मृदा परीक्षण फसल अनुक्रिया सह–सम्बन्ध (एस.टी.सी.आर.) पर अखिल भारतीय समन्वित अनुसंधान परियोजना से सम्बंधित परीक्षणों का नियोजन, डिजाइनिंग और विश्लेषण

PLANNING, DESIGNING AND ANALYSIS OF EXPERIMENTS RELATING TO AICRP ON SOIL TEST CROP RESPONSE CORRELATION

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प्राक्कथन

फसल उत्पादन बढ़ाने के लिए विस्तारित सिंचाई सुविधाओं के तहत उच्च उपजशील किस्मों और गहन बहु फसल प्रणाली के आने से मृदा परीक्षण मानों पर आधारित संतुलित उर्वरक के महत्व को भारतीय किसानों ने भली–भांति समझा है । संतुलित उर्वरक की सिफारिशों के लिए मृदा परीक्षण मानों और फसल अनुक्रिया के बीच एक सम्बन्ध विकसित करने के विचार से भारतीय कृषि अनुसंधान परिषद ने सन् 1967–68 के दौरान मृदा परीक्षण फसल अनुक्रिया सहसम्बन्ध (Soil Test Crop Response Correlations) पर एक अखिल भारतीय समन्वित अनुसंधान परियोजना (All India Coordinated Research Project) शुरु किया । इस परियोजना द्वारा विगत 35 वर्षों में लक्षित उपज प्राप्त करने के उद्देश्य से भिन्न–भिन्न फसलों की उर्वरक अनुसूचियां निर्धारित करने के लिए अनेक उर्वरक समायोजन समीकरण(fertilizer adjustment equations) एवं अंशांकन चार्ट(calibration charts) तैयार किए जाते रहे हैं । विगत वर्षों में यह देखा गया है कि किसी एक अनुसंधान केन्द्र पर किसी एक फसल की उर्वरक समायोजन समीकरण पर आधारित सिफारिशें संगत(consistent) नही हैं । इसके अलावा अधिकांश मामलों में बहु–समाश्रयण (multiple regression) विधि की सहायता से उर्वरक पोषकों की अनुकूल खुराकें प्राप्त नही की जा सकी हैं ।

मृदा परीक्षण फसल अनुक्रिया सहसम्बन्ध पर अखिल भारतीय समन्वित अनुसंधान परियोजना के परियोजना समन्वयक(Project Coordinator), भारतीय मृदा विज्ञान संस्थान (I.I.S.S.) भोपाल, इन समस्याओं के साथ भारतीय कृषि सांख्यिकी अनुसंधान संस्थान, नई दिल्ली में आए और एक लम्बे विचार–विमर्श के बाद आपस में सहमति हुई कि भारतीय कृषि सांख्यिकी अनुसंधान संस्थान में एक परियोजना शुरु की जाएगी ताकि इन समस्याओं के समाधान की संभावनाओं को तलाशा जा सके और नई विश्लेषणात्मक तकनीकों का विकास करने के साथ–साथ परीक्षण करने की नई डिज़ाइनों को सुझाया जा सके । विगत वर्षो के दौरान इस परियोजना में भारी मात्रा में आंकड़े एकत्रित किए गए जिसके लिए इस परियोजना में एक डाटा–बेस बनाने की भी जरुरत थी । परिणाम स्वरुप दिनांक 01 मार्च, 2000 को भा.कृ.सां.अ.सं. में मृदा परीक्षण फसल अनुक्रिया सहसम्बन्ध पर अखिल भारतीय समन्वित अनुसंधान परियोजना से सम्बंधित परीक्षणों का नियोजन, डिज़ाइनिंग और विश्लेषण"(Planning, designing and analysis of experiments relating to AICRP on Soil Test Crop Response Correlations) नामक एक सहयोगी परियोजना शुरु की गई ।

