $r \leq 15$. So single block of a similar design is vanished and it may result in a way that A-efficiency is spelled out as the ratio of the average variance for pair wise will have a distinction from (GCA) effect. Observe the CDC design (i.e. no loss of observations) under the residual design. Das (2002) presented satisfactory conditions for diallel experiment to be A-optimal and MS-optimal in the set up of complete replicate (CR) design. Das, Gupta and Kageyama (2002), Choi et al.(2004) extended the diallel experiment by using the concept of supplemented balanced design applied to diallel experiments. Different precisions have been used for comparing general combining ability effects.

- Comparing a non control line with control line.
- Comparing two non control lines.

Those styles of comparisons of gca were obtained for unblocked blocked situations.

Gosh and Das (2005) figuring out the idea of basis for optimal designs by presented theorem for estimation of heritability. Gosh, Das and Midha (2005) investigated the cases in which (SCA) effects excluded. Also obtained components of estimate by using optimality criteria which minimizes sum of variance components to estimate heritability for optimal design. Gosh et al. (2005) also obtained unbiased estimator (T) and calculated expressions of variance this estimator. Das, Gupta and Kageyamma (2006) worked on test versus control comparisons and developed sufficient conditions of A-optimality of control line versus test line comparisons. Furthermore distinguish a class of S-type design provided a lower bound to A-efficiency and communicate about the S-type designs and are highly efficient for test versus control comparison. Jaffrey G. Shaffer and Sudesh K. Srisvavtav (2009) an extensive BIBDCs construction errection approach is extract using class of BIBD with nested row and column design. This approach is applied to demonstrate such series collection creation plans. This universal optimality of all design layout springing up from the construction techniques introduced. Also imprecise the errection techniques for diallel cross design and layout as nested BIBD and sub block size will be 2. The new strategies are applied to BIBD and row column are nested for developing such constructions plans. M.K Sharma and Sileshi and Fanta (2009) extended the work on optimal block design for diallel crosses. They obtained some additional IBD for some mating designs by utilize two associate classes. Such that none of λ zero in PBIB designs. They consider model in these designs only include (GCA) effects and (SCA) effects being excluded because they obtained are not linked for cross effects. M.K Sharma and Sileshi Fanta (2010) presented some simple and easy techniques for developing BIBD for diallel experiment. Some technique also developed for construction of orthogonal block designs for diallel cross experiment. For each value of 'p' parental lines for CDC design (plans). Which can be related to cross effect and designs allows similar precision for estimation of contrasts for general and specific combining ability of lines. Labdi et al. (2015) studied ascochyta blight resistance by using half diallel crosses. They selected eight genotype of chickpea at seeding and adult stage. Haymann and Griffing methods are used for the analysis. According to the results, the (SCA) effects was less important than (GCA) effects. Iqbal et al. (2018) constructed new complete diallel. Cross designs through resolvable balance incomplete block design by using the methods of cyclic shifts. Also compute MS-optimality criteria by shah (1960), Eccleston and Hedayat (1974).

3.Definitions and Terminologies

Definition.3.1. A diallel is a mating system that involves all possible crosses between several genotypes which may be individuals, clones, homozygous lines are called diallel.

Definition.3.2. The diallel cross is a type of mating design, which is used to study the genetic properties of inbred lines are called diallel cross.

Definition.3.3. When each (${}^{P}C_2$) crosses appears more than once then diallel designs is said to be a complete diallel cross design.

Definition.3.4. While strains will increase because of huge range of parents then it for hard to handle by CDCs in such state uses PDCs. Wherein every figure is concerned in crosses same verity of time.

Definition.3.5. Mating design is schematic crosses between the groups and used to observe inheritance property in breeding system. Categories are

- Single mating design
- Complementary mating desig

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4. Method of construction

4.1: Construction of (BIB) Complete Diallel Crosses by using Method of Cyclic Shift: The lay out were developed through the usage of newly proposed technique primarily based on cyclic shifts. Given units of shifts that should be used to assemble such designs for distinct values of "p, r" and "**λ**", k=2.

Example.4.1. If number of treatment or parental lines p=9, block size k=3, replication r=8, number of blocks b=24, occurrence of pair of crosses λ=2 the given set of shifts are [1,2]+[1,3]+[2]t then we construct the diallel cross design as follows.

