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DIVISION OF DESIGN OF EXPERIMENTS:1990-2000

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Compiled
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FOREWORD

The Indian Agricultural Statistics Research Institute is a premier Institute in the discipline of Agricultural Statistics and Computer Applications in the country. The Institute has been engaged in conducting research and organizing teaching and training programmes in Agricultural Statistics and Computer Applications so as to generate trained manpower in the country to meet the challenges of research in the National Agricultural Research System (NARS). The research and teaching cum training activities are being organized under six divisions namely Sample Surveys, Design of Experiments, Biometrics, Forecasting Techniques, Econometrics and Computer Applications. The Institute has now taken a lead in developing Statistical Software Packages useful for scientists of the NARS.

Designing an experiment is an integral component of research in agriculture and allied sciences. It is through the data collected from designed experiments that valid inferences are drawn. In order to make research globally competitive, it is essential that sound statistical methodologies be adopted in the collection and analysis of data. The Institute has made many significant contributions in the field of Design of Experiments in terms of development of efficient and cost effective experimental designs and analytical techniques of the experimental data. The scientists in the division of Design of Experiments have published many research papers in National and International Statistical Journals of repute. Several books and monographs in the field of Design of Experiments have also been published. The division has also been actively involved in the development of Information Systems of the agricultural field experiments and development of Statistical Software packages for the generation of randomized layout of the design and the analysis of data. In order to disseminate the research in experimental designs to the actual users in the agricultural sciences so as to make research in agricultural sciences more meaningful with the analyses carried out using sophisticated statistical methodologies, various training programmes are organized.

The monograph on the achievements of the Division of Design of Experiments during 1990-2000 is a well-prepared document. It consists of the research highlights of the division alongwith training programmes conducted, softwares and Information Systems developed, publications viz. technical reports, research papers, books and students dissertations. The most important section of the monograph is the Designs recommended and Analytical Techniques suggested to the research workers in NARS. This will be quite useful in planning the future experiments and analysis of experimental data.

I wish to complement the team comprising of Dr V.K.Gupta, Dr. Rajender Parsad and Dr. Seema Jaggi for bringing out this valuable document. We look forward to suggestions from every corner in improving this monograph so as to make it more acceptable.

S.D.Sharma
DIRECTOR
IASRI, NEW DELHI

PREFACE

The Indian Agricultural Statistics Research Institute has been and continues to be a premier Institute in the discipline of Agricultural Statistics and Computer Applications. During 1983-1990, the Institute functioned as a Centre of Advanced Studies in Agricultural Statistics and Computer Applications under the aegis of UNDP of FAO. As of now the Institute is functioning as a Centre of Advanced Studies in Agricultural Statistics and Computer Applications under the aegis of Human Resource Development Programme of the Education Division of ICAR.

The Institute has been conducting research and organizing teaching and training programmes in applied statistics with special emphasis on Experimental Designs, Sampling Techniques, Statistical Genetics and Crop Forecasting Techniques. Besides, the Institute has also been very actively engaged in research in the disciplines of Bio-statistics and Econometrics. Statistical Computing and Computer Applications have always been an integral part of the major research activities of the Institute. The Institute has now ventured in the field of developing Statistical Software Packages useful for scientists in the National Agricultural Research System.

Experimental Design forms the backbone of any research endeavor in the discipline of agriculture and allied sciences. In order to make our research globally competitive, it is of paramount importance that sound and modern statistical methodologies are used in the collection and analysis of data and then the interpretation of results. The Institute has established itself in the world of Statistics so far as research in Experimental Designs is concerned. Many notable and original contributions have been made in the field of experimental designs at this Institute and the research papers have appeared in international statistical journals of repute. As many as 4 textbooks and one handbook on Experimental Designs have been published by the scientists of this Institute. Besides, this Division has also developed an electronic book on Design and Analysis of Agricultural Experiments. The book is divided into 5 modules and consists of 55 lectures.

Despite many important contributions made by this Institute in Experimental Designs, one question that has always been haunting the scientists of this Institute is as to why these new designs developed at the Institute and elsewhere have not been used by the experimenters? The Institute arranged meetings with the actual users who use the experimental designs in their research endeavor to find out the problems faced by them in planning and designing of experiments and then subsequent analysis of data generated and the interpretation of results. Having benefitted from the experience of the users, the Institute planned various training courses for the participants drawn from the National Agricultural Research System. The participants were the scientists in the discipline of Agricultural Statistics as well as scientists engaged in conducting research in the field of agriculture and allied sciences with a good working knowledge of statistical methodology and for whom experimental designs is an essential component of their research activity.

The Division of Design of Experiments has conducted many training courses in such a way that these are a blend of theory and application. These training programmes have built a bridge between the Institute and the scientists who are the actual users.

As a consequence of this, the institutions like (i) Divisions of Agronomy, Vegetable Crops, Fruits and Horticultural Technology, Seed Technology and Agricultural Engineering of IARI, New Delhi (ii) Department of Chemistry and Physics, CCS, HAU, Hisar, (iii) Division of Biotechnology, IVRI, Izatnagar (iv) AICRP on utilization of Animal Energy (vi) AICRP on Rapeseed and mustard (vii) AICRP on Oilseeds (Safflower) (viii) AICRP on underutilized crops (ix) AICRP or Cropping Systems Research, (x) All India Co-ordinated Research Project (AICRP) on Long Term Fertilizer Experiments have actually adopted the designs and/or analytical techniques suggested by our institute.

To propagate the research activities of the Division, it was thought that the achievements of the division might be documented in the form of a monograph. The present endeavour is a step in this particular direction. This monograph gives a brief account of both, the basic and applied research conducted by the division during the last decade. Besides, it also consists of the research projects undertaken by the division, various publications like technical reports, research papers, books, popular articles, etc. The summary of teaching and training activities and a list of the training programmes conducted by the Division are given. A table of M.Sc. and Ph.D. Dissertations approved in the field of Design of Experiments is also presented. The inclusion of various designs recommended and analytical techniques suggested would be helpful to the practicing statisticians and agricultural research workers.

We take this opportunity to thank all the scientists of the Division of Design of Experiments who have helped us in compiling this information in time. We are also grateful to Dr. S.D. Sharma, Director, IASRI, for his guidance and making all necessary facilities available to us. We are also thankful to Dr.(Mrs.)] Manisha Jain and Mrs. Sunita for their untiring efforts and help in preparing this manuscript.

New Delhi
Date: January 2001

V.K.Gupta
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1. Mandate of the Division

- To develop experimental designs suited to the fields of agriculture, animal, fishery, horticulture, etc. research and appropriate methods of analysis in various situations.
- To evolve suitable statistical methodology for the analysis of data for specified problems like groups of similar experiments, long term trials etc., and also to undertake statistical overview of the past experimental data on different agricultural and animal research programmes.
- To collaborate with All India Coordinated Research Project (AICRP) on Cropping Systems of ICAR under Project Directorate of Cropping Systems Research, Long Term Fertilizer Experiment (LTFE) and Agro forestry in planning, designing and analysis of data and also to organize training programmes under these projects.
- To develop and organize Agricultural Experiments Information System for agriculture and animal sciences.
- Teaching of various courses related to experimental designs, statistical methods, statistical inference etc. for M.Sc. and Ph.D. degree students and other training programmes.
- To engage in the research guidance of M.Sc./Ph.D. students.
- To render advisory and consultancy services related to statistical aspects to various organizations, ICAR institutes, State Agricultural Universities (SAUs) and national and international agencies engaged in different scientific activities.

2. Introduction

The Division of Design of Experiments has been engaged in conducting research for the development of statistical designs and methodology for analysis of data relating to field and laboratory experimentation in agricultural, animal, fishery and horticultural sciences and in developing and organizing the National Information System on Agricultural and Animal experiments. The research work is carried out in the form of research projects, M.Sc. and Ph.D. students' thesis work and interactive research. The research work done in the division can be categorized into basic research, applied research, collaborative research, database development, software development etc. The Division has also been actively involved in the human resource development programme. This activity has been organized in the form of M.Sc. and Ph.D. programmes as well as organizing training programmes for statisticians and agricultural scientists in the National Agricultural Research System (NARS). The training programmes have also been organized for the forestry scientists. The fundamental concept of organizing training programmes is to disseminate knowledge acquired during the recent past so as to carry the research to its logical users. During the recent past, the Division has made a dent in the NARS and now the scientists of NARS are engaged in a serious collaborative research with this Division.

3. Research Activities

The scientists of the Division have been very actively involved in the basic, applied and collaborative research in the field of Design of Experiments. The areas of interest and the results obtained in the areas of interest are briefly described in the sequel. The research papers emerged from these research findings are given as Table 1 in the Annexure. A list of ongoing projects is given as Table 2 in the Annexure.

3.1.1. Basic Research

3.1.1 Optimality of Designs

Experimentation is an essential part of any problem of decision-making. Sir Ronald A. Fisher laid the foundations of the statistical approach to experimentation in the early 1930s. The aim of any experiment, by and large, is to compare a number of treatments on the basis of the responses produced from the experimental material. Whenever one is faced with the necessity of accepting one out of a set of alternative decisions, one has to conduct an experiment to generate data using which a statistical decision may be based. Experimental designs are, therefore, useful for either estimating some unknown parameters in the model or testing certain hypotheses (or assertions) about these unknown parameters, generally some contrasts of the treatment effects. The confidence and accuracy with which treatment differences can be assessed depends to a large extent upon the size of the experiment in terms of the number of experimental units used and also on the inherent variability present in the experimental material, besides the variability arising because of the application of treatments. In order that it may be possible to select an optimum decision procedure, the choice of the experimental design must also be optimum. The optimum design is that design which is good in terms of some meaningful statistical criterion or a family of criteria with respect to a given problem and in a given class of designs defined by the number of treatments and other design parameters. This is how the problem of optimum designing of experiments arises.

In the initial stages of development of experimental designs, emphasis was laid on constructing designs that were in some sense as symmetric as possible in their treatment of the statistical parameters of interest (for example, randomized complete block designs, balanced incomplete block designs, Latin square designs, Youden square designs, etc.). Such designs yielded "information matrices" (coefficient matrices of the reduced normal equations for estimation of treatment effects) that, especially in the pre-computer age, made statistical calculations easy; the designs had aesthetic appeal to mathematicians and often had algebraic or geometric representations that helped one to understand and construct them; and the symmetric treatment of parameters of interest seemed a reasonable property that made such designs yield statistical estimators that looked intuitively as accurate as possible for the given number of observations.

The advent of high speed computers, importance and need to choose and adopt an experimental design that is best according to some well defined statistical criterion, led to the development of a subject like optimality of designs. The theory of optimal designs was almost non-existent till about the end of the Second World War, except for a remarkable early paper by Smith and the important paper of Wald. Professor Jack K. Kiefer initiated the serious and rigorous work on optimality aspects of designs. For the given experimental situation and an inference problem, there are a number of designs available, called a class of designs, which can be used to achieve some specified set of objectives. To make the exposition simple and clear, we shall take the following examples:

Example 1: Consider an experimental situation where an agricultural scientist is interested in making all possible paired comparisons among the 8 treatments to be tried in the experiment. The experimenter has 56 experimental units available with him. The 56 experimental units are not homogeneous and can be grouped into 14 blocks of 4 homogeneous experimental units each. Therefore, here the appropriate class of designs for estimating all the 28 paired comparisons among 8 treatments is **D**(v, b, k), where **D**(v, b, k) is the class of all connected designs in which $v = 8$ treatments are arranged in $b = 14$ blocks each of size $k = 4$. The class of designs **D** contains many designs, two of which are as given below.

