A Profile of Design of Experiments at IASRI

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1. Importance and Historical Development

The genesis of the Institute dates back to 1930 when a small Statistical Section came into existence in the then Imperial Council of Agricultural Research to assist the State Departments of Agriculture and Animal Husbandry in planning their experiments, analysis of experimental data, interpretation of results and also rendering advice on the formulation of the technical programmes and examining the progress reports of the schemes funded by the Council. Ever since then, the division of Design of Experiments has been the pride division of the Indian Agricultural Statistics Research Institute (IASRI) enjoying recognition all over the globe.

Designing experiments forms the backbone of any research endeavor in the discipline of agriculture and allied sciences. Dr. MS Swaminathan in his message to International Conference on Statistics and Informatics in Agricultural Research said, "*It is the effective use of the tools of statistical design of experiments that paved the way for the green revolution*." This statement spells out the importance of the subject of Design of Experiments for improving the quality of agricultural research.

The advisory work relating to agriculture and animal husbandry of the statistical section was separated into two units in 1945. The two units *viz.*, crops and animal husbandry were separately under the charge of a statistician. After getting the status of a full fledged Institute in 1970, the concept of Divisions was introduced and the Division of Statistical Research in Crop Sciences was created. On the recommendations of Quinquennial Review Teams (QRT) in 1985, the Division of Statistical Research in Crop Sciences was renamed as Division of Design of Experiments and Analysis of Experimental Data. Again on the recommendations of QRT in 1998-99, the Division was rechristened as Division of Design of Experiments.

In the early years of development of the Institute, the emphasis of research was more on the analysis of designed experiments rather than developing new designs. At IASRI of those days, one of the major activities was 'advisory' work related to agricultural and animal husbandry experiments. During the course of such advisory work, it was often found necessary to develop methods of analysis appropriate to the experiment and to that end, several contributions were made. It was during the decade of 1950 that the Institute started making important theoretical contributions in developing new methods of construction and analysis of experiments. In late 1950's with the efforts of Dr JN Srivastava suitable confounded designs for asymmetrical (or mixed) factorial experiments were obtained. The decade of 1960 saw many major contributions, particularly from Dr MN Das in designs for factorial experiments, rotatable and other designs for fitting response surfaces and designs for experiments with mixtures. During early1970's till late 1980's the research in Design of Experiments got a very good impetus under the guidance of two leading statisticians Dr. Aloke Dey and Dr. AK Nigam. Among other statisticians who helped in building collaborations and analysis of voluminous data were Shri MG Sardana, Shri. KS Krishnan, Dr. SK Raheja, Ms. CR Leelawathi, Shri SR Bapat, Dr. PN Bhargava, Shri RC Khanna, Shri PN Soni, to mention a few. The present day generation has given a new shape to the theory and applications of design of experiments by maintaining an ideal balance between theory and applications. The scientists of the Division participate

actively in planning and designing of experiments in the National Agricultural Research System (NARS) and also involve themselves in the analysis of experimental data.

The present agenda of research in the Division is the following:

- Cropping system research
- Experimental designs for agricultural, animal, agro-forestry and fisheries research
- Development of information systems for agricultural and animal experiments

2. Designs in National Agricultural Research System (NARS)

Generally speaking, there are two broad categories of experiments, one comprising of designs with unstructured treatments also popularly known as varietal designs. These designs are single factor experiments with many levels and all possible pair wise treatment comparisons or a subset of such comparisons are of interest to the experimenter. The other type of experiments is the factorial experiments with several factors each having many levels. All the possible combinations of the levels of all the factors, or a subset of all possible level combinations, form the treatments. The interest in such experiments is in the factorial effects like main effects of all the factors and their interactions. Not only is the choice of design important, but the choice of treatments in the experiment is also important. And while selecting a design one should not lose sight of the inference problem and the analysis to be performed. A design good for one inference problem may become worse for another inference problem. In the sequel we describe salient achievements in the field of design of experiments.

3. Research Achievements

The achievements of the division of design of experiments are many and widely spread. Several important, useful and original contributions have been made in both basic research and innovative applications of the theory of statistical designs and analysis of experimental data. The scientists of the division have published 5 text books *viz*., (i) Handbook of Design and Analysis of Agricultural Experiments; (ii) Design and Analysis of Experiments; (iii) Theory of Block Designs; (iv) Characterization and Analysis of Block Designs; and (v) Fractional Factorial Plans. Five research monographs *viz.* (i) Supplemented Block Designs; (ii) Orthogonal Main Effect Plans; (iii) Optimality of Multi-dimensional Designs; (iv) α-Designs; and (v) Hadamard Matrices have been published and have received wide appreciation because of their usefulness. The Division has established closer linkages and collaborations with All India Co-Ordinated Research Projects (AICRP) of the Indian Council of Agricultural Research (ICAR). Collaborations have also been established with CGIAR organizations such as Rice–Wheat Consortium for Indo-Gangetic plains; International Centre for Agricultural Research in Dry Areas, etc. The Division has also taken lead in getting outside funded projects, particularly from the AP-Cess Fund of ICAR, Department of Science and Technology and National Agricultural Innovation Project.