Block 1

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
0	1	2	3	4	5	6	7
1	2	3	4	5	6	7	0
3	4	5	6	7	0	1	2

Block 2

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
0	1	2	3	4	5	6	7
1	2	3	4	5	6	7	0
4	5	6	7	0	1	2	3

Block 3

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
0	1	2	3	4	5	6	7
2	3	4	5	6	7	0	1
8	8	8	8	8	8	8	8

Expected crosses can be made as follow;

(0×1)	(1×2)	(2×3)	(3×4)	(4×5)	(5×6)	(6×7)
(7×0)	(0×1)	(1×2)	(2×3)	(3×4)	(4×5)	(5×6)
(6×7)	(7×0)	(0×2)	(1×3)	(2×4)	(3×5)	(4×6)
(5×7)	(6×0)	(7×1)	(0×3)	(1×4)	(2×5)	(3×6)
(4×7)	(5×0)	(6×1)	(7×2)	(0×4)	(1×5)	(2×6)
(3×7)	(4×0)	(5×1)	(6×2)	(7×3)	(0×8)	(1×8)
(2×8)	(3×8)	(4×8)	(5×8)	(6×8)	(7×8)	(1×3)
(2×4)	(3×5)	(4×6)	(5×7)	(6×0)	(7×1)	(0×2)
(1×4)	(2×5)	(3×6)	(4×7)	(5×0)	(6×1)	(7×2),
(0,3)	(2×8)	(3×8)	(4×8)	(5×8)	(6×8)	(7×8)
(0×8)	(1×8).					

Hence CDC Design has over all of (72) crosses within side the experiment considering that every cross replicate identitical number of time.

4.2: Construction method for optimal block design for Diallel crosses: This approach is truly stated as from table of Clatworthy (1973), take (v) traces under evolution and quantity randomly 2 associate (PBIB) designs with parameter v=b, r=k, λ_1, λ_2, n_1,n_2,P_{ijk} (i, j, k=1,2) having none of the λ's equal to zero. These assumptions are follows,

- Number of pairs per block=k (k-1)/2.
- Number of pairs = bk (k-1)/2.
- plots= k (k-1)/2.
- b = v

We name this agreement is mating design. These optimal block design for diallel crosses having 2 classes.

Example.4.2. If we remember the following C12 (Clatworthy 1973) construction method. Parameters v= b = 5, r=k=3, n_1=n_2 =2, λ_1= 1 and λ_2=2.

Plan (auxiliary designs d_1)

B_1	B_2	B_3	B_4	B_5
1	2	3	4	5
2	3	4	5	1
4	5	1	2	3

Treatment	First associate	Second associate
1	2,5	3,4
2	1,3	4,5
3	2,4	1,5
4	3,5	1,2
5	1,4	2,3

Plan (auxiliary designs d_2)

B_1	B_2	B_3	B_4	B_5	B_6
1	2	3	4	5	6
2	3	4	5	6	1
4	5	6	1	2	3

Treatment	First associate	Second associate
1	4	2,3,4,5
2	5	1,3 4,6
3	6	1,2,4,5
4	1	2,3,5,6
5	2	1,3,4,6
6	3	1,2,4,6

4.3: Construction of (RBIBDs) by System of cyclic shift [1, 1, 2, 2], [2, 1, 2]t come after the smaller design as reported by Iqbal (1991). Index quantity of blocks which comprise entire replicate. Transform (RBIBDs) into CDC Design.

- B=1/2(k(k-1)) in every block.
- Total crosses= ½ bk(k-1)

Example 4.3: v =12 k = 5 r=11 b = 22 by shift [1, 1, 2, 2], [2, 1, 2]t

Block 1

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}
0	1	2	3	4	5	6	7	8	9	10
1	2	3	4	5	6	7	8	9	10	0
2	3	4	5	6	7	8	9	10	0	1
4	5	6	7	8	9	10	0	1	2	3
6	7	8	9	10	0	1	2	3	4	5

Block 2

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}
0	1	2	3	4	5	6	7	8	9	10
2	3	4	5	6	7	8	9	10	0	1
3	4	5	6	7	8	9	10	0	1	2
5	6	7	8	9	10	0	1	2	3	4
11	11	11	11	11	11	11	11	11	11	11