D1: 1 2 3 4 5 6 7 3 4 5 6 7 1 2
2 3 4 5 6 7 1 5 6 7 1 2 3 4
4 5 6 7 1 2 3 6 7 1 2 3 4 5
8 8 8 8 8 8 8 7 1 2 3 4 5 6

This is a balanced incomplete block (BIB) design with parameters $v = 8, b = 14, r = 7, k = 4, \lambda = 3.$ Using the design *D1*, all the *28* elementary contrasts are estimated with same variance = $(5/15)\sigma^2$. Here σ^2 is the intra block variance. The average variance of all the *28* elementary contrasts is $(140/(15 \times 28))\sigma^2$.

For the same experimental setting consider another design *D2:*

D2: 1 2 3 4 5 6 7 1 2 3 4 5 6 7
2 3 4 5 6 7 1 3 4 5 6 7 1 2
4 5 6 7 1 2 3 4 5 6 7 1 2 3
8 8 8 8 8 8 8 8 8 8 8 8 8 8.

The design *D2* has the parameters $v = 8, b = 14, k = 4, r_1 = r_2 = \ldots = r_7 = 6, r_8 = 14.$ Using the design *D2*, out of a total of *28* elementary contrasts, *21* elementary contrasts among the first *7* treatments are estimated with same variance $(6/15)\sigma^2$ and each of the remaining *7* contrasts of treatment *8* with each of the first *7* treatments are estimated with variance $(4/15)\sigma^2$. The average variance of all the *28* elementary contrasts is $(154/(15 \times 28))\sigma^2$.

Thus, one can see that if the interest of the experimenter is in estimating all the *28* elementary contrasts, then *D1* is better than *D2* on the basis of the average variance. However, if the treatment *8* is a control treatment and *1,2,…,7* are test treatments and the interest of the experimenter is to make test treatments *vs* control comparisons and comparisons among test treatments are of no interest, then the average variance of all the *28* estimated elementary treatment contrasts is not a meaningful criterion. In this case the average variance of the *7* estimated elementary contrasts of treatment *8* with each of the first *7* treatments is a meaningful criterion. On comparing *D1* with *D2* one finds that the design *D2* is a better design than *D1* for making test treatments-control comparisons.

Example 2: Consider an experimental situation where the experimenter is interested in making all the possible paired comparisons among the *5* treatments to be tried in the experiment. The experimenter has *21* experimental units, which can be arranged in *7* blocks of arbitrary sizes. Therefore, here the appropriate class of designs for estimating all the *10* paired comparisons among *5* treatments is **D**(*v, b, n*), where **D**(*v, b, n*) is the class of all connected block designs in which $v = 5$ treatments are arranged in $b = 7$ blocks such that total number of experimental units is $n = 21$. The class of designs **D** contains many designs, two of which are

D1: $v = 5, b = 7, k = 3, r_1 = r_2 = r_3 = r_5 = 4, r_4 = 5.$

1	1	2	2	1	1	3
3	4	3	4	2	2	4
5	5	5	5	3	4	4

D2: $v = 5, b = 7, r_1 = 5, r_2 = r_3 = r_4 = r_5 = 4, k_1 = k_2 = 4, k_3 = k_4 = k_5 = k_6 = 2, k_7 = 5.$

2	2	1	1	1	1	1
3	3	2	3	4	5	2
4	4					3
5	5					4
						5

Both the designs *D1* and *D2* are variance balanced. Using *D1* and *D2*, all the *10* elementary contrasts are estimated with variances $(21/35)\sigma^2$ and $(20/35)\sigma^2$ respectively.

Thus we see that *D2* is a better design than *D1* on the basis of average variance of the estimated elementary contrasts. Although both the designs are variance balanced and estimate all the elementary contrasts with same variance, yet the variance from both the designs is not same, suggesting thereby that all variance balanced designs are not equivalent and a choice is to be made among the variance balanced designs as well.

Through these examples, the problem has been introduced. The choice of an appropriate design for a particular setting depends upon (a) the inference problem whose answer is sought for; (b) the class of designs in which choice is to be made (the class should have more than one design); and (c) the criterion or criteria to be used for the selection of the design.

Some commonly used optimality criteria in the literature are A-optimality, D-optimality, E-optimality, MV-optimality, S-optimality, MS optimality, ϕ_p - optimality, universal optimality, etc. In the sequel some significant results obtained are reported.

Optimality aspects of designs for one-way elimination of heterogeneity settings have been studied under the usual fixed effects and mixed effects model. Optimality aspects have also been investigated under correlated error structures. Optimality aspects of row-column designs have also been investigated.

In many experimental situations, the experimenter is interested in comparing a set of treatments called test treatments with another set of treatments called control treatment(s). For these experimental situations, the usual optimal designs for making all possible paired comparisons among treatments may not be efficient. A-optimal proper and non-proper block designs for making tests-control(s) comparisons under the usual fixed effects and mixed effects model have been obtained. Sometimes the experimenter may be interested in comparing test treatments among themselves besides making tests *vs* controls comparisons. To deal with such situations, weighted A-optimal block designs have been obtained by giving different weights to tests *vs* controls and tests *vs* tests comparisons. For the varietal trials the tests may include newly developed varieties and the two controls may be a disease resistant variety and a locally popular variety (local control). The experimenter may require the paired comparisons of tests with these controls with different precision. To deal with such situations weighted A-optimal designs have also been obtained. Various designs obtained for different experimental situations have been catalogued. Some general methods of construction of efficient row-column designs and block designs with nested rows and columns have also been obtained for comparing a set of tests with a set of controls.

In a meeting of the Project Co-ordinators with DDG (Soils) and DDG (Crop Sciences) held at IASRI, the experimenters raised a question. They wanted to know how many times the control treatments be replicated in each of the blocks so as to maximize the efficiency per observation for making test treatments Vs control treatments(s) comparisons. Optimum number of replication of control treatments in an Augmented Randomized complete Block designs have been obtained that maximizes the efficiency per observation.

Optimality aspects of nested block designs under non-proper block design set up have been studied. Some methods of construction of nested balanced block designs have also been given.

Optimal proper and non-proper incomplete block designs for diallel cross experiments for the estimation of contrasts among the general combining ability effects have been obtained and catalogued. Optimal balanced augmented block designs for diallel crosses have also been obtained and catalogued.

Universal optimality aspects of non-proper block designs with nested rows and columns have been studied. Some general methods of construction of optimal designs have also been given. Some methods of construction of block designs with nested rows and columns that are optimal according to type 1 criteria have also been obtained.

Optimal structurally incomplete row-column designs with same or different rows and/or columns sizes have also been obtained. These designs are useful for the situations where two non-interacting sets of treatments are applied in succession. The optimality aspects of designs for two non-interacting sets of treatments applied in succession have also been studied and a catalogue of optimal block designs have been prepared.

A catalogue of Binary balanced block designs has been prepared for average replication number less than equal to 30. These designs are universally optimal over a wide class of designs. The catalogue also includes the binary balanced block designs under the heteroscedastic models where intra block variances are assumed to be proportional to non-negative real power of block sizes.

Optimal change-over designs in presence of first and second order residual effects have been obtained and a catalogue of optimal repeated measurement designs balanced for first and second order residuals have been prepared. Some methods of construction of change-over designs balanced for first order residual effects of treatments have been given.

Schur optimality aspects of change-over designs for comparing several treatments with a control have been studied. It has been shown that the Schur-optimal control change-over designs are necessarily balanced. Some methods of construction of Schur-optimal balanced control change over designs have been given.

3.1.2. Robust Designs

Accidents and disturbances do occur even in a well-planned experiment and they render even an optimal design perform poorly and results in loss in efficiency. Various disturbances that occur commonly are – missing observations(s), loss of all the observations pertaining to a (set of) treatment(s), exchange of a treatment, interchange of a pair of treatments, presence of outlier(s), model inadequacies, etc. A design d is said to be robust against one or more of the above disturbances if it remains insensitive to the presence of one or more of the above disturbances in terms of design properties like connectedness, variance balance, efficiency, optimal properties, etc. Consider a design d having some property "*A*". Let d^* be the resulting design after some disturbance(s) η has taken place. The design d is said to be robust against disturbance(s) η if d^* possesses property "*A*".

Example 3. Consider the following block design d with parameters $v = 8, b = 13, k = 2, n = 26,$ the columns representing the blocks:

Blocks												
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
1	3	3	8	1	2	5	6	7	2	5	6	1
2	4	1	5	4	4	7	8	8	3	6	7	5

Suppose that the observation pertaining to treatment *5* is lost in block XIII. The resulting design is disconnected and, therefore, the original design is not robust as per the connectedness criterion. It may be mentioned here that connectedness is an important property of block designs, as this property ensures the estimability of all the paired differences among the treatment effects.

Example 4. Consider the following block design d with parameters $v = 8, b = 10, k = 3, n = 30,$ the columns representing the blocks:

Blocks									
I	II	III	IV	V	VI	VII	VIII	IX	X
1	2	3	5	6	1	5	3	6	7
2	3	5	4	7	2	6	1	5	8
3	4	4	6	8	4	7	4	8	5

Suppose that during the laying out of the experiment treatments *5* and *4* in blocks III and IV, respectively get interchanged. The resulting design is disconnected and hence design d is not robust against the interchange of a pair of treatments as per the connectedness criterion.

The above examples give a clear exposition to the problem of robust designs. In the sequel some results obtained are presented.

The robustness of designed experiments has been studied under a general linear model for inferring on a set of treatments as per the connectedness criterion as well as the A-efficiency criterion. It has been shown that a design robust under a homoscedastic set up is also robust under the general heteroscedastic set up with correlated observations. The robustness of block designs has been studied in particular against the loss of data, in general against loss of any *t* observations. Designs robust against the loss of one, two and three observations have been identified. Robustness of block designs against the loss of any two blocks, not necessarily disjoint, has also been studied. Similarly, the robustness of row-column designs has also been investigated against the loss of data. The resistance of variance balanced block designs with unequal block sizes that are universally optimal has been investigated against the loss of all the observations pertaining to a treatment. Some methods of construction of resistant designs have also been obtained. Balanced treatment incomplete block designs have been obtained that are robust against one missing observation or all the observations pertaining to a block. Balanced Bipartite Block designs that are resistant against the loss of all observations pertaining to a test treatment have been introduced. Binary Variance Balanced Block designs have been shown to be robust against the exchange of a treatment or interchange of a pair of treatments. Binary balanced block designs for diallel crosses have been shown to be robust against any one of the following (i) single missing observation (ii) one block missing (iii) exchange of a cross (iv) interchange of a pair of crosses.

Several diagnostic criteria for detection of outliers in experimental data have been developed. Robustness aspects of designs against the presence of one outlier have been investigated. It has been shown that all BIB designs and all other E-optimal designs are robust in presence of one outlier.

For multi factor experiments, sometimes a level of a particular factor may be lethal or experimental material pertaining to this level of the factor could not be procured in time and as such all the observations pertaining to the treatment combination containing that level of the particular factor are lost. Robustness aspects of designs for such situations have been studied and structure resistant designs have been obtained.

Robustness aspects of change over designs have also been investigated using efficiency criterion. Change over designs balanced with respect to first order residual effects were found to be robust against the loss of observation(s) from any one of the experimental units.

3.1.3. Factorial Experiments

Efficient confounded designs for asymmetrical factorial experiments have been obtained using the technique of collapsing and replacement and a catalogue of efficient designs has also been prepared. A method of construction of fractional factorial plans for asymmetrical factorial experiments has also been given.