The research work done in the division can be categorized into following broad headings.

3.1 Basic research

The intense research activity in the area of design and analysis of experiments has continued rigorously throughout. Many notable contributions have been made in basic research that has been accepted at an international level. To mention a few: designs for symmetrical and asymmetrical factorial experiments;

designs for fitting response surfaces; designs for experiments with mixtures; weighing designs; fractional factorial and orthogonal resolution plans, orthogonal arrays; supersaturated designs for two-level, multi-level and mixed level factorial experiments; block designs with factorial treatment structure with emphasis on extended group divisible designs; variance balanced, efficiency balanced, partially efficiency balanced, simple partially efficiency balanced and generalized efficiency balanced block designs; optimality and combinatorial aspects of designs (designs for making test treatments-control treatments comparisons; row-column designs and structurally incomplete row-column designs; resolvable block designs; designs for bioassays, cross over designs; designs for estimation of competition effects; designs with correlated observations; designs with nested blocking structure; designs for microarray experiments; designs for bio-equivalence trials; designs for multi-stage experiments with more than one set of non-interacting treatments applied in succession; designs for diallel and double cross experiments); designs for on-Farm trials; design and analysis of multi-response experiments; detection and handling of outliers, etc.

Robustness aspects of designs against loss of data (both single factor and multi-factor experiments); presence of outliers, interchange and exchange of treatments, model inadequacy, presence of systematic trends, etc. have been studied.

More recently, a breakthrough in research has been the computer aided search of efficient designs for various experimental settings. This has been possible by making use of computer algorithms based on exchange and interchange procedures.

Use of combinatorial designs in obtaining efficient survey sampling plans with unequal probabilities of selection leading thereby to controlled selection was another major contribution. The use of mixed orthogonal arrays as Balanced Repeated Replications in the variance estimation of a non-linear statistic from a large scale complex survey data was an original contribution of the Division. Balanced sampling plans have also been obtained using the applications of polygonal designs. A detailed description of these achievements is given in separate article on “Glimpses of Basic Research in Design of Experiments at IASRI”.

3.2 Applied research

The contributions made in the applied research in Design of Experiments have been monumental. Significant research contributions in applied research are described in the sequel.

Shape and size of plots and blocks

It is well known that the statistical designing of experiments requires proper blocking of experimental units. The past experience in the NARS shows that in majority of the experiments, the block mean square is small as compared to the error mean square. As a consequence, the precision for treatment comparisons is small. The analysis of several uniformity trials data sets has revealed that long rectangular or square blocks are not homogeneous because several fertility patches are nested within these blocks. So either incomplete block designs or nested block designs with smaller sub blocks nested within bigger blocks would be more beneficial in controlling experimental error. In the absence of uniformity trials, strategy for preparing contour maps and for their periodic updation has also been devised. The procedure of preparing yield and fertility contour maps based on moving averages and cluster analysis developed for determining the shape of plots and blocks has been used by Allahabad Agricultural Institute, Allahabad in

preparing yield and fertility contour maps for Development of Site Specific Nutrient Management.

Diagnostics in designed field experiments

In NARS, a large number of experiments are conducted. The data from these experiments is generally analyzed without giving any importance to the validity of assumptions. The departures from these assumptions make the interpretation based on these statistical techniques invalid. Division has taken a lead in carrying out a diagnostic study of design and analysis of field experiments using the data from a large number of experiments. The main emphasis was given on normality and homogeneity of error variances. The departure from these assumptions was observed in large number of cases. Remedial measures like Box-Cox transformations and non-parametric measures have been suggested. A SAS code that is capable of carrying out the diagnostics and remedial measures at one go has been developed. This will encourage the use of diagnostic measures in the experimental data and arriving at statistically valid conclusions. The experimental data with non-normal and /or heterogeneous errors is then tested for presence of outliers. It was found that in most of these experiments, at least one outlier was present. Nearest neighbour methodology has been used for improving the precision of treatment comparisons where the randomized layout was available. Dr. R. Chidambaram, Principal Scientific Advisor to Government of India in his inaugural address delivered during the 57th Annual Conference of Indian Society of Agricultural Statistics held at GBPUA & T, Pantnagar during February 05 – 07, 2004 emphasized the importance of the work done on diagnostics in designed field experiments.