B	Treatments (crosses)									
1	0×1	0×2	0×4	0×6	1×2	1×4	1×6	2×4	2×6	4×6
2	1×2	1×3	1×5	1×7	2×3	2×5	2×7	3×5	3×7	5×7
3	2×3	2×4	2×6	2×8	3×4	3×6	3×8	4×6	4×8	6×8
4	3×4	3×5	3×7	3×9	4×5	4×7	4×9	5×7	5×9	7×9
5	4×5	4×6	4×8	4×10	5×6	5×8	5×10	6×8	6×10	8×10
6	5×6	5×7	5×9	5×0	6×7	6×9	6×0	7×9	7×0	9×0
7	6×7	6×8	6×10	6×1	7×8	7×10	7×1	8×10	8×1	10×1
8	7×8	7×9	7×0	7×2	8×9	8×0	8×2	9×0	9×2	0×2
9	8×9	8×10	8×1	8×3	9×10	9×1	9×3	10×1	10×3	1×3
10	9×10	9×0	9×2	9×4	10×0	10×2	10×4	0×2	0×4	2×4
11	10×0	10×1	10×3	10×5	0×1	0×3	0×5	1×3	1×5	3×5
12	0×2	0×3	0×5	0×11	2×3	2×5	2×11	3×5	3×11	5×11
13	1×3	1×4	1×6	1×11	3×4	3×6	3×11	4×6	4×11	6×11
14	2×4	2×5	2×7	2×11	4×5	4×7	4×11	5×7	5×11	7×11
15	3×5	3×6	3×8	3×11	5×6	5×8	5×11	6×8	6×11	8×11
16	4×6	4×7	4×9	4×11	6×7	6×9	6×11	7×9	7×11	9×11
17	5×7	5×8	5×10	5×11	7×8	7×10	7×11	8×10	8×11	10×11
18	6×8	6×9	6×0	6×11	8×9	8×0	8×11	9×0	9×11	0×11
19	7×9	7×10	7×1	7×11	9×10	9×1	9×11	10×1	10×11	1×11
20	8×10	8×0	8×2	8×11	10×0	10×2	10×11	0×2	0×11	2×11
21	9×0	9×1	9×3	9×11	0×1	0×3	0×11	1×3	1×11	3×11
22	10×1	10×2	10×4	10×11	1×2	1×4	1×11	2×4	2×11	4×11

It satisfies all the effects of CDC design which is narrated by Srivastava and Shankar (2007).

4.4: Construction of Nested balance incomplete block designs for CDCs developed the (NBIBDs) having 0,1,2,...,p-1.P=9 ,R=8 ,k_1=8, b_1=9, b_2=36, k2=2

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9
0	1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8	0
2	3	4	5	6	7	8	0	1
5	6	7	8	0	1	2	3	4
3	4	5	6	7	8	0	1	2
7	8	0	1	2	3	4	5	6
4	5	6	7	8	0	1	2	3
6	7	8	0	1	2	3	4	5

The design is BIBDs. If we take into account the primary rows collectively and the closing rows collectively.

D1

0	1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8	0

D2

2	3	4	5	6	7	8	0	1
5	6	7	8	0	1	2	3	4

D3

3	4	5	6	7	8	0	1	2
7	8	0	1	2	3	4	5	6

D4

4	5	6	7	8	0	1	2	3
6	7	8	0	1	2	3	4	5

It satisfies all the effects of CDC design which is narrated by Srivastava and Shankar (2007).

(0×1)	(1×2)	(2×3)	(3×4)
(4×5)	(5×6)	(6×7)	(7×8)
(8×0)	(2×5)	(3×6)	(4×7)
(5×8)	(6×0)	(7×1)	(8×2)
(0×3)	(1×4)	(3×7)	(4×8)
(5×0)	(6×1)	(7×2)	(8×3)
(0×4)	(1×5)	(2×6)	(4×6)
(5×7)	(6×8)	(7×0)	(8×1)
(0×2)	(1×3)	(2×4)	(3×5)

4.5: Construction method for variance balanced design for complete diallel cross: The technique of IBD for CDC system of GRIIFING (1956) technique IV. The assumptions are

- v = p(p-1)/2,
- b = p, r=2,
- k = p-1.