3.1.4. Response Surface Designs

Some modified and/or rotatable response surface designs useful for response optimization for symmetric as well as asymmetric factorials have been obtained and a catalogue of second order rotatable response surface designs for response optimization has been prepared for a maximum of 10 factors using central composite designs, BIB designs and pairwise balanced block designs. Some methods of construction of modified slope rotatable designs with equispaced doses have been obtained and a catalogue of modified and/or rotatable second order response surface designs for slope estimation has also been prepared. Some efficient response surface designs for slope estimation have been obtained using MINIMAX criterion.

A modified second order rotatable response surface design for 3 factors each at 5 equispaced levels in 36 design points has been adopted by one Ph.D. (Agricultural Engineering) student of IARI, New Delhi. The experiment is related to osmotic dehydration of the banana slices. The detail of the experiment and the treatment structure is given in Section 4.1.

The problem of selecting explanatory variables for the case of non-linear models has also been investigated. The design criterion heavily depends on initial guess of the parameters in non-linear set up. The criterion of D-optimality is used for selecting any design.

Replication structure of the experiments under a non-linear set up has been examined. Replicating all the basic design points equally gives increased valued of the criterion. A sufficient condition for a replicated design to be optimum is provided.

3.1.5. Experiments with mixtures

In some experimental situations it may not be possible to explore the total range of all the components because one may require that at least a certain amount of a particular component may be present in all blends or one may insist that the proportion of component may not exceed a certain proportion. Such constraints give lower and/or upper bound on different components of mixtures. In certain experimental situations there may be one or more factors that are not the component(s) of mixture but influence the response. This type of factor(s) is(are) called process variable(s). A method of construction of Restricted Region Simplex Design in the presence of process variables when upper bound is imposed on one of the components of the mixture has been obtained using response surface designs with equispaced doses.

3.1.6. Designs for Estimation of Competition Effects

Competition is defined as the effect of one individual or a set of individuals upon another individual or a set of individuals. Several methods of construction of serial designs have been obtained and the analytical procedure have been developed using the linear model accommodating the left and right neighbour effects on each treated plot. Several methods of construction of complete as well as incomplete block designs have been obtained by making use of the directed graphs and factorial structure. An analytical procedure for the analysis of these designs under the assumption of (i) equal left and right neighbour effects and (ii) no competition effect of a treatment with itself has also been developed.

3.1.7. Computer Aided Search for Optimal Designs

An algorithm to search for optimal block designs has been developed using the concept of exchange and interchange procedures. D-optimal saturated main effect plans for three factors when the first factor is at three levels have been obtained. A row-column design has been obtained by keeping minimal number of experimental units when the number of rows is three.

3.1.8 Sampling vis-à-vis Design of Experiments

For estimating the variance of nonlinear statistics like regression and correlation coefficients in stratified designs the method of balanced repeated replication has become popular like other procedures like linearization and jackknife repeated replications. It has been shown that the balancing can be achieved using certain proportional frequency plans. A method of estimation of variance from complex survey data has been developed using the proportional frequency plans. A bias corrected non-linear statistic is also obtained. Based on simulation studies, it has been shown that the proposed method is better than the grouped method.

3.1.8. Change Over Designs

A procedure of estimation of various treatment effects (direct and residual) of two - treatment change-over designs by adding a pre - period with appropriate treatments more precisely have also been developed.

General methods of construction of balanced ternary changeover designs and cyclic changeover designs have been given. Methods of constructions and analytical procedure for two-factor change over designs have been developed.

Some methods of construction of extra-balanced change-over designs with minimum number of experimental units called as 'minimal extra balanced change over designs' have been given under the assumption that the number of periods is less than the number of treatments. The extra-balanced property of constructed designs is achieved (in order of application) that each treatment precedes each other treatment including itself once. A catalogue of extra-balanced minimal change-over designs has also been prepared.

3.1.9. Sampling Techniques

Systematic sampling is quite simple to adopt but it has the drawback that it cannot provide an accurate estimate of the population mean. A new technique is proposed wherein, using a probability scheme, systematic sampling scheme can be combined with simple random sampling without replacement thereby reducing the drawback but retaining the advantages of the schemes. The method ensures that if for at least one of the sampling schemes the variance of mean is estimable then for the combined scheme also this variance is estimable.

3.2. Applied Research

The scientists of the Division have also been very actively involved in the applied research in the field of Design of Experiments. The areas of interest and the results obtained in the areas of interest are briefly described in the sequel. The research papers emerged from these research findings are included in Table 1 in the Annexure.

3.2.1. Variance Components Estimation

The technique of obtaining the estimates of the variance components from a mixed model under a general, proper block design set up has been developed. This technique utilizes the analysis of a dual design under a mixed model. The technique also enables to get the covariance estimate of two characters by getting the estimates of the variance components of the individual characters and the sum of the characters. This technique has got application in genetic experiments where the genotypes are considered as a random sample from some parent population and inferences are required to be made on the parent population itself and not on the individual genotypes. The experimenter is interested in obtaining various statistics like genotypic and phenotypic variances, genotypic and phenotypic correlation, heritability coefficient, path analysis, etc. With the availability of this technique, the experimenters can be convinced in the use of incomplete block designs. The methodology has been developed for a M.Sc. student of Division of Vegetable crops, IARI, New Delhi.

3.2.2. Experiments with mixtures

A strategy for design and analysis of experiments involving fixed quantity of inputs applied in splits at different crop growth stages has been developed. This strategy has enabled the experimenters to conduct such experiments using more efficient designs and establish a relationship between various splits and response. This relationship can be used for interpolation of the response at the design points that are not tried in the combination.

The Ph.D. students of I.A.R.I., New Delhi, have also used the methodology of experiments with mixtures in the analysis of experimental data on preparation of ready to serve fruit beverages. A procedure for obtaining optimum mix has also been obtained.

3.2.3. Analysis of Groups of Experiments

The analysis of data generated from the experiments conducted over locations and/or environments have been analyzed using nested models. The location/years have been assumed as bigger blocks and experiments *i.e.* replications are nested within the environments. A method of combined analysis of repeated experiments with some treatments common to all the experiments and some treatments common to some experiments have been developed. Analytical procedure for the combined analysis of experiments with factorial treatment structure with some treatment combination common has also been developed.

3.2.4. Post Harvest Experiments

To study the storage behaviour of vegetables/fruits, many post harvest experiments are conducted under different storage conditions. The data generated from these experiments have been analyzed using the storage temperatures as artificially created environments. This analytic technique has helped many M.Sc. and Ph.D. students of the Division of Vegetable Crops, IARI to draw statistically valid inferences from their data.

3.2.5. Covariance Analysis

Analysis of covariance has been used in various experimental situations by taking residuals from previous data, soil status, plant stand, etc. as covariates. Taking initial body weights of animals as covariate in grazing systems analysis, the analysis of covariance has been performed.

3.2.6. Block designs with factorial structure

The data pertaining to partially balanced confounded asymmetrical factorial experiment 2×3^2 in 6 plots per block augmented by one extra treatment in each block has been analyzed using the general block design analysis followed by contrast analysis for obtaining main effects and interaction components. Using this procedure many data sets of Ludhiana centre of AICRP On Station experiments under Project Directorate of Cropping Systems, Modipuram have been analyzed.

3.2.7. Fatigue scorecard development for camels

An animal fatigue score card based on physiological characteristics (pulse rate, respiration rate, speed and rectal temperature) and physical symptoms like frothing, watering from nostrils and eyes, legs uncoordination, excitement) has been developed in collaboration with Krishi Vigyan Kendra, Rewari under the aegis of All India Co-ordinated Research Project on Utilisation of Animal Energy. This fatigue scorecard is very useful for the farmers, military farms, etc. Suitable workcycles have also been obtained for various drafts. The details are given in Section 4.1.

3.2.8. Fertilizer-Response studies

Methodological investigations in predicting fertilizer response using soil test values and other site variables have been carried out. The data of experiments conducted on cultivators' field during 1977-81 under A.I.C.A.R.P. (ICAR) in respect of 13 district centres situated in different agro-climatic regions were utilized.

For rice crop, it was observed that reduction in general regional recommended doses of fertilizer is possible at Muzaffarpur and Purnea (Bihar) to the extent of 5-10%, at Krishna 6-21%, at Thiruchirapalli 10-25%. At other places reduction is possible for obtaining maximum response of 45-60q/ha without economic gain.

For wheat crop, in the district of Muzaffarpur and Purnea (Bihar), Amritsar and Gurdaspur (Punjab), Faizabad (U.P.) and Sundargerh (Orissa), the general regional recommended dose was better than the soil test based fertilizer dose whereas using the later fertilizer dose, maximum response could be achieved.

The Institute has been engaged in formulating and updating yardsticks of additional production from time to time of various crops from the use of several agricultural inputs.

Yardsticks of rice were worked out for high yielding, locally improved and locally indigenous varieties for nitrogen, phosphorus, potassium, zinc, lime, FYM, green manure, bio-fertilizers, herbicides etc. For cereals other than rice yardsticks of nitrogen, phosphorus and nitrogen, phosphorus, potassium was formulated. Yardsticks due to irrigation were worked out for various crops utilizing the limited available data.

Methodology for construction of yardsticks of additional production from the combined application of several inputs has been developed. Utilising the methodology yardsticks of additional production of pulses Red gram, Green gram (Linseed, Sesamum, Mustard and Groundnut) due to nitrogen, phosphorus when they are applied singly and jointly were worked out.

Fertilizer - Response ratios were also worked out for all major crops using the data of experiments on cultivator's fields on the request of Ministry of Agriculture.

A study entitled 'Statistical evaluation of fertilizer requirements according to dates of sowing' was carried out with the objective of estimation of fertilizer requirement corresponding to the normal and delayed sowing for different crops. It is found that delayed sowing of rice by 30 days generally reduced the yield of the crop by 28%. In wheat the percentage reduction is in the range of 15-30% with late sowing by 10-20 days.

Some studies on the estimation of direct and residual effects of nitrogenous fertilizers applied alone or in combination with organic and biofertilizers *viz*., FYM, Azolla in crop sequences has been made in the division. The result indicated that one could make economical use of Nitrogen upto 50% in rice-sequence and 25% in rice-wheat sequence by making use of FYM. Application of slow release nitrogenous fertilizers to Kharif-rice was quite useful as compared to urea both from the point of view of productivity and stability considerations. Similarly Nitrogen-requirement can also be met through Azolla alone or in combination with organic source.

A study on the interactions with reference to resource constraints of agronomic factors was carried out with the broad objective of identifying certain interactions in relation to crop production, of different crops at reduced level of certain agronomic factors and to obtain optimum number of replications, locations and years required to test the performance of such interactions.

3.2.9. Long Term Fertilizer Experiments

Under All India Coordinated Research Project on Long Term Fertilizer Experiments continuous cropping and manuring for more than two decades has resulted in sizeable build up of certain nutrients like phosphorus or depletion of some plant nutrients like zinc in the soil at several locations. To examine the reduction or even temporary suspension of phosphatic fertilizers or addition of any other deficient nutrient element over the prescribed minimum, a nested two way design have been suggested using mid course bifurcation of plots in one of the replications. These bifurcated plots were used for superimposition of suitable treatments. In long-term fertilizer experiments the unit plot sizes ranges between 150 to 300 square meters that becomes unmanageable especially for harvesting due to shortage of labor, time and budgetary provisions. The researchers are forced to go in for sample harvests purely based on operational conveniences without any scientific reasoning. It results in large errors. A scientific method of locating the sample plot for harvest in the main experimental plot considering the practical feasibility and operational convenience has been suggested. The sampling technique consists of locating a sample plot within the whole plot by selecting a row at random from the Southwest corner of the main plot and a plant within the selected row at random along the length of the whole plot. The plant would serve as the Southwest corner for demarcating a sample plot of specified size. The dimensions of the sample plot are determined by first fixing its size, which is generally 10-15 percent of the whole plot, and then obtaining the number of consecutive rows to be included in the sample which is equal to one less than the integral part of the ratio of the square root of the sample plot size divided by row spacing. The number of rows multiplied with row spacing would provide the breadth of the plot that is then used for computing the length of the sample plot. Starting from the S-W corner of the sample plot and moving along the length and breadth of the whole plot, the sample plot of calculated dimensions is demarcated. This method was tried on wheat crop of long-term fertilizer experiment that is in progress at IARI, New Delhi. Analysis of data collected from sample plots didn't reveal any significant difference between the sampled and whole plot yields.