Plot sampling in designed field experiments

The plot-sampled data from designed field experiments is generally analyzed as per analytical procedure of the design adopted on the plot means. The plot variances, however, are different from plot to plot and may violate the assumptions of constancy of variances and normality of observations. Through some empirical investigations, plot-sampled data from field experiments has been used to evolve variance-stabilizing transformations so as to satisfy the assumptions of analysis of variance and it is recommended that this data may be used for obtaining appropriate transformations. Fuzzy regression theory was modified and used in the analysis of plot sampled data from field experiments.

On-farm research

On-Farm research helps in testing the technologies developed at the research stations by taking into account the realistic environment. Therefore, more and more emphasis is being laid by different organizations on On-Farm research. Based on the degree of the control of the researchers and farmers, the On-Farm trials can be classified into three categories *viz.* (i) trials designed and managed by researchers, (ii) trials designed by researcher and managed by farmers, and (iii) trials designed and managed by farmers. The on-farm research suffers primarily from lack of control on variability due to (a) variation in farmers' managerial skills and resources, (b) plot to plot variation, etc. It has been shown that the resolvable block designs are quite helpful in On-Farm research to take care of variation due to management skills of the farmers or plot to plot variation. An application of augmented designs has been shown in the trials designed and managed by farmers, with some intervention of the researcher. A linear, nested mixed effects model has been suggested for the analysis of on-farm trial data currently being generated by Project Directorate of Cropping Systems Research (PDCSR), Modipuram. This will be helpful in identifying the specific development blocks that seemed to favour one treatment over the other. This will

also help in identification of the recommendation zones that is not possible through comparing the treatment effects averaged over all the development blocks alone.

Fertilizer-response studies

The data from experiments on cultivators' fields have been used extensively for obtaining fertilizer-response ratios. These ratios have also been used by the researchers in studying the trends of fertilizer response ratios over years. The fertilizer response ratios have also been obtained for micronutrients. The fertilize-response ratios developed have been used by the planners and Task Force on Balanced Use of Fertilizers constituted by Ministry of Agriculture, Government of India.

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 besides fertilizers. 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. Yardsticks due to irrigation were worked out for various crops utilizing the limited available data.

Statistical investigations on the fertilizer use efficiency in relation to cultural practices have also been carried out. It has been shown that through the use of recommended cultural practices, fertilizer efficiency and fertilizer response ratios can be improved.

A study entitled 'Statistical evaluation of fertilizer requirements according to dates of sowing' was carried out with the objective of estimating fertilizer requirement corresponding to the normal and delayed sowing for different crops.

Some studies on the estimation of direct and residual effects of nitrogenous fertilizers applied alone or in combination with organic and biofertilizers *viz*., farmyard manure (FYM), Azolla in crop sequences has been made in the division. 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.

Long term fertilizer experiments

Under All India Coordinated Research Project (AICRP) on Long Term Fertilizer Experiments (LTFE) 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 has 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 range between 150 to 300 square meters and it

becomes unmanageable, especially for harvesting, due to shortage of labour, 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 South-West corner of the main plot and a plant within the selected row at random along the length of the whole plot. This randomly selected plant would serve as the South-West 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, which is then used for computing the length of the sample plot. Starting from the South-West 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.

From the analysis of data from AICCRP on LTFE, it has been observed that incorporation of FYM 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.

Long term fertilizer experiments are generally conducted on a fixed crop sequence with treatments as graded levels of fertilizers. Same design with the same randomization is used over years. The observations are collected from same experimental plots over years. As a consequence, the observations may be correlated. To account for the correlation among the observations over years, multivariate analysis of variance (MANOVA) is suggested for the analysis of data from these experiments. The comparison of treatments after MANOVA is a problem. To tackle this problem, a multivariate treatment contrast analysis procedure based on Wilk's Lambda criterion has been developed. This procedure will be of immense use in the analysis of data from AICCRP on LTFE.

Crop sequence experiments

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. 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.

A statistical investigation on production, economic and energy potential of crop sequences in different agro-ecosystems has also been carried out. Statistical investigations have also been carried out to investigate the long-term effect of fertilizers on productivity of cereal crop sequences.

Some experiments have been conducted by PDCSR on Research Stations to assess the relative performance of the crop rotations of different periods in terms of crop productivity, yield stability and

soil health. Analytical procedures for such experiments have been developed and are illustrated with the help of examples. Statistical analysis of experiments on determining level and frequency of phosphorus application in different cropping systems has been carried out.