इस परियोजना के तहत अनुक्रिया अन्तरापृष्ठ (response surface) पद्धति की सहायता से उर्वरक पोषकों के अनुकूलतम मानों को प्राप्त करने के लिए विश्लेषणात्मक तकनीक विकसित की गई है । इस पद्धति को किसी एक विशेष स्थान के मृदा परीक्षण मानों के नियत सैट के लिए उर्वरक पोषकों की अनुकूलतम जरुरत प्राप्त करने के लिए लागू किया जा सकता है । आंकड़ों में आउटलायरो (outliers) का पता लगाने के लिए विभिन्न समाश्रयण निदान (regression diagnostics) भी लागू किए गए और संभव उपचारों पर विचार किया गया है ।

विभिन्न डिजाइन बिन्दुओं वाली अनेक नई डिज़ाइनों का प्रस्ताव रखा गया है । कुछ ऐसी डिजाइनें भी तैयार की गईं जिनके उपचार संयोजनों में कार्बनिक और अकार्बनिक उर्वरक शामिल हैं । इन डिजाइनों पर भा.कृ.सां.अ.सं. में विचार–विमर्श करने के लिए एक बैठक की गई । इस बैठक में डा. जे.एस. सामरा, उप–महानिदेशक (एन.आर.एम.), डा.एन.एन.गोस्वामी और डा.जी.एस.शेखों के अलावा जाने–माने मृदा वैज्ञानिको, परियोजना समन्वयक (एस.टी.सी.आर), एवं भा.कृ.सां.अ.सं. और भा.मृ.वि.सं. के वैज्ञानिको ने भाग लिया ।

मृदा परीक्षण फसल अनुक्रिया सहसम्बन्ध पर अखिल भारतीय समन्वित अनुसंधान परियोजना की आगामी कार्यशाला में विचार–विमर्श और तदन्तर परीक्षण के लिए सुझाए गए डिजाइनों में से एक डिज़ाइन को लिया जा रहा है । परीक्षणात्मक आंकड़ों और इसकी सहायक सूचनाएं एकत्रित करने के लिए एक छोटा सा डाटा बेस भी तैयार किया गया है ।

मैं, भारतीय कृषि सांख्यिकी अनुसंधान संस्थान, नई दिल्ली और भारतीय मृदा विज्ञान संस्थान, भोपाल के वैज्ञानिकों के प्रयासों की सराहना करता हूं जिन्होंने बड़े ही मनोयोग से इसे तैयार किया है । आशा करता हूं कि इस परियोजना के परिणामों से मृदा परीक्षण फसल अनुक्रिया सहसम्बन्ध के क्षेत्र में काम कर रहे कृषि कर्मियों को लाभ मिलेगा । मैं, यह भी कामना करता हूं कि यह सहयोग भविष्य में और सुदृढ़ होगा ।

(सुखदेव शर्मा)
निदेशक

FOREWORD

With the introduction of high yielding varieties and intensification of multiple cropping under expanded irrigation facilities, the importance of balanced fertilization based on soil test values was well recognized by the Indian farmers for increased crop production. With a view to develop a relationship between soil test values and crop response to fertilizer for balanced fertilizer recommendations, the Indian Council of Agricultural Research launched the All India Coordinated Research Project on Soil Test Crop Response Correlation during the year 1967-68. This project over the last 35 years has generated numerous Fertilizer Adjustment Equations and calibration charts for prescribing fertilizer schedules for different crops for obtaining targeted yields. However, these fertilizer equations vary widely over the years for a crop at a particular centre. Moreover, at most of the time the optimal doses of the fertilizer nutrients could not be obtained using multiple regression method.

The Project Coordinator AICRP on STCR, Indian Institute of Soil Science, Bhopal approached IASRI, New Delhi with these problems. It was mutually agreed that a project would be taken up at IASRI to explore the possibility of solving these problems and to develop new analytical techniques and suggest new designs for carrying out experiments. As over the years, large amount of data have been gathered under the project, the creation of a database under the project was also solicited. Consequently, a Collaborative project entitled "Planning, Designing and Analysis of experiments relating to AICRP on soil test crop response correlation" was under taken at IASRI with effect from 1st March 2000.