It has also been observed that the yields obtained at one and a half times the optimum rates of fertilizer application were significantly higher than those under optimum levels for most of the crops in cereal based cropping systems.

Incorporation of farmyard manure at the rate of 10-15 t/ha/year with recommended NPK fertilizer doses to the kharif crop in the sequence has a pronounced effect in enhancing the efficiency of chemical fertilizers. The crosswise-pooled results over 25 years have indicated significant improvements in crop productivity with the integrated use of organic and inorganic fertilizers by 11 to 44 and 15 to 26% respectively over optimal (100% NPK) and superoptimal (150% NPK) levels of chemical fertilizers.

3.2.10. Crop-Weather studies

A methodology was developed to study the behaviour of crop response to long-term fertilizer treatment with reference to weather and to examine the association between the responses of different crops of successive seasons. Investigations revealed that most of the variation in responses of rainfed (sorghum) as well as irrigated (wheat) crop, over a period of 13 years was due to weather. However, in case of unbalanced fertilizer doses (without P_2O_5), a diminishing cubic trend also caused significant amount of variation in responses. But this variation was very small as compared to the variation caused by weather. Characteristics (values of weather variables at different stages of crop growth) of favourable and unfavourable years for sorghum and wheat crop were also identified.

Fertilizer dose $N_{80}P_{80}K_{40}$ was found to be best among set of doses in favourable as well as unfavourable years for both the crops. Statistical aspects for characterization of drought in relation to crop with the main objective of working out drought threshold values related to a crop and to know the possibilities of occurrence of drought under various durations were studied. A method of quantifying drought threshold rainfall value for droughts of various durations such as 1^{st} week through seventeen weeks for bajra, cotton and groundnut crops for one district each of Karnataka and Maharashtra was developed. Chances of occurrence of droughts of various durations at different stages of crop growth are also obtained. Out of these crops drought threshold values were the lowest for cotton crop in both the districts.

To study the effect of moisture stress on yields, an investigation was carried out with the objectives of examining reduction in yield and preparing stress index along with testing of the efficiency of the model when unit is changed from a day through fortnight. Soil moisture model developed by R.H. Show was modified to suit the requirements for the data on rainfall, evaporation, yield, soil and crop characteristics. Percentage reduction in the observed yield has been successfully estimated and the model itself provides for predicting yield during any time of the season between sowing and harvesting.

3.2.11. Crop-Sequence studies

A study on crop sequence in terms of their agronomic productivity, monetary returns and energy equivalents has been made in different agro-climatic zones of various states in the country. Data on each crop were analyzed by an appropriate analysis of variance technique after their conversion into protein, carbohydrate and calorie equivalents. Utilizing Duncan's Multiple Range Test (DMRT) various sequence means were compared. For examining the consistency of the performance of a sequence over years, it was assumed that the sequence that has retained by and large, same rank in the individual year as well as combined over the years is considered consistent in its performance over years.

3.2.12. Agroforestry experiments

Methodological studies relating to agroforestry experiments were taken up. The various limitations in the data collection of agroforestry experiments have been identified. A review of designs used for agroforestry experiments has also been prepared.

3.2.13. Intercropping experiments

Interpretation of intercropping data and its analysis presents considerable problems where the magnitude or even the existence of yield advantage over sole cropping is not immediately apparent. There are several analyses to be carried out on the basis of separate component crop-wise yields and combined yields. Usually a homoscedastic model is assumed for the analysis of such data. But this assumption may not be valid in intercropping experiment because the factors such as spacing, crop geometry and intercropping proportions etc. may be responsible for the heteroscedasticity. So the presence of heteroscedasticity in Intercropping experiment and its effects on drawing inferences on the performance of component crops both individually and collectively were studied on the basis of eleven sets of data on Intercropping experiments, collected in the past, drawn from different places and/or years under the aegis of All-India Coordinated Agronomic Research Project.

It was observed that the heteroscedasticity is more prevalent in Gram crop than in wheat crop. This could possibly be attributable to the fact that the C.V. of the proportional areas occupied by Gram and wheat crops were in the ratio of 11:5. Also the effect of such unequal variances on the comparison of treatment effects separately on each component crop was observed.

In case of presence of heteroscedasticity the relative values of the unequal variances associated with the different levels of a factor were estimated with the help of componentization of Error mean squares. These ratios were utilized for drawing conclusions with the help of approximated distributions of the usual F-ratio under the homoscedastic model.

A comparison of the bivariate method of analysis and the univariate method showed that the bivariate method tends to show the significance of different effects more often than they actually exist. Drawing of contours might help for the pairwise comparison of the levels of different factors in case of real significance under the bivariate method. However, this has certain limitations. The univariate method of analysis has provided methods for drawing the conclusions of the significance of various main effects, interactions and other treatment contrasts under different situations/criteria.

3.3. Project Reports

The scientists undertook the following research projects during the period under report. The research output emerging from these projects has been reported as project reports that are IASRI publications.

1. Rajinder Kaur, Ajit Kaur, Madan Mohan and P.N. Bhargava (1992). Statistical evaluation of fertilizer requirement according to date of sowing.
2. Rajinder Kaur, Ajit Kaur, Madan Mohan and P.N. Soni (1992). Statistical studies on nitrogen economy through organic sources.
3. Asha Saksena and P.N.Bhargava (1995). A Statistical model to assess the effect of moisture stress on yield.
4. Seema Jaggi and V.K. Gupta (1997). A-optimality of block designs for comparing two disjoint sets of treatments.
5. J.K. Kapoor and V.K. Gupta (1997). Methodological studies and critical analysis of data relating to repeated experiments with some common treatments.
6. Basant Lal, J.K. Kapoor and P.R. Sreenath (1997). Methodological studies relating to agroforestry experiments.
7. Asha Saksena, Ajit Kaur Bhatia and Harnam Singh Sikarwar (1997). A study of behaviour of crop response to long term fertilizer application with reference to weather parameters.
8. G.L. Khurana and K.C. Bhatnagar (1998). A study of interactions with reference to resource constraints of agronomic factor.
9. P.K. Batra, Rajender Parsad and O.P. Khanduri (1999). Some statistical studies relating to design and analysis of experiments involving fixed quantity of inputs.
10. P.R. Sreenath (1999). Balanced incomplete block designs with nested rows and columns.
11. C.H. Rao, Seema Jaggi and G.L. Khurana (1999). Yardsticks of additional production of pulses and oilseeds from the combined application of fertilizers.
12. Seema Jaggi, R. Srivastava and V.K. Gupta (1999). Study of designs for two or more sets of treatments applied at different periods of experimentation.
13. Aloke Lahiri, D.K. Mehta, N.K. Sharma and S.M.G. Saran (1999). Methodological Investigations in predicting fertilizer response using soil test values and other site variables.
14. R. Srivastava, V.K. Gupta and Rajender Parsad (2000). Studies on optimality of block designs for making test treatments-control comparisons.

15. D.P. Handa and P.R. Sreenath (2000). Construction of efficient designs for asymmetrical factorial experiments.
16. Rajender Parsad, V.K. Gupta and O.P. Khanduri (2000). Cataloguing and construction of variance balanced block designs: computer algorithms for construction.
17. R. Srivastava, A. Dey and V.K. Gupta. Studies on robust designs.
18. A. Dey and V.K. Gupta. Studies on designs for animal experiments.
19. V.K. Gupta. Studies on optimality of designs for one-way and two-way elimination of heterogeneity.

The scientists of the division have published some other technical reports either in association with other research organizations or on the demand of government departments. A list of such reports is given below:

1. Ashish Das, V.K. Gupta and Praggya Kisan (1990). E-optimal block designs under heteroscedastic model. *Tech. Report No. 1190, Stat.-Math. Division, ISI, Calcutta, India*
2. Ashish Das, V.K. Gupta and William I. Notz (1996). A class of universally optimal block designs. *Technical Report No. 572, The Ohio State Univ., Columbus, USA.*
3. V.K. Gupta (1999). Studies on optimality of designs useful in agricultural and animal experiments. Project of National Fellow of ICAR.
4. C.H. Rao, A.R. Rao and V.K. Sharma (1998). Response-fertiliser ratios of foodgrains and oilseeds in India. IASRI, Publication.
5. M. Din, Jyotsana, P.K. Srivastava and Rajender Parsad(2000). Evaluation of fatigue scorecard for animals. *Annual Report for AICRP on Increased Utilization of Animal Energy with Enhanced System Efficiency.*

3.4. Collaborative Research

- Planning, designing and analysis of experiments planned On Stations under the Project Directorate for Cropping Systems Research.
- Planning, designing and analysis of On Farm research experiments planned under the Project Directorate for Cropping Systems Research
- Planning, designing and analysis of data relating to experiments conducted under AICRP on Long-term fertilizer experiments.
- Design and analysis of agroforestry experiments.
- Planning, designing and analysis of experiments related to soil test crop response correlations.
- Evaluation of fatigue score card for animals (AICRP on increased Utilization of Animal Energy with enhanced system efficiency in collaboration with KVK, Rewari)

3.5. Ongoing Projects

A list of ongoing research projects of the Division is given in Table 2 in the Appendix.

4. Consultancy/Advisory Services

In order to make the fruits of research to be enjoyed by the agricultural scientists in their research, the activity of consultancy and advisory services was taken up rigorously. The actual problems of the experimenters in terms of the design to be used, generation of the randomized layout of the design, the actual analysis of data already generated by using modern, sophisticated statistical techniques, etc. were taken and the agricultural scientists felt satisfied with this service. Project Directorate of Cropping Systems Research has adopted incomplete block designs and balanced confounded designs. As a consequence of this, a technical bulletin is being prepared that describes some real, live cases of the experimenters. The design, the analysis of data and the interpretation of results have been included. The data analysis has been carried out using SAS. This bulletin will be immensely useful not only for the agricultural scientists but also will be useful for the practicing statisticians. This activity needs to be strengthened further. A sample of designs recommended and analytical techniques suggested, as a consequence of the consultancy and advisory services, is given in the sequel.

4.1. Designs Recommended and Analytical Techniques Suggested

- Generally the designs adopted in the experiments with treatments as different crop sequences for Project Directorate of Cropping Systems Research are the Randomized Complete Block designs and the split - plot designs. Instead, Balanced Incomplete Block (BIB) designs have been recommended as an alternative for these experiments. The BIB designs with parameters (v, b, r, k, λ) being used now are the following:

  (9, 12, 4, 3, 1), (7, 7, 4, 4, 2), (6, 10, 5, 3, 2), (13, 13, 4, 4, 1), (15, 35, 7, 3, 1).