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 experiments 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 experiments and its effects on drawing inferences on the performance of component crops both individually and collectively have been studied on the basis of eleven sets of data on Intercropping experiments, collected in the past, drawn from different places and/or years. It was observed that the heteroscedasticity is more prevalent in gram crop than in wheat crop. 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 strategy for analysis of data from replacement series experiments using experiments with mixtures methodologies has been suggested. A method of analysis of intercropping experiments involving sole crop treatments has been developed using Wilk's lamda criterion. A procedure of bivariate stability analysis of data has also been developed.

Agroforestry experiments

Methodological studies relating to agroforestry experiments were taken up. Various limitations in the data collection of agroforestry experiments have been identified. A review of designs and analytical techniques useful for agroforestry experiments has also been prepared. Non-linear models have been developed for the decline in crop yield over years in agroforestry experiments. A procedure based on land equivalent ratios has also been developed for analysis of data from agroforestry experiments. Analytical techniques based on linear nested models have also been suggested. The analytical techniques developed have been used for the analysis of data generated from agroforestry experiments on evaluation of fodder trees with and without crops under rainfed arable farming for semi-arid conditions conducted at Indian Grassland and Forage Research Institute, Jhansi.

Variance components estimation

The use of incomplete block designs has been restrictive because the experimenters did not have analysis of variance based method to estimate genetic parameters like genotypic and phenotypic variance and correlation from unbalanced data. A procedure of estimation of these parameters from a non-orthogonal design has been developed based on the analysis of variance of a dual design under a mixed effects model. The expressions of the estimates of the variances of the estimated genotypic and phenotypic variances have also been obtained. This technique has been used successfully in the research work on

Garden Pea of the Division of Vegetable Crops, IARI, New Delhi; Sunflower in Panjabrao Krishi Vidyapeeth, Akola and Pearlmillet in CCS Haryana Agricultural University, Hisar.

Experiments with fixed quantity of inputs applied in splits

Experiments with mixtures methodology is very useful strategy in designing and analyzing experiments involving fixed quantity of inputs applied in splits at different crop growth stages. Such experiments could involve a fixed quantity of nitrogen application at different crop growth stages; fixed quantity of nitrogen from different sources applied in splits; split doses of fixed quantity of irrigation, etc. This strategy has enabled the experimenters to conduct such experiments using more efficient designs and establish a relationship between various splits and response that can be used for interpolation of the response at the design points not tried in the mixtures (combinations). The experiments with mixtures methodology has also been used in the development of an analytical procedure for obtaining optimum proportion of area allocated to different crops in replacement series intercropping experiments. This methodology has also been used in experiments where more than one factors are involved, like fixed doses of nitrogen and irrigation.

Food processing experiments

Experiment with mixture methodology has been used for obtaining the optimum combination of different fruit juices in the quality evaluation of Ready to Serve fruit beverages. This technique has been used in the research work of the Division of Fruits and Horticultural Technology, IARI, New Delhi. Principal component analysis has been applied in developing an index of the quality of the processed food based on the hedonic scores on taste, colour, flavour, texture, overall acceptability, etc. This index has further been used for identification of the best treatment. This technique has been used in the research work of the Division of Agricultural Engineering and Division of Post Harvest Technology, IARI, New Delhi.

Analysis of groups of experiments

The method of combined analysis of data from experiments conducted in different environments (locations or years) using the concept of nested models has also been developed. 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 groups of experiments with some treatments common to all the experiments and some treatments common to some experiments has been developed. Analytical procedure for the combined analysis of experiments with factorial treatment structure with some treatment combinations common has also been developed.The procedure of combined analysis of data when the environment effect is random, has also been developed and used in the analysis of data from initial varietal trials conducted under the aegis of National Research Centre for Rapeseed and Mustard, Bharatpur. In case of cross over interactions, site regression biplot technique has been suggested for identification of entries for a subset of locations.

Experiments with artificially created environments

There are many multi-factor experiments wherein it is difficult to change the levels of one factor. Consider an experiment in which three levels of irrigation are complete submergence of the field, 3 days submergence and one day submergence. The other factors are the fertilizers with four doses of nitrogen and three doses of phosphorous. The experiment is conducted in three replications. In this experiment in

one block all the three levels of irrigation can not be experimented. However, with each level of irrigation the 12 combinations of nitrogen and phosphorous can be tried. The levels of irrigation can be treated as artificially created environments (with environment effects taken as fixed) and groups of experiments methodology can be applied for analysis of data. This concept led to valid statistical analysis of several experiments dealing with water management conducted at Water Technology Centre, IARI, New Delhi.

The procedure has also been used for the analysis of experimental data pertaining to pollination studies under different artificially environments (sowing dates) and population geometry (different planting ratios for male and female rows) in sunflower hybrid seed production. In case of artificially created environments it is suggested that the data on some auxiliary variables may also be collected. These auxiliary variables may be taken as covariates in the analysis.