Example 4.5: In first block are 7.first stricter will consists subsequent crosses (0×1),(0×2),(0×3),(0×4),(0×5),(0×6). For mod (7) revered the following design. v=21, b=7, r=2, k=6.

B_1	B_2	B_3	B_4	B_5	B_6	B_7
0×1	1×2	2×3	3×4	4×5	5×6	6×0
0×2	1×3	2×4	3×5	4×6	5×0	6×1
0×3	1×4	2×5	3×6	4×0	5×1	6×2
0×4	1×5	2×6	3×0	4×1	5×2	6×3
0×5	1×6	2×0	3×1	4×2	5×3	6×4
0×6	1×0	2×1	3×2	4×3	5×4	6×5

4.6: Construction method for optimal complete diallel crosses: Take (d) as a (BIBD) with some assumptions traces =b=(2t+1), replicates equivalent =$k^{'}$=(2t), mod= (2t-1) λ=2t-1.Initial block acquire by {1, 2t, 2, 2t-1, t, t+1}.

Example: 4.6: Let (D) be ($BIBD_S$) with p=7, b=7, ($k^{'}$=2k=6), total replication (r=6) of each treatment and number of connective (λ=5) having blocks.

[1,2,3,4,5,6], [1,2,3,4,5,7], [1,2,3,4,6,7],
[1,2,4,5,6,7], [1,3,4,5,6,7], [1,2,3,5,6,7]

The blocks are dived into sub blocks.

{(1,3),(2,5),(4,6)},{(1,5),(2,4),(3,7)},
{(1,4),(3,6),(2,7)}{(1,2),(4,6),(5,7)},
{(1,6),(3,5),(4,7)},{(1,7),(2,6),(3,5)}

The first block {(1,3),(2,5),(4,6)},consists three crosses. This contains three block of Dn. These designs will be optimal.

4.7: Construction method for optimal block design for diallel: Count on that (P) are inherent lines and prepared (IBDs) for (d) pattern. Examine triangular (PBDs) d_1 had common variables.

- Traces obtain by v=P (P-1)/2
- Treatments similar to crosses
- For inherent lines for (i, j, k=1, 2).
- for i<j=1, 2,..., P.
- Two treatments, say (α, β) and (γ, δ)
- First associate if either ($\alpha = \gamma$, $\beta \neq \delta$) or ($\alpha \neq \gamma$, $\beta = \delta$) or ($\alpha = \delta$, $\beta \neq \gamma$) or ($\alpha \neq \delta$, $\beta = \gamma$), otherwise second associate.

Example 4.7: Let P=5 taking triangular designs having v=10, b=15, r=3, k=2, λ_1=0, λ_2=1. Cross of blocks is as follows:

[(1×2), (3×4)], [(1×2), (3×5)],
[(1×2), (4×5)], [(1×3), (2×4)],
[(1×3), (2×5)], [(1×3), (4×5)],
[(1×4), (2×3)], [(1×4), (2×5)],
[(1×4), (3×5)], [(1×5), (2×3)],
[(1×5), (2×4)], [(1×5), (3×4)],
[(2×3), (4×5)], [(2×4), (3×5)],
[(2×5), (3×4)]

4.8: Construction method for partial diallel crosses (PDCs): Singh and Hinkelmann (1990) develop Occurrence of PDCs in title PBDCs where defined as follows

For p is odd the PDCs are S_1 S_2 S_3, ...,S_m

S_l = {i× (i+l), i=1, 2,..., P, Mod (P)}

l = 1, 2, ..., m

m = (P- 1)/2

Example 4.8: for P=11, m=5, l=1, 2, 3, 4, 5

S_1 = {1×2, 2×3, 3×4, 4×5, 5×6, 6×7, 7×8, 8×9, 9×10, 10×11, 11×1}

S_2 = {1×3, 2×4, 3×5, 4×6, 5×7, 6×8, 7×9, 8×10, 9×11, 10×1, 11×2}
S_3 = {1×4, 2×5, 3×6, 4×7, 5×8, 6×9, 7×10, 8×11, 9×1, 10×2, 11×3}
S_4 = {1×5, 2×6, 3×7, 4×8, 5×9, 6×10,7×11, 8×1, 9×2, 10×3, 11×4}
S_5 = {1×6, 2×7, 3×8, 4×9, 5×10, 6×11,7×1, 8×2, 9×3, 10×4, 11×5}