  Here v denotes the number of treatments, b the number of blocks, r the replication of the treatments, k the block size and λ the number of blocks in which any pair of treatments appears together.
- A rectangular lattice design with three replications was recommended for an experiment conducted at Division of Vegetable Crops, IARI, New Delhi with 30 indigenous and exotic collections / cultivars of garden pea. The block size was *5* and there were *6* blocks in each replication. The characters observed were the day of first appearance of first flower, first flowering node number, length of internode, the day of *50%* flowering, the days of first green pod harvest, number of primary branches, the length of pod, breadth of pod, the number of seeds per pod, the number of pods per plant, the pod yield per plant, seed yield per plant, plant height, *100* seed weight, shelling percentage and protein content. The layout of the design is given as under:

Replication-I ←Blocks→					
1	**2**	**3**	**4**	**5**	**6**
11	1	26	6	21	16
12	2	27	7	22	17
13	3	28	8	23	18
14	4	29	9	24	19
15	5	30	10	25	20
Replication-II ←Blocks→					
1	**2**	**3**	**4**	**5**	**6**
6	2	5	4	1	3
11	7	10	9	12	8
16	18	15	14	17	18
21	23	20	19	22	24
26	28	25	30	27	29

Replication-III ←Blocks→					
1	**2**	**3**	**4**	**5**	**6**
2	5	3	4	1	7
9	14	10	6	8	13
15	16	11	12	20	19
22	23	17	18	21	25
26	29	28	24	30	27

- A Balanced confounded asymmetrical factorial experiments 4×2^2 in *8* plots per block where the treatments are *4* levels of phosphorous as P_2O_5 (*0, 30, 60, 90* Kg./ha.) in Kharif rice, and two doses of phosphorous (*0, 60 Kg./ha*.) in each of the two-summer crops *viz. Sasbenia* for green manure and *Green gram* for grain to Project Directorate of Cropping Systems Research. The actual layout of the design is given below:

Replication - I		Replication - II		Replication - III	
Block I	Block II	Block I	Block II	Block I	Block II
0 0 0	0 0 1	0 0 0	0 0 1	0 0 0	0 0 1
0 1 1	0 1 0	0 1 1	0 1 0	0 1 1	0 1 0
1 0 0	1 0 1	1 0 1	1 0 0	1 0 1	1 0 0
1 1 1	1 1 0	1 1 0	1 1 1	1 1 0	1 1 1
2 0 1	2 0 0	2 0 1	2 0 0	2 0 0	2 0 1
2 1 0	2 1 1	2 1 0	2 1 1	2 1 1	2 1 0
3 0 1	3 0 0	3 0 0	3 0 1	3 0 1	3 0 0
3 1 0	3 1 1	3 1 1	3 1 0	3 1 0	3 1 1

- A Ph.D. student of Division of Agronomy, IARI, New Delhi, was interested in conducting an experiment on crop sequences, 5 herbicidal treatments were to be applied to the Kharif crop and 4 herbicidal treatments to the Rabi crop. The interest was to compare the direct effects of Kharif and Rabi treatments, residual effects of Kharif treatments and interaction between the residual effects of Kharif treatments and direct effects of Rabi treatments. If we denote the Kharif treatments as 1, 2, 3, 4, 5 and Rabi Treatments as a, b, c, d, then the layout of the design is given as:

Block 1	1a	2a	3a	4a	5a	1b	2b	3b	4b	5b
Block 2	1a	2a	3a	4a	5a	1c	2c	3c	4c	5c
Block 3	1a	2a	3a	4a	5a	1d	2d	3d	4d	5d
Block 4	1b	2b	3b	4b	5b	1c	2c	3c	4c	5c
Block 5	1b	2b	3b	4b	5b	1d	2d	3d	4d	5d
Block 6	1c	2c	3c	4c	5c	1d	2d	3d	4d	5d

This is an extended group divisible design with *20 (5 x 4)* treatments and is based on the association scheme

1a	1b	1c	1d
2a	2b	2c	2d
3a	3b	3c	3d
4a	4b	4c	4d
5a	5b	5c	5d

The two treatments are $(01)^{th}$ associates if first factor is at same levels *i.e.* in the same row, $(10)^{th}$ associates if the second factor is at same levels *i.e.* in the same column and rest are $(11)^{th}$ associates. As a result the parameters of the design are $v = 5x4\ (=20)$, $b = 6, r = 3, k = 10$, $\lambda_{01} = 1, \lambda_{10} = 3, \lambda_{11} = 1$, and the efficiencies of different factorial effects as compared to the randomized complete block design are $\in(10) = 1, \in(01) = 2/3, \in(11) = 1$, respectively. Here $\in(10), \in(01), \in(11)$ denote respectively the efficiencies of main effect of first factor, main effect of second factor and interaction of first and second factors respectively.

- In rice hybridization programme, it is necessary that the flowering in male and female parents occur at the same time. In some cases, it has been observed that there is a difference of *15* to *20* days in flowering dates of male and female parents. Therefore, it is needed that the flowering dates of male and female parents be synchronized. Division of Seed Technology planned an experiment to study the effect of 8 chemical treatments (4 chemicals each at two doses) and one control applied at different four stages of crop growth. The total number of treatment combinations is $(8 \times 4) + 1 = 33$. The major interest is in comparing the *32* treatment combinations with the control. Also it is expected that the effect of stages will be more prominent. The experimenter is also interested in main effects of chemical treatments, stages of application and their interactions. A group divisible treatment design obtained by adding the control treatment once to each of the blocks of singular group divisible design $v = 32\ (8 \times 4), b = 6, r = 2, k = 17, \lambda_1 = 3, \lambda_2 = 1, m = 4, n = 8$ was suggested.

  If we denote the chemical treatments by 1 to 8, stages as A, B, C and D and control as 0, the layout of the design, with rows as blocks denoted by B1, B2, …, B6, is given as

B1	1A	2A	3A	4A	5A	6A	7A	8A	1B	2B	3B	4B	5B	6B	7B	8B	0
B2	1C	2C	3C	4C	5C	6C	7C	8C	1D	2D	3D	4D	5D	6D	7D	8D	0
B3	1A	2A	3A	4A	5A	6A	7A	8A	1C	2C	3C	4C	5C	6C	7C	8C	0
B4	1B	2B	3B	4B	5B	6B	7B	8B	1D	2D	3D	4D	5D	6D	7D	8D	0
B5	1A	2A	3A	4A	5A	6A	7A	8A	1D	2D	3D	4D	5D	6D	7D	8D	0
B6	1B	2B	3B	4B	5B	6B	7B	8B	1C	2C	3C	4C	5C	6C	7C	8C	0

The design has been recommended to one Ph.D. student of the Division of Seed Technology, IARI, New Delhi.

- A modified second order rotatable response surface design for 3 factors each at 5 equi-spaced levels in 36 design points was recommended to one Ph.D. (Agricultural Engineering) student of IARI, New Delhi. The experiment is related to osmotic dehydration of the banana slices. The factors and levels are as given below:

S.No.	**Factor**	**Levels**
1.	Concentration of sugar Solution	40%, 50%, 60%, 70% and 80%
2.	Solution to sample ratio	1:1, 3:1, 5:1, 7:1 and 9:1
3.	Temperature of Osmosis	25^0c, 35^0c, 45^0c, 55^0c, and 65^0c

  Layout of the design with levels coded as –2a, -a, 0, a, 2a and factors coded as A, B, C, is as given below:

Design Point No.	A	B	C	Design Point No.	A	B	C
1.	-a	-a	-a	19.	0	-2a	0
2.	-a	-a	a	20.	0	2a	0
3.	-a	a	-a	21.	0	0	-2a
4.	a	-a	-a	22.	0	0	2a
5.	-a	a	a	23.	0	0	0
6.	a	-a	a	24.	0	0	0
7.	a	a	-a	25.	0	0	0
8.	a	a	a	26.	0	0	0
9.	-a	-a	-a	27.	0	0	0
10.	-a	-a	a	28.	0	0	0
11.	-a	a	-a	29.	0	0	0
12.	a	-a	-a	30.	0	0	0
13.	-a	a	a	31.	0	0	0
14.	a	-a	a	32.	0	0	0
15.	a	a	-a	33.	0	0	0
16.	a	a	a	34.	0	0	0
17.	-2a	0	0	35.	0	0	0
18.	2a	0	0	36.	0	0	0

The experiment has been conducted and the data received. The data has been analysed as per procedure of response surface methodology.

- In the Division of Fruits and Horticultural Technology, an experiment was conducted to study the feasibility of blending of fruit juice/pulp of lime, aonla, grape, pineapple and mango in different proportions (5 – 95 %) for preparation and standardization of Ready to Serve (RTS) beverages. In total four different combinations of fruit juices *viz*. lime - aonla , mango – pineapple, grape – pineapple, and mango – grape mixed in different ratios, *viz., 0 : 100, 5 : 95, 10 : 90, 15 : 85, 20 : 80, 25 : 75, 50 : 50, 75 : 25, 80 : 20, 85 : 15, 90 : 10, 95 : 5, 100 : 0* were studied. A panel of 9 members adopting a-point hedonic scale organoleptically evaluated the prepared beverages. The experiment was replicated three times. The data collected were being analyzed as a one-way classified data separately for all the *4* mixtures. At IASRI, we felt that since there had been a wide difference in the age of the panel members (respondents), the age of the respondent may have an effect on the characteristics of the beverages prepared from different fruit juice/pulp blends. The data generated were divided into three groups based on the age of the respondents, *viz., 22 – 34 years, 35 – 44 years,* and *45 – 55 years.* The data were analyzed as a two-way classified data and significant differences were observed among the age groups. The second objective of the experiment was to establish a relationship between the different proportions and responses (*viz., hedonic scores on colour, aroma, taste, and overall).* And to find out the optimum proportion for maximizing the responses. The experiments with mixtures methodology have been applied. The optimum proportion of different fruit juices has also been obtained. The above analysis has been carried out in collaboration with Division of Fruits and Horticultural Technology, IARI, New Delhi.

- An M.Sc.(Agricultural Statistics) student of ANGR Agricultural University, Rajendranagar, Hyderabad, was advised on the “Pooled analysis of data and fitting of response surfaces of different agricultural field experiments”. The data were analyzed following appropriate methodologies using SAS. The results obtained were also interpreted for drawing statistically valid conclusions.