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. Here, the artificially created environment effects have been assumed as fixed. This analytical technique has helped many M.Sc. and Ph.D. students of the Division of Vegetable Crops and Division of Agricultural Engineering, IARI, New Delhi to draw statistically valid inferences from their data. This concept of artificially created environments has applications in silviculture experiments as well.

Energy requirement in agricultural sector

A linear programming approach has been developed for estimating/projecting the energy requirement in agricultural sector. The approach uses the maximization of yield subject to the constraints on the availability of energy from different sources like Human Labour, Animal labour, Diesel, Electricity, Seed Rate, Farmyard Manure (FYM), Fertilizer, Chemicals, Machinery, Total Energy, etc. The procedure has also been used for minimization of total energy requirement for obtaining a given level of yield. The concept of energy use efficiency has also been introduced. This technique has been extensively used by the All India Co-ordinated Research Project on Energy Requirement in Agricultural Sector, Central Institute of Agricultural Engineering, Bhopal at all its 12 Centres around the country.

Development of fatigue score on camels

A fatigue score card based on qualitative and quantitative physiological characteristics of camel has been developed in collaboration with Krishi Vigyan Kendra, Rewari under the aegis of All India Co-ordinated Research Project on Utilization of Animal Energy. This fatigue score card is very useful for the farmers, military farms, etc. in deciding the tiredness of the camel. Suitable work cycles have also been obtained for various drafts.

Farmers' participatory trials for resource conservation technology

The Rice-Wheat Consortium (RWC) for the Indo-Gangetic plains generally evaluates different resource-conserving technologies (RCTs) in a farmers' participatory mode. It is a key challenge to analyze unbalanced data (due to variations in the number of replications of different RCTs, the use of different varieties, farmers' preferences for testing different options, etc.) generated from these trials using proper statistical tools so as to draw meaningful and valid conclusions. To achieve this, data collection and data preparation are of paramount importance. An additional problem with the analysis of data generated from these trials is that different researchers use different terms for similar practices. IASRI has reiterated the use of

uniform terminology for RCTs and experimental variables and a common data entry format, including specified units. The usefulness of the linear mixed effects model has also been emphasized to analyze the data generated from these trials by taking farmer effects or field effects as random and RCT effects (henceforth called treatments) as fixed. To identify the best performance of any treatment in a given environment, one can make all possible pair-wise treatment comparisons using adjusted means / best linear unbiased predictors of treatments. The procedure of analyzing groups of experiments has been used to study the interaction of treatments with crop varieties, years, soil types, and land leveling, etc. In the case of crossover interactions, the site regression biplot technique has been suggested to identify subsets of treatments to be recommended for specific environments. All the techniques developed / suggested have been illustrated with examples. The whole data generated from farmers' participatory trials for conservation agriculture conducted under the aegis of Asian Development Bank Project on Enhancing Farmers Income and Livelihoods through Integrated Crop and Resource Management in the Rice-Wheat System in South Asia at Bangladesh, Pakistan, Nepal, India (Modipuram and Balia) centres have been analyzed by Rice-Wheat Consortium for Indo-Gangetic plains using the techniques developed at IASRI in collaboration with CIMMYT and IRRI.

Covariance analysis

Analysis of covariance has been used in various experimental situations by taking residuals from previous season / year 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.

Bayesian analytical techniques for experimental data

Bayesian analytical technique for the analysis of experimental data generated through randomized complete block design has been developed both for conjugate and non-conjugate family or prior distributions. The procedures developed improved the precision on treatment comparisons in the analysis of experimental data from long term fertilizer experiments.

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.

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 1st 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 were 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.

Spatial analysis of data

A software for analyzing Spatial Variability and Interpolation (SVI) has been developed. It enables the user to visualize the spatial variability in graphical form (both 2D and 3D). It includes Variogram Specification Wizard and Graphical Visualization Tool. Variogram Specification Wizard guides the user about the steps necessary for specifying a variogram type viz. isotropic or anisotropic. Graphical Tool visualizes the calculated results in 2D (for isotropic) and 3D (for anisotropic) graphical form. Computer programs for obtaining variograms in different directions and at different lags have been incorporated in SVI. Programs for kriging in regular grids, with four inbuilt fitting models viz. spherical, Gaussian, exponential, and logarithmic have been developed.

Spatial variations in the analysis field trial data have been investigated using the procedure of variograms and REML. The procedures have been illustrated with the help of data pertaining to experiments conducted on Aonla, Kinno and Tuber crops.