Example 4.9: for P=11, m=5, l=1, 2, 3, 4, 5

S_1= {1×2, 2×3, 3×4, 4×5, 5×6, 6×7, 7×8, 8×9, 9×10, 10×11, 11×12, 12×1}
S_2 = {1×3, 2×4, 3×5, 4×6, 5×7, 6×8, 7×9, 8×10, 9×11, 10×12, 11×1, 11×2}
S_3 = {1×4, 2×5, 3×6, 4×7, 5×8, 6×9, 7×10, 8×11, 9×12, 10×1, 11×2, 12×11}
S_4 = {1×5, 2×6, 3×7, 4×8, 5×9, 6×10, 7×11, 8×12, 9×1, 10×2, 11×3, 12×4}
S_5 = {1×6, 2×7, 3×8, 4×9, 5×10, 6×11, 7×12, 8×1, 9×2, 10×3, 11×4, 12×5}

4.10: Construction method for some optimal plans for partial diallel crosses: Inherent lines n= ks/2 crosses (s≥2),(s≤ k-1). can be selected from ($^{N}C_{n}$), different ways so that each line occurs is (s) crosses. j>i=1,2, ...,k, (i=1, 2,...,k-1).

Example 4.10: The method consists of distinct values for K=17, S=8 change into select following optimal crosses.

(1×3),(1×5),(1×7),(1×9),(1×11),(1×13)
(1×15), (1×17), (2×4), (2×6), (2×8),
(2×10), (2×12), (2×14), (2×16), (2×17),
(3×5), (3×7), (3×9), (3×11), (3×13),
(3×15), (4×6), (4×8), (4×10), (4×12),
(4×14), (4×16), (4×17), (5×7), (5×9),
(5×11), (5×13), (5×15), (5×17), (6×8),
(6×10), (6×12), (6×14), (6×16), (6×17),
(7×9), (7×11), (7×13), (7×15), (7×17),
(8×10), (8×12), (8×14), (8×15), (8×16),
(9×11), (9×13), (9×15), (9×17), (10×12),
(10×14),(10×15),(4×16),(11×13), (11×14),(11×16),(12×13),(12×14), (12×16), (13×15),(14×16)

4.11: Construction method for variance balanced CDC design for Greco-Latin Square Design: developing CDC designs by following Greco-Latin square I terms of P traces.

1×1	2×2	3×3	4×4	5×5	6×6
2×1	3×4	4×5	5×1	6×2	1×5
3×1	4×5	5×2	6×3	1×6	2×4
4×1	5×1	6×1	2×5	2×4	3×2
5×1	6×5	2×1	3×2	3×1	4×3
6×1	1×6	1×4	1×6	4×3	5×1

4.12: Construction method for Resolvable PBIB design for PDCs block design: Choi, Gupta, and Son (2002), they proved the existence of a resolvable PBIB design implies the existence of a partially balanced PDC block design.

Example: 3.17.Consider the following replication sets of a resolvable group divisible PBIB Design with parameters v=8, b=16, r=4, λ_1=0,λ_2=1.

R_1	[(1×3),(2×6),(4×7),(5×8)]
R_2	[(1×4),(2×5),(3×7),(4×8)]
R_3	[(1×5),(2×4),(3×7),(6×8)]
R_4	[(1×6),(2×3),(4×7),(5×8)]

Discussion

In this study, a detailed and systematic review of diallel crosses designs has been discussed. These types of designs have been frequently used in genetic studies to determine the mode of inheritance of the examined trait, as well as the number of genes that control the trait and gene effects. Several kinds of diallel crosses as mating designs are used in animal and plant breeding to study the genetic properties and potential of inbred lines or individuals. This design is the most stabilized and organized approach to examine the variations among genotypes. Diallel cross designs have many techniques to investigate the genetic properties of inbred lines and the genetic properties of homozygous lines. The Diallel Crosses have been used to obtain the history of human life and approximate the genetic variations in discrete elements like breeding and genetics since (1950). In this study, several methods of construction of diallel crosses designs have been discussed with their examples.

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