- Dr. Rajiv Rai, Scientist-SD, Tropical Forest Research Institute, Jabalpur has been advised to use a reinforced rectangular lattice design with three replications for the provenancial trial on Neem. The layout of the reinforced lattice in 21 provenances of Neem (20 collections from different environments and one local) has been recommended.
- The data related to 12 Rapeseed – Mustard varietal trials of AICRP on Rapeseed and Mustard, which were rejected due to high Coefficient of Variation (CV), was analysed using different statistical techniques. The within treatment variances and within replication variances of all the trials were obtained. The data on yield were transformed by dividing yield with standard deviation of treatments to get variable, say X_1 and yield with standard deviation of replications to get another variable, say X_2. The data on yield, X_1 and X_2 were analysed separately as per analysis of randomized block design and analysis of covariance using plant stand as covariate. In two trials the CV was quite low as compared to the given in the proforma. In four of the trials the CV reduced to more than half when the analysis was performed on X_1. In most of the experiments, block differences were non-significant. It can be suspected that blocking is not done properly. We couldn't establish whether incomplete block designs may be more useful for these situations as neither the field layout nor the plot wise soil status data was made available. It is suggested that the field layout for all the experiments and plot-wise soil status data should be kept at headquarters so that these can be analysed as and when required. It is also suggested that the background of the various varieties like F_1's, F_2's etc. or their behaviour of tolerant or susceptible to stress be maintained as these may effect the variances of the varieties. The recommendations have been sent to Dr J.S. Yadava, Project Co-ordinator of AICRP on Rapeseed and Mustard on July 13, 1999.
- A Ph.D. Student from Department of Chemistry and Physics, CCS HAU, Hisar, has been advised in the analysis of data on different characteristics of Neem seeds collected for different agro-ecological zones. The data has been further classified into states, agro climatic regions within the state, locations within the agro climatic region within the state and sample within the location within the agro climatic regions within the state. The nested model has been used to see the variability due to states, agro climatic regions within state, locations within agro climatic region within state, sample within location within agro climatic region within state. Further, one way classified ANOVA were performed to identify the effect of age, canopy, size of the seed, shape of the seed, weight of 100 seeds, soil type, temperature, *etc.* separately that give the maximum azadirachtin content.
- A study for "Evaluation of fatigue score card for camels" was initiated following the letter from ADG(Engg.) in collaboration with Sh. M. Din, Dr. Jyotsana and Dr. P.K. Srivastava of KVK, Rewari under the aegis of AICRP on Utilisation of Animal Energy. The study was aimed at (i) to develop and evaluate fatigue score card based on physiological parameters like pulse rate, respiration rate, speed and rectal temperature and physical symptoms like frothing, water from nostrils and eyes, leg unco-ordination and excitement and (ii) to assess work rest schedule at different drafts and duration of work. To develop the fatigue scorecard for the camels, it is desired to obtain cut of points for increase in pulse rate, respiration rate, rectal temperature and decrease in speed. The increase/decrease in the physiological parameters were obtained by subtracting the initial values of these parameters from their respective hourly observations. For this purpose, the data obtained from 4 hours sustained work of animals for 16%, 18%, 20%, 22%, 24% and 26% drafts and also data obtained from 7 hours sustained work of the camels at 16% draft were utilised. The physical symptoms like frothing, water from nostrils and eyes, leg uncoordination, excitement noted were divided into 6 categories, the first category is no change in initial physical symptoms and this category was given a weight as zero. The weights given to different categories are from 0 to 5 and are given in the following table.

Physical symptom	Scoring					
	0	1	2	3	4	5
Frothing	No	First appearance of frothing	Occasional opening of mouth	Occasional falling of froth	Continuous falling of froth	Continuous flow
Water from nostrils and eyes	No	First appearance of water from nostrils	Occasional watering from nostrils	Tears from eyes	Frequent appearance of water from nostrils and tears from eyes	Continuous flow
Leg un-coordination	No	Slow walking and steps uneven	Occasional dragging of feet	Frequent dragging of feet	No coordination between fore and hind legs	Staggered walking
Excitement	No	Calm and composed	Abdominal vein prominence and Disturbed	Nostril dilation and disturbed	Sometimes crying	Furious and crying

The scores *0* to *5* were considered as *6* levels of the classificatory variable considering the increase in pulse rate, respiration rate, rectal temperature and decrease in speed as response variable. One way classified ANOVA was obtained for each of the physical symptoms categories and physiological parameters. All the possible pairwise comparisons for each of the classification were also made. To overcome the problem that the above procedure gives different cut off points for different physical symptoms, a total score is obtained for each of the animals for each combination of draft and work cycle tried. This scoring may result into *21* classes *i.e*., scores from *0* to *20*. To decide upon the cut off points, these scores were categorized into different class intervals as *2, 3* and *4* respectively. Now considering these categories as classificatory variable, one way classified ANOVA was performed for each of the physiological parameters and all possible paired comparisons of the classes were tested for their equality. If two classes were found to be non-significantly different at *5*% level of significance, these classifications were collapsed into one. The fraction class means were approximated to nearest integer value. It may be worthwhile mentioning here that ANCOVA was also performed using the initial body weight as covariate, but the covariate was found to be non-significant. Suitable cut off points were obtained for different physiological parameters. These cut off points were then used in developing the reliable fatigue scorecard.

For obtaining the suitable work rest schedule at different drafts and duration of work, a total of 8 work rest cycles were tried with *6* drafts *viz. 16%, 18%, 20%, 22%, 24%* and *26%.* Out of these *48* combinations of work rest cycles and drafts, *18* combinations were tried. Other *30* treatment combinations were left due to their non-suitability for testing in discussion with the animal physiologist. For example with *16%* draft only two work rest cycles were tested out of eight work rest cycles, because *16%* draft falls under the category of light draft. At this draft the animals can be operated for *7* hours with least change in physiological parameters. Therefore, the work rest cycles with longer rest period are not required to be tested at *16 %* draft. Similarly the *24%* and *26%* draft are considered as heavy draft and it is not possible for the animal to work continuously *7* hours or with smaller work rest cycles. Observations were recorded on hourly basis and three camels were used for the study. The data obtained were analysed using three way classified, additive, linear models. Three classifications were the treatment combinations, camel and hours nested within work rest cycles-draft combination. We have been able to develop a statistically reliable fatigue scorecard and identify the suitable work rest schedules. The results obtained were presented by Sh. M. Din at VII Biennial Workshop held at Allahabad Agricultural Institute, Deemed University, Allahabad.

- One set of data on Oilseeds (Safflower) on Chickpea - Safflower rotation was received from All India Co-ordinated Research Project on Oilseeds (Safflower) for two years viz., 1995-1996 as follow up action of meeting of Crop Project Co-ordinators with DDG(CS) at IASRI held on 23.10.1997. The experiment was conducted to find out the better method of phosphorus management in safflower based cropping system to increase 'P' use efficiency. 12 treatments have been considered *viz*.,

Treatment No.	**Chick pea**	**Safflower**
1	No Phosphorus	No Phosphorus
2	100% Recommended P	100% Recommended P
3	50% Recommended P	100% Recommended P
4	50% Recommended P	50% Recommended P
5	50% Recommended P+PSB	50% Recommended P+PSB
6	No Phosphorus	100% Recommended P
7	5 ton FYM/ha	100% Recommended P
8	PSB + 5 ton FYM/ha	100% Recommended P
9	100% Recommended P	50% Recommended P
10	100% Recommended P	No Phosphorus
11	100% Recommended P	5 ton FYM/ha
12	100% Recommended P	PSB + 5 ton FYM/ha

The experiment takes two years to complete one cycle, therefore, the experiment was conducted in two series *i.e*. Chickpea - Safflower and Safflower - Chickpea so that at the end of two years, we have 2 cycles of data. However, on critical evaluation of treatment structure, one finds that there are only 6 distinct treatments for individual crops *viz*., No Phosphorus - T_1, 50% Recommended P- T_2, 100% Recommended P - T_3, 50 %Recommended P + PSB - T_4, 5 ton FYM/ha - T_5, PSB + 5 ton FYM/ha - T_6. Here T_1 is replicated twice, T_2 - twice, T3 - five times, T_4 - once, T_5 - once, T_6 - once in each block. At the first instance, the data on both sequences were analysed as general block designs separately for each crop, with 6 distinct treatments with two blocks of size 12 each.

To our surprise, in each of the sequences, we get treatment differences as non-significant. It may be due to enough availability of phosphorus in the soil and therefore phosphorus may not have any role to play in the yields of Chickpea and Safflower.

As the combination of treatments in both the seasons give 12 distinct treatments, therefore, the data on both the sequences were converted to their respective economic values and were analyzed as per RBD procedure using total return as dependent variable and no significant differences were detected.

To test the equality of residual effects of phosphorus treatments of Chickpea in Safflower in series -I and phosphorus treatments of Safflower on Chickpea in series -II, the treatments were divided into two sets viz.,

	First Set	Second Set
Series-I	Chickpea	Safflower
Series-II	Safflower	Chickpea

Series-I

	First Set					
	1	**2**	**3**	**4**	**5**	**6**
Rep. I	1,3	3,2	3,2,1,5,6	4	3	3
Rep. II	1,3	3,2	3,2,1,5,6	4	3	3

The treatments listed in the cells are the second set of treatments. It was noted that the design in second set of treatments is disconnected *i.e.,* the residual effects were non-estimable using the model

Y = General Mean + Rep + First Set of Treatments + Second Set of Treatments + Error.

Similar phenomenon was observed for Series -II. However, if in the above set up the combination of 50% P +PSB and 50% P +PSB could be changed with some other combination, and then it would have been possible to estimate the effects. Another experimental design that can be taken up is given as follows:

Rep. I		Rep. II		Rep. III		Rep. IV		Rep. V	
I	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
T3	T6	T3	T1	T4	T5	T4	T4	T4	T6
T1	T1	T4	T3	T2	T3	T1	T5	T3	T5
T5	T5	T5	T6	T6	T6	T2	T6	T6	T3
T4	T1	T6	T5	T3	T2	T5	T1	T5	T2
T2	T2	T2	T4	T5	T4	T3	T3	T2	T1
T6	T4	T1	T2	T1	T1	T6	T2	T1	T4

I represents the treatments for the first crop in both the sequences.
II represents the treatments for the second crop in both the sequences.

5. Teaching and research guidance

The scientists of the Division have been involved in teaching of various courses on Mathematical Methods in Statistics, Statistical Methods, Statistical Inference, Linear Models, Advanced Regression Analysis, Econometrics, Discrete Mathematics and all basic and advanced courses in Design of Experiments to M.Sc./Ph.D. Students of P.G. School, IARI, New Delhi. Besides, the scientists have also been engaged in organizing and participating in various adhoc-training programmes from time to time. The adhoc-training programmes basically fall under two categories viz. (i) ICAR sponsored and (ii) resource generation programmes. The scientists have also been involved in the research guidance of M.Sc./Ph.D. (Agricultural Statistics) students of P.G. School, IARI, New Delhi, and M.Sc./Ph.D. students of different disciplines of IARI, New Delhi as member in their advisory committees. An account of the training programmes organized by the scientists of the Division is given below. The list of M.Sc. and Ph.D. (Agricultural Statistics) students produced in the subject of Design of Experiments is given in Tables 3a and 3b of the Annexure.