The data pertaining to different parameters of soil (organic carbon, pH, electrical conductivity, etc.) from different locations and over years has been analysed using principal component analysis and variograms have been created to study the spatial and temporal variability in rice-wheat cropping system for assessment of spatial and temporal variation of soil microbial diversity. The methodology for spatial analysis of experimental data with interference effects has been developed and illustrated.

Analysis of growth data

The repeated measures data obtained from Jabalpur and Tirupati pertaining to growth of body weights of pigs for the period 1986 to 1990 have been analyzed using multivariate analysis of variance and profile analysis. The technique of profile analysis gives a detailed analysis of growth data. From profile analysis it is observed that there is no interaction between groups (male and female) and time points. Significant differences were observed among the time points but there is no difference among groups. The growth trend of pigs is studied by using the non-linear growth models.

3.3 Collaborative research

One of the major activities of Design of Experiments at IASRI since its inception has been working in close collaboration with its NARS partners. The collaborations with NARS partners dates back to 1956 when the Institute started the research work on planning, designing and analysis of experiments conducted under the All India Co-ordinated Agronomic Experiments Research Project (AICRP) of the ICAR. This project consisted of two components *viz.,* (a) complex experiments conducted at research centres (model agronomic experiments) and (b) simple fertiliser experiments conducted as experiments conducted on cultivators' fields. Today we work in close collaboration with large number of sister Institutes, non-governmental organizations, CGIAR organizations, etc. These are given as under:

Planning, designing and analysis of data relating to

– On Station and On Farm experiments under the Project Directorate for Cropping Systems Research {All India Co-ordinated Agronomic Experiments Research Project (1956-57 to 1982-83); AICRP on Cropping Systems Research and Experiments on Cultivators' Fields (1982-83 to 1988-89); Project Directorate of Cropping Systems Research (since 1988-89).

– All India Co-ordinated Research Project on Long-Term Fertilizer Experiments (since July 1985);

– All India Co-ordinated Research Project on Soil Test Crop Response Correlations (since March 2000)
– All India Co-ordinated Research Project on Rapeseed and Mustard (since April 2004)
– All India Co-ordinated Research Project on Wheat and Barley (since 2006)
– AICRP on Utilization of Animal Energy in collaboration with KVK, Rewari (01.12.1998 - 31.03.2000)
– AICRP on Energy Requirement in Agricultural Sector (07.04.2000-31.07.2001)
– Some investigations on design and analysis of agro-forestry experiments (IGFRI, Jhansi: 01.03.2000 – 31.08.2006)
– Assessment of spatial and temporal variation of soil microbial diversity in Rice-Wheat Cropping System with different management practices (IARI, New Delhi during June 2001 – May 2004)
– Institute of Applied Statistics and Development Studies, Lucknow (15.09.2001-14.12.2003)
– Design and analysis of farmer participatory research trials for conservation agriculture (Rice-Wheat Consortium for Indo-Gangetic Plains, CIMMYT and IRRI (since January 2005)
– Long term manurial and fertilizer experiment on potato based cropping systems (CPRS, Modipuram since January 2007).

4. Advisory Services

Despite the developments in design of experiments at global level in general and in NARS in particular, the status of experimentation is not at expected level. Most of the experiments are conducted in Randomnized Complete Block (RCB) designs / split plot designs. In most of these experiments, percent coefficient of variation is high and as a consequence precision on treatment comparison is low. Concerted efforts are being made to improve status of experimentation in the NARS through training programmes-cum-workshops; dissemination workshops; participation in annual workshops of AICRPs and rigorous advisory services. This has witnessed a revolution in the form of adoption of newer, efficient designs and sophisticated analytical techniques for statistical data analysis by agricultural researchers in their research endeavors. The efforts made have enabled the Institute to enrich the quality of agricultural research in the NARS. Through its advisory, IASRI has made its presence visibly felt in NARS and now experimenters look to IASRI for designing experiments and analysis of experimental data. The adoption of sophisticated analytical techniques for statistical data analysis has helped to improve the quality of agricultural research. Some of the adaptations are given below:

- Balanced incomplete block designs for identification of appropriate crop sequence with high productivity to suit specific needs of different agro-eco systems.
- Group divisible and extended group divisible designs, reinforced group divisible designs, reinforced balanced confounded factorial designs for crop sequence experiments and experiments for rainfed agriculture.
- Second order rotatable response surface designs with equispaced doses and experiments with mixtures for food processing and value addition experiments.
- Square and rectangular lattice designs, α-designs, augmented designs, etc. for varietal trials and crop improvement programmes.
- Modern sophisticated analytical techniques such as experiments with mixture methodology, principal component analysis, cluster analysis, canonical correlation analysis, analysis of nested structures,

covariance analysis, etc. have also been adopted. The analytical techniques for the analysis of data from the experiments conducted to study the post harvest storage behaviour of the perishable commodities like fruits and vegetables are being widely used in NARS.