Training Programmes Organized

Sl. No.	Title	Duration	Course Director	Co-Director	Core Faculty	Sponsor
1	***Recent Advances in Agricultural Statistics***	May 17 to June 5, 1993	P.R. Sreenath	-	V.K.Gupta	I.C.A.R.
2.	***Optimality and Robustness of Designs***	April 24 - 29, 1994	Randhir Singh	V.K. Gupta	-	
3.	***Advances in Agricultural Statistics with Special Reference to General Linear Models and Applied Regression Analysis***	May 16 - June 4, 1994	R.K. Pandey	V.K. Gupta	Rajender Parsad	I.C.A.R.
4.	***Advances in Experimental Designs***	March 11 - 27, 1996	V.K. Gupta	-	Rajender Parsad; Seema Jaggi	CAS
5.	***Design and Analysis of Field Experiments***	March 30, - April 14, 1998	V.K. Gupta	-	R.Srivastava; Rajender Parsad; V.K. Sharma	CAS
6.	***Advances in Statistical Designs for Agricultural Research***	June 24-July 14, 1998	V.K.Sharma	-	R.Srivastava; P.K. Batra; Rajender Parsad	I.C.A.R.
7.	***Research Methodology with Special Emphasis on Statistics***	I: September 1-30, 1998; II: October 6-November 5, 1998; III: January 5-February 3, 1999	V.K.Sharma	-	P.K. Batra; Rajender Parsad; Seema Jaggi	ICFRE, Dehradun
8.	***Research Methodology with Special Emphasis on Statistics***	I: August 9-20, 1999; II:September 6-17, 1999.	V.K.Sharma	-	P.K. Batra; Rajender Parsad; Seema Jaggi	ICFRE, Dehradun
9.	***Efficient Designing of Experiments and Analysis of Experimental Data***	February 16 - March 1, 1999	V.K.Gupta	-	Rajender Parsad; Seema Jaggi; R. Srivastava	CAS
10	***Efficient Experimental Designs for Generation of Agricultural Technologies***	March 16 – 30, 2000	V.K.Sharma	P.K.Batra	Rajender Parsad; Seema Jaggi	CAS

Sl. No.	**Title**	Duration	Course Director	Co-Director	Core Faculty	Sponsor
11.	***Energy Requirement in Agricultural Sector: Analytical Techniques and Statistical Software Packages***	March 27-April 5, 2000	V.K.Gupta	-	Rajender Parsad	CIAE, Bhopal
12.	***Design and Analysis of Agricultural Experiments***	September 15 -October 5, 2000	R.Srivastava	Rajender Parsad	V.K.Gupta, P.K.Batra, Seema Jaggi	CAS

The other important activities of the Division are the following:

6. Database Development

The Division has been involved in a very important activity of creating an information system on the designed experiments conducted in the National Agricultural Research System. This information system has a facility of selective retrieval of information. This system is of immense use to both the researchers and planners. So far the following information systems have been developed:

- Agricultural Experiments Information Systems
  - Field Experiments
  - Animal Experiments

7. Statistical Software Packages Development

IASRI has made important contributions to the subject of design of experiments. But these designs have not found much favour of the experimenters. The reasons are not far to seek. The generation of the layout of the design, a randomized layout, and then subsequently the analysis of the data generated may be a stumbling block with the experimenters. Therefore, a need was felt to develop software packages that give us a catalogue of designs from where the experimenter may choose a design for his experiment, to get a randomized layout of the design and then to get the data analyzed by the package. The package must be user friendly and may be operative without the aid of a manual. Online help and details should be available in the package.

With these ends in view a **Statistical Package for Block Designs (SPBD) Release 1.0** is developed by a group of scientists comprising of Rajender Parsad, V.K. Gupta and O.P. Khanduri. This package deals with the balanced block designs. The package gives the contrast analysis also. This package is now commercially available at a cost of Rs.1000.00. The package has been widely appreciated by both the statisticians and agricultural experimenters.

A group of students/scientists comprising of Sangeeta Ahuja, Rajender Parsad, Mahesh Kumar and V.K. Gupta at IASRI have developed a statistical package **SPFE (Statistical Package for Factorial Experiments)**. This package is essentially for symmetrical factorial experiments. There is a provision of generation of designs as well as the randomized layout of the designs including totally and partially confounded designs. The design is generated once the independent interactions to be confounded are listed. One can give different number of independent interactions to be confounded in different replications. Provision has also been made in this package for analyzing the data generated from the experiments using these designs. The data generated are analyzed as a general block design and the contrast analysis is carried out to obtain the sum of squares due to main effects and interactions. Separate modules have been developed for generating the probabilities using χ^2, F and t distributions for testing the levels of significance.

8. Books published

1. Two blocks of Statistical Inference in the lecture notes on **Probability and Statistics** brought out by the Indira Gandhi National Open University, New Delhi, India (V.K. Gupta).
2. The Golden Jubilee Number 1996-97 of the Journal of the Indian Society of Agricultural Statistics. This special issue of the Journal was released during the inaugural session of the Conference held at Vigyan Bhavan. The Editorial Committee for this comprised of A. Dey, V.K. Gupta, V.K. Bhatia and A.K. Srivastava.
3. Proceedings of the First Annual Conference of the Society of Statistics, Computers and Applications held at CCS HAU, Hisar during October 23-25, 1998 (L.S. Kaushik, M.N. Das and V.K. Gupta).

9. Books Review

1. Gupta, V.K. (1992). *Probability, Statistics, and Design of Experiments,* Proceedings of the International Symposium held in the honour of Late Professor R.C. Bose at the University of Delhi, Delhi 1988. Ed. Professor R.R. Bahadur, Wiley Eastern Limited, **OPSEARCH**, Journal of Operational Research Society of India, 29(3).
2. Gupta, V.K. (2000). *Design and Analysis of Experiments*. By Angela Dean and Daniel Voss, Springer Texts in Statistics, *Journal of Statistical Planning and Inference.*

10. Conferences/Symposia/ Workshops Organized

- Group Discussion on "**Statistical Requirements in relation to Agroforestry Research**" during October 11-12, 1993.
- A technical session on "**Identification of Problems for Future Research"** in XI National Conference of Agricultural Research Statisticians held at H.P.K.V. Palampur during October 16-18, 1995.
- Meeting with Project Co-ordinators/Project Directors/ADGs was held at IASRI on 23.10.1997 under the chairmanship of Dr. Mangla Rai, Deputy Director General (Crop Sciences) to look into the problems related to designing and analysis of experiments of the experimenters.
- A technical session on "**Improvement of Quality of Agricultural Statistics"** in XII National Conference of Agricultural Research Statisticians held at Rajasthan College of Agriculture, Rajasthan Agricultural University, Udaipur during August 8-10, 1998.
- Symposium on "**Recent Trends of Research in Design of Experiments**" during April 6-7, 1999.
- Symposium on "**Statistical Methodology for Agroforestry Research"** in the 53rd Annual Conference of Indian Society of Agricultural Statistics held at St. Joseph's College, Tiruchirappalli during December 2-4, 1999.
- Three sessions of Invited papers on "**Design of Experiments**" during Joint Statistical Meeting of the International Indian Statistical Association-2000-2001 held at New Delhi during December 30, 2000 to January 2, 2001.

11. Research Areas of Current Interest

The current research activities of the scientists of the Division are once again focussed on basic research as well as applied research. In the basic research the scientists are engaged in conducting research on the topics of current interest at the international level and have relevance to the activities of the Institute. The topics on which the scientists are conducting research involve the designs for fitting response surfaces for both qualitative and quantitative factors with unequal and equal spaced levels, cataloguing of designs and developing user friendly software package for the generation of randomized layout of the design and the analysis of data generated. This study assumes significance because the designs for fitting response surfaces have not found the attention of the experimenters. Partially balanced incomplete block designs with two associate classes have been extensively studied and catalogued, but designs with higher associate classes have not been catalogued. These designs have interesting applications particularly in diallel crosses and in designing factorial experiments that are structure resistant. Therefore, construction and cataloguing of partially balanced incomplete block designs with three associate classes and developing a software package for the generation of designs and the analysis of data generated from these designs is another area of research. Further, studies are also being undertaken on optimality aspects of designs for diallel and triallel crosses, optimal designs for bio-assays, designs for estimation of competition effects, optimality aspects of structurally incomplete row - column designs, optimal nested block designs, designs for multistage experiments, robustness aspects of designs against loss of data, presence of outliers, interchange and exchange of treatments, loss of treatment combinations pertaining to a particular level of a given factor, etc.

In the area of applied research also, the scientists are engaged in conducting research on problems of interest to the experimenters. There is a gold mine of data available in the division collected under various All India Coordinated Research Projects and Information Systems. It is indeed possible and of importance to undertake innovative studies using these data available. The division has undertaken several studies regarding the diagnostics in design and analysis of field experiments by considering the assumptions involved in the analysis, designs and analysis of agro forestry experiments, design and analysis of intercropping experiments, data processing techniques of spatial variability in field experiments, etc. Similar studies may be undertaken more rigorously. The scientists are also actively involved in the development of software packages for generation of catalogues of designs for factorial and non-factorial experiments, randomized layout of the designs and analysis of experimental data giving contrast analysis and covariance analysis, development of information system on designed experiments in agricultural and allied sciences experiments.

Consultancy and advisory services also form an important activity of the division. This activity has made a dent in the National Agricultural Research System and the researchers are now adopting the efficient and cost effective designs developed. This activity needs to be rigorously pursued.

ANNEXURE

Table 1. Research Papers

❖ Research Papers Published in Foreign Journals

1. P.R. Sreenath (1990). Construction of some balanced incomplete block designs with nested rows and columns. *Biometrika,* **76(2)**, 399-402.
2. R. Srivastava, V.K. Gupta and A. Dey (1990). Robustness of some designs against missing observations. *Communications in Statistics: Theory & Methods*, **191(1)**, 121-126.
3. A. Dey, R. Srivastava and V.K. Gupta (1991). Robust designs - A review and bibliography. *Cahiers du CERO,* **33(1-2**), 51-62.
4. R. Srivastava, V.K. Gupta and A. Dey (1991). Robustness of some designs against missing data. *Journal of Applied Statistics,* **18(3)**, 303-308.
5. Rajeshwar Singh and V.K. Gupta (1991). Resistance of block designs. *Journal of Statistical Planning and Inference,* **27**, 263-269.
6. V.K. Gupta, A. Das and A. Dey (1991). Universal optimality of block designs with unequal block sizes. *Statistics and Probability Letters,* **11**, 177-180.
7. V.K. Gupta, B.V.S. Sisodia and S.K. Agarwal (1991). A Study of performance of an alternative estimator of population total for unequal probability sampling procedures. *Cahiers du CERO,* **33(1-2**), 71-78.
8. Ashish Das, V.K. Gupta and P. Das (1992). E-optimal block designs under heteroscedastic model. *Communications in Statistics: Theory & Methods,* **21(6)**, 1651-1666.
9. V.K. Gupta and D.V.V. Ramana (1993). Robustness of designs against a single missing observation. *International Journal of Mathematical and Statistical Sciences,* **2(1)**, 45-56.
10. Rajender Parsad and V.K. Gupta (1994). A optimality of group divisible designs with unequal block sizes for making test treatment control comparisons under a heteroscedastic model. *International Journal of Mathematical and Statistical Sciences,* **3(1)**, 5 – 31.
11. Rajender Parsad, V.K. Gupta and N.S.G. Prasad (1995). On construction of A-efficient balanced test treatments incomplete block designs. *Utilitas Mathematica,* **47**, 185-190.
12. Seema Jaggi and K.N. Agarwal (1995). Augmented partial diallel design for estimating combining ability of parents. *Biometrical Journal,* **37(7)**, 879-887.
13. Seema Jaggi, V.K. Gupta and Rajender Parsad (1996). A-efficient block designs for comparing two disjoint sets of treatments. *Communications in Statistics: Theory & Methods,* **25(5)**, 967-983.
14. V.T. Prabhakaran and Seema Jaggi (1996). On the estimation of intra-sire regression heritability subject to linear constraint. *Biometrical Journal*. **38(4)**, 455-460.
15. V.K. Gupta, D.V.V. Ramana and S.K. Agarwal (1998). Weighted A-optimal row-column designs for making treatment-control and treatment-treatment comparisons. *Journal of Combinatorics, Information and System Sciences,* **23(1-4)**, 333-344 (Special Issue in honour of Professor J.N. Srivastava).
16. V.K. Gupta, D.V.V. Ramana and Rajender Parsad (1999). Weighted A-efficiency of block designs for making treatment-control and treatment-treatment comparisons. *Journal of Statistical Planning and Inference,* **77(2)**, 301-319.

17. Rajender Parsad and V.K. Gupta. Balanced Bipartite Row- column Designs. *Ars. Combinatoria*. To Appear.
18. V.K. Gupta, D.V.V. Ramana and Rajender Parsad. Weighted A-optimal block designs for comparing test treatments with controls with unequal precision. *Special issue of Journal of Statistical Planning and Inference in the memory of Professor YAMAMOTO.* To Appear.
19. Krishan Lal, V.K. Gupta and Lal Mohan Bhar. Robustness of designs against missing data. *Journal of Applied Statistics*. To Appear.