- A design for fitting response surface for the AICRP on Soil Test Crop Response Correlations that incorporates the effect of both the inorganic and organic fertilizers into the model has been developed. The experiment is a symmetrical factorial of the type 3×3×3 in 21 runs. QRT team of AICRP on STCR has approved the design. This design is being adopted by all the centres.
- α-designs are being used at 22 co-operating centres of AICRP on Rapeseed and Mustard, National Bureau of Plant Genetic Resources, New Delhi and CSK HPKV, Palampur.

5. Information Systems

In the early 1950's an effort was initiated to develop a system of maintaining at a central place the information on all the experiments conducted in NARS. The objective was that for future experimentation it can provide useful information in choice of size and shape of plots, selection of treatments, etc. This effort was initiated in the form of a project on National Index of Agricultural Field Experiments. Ever since its initiation, this project has been continued with modifications from time to time. In 1960's and 1970's for the benefit of research workers, the data on experiments collected from different regional research centres were compiled and published in the form of compendia volumes so that the experimenters can use the information in their future experimentation. With the advent of fast speed computers in 1970's the data was stored on Magentic tapes. In 1980s this was converted into Information System. With the availability of network facilities, now we have following online information systems

- Agricultural Field Experiments Information System
- National Information System on Long Term Experiments
- National Information System on Animal Experiments

Agricultural Field Experiments Information System contains data on more than 27,000 experiments conducted in NARS. This system is available online. Data entry can be made online. User can analyze the data generated through basic designs online once the data is entered. This information system can be further strengthened by sensitizing the policy managers, researchers so as to make this more effective and useful. Additional data on experiments pertaining to cropping systems research, agricultural, animal, horticultural, fishery sciences, and wasteland experiments conducted in the NARS, along with value addition, will further enhance the usage of this information system. To ensure the continuous data flow, it should be made mandatory for the experimenters to put the data into the information system. A part of this can be achieved through ensuring the availability of general purpose software for all and having the customized modules for the analysis. Further, to utilize the information systems developed at IASRI, research projects are undertaken to convert the information into knowledge that can be fruitfully utilized by the subject matter divisions.

6. Statistical Software Packages

Without the availability of reliable, easy to use and cost effective software, it would be difficult to use the best statistical analytical techniques in research. Hence, development of indigenous, need based, user-friendly Graphic User Interface (GUI) based statistical software packages for experimental designs,

useful for NARS, requires urgent attention. A lead has been taken in the development and commercialization of indigenous statistical software packages like

- Statistical Package for Balanced Incomplete Block Designs (SPBD Release 1.0)
- Statistical Package for Factorial Experiments (SPFE 1.0)
- Statistical Package for Augmented Designs (SPAD)

for cataloguing and generating randomized layout of designs and analysis of experimental data. These packages have been developed and have been widely appreciated by both the statisticians and agricultural experimenters. A lot of requests over the globe have been received for SPAD. These indigenous softwares can be used for class room teaching and helps in improving the quality of teaching.

Some other indigenous statistical packages that have been developed or are being developed include Statistical Package for Repeated Measurement Designs; Statistical Package for Multivariate Analysis of variance; Statistical Package for Partially Balanced Incomplete Block Designs.

7. Web Resources on Designed Experiments

Although important and useful contributions have been made in Agricultural Statistics so as to help in improving the quality of agricultural research, yet it is impossible to reach every field of agricultural sciences in NARS. In view of this it is desirable to initiate an e-advisory service.

A beginning in this direction has already been made through initiating a Design Resources Server (www.iasri.res.in/design) with an objective to popularize and disseminate research in design of experiments among experimenters in agricultural sciences, biological sciences, animal sciences, social sciences and industry in planning and designing their experiments for making precise and valid inferences on the problems of their interest, generally treatment contrasts. It also provides support for analysis of data generated so as to meet the objectives of the study. This server also aims at providing a platform to the researchers in Design of Experiments for disseminating research and also strengthening research in newer emerging areas so as to meet the challenges of agricultural research. This server attempts to spread advances in theoretical, computational and statistical aspects of Design of Experiments among the mathematicians and statisticians in academia and among the practicing statisticians involved in advisory and consultancy services.

The Design Resources Server contains a lot of useful information for scientists of NARS. The material available on the server has been partitioned into four main components:

- **Useful for experimenters:** Electronic Books, online generation of randomized layout of designs, online analysis of data, analysis of data using various softwares
- **Useful for research statisticians:** Literature and catalogues of BBB designs, designs for making test treatments-control treatment comparisons, supersaturated designs, block designs with factorial treatment structure, online generation of Hadamard matrices, MOLS and orthogonal arrays
- **Other useful links:** Discussion Board, Ask a Question, Who-is-where, Important links
- **Site information:** Feedback, How to Quote Design Resources Server, Copyright, Disclaimer, Contact us and Site map

The Design Resources Server is like a mobile Library on Design of Experiments in particular and Statistics in general. It provides useful information both for active researchers in statistics as well as stake holders like scientists in NARS and others all over the globe. The server is dynamic in nature and new links on various topics are added to it regularly.

It is a copyright of IASRI(ICAR). For the period May 26, 2008 – May 25, 2009, Google Analytics gave 5786 page views, 4698 unique page views and usage through 566 cities across 80 countries in 6 continents.

Some other similar type of activities are: Web solutions for PBIB designs (http://www.iasri.res.in/webPBIB3/); Circular Designs (http://iasri.res.in/Circular_Designs/) and Lattice Designs (http://www.iasri.res.in/Lattic_designs/main.htm).

8. Human Resource Development

The Division has played a key role in human resource development. Besides teaching the M.Sc./ Ph.D. Students of P.G. School, I.A.R.I., New Delhi, Division takes active part in organization of summer/ winter schools on Advances in Design of Experiments and related topics for Statisticians and experimenters; Training programmes under Centre of Advanced Studies in Agricultural Statistics and Computer Applications. In fact the training programmes that are being organized to bring agricultural scientists and statisticians together so as to derive the maximum academic advantage through interaction with the faculty and among the fellow participants are being widely appreciated in NARS. The Division is also conducting sponsored training programmes for scientific personnel of Indian Council for Forestry Research and Education (ICFRE); Central Statistical organization, E.I. DuPont India Pvt. Ltd. Customized and tailor made training programmes for research personnel of AICRP on Energy Requirement in Agricultural Sector; AICRP on Rapeseed and Mustard and Rice-Wheat Consortium for Indo-gangetic plains have also been conducted.

9. Future Perspective

The research in the area of Design of Experiments has been of high quality and maintaining the tradition, the research programmes would be further strengthened to meet the challenging requirements in the newer emerging areas of agricultural research. Some important areas on which the attention would be focused are described in the sequel.

Research in newer emerging areas would be the priority. Research on designs for factorial experiments with scarce resources, mixed orthogonal arrays and especially mixed orthogonal arrays of strength one would be undertaken. Block designs having orthogonal factorial structure with balance having full efficiency on main effects and controlled efficiency on interactions would also receive attention. With proper modifications these would have applications in micro array experiments, computer experiments, designs for cropping systems research, etc. Efficient designs for multi-response experiments useful in food processing, intercropping and agroforestry experiments would be obtained. Integrated farming systems research is another emerging area that would be taken up. Data requirements for such experiments would be studied and the problems of data designing, which includes the experimental design, the choice of treatments, the inference problem and the analysis of data to be performed, etc. would be studied. Designing and analysis of experiments for identification of varieties resistant to biotic and/ or abiotic stresses would

also be the research priority. Designing experiments and analytical techniques for experiments involving very few treatments (may be only two) but very large plots (may be one hectare or more) would be developed. Efficient and robust designs for animal experiments, horticultural experiments and fisheries experiments would be generated. Bayesian designing of experiments and Bayesian analysis of data would be another priority area of research. Efficient designs for bio-equivalence trials and for biological assays would be obtained. Designing geo-spatial experiments and analysis of geo-spatial data would become another priority of research. Exploiting the information technology, efforts would be made to generate computer aided efficient designs for different experimental settings. The activity of developing indigenous software for generation of randomized layout of the design and then subsequent analysis of data including contrast analysis, groups of experiments, etc. would be reinvigorated.

Concerted efforts would be made to strengthen linkages with the All India Coordinated Research Projects for planning and designing of experiments and analysis of experimental data. These linkages would also be extended to subject matter divisions, State Agricultural Universities (SAUs) and National Research Centres (NRCs). The possibility of undertaking collaborative projects with CGIAR organizations in Consortium Mode would be explored.

For dissemination of research and for capacity building of scientists, need based, customized, tailor made training programmes would be organized. These would be supplemented with travel seminars, workshops, etc. The consultancy and advisory services would be strengthened so as to provide leadership in the planning and designing of experiments and analysis of experimental data to the students and scientists in NARS. This would be possible through rigorous use of Design Resources Server and by further strengthening it for providing e-learning and e-advisory services.

The above steps will definitely help in strengthening the basic, applied and adaptive research as well as teaching and training in Design of Experiments.