❖ Indian Statistical Journals

1. V.K. Gupta and N.S.G. Prasad (1990). On general efficiency balanced row-column designs. *Calcutta Statistical Association Bulletin,* **39**, 172-183.
2. V.K. Gupta and Rajeshwar Singh (1990). Characterization and construction of E-optimal block designs. *Sankhya B,* **52**, 204-211.
3. Rajeshwar Singh and V.K. Gupta (1991). E-optimal designs for two-way elimination of heterogeneity. *Sankhya B,* **53(1)**, 97-104.
4. V.K. Gupta and N.S.G. Prasad (1991). On construction of general efficiency balanced block designs. *Sankhya B,* **53(1)**, 89-96.
5. V.K. Gupta and R. Srivastava (1992). Investigations on robustness of block designs against missing observations. *Sankhya B,* **54(1)**, 100-105.
6. G.C. Chawla and V.K. Gupta (1993). Two-factor change over designs based on William's squares. *Indian Journal of Applied Statistics.,* 326-334.
7. V.K. Gupta (1993). Optimal nested block designs*. Journal of Indian Society of Agricultural Statistics,* **45(2)**, 187-194.
8. Rajender Parsad and V.K. Gupta (1994). Optimal block designs with unequal block sizes for treatment control comparisons under a heteroscedastic model. *Sankhya B,* **56(3)**, 449-461.
9. A. Dey, G.C. Chawla and Balachandran (1995). Cyclic changeover designs. *Journal of Indian Statistical Association*, **33(2)**, 71-76.
10. Rajender Parsad and R.C. Jain (1995). Yield forecast using curvilinear study of yield and biometrical characters. *Journal of Indian Society of Agricultural Statistics*, **3**, 253-261.
11. V.K. Gupta (1995). Universally optimal generalized binary balanced block designs of type alpha. *Sankhya B,* **57**, 420-427.
12. A. Dhandapani, V.K. Gupta and A.K. Nigam(1996). Variance estimation using proportional frequency plans. *Golden Jubilee Volume of the Indian Society of Agricultural Statistics,* **Vol. XLIX**, 267-276.
13. R. Srivastava, Rajender Parsad and V.K. Gupta (1996). Robustness of block designs for making test treatments - control comparisons against a missing observation. *Sankhya B,* **58(3**), 407-413.
14. Rajender Parsad, V.K. Gupta and V.P.N. Singh (1996). Trace optimal designs with unequal block sizes for comparing two disjoint sets of treatments. *Sankhya B,* **58(3)**, 414-426.
15. Seema Jaggi (1996). A-efficient block designs with unequal block sizes for comparing two sets of treatments. . *Journal of Indian Society of Agricultural Statistics*, **48(2)**, 125-139.
16. P.K. Batra, P.R. Sreenath and Rajender Parsad (1997). Robustness of block designs against interchange of treatments. *Journal of Indian Society of Agricultural Statistics,* **50(2)**, 156-167.
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5. Rajender Parsad, P.K. Batra, V.K. Gupta and R.R. Sharma. Variance component estimation from unbalanced data. *Biometrical Journal.*
6. Rajender Parsad, V.K. Gupta and Sudhir Gupta. Optimal designs for multi-allel cross experiments. *Journal of Statistical Planning and Inference.*
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22. D.K.Panda, V.K.Sharma and Rajender Parsad. Robustness of optimal block designs for triallel cross experiments against exchange of a cross. *Journal of Indian Society of Agricultural Statistics.*

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4. G.C. Chawla (1998). Analysis of change-over Designs for s^2-Factorial Experiments. *Advances in Agricultural Statistics and Computer Applications: Souvenir for Golden Jubilee Celebrations of Independence,*130-137.
5. C.H. Rao, Seema Jaggi and G.L. Khurana (1998). Yardsticks of Additional Production of Pulses from the Combined Application of fertilizers. *Advances in Agricultural Statistics and Computer Applications: Souvenir for Golden Jubilee Celebrations of Independence,* 138-144.
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8. V.K. Sharma (1998). Analysis of changeover designs balanced for first and second residuals. *Advances in Agricultural Statistics and Computer Applications: Souvenir for Golden Jubilee Celebrations of Independence,* 163-171.

Table 2. List of ongoing projects

S. No.	Title of the Project	Principal Investigators (PI)/ Co-investigators (CoI)	Date of start	Date of termination
1.	A statistical investigation on the long term effects of fertilizers on productivity of cereal crop sequences	VK Sharma (PI) Rajinder Kaur (CoI)	01.02.1998	31.01.2001
2$.	Designs for fitting response surfaces in agricultural experiments	Rajender Parsad (PI) R Srivastava (CoI) PK Batra (CoI)	01.02.1999	31.01.2001
3.	A diagnostic study of design and analysis of field experiments	Rajender Parsad (PI) VK Gupta (CoI) R Srivastava (CoI) PK Batra (CoI) Rajinder Kaur (CoI) Ajit Kaur (CoI) Praween Arya (CoI)	01.03.2000	28.02.2003
4.	Design and analysis of agroforestry experiments	DP Handa (PI) Seema Jaggi (CoI) VK Sharma (CoI)	01.03.2000	28.02.2002
5.	Planning, designing and analysis of experiments relating to soil test crop response correlations	Aloke Lahiri (PI) VK Sharma (CoI) A Subba Rao (CoI) MR Vats (CoI) DKL Mehta (CoI) Rajender Parsad (CoI)	01.03.2000	28.02.2003
6.	Agricultural field experiments information system	PK Batra (PI) OP Khanduri (CoI) DC Pant (CoI) GL Khurana (CoI)	01.04.1997	31.03.2002
7.	Planning, designing and analysis of experiments planned on stations under the Project Directorate of Cropping Systems Research	Rajinder Kaur (PI) Ajit Kaur (CoI)	01.04.1997	31.03.2002
8.	Planning, designing and analysis of on farm research experiments planned under Project Directorate for Cropping Systems Research	NK Sharma (PI) PK Batra (CoI) Mahesh Kumar (CoI)	01.04.1997	31.03.2002
9.	Planning, designing and analysis of data relating to experiments conducted under AICRP on Long Term Fertilizer Experiments	MR Vats (PI) DK Sehgal (CoI) DK Mehta (CoI)	01.04.1997	31.03.2002

S. No.	**Title of the Project**	**Principal Investigators (PI) / Co-investigators (CoI)**	**Date of start**	**Date of termination**
10.	Statistical investigations on the fertilizer use efficiency in relation to cultural practices	RK Maheshwari (PI) JK Kapoor (CoI)	01.09.2000	31.08.2002
11.	Three associate class partially balanced incomplete block designs and their application to partial diallel crosses	Cini Varghese (PI) VK Sharma (CoI) Seema Jaggi (CoI) Saurabh Prakash (CoI)	01.09.2000	31.08.2003
12[#].	Studies on data processing techniques for statistical analysis of large field variability in hilly and salt affected soil regions	V.K. Bhatia (PI) Rajender Parsad (CoI)	01.08.2000	31.07.2003
13[#].	Reduction in post-harvest losses of fruits and vegetables	R.K. Jain, CIPHET (PI) Seema Jaggi (CoI) G.K. Jha (CoI)		
14[&].	Fertilizer response ratio for different crops in India	PK Batra (PI) SD Sharma (CoI) VK Sharma (CoI) NK Sharma (CoI)	01.06.2000	31.12.2000
15[@].	Design of experiments and analysis of data from on-field and on-farm agricultural research.	AK Nigam, IASDS (PI) Rajender Parsad (CoI) VK Gupta (CoI)		
16[@].	National Information System on Animal Experiments	P.K.Batra, V.K.Sharma, D.K.Sehgal and R.C.Goyal		

 # - This is an externally funded project. The source of funding is NATP of the ICAR.

$ - This is an externally funded project. The source of funding is AP Cess Fund of the ICAR.

& - This is an externally funded project. The source of funding is Ministry of Agriculture.

@ - This is a project proposal submitted for external funding from AP Cess Fund of the ICAR.

Table 3a. Approved dissertations of Ph.D. students

S. No.	Name of the student	Year	Title of thesis	Name of the Guide
1.	Ashish Das	1989-90	Some investigations on optimal designs	A. Dey
2.	N.S.G.Prasad	1989-90	Some investigations on GEB designs	S.K. Raheja
3.	Ravinder Malhotra	1989-90	Some studies on design and analysis of factorial experiments	A.K. Banerjee
4.	P.P.Yadav	1990-91	Some studies on designs involving sequences of treatments	A. Dey
5.	D.P.Handa	1990-91	Investigations on design and analysis of factorial experiments	A.K. Banerjee
6.	Manisha Gupta	1990-91	Some studies on response surface designs	A.K. Banerjee
7.	Praggya Das	1991-92	Studies on optimality of designs	V.K. Gupta
8.	Rajender Parsad	1991-92	Studies on optimality of incomplete block designs with unequal block sizes for making test treatments control comparisons under a heteroscedastic model	R.C. Jain
9.	Seema Jaggi	1992-93	Study on optimality of one way heterogeneity designs for comparing two disjoint sets of treatments	R.C. Jain
11.	K.V. Palanichamy	1993-94	Some contributions to designs for fitting non-linear response surfaces	R.C. Jain
12.	Archana Pandey	1993-94	Study on optimality of block designs under a mixed effects model	V.K. Gupta
13.	P.K.Batra	1993-94	Some studies on robustness of block designs against exchange or interchange of treatments	P.R. Sreenath
14.	Niti Agarwal	1995-96	Studies on block designs with nested rows and columns for test treatment control comparisons	P.R. Sreenath
15.	Vijayaraghava Kumar	1995-96	Design and analysis of experiments for investigating competition effects among neighbouring units	P.R. Sreenath
16.	A. Dhandapani	1996-97	Variance estimation from complex survey data using proportional frequency plans	V.K. Gupta
17.	D.V.V.Ramana	1996-97	Optimality aspects of designs for making test treatments control treatments comparisons under fixed and mixed effects model	V.K. Gupta
18.	Asim Kumar Chakraborty	1996-97	Studies on block designs with nested rows and columns	P.R. Sreenath
19.	Lal Mohan Bhar	1997-98	Outliers in experimental designs	V.K. Gupta
20.	S.K.Dwivedi	1997-98	Computer aided search for optimal designs	R.C. Jain
21.	Krishan Lal	1998-99	Robustness of designs against missing data	V.K. Gupta
22.	Somy Kuriakose	1999-2000	A study on balanced and partially balanced incomplete block designs	R.C. Jain
23.	Cini Varghese	1999-2000	A study on experimental designs involving sequences of treatment	V.K. Sharma

Table 3b. Approved dissertations of M.Sc. students

S. No.	Name of the student	Year	Title of thesis	Name of Guide
1.	Archana Pandey	1990-91	E-optimal designs for two-way elimination of heterogeneity	V.K. Gupta
2.	Rajendra Kumar	1990-91	Methodological study on estimation of simple and composite yardsticks of additional production from the use of crop improvement measures.	P.N.Soni
3.	M.S. Anuradha	1991-92	Analysis of data from intercropping experiments	P.R. Sreenath
4.	D.V.V.Ramana	1991-92	Some investigations on robustness of designs against a single missing observation	V.K. Gupta
5.	B.Vijaya	1992-93	Some investigations on changeover designs	V.K. Sharma
6.	Lal Mohan Bhar	1993-94	On missing value estimation in block designs	V.K. Gupta
7.	Hemant Kumar	1999-2000	Design and Analysis of experiments with mixtures in feeding trials	G.C.Chawla
8.	Amitava Dey	2000-2001	Robust block designs for diallel crosses against missing observations	R.Srivastava