Under the project, an analytical technique has been developed for obtaining the optimal values of the fertilizer nutrients using Response Surface Methodology. This methodology can be applied usefully for obtaining optimal requirement of fertilizer nutrients for a given set of soil test values of a particular site. Various regression diagnostics to detect the outliers in the data were also applied and possible remedies were discussed.

A number of new designs have been proposed with various design points. Also, some designs were generated in which the treatment combinations included organic and inorganic fertilizers. These designs were discussed in a meeting held at IASRI in which Dr JS Samra, DDG (NRM); Dr NN Goswami and Dr.G.S.Sekhon, prominent Soil Scientists, Project Co-ordinator of STCR and Scientist of IASRI and IISS took part. One of the designs is going to be taken up for discussion and subsequent experimentation, in the next workshop of the AICRP on STCR. A small database was also created to store the experimental data and its ancillary information.

I appreciate the efforts of the Scientists of IASRI, New Delhi and IISS, Bhopal for bringing out this report. It is hoped that the agriculture workers in the field of Soil Test Crop Response Correlation shall be benefited by the findings of the project. I also wish that this collaboration would be strengthened in future.

(S.D. SHARMA)
DIRECTOR

आमुख

भारतीय कृषि अनुसंधान परिषद द्वारा 1967–68 के दौरान फसलों की उच्च पैदावार देने वाली किस्मों के साथ–साथ गहन खेती की दशाओं के लिए मृदा परीक्षण अंशांकन का विकास करने के उद्देश्य से मृदा परीक्षण फसल अनुक्रिया सहसंबंध(Soil Test Crop Response Correlations) पर एक अखिल भारतीय समन्वित अनुसंधान परियोजना(All India Coordinated Research Project)शुरु की गई थी । फिलहाल, देश के विभिन्न सस्य जलवायवीय क्षेत्रो (agro climatic zones) में इसके 16 केन्द्र है । गत 35 सालों के दौरान इस परियोजना में आंकड़ों का बृहत् खण्ड तैयार किया गया है । विगत वर्षों में यह देखा गया कि किसी खास केन्द्र पर किसी एक फसल की उर्वरक समायोजन समीकरण(fertilizer adjustment equation) पर आधारित सिफारिशें संगत(consistent) नही हैं । इसके अलावा, बहु समाश्रयण विधि(multiple regression) से निकाले गए पोषक तत्वो (nutrients) के इष्टतम मान(optimal dose) हर समय सफल नही होते हैं । इसलिए यह जरूरी था कि अपनाई गई डिज़ाइन के हर पहलू की ओर इष्टतम मानों के निर्धारण के साथ–साथ सांख्यिकीय विश्लेषण(statistical analysis) करने की जरूरी परिस्थितियों की समीक्षा की जाए ।

मृदा परीक्षण फसल अनुक्रिया सह–सम्बन्ध पर अखिल भारतीय समन्वित परियोजना के परियोजना समन्वयक(Project Coordinator), भारतीय मृदा विज्ञान संस्थान, भोपाल द्वारा भारतीय कृषि सांख्यिकी अनुसंधान संस्थान, नई दिल्ली, के परीक्षण अभिकल्पना(design of experiments) प्रभाग के वैज्ञानिकों के साथ विचार–विमर्श के दौरान इन समस्याओं पर प्रकाश डाला गया और आपसी सहमति हुई कि भारतीय कृषि सांख्यिकी अनुसंधान संस्थान में एक परियोजना शुरु की जाए ताकि इन समस्याओं के समाधान की संभावनाएं तलाशी जा सकें और नई डिज़ाइन विकसित करने के साथ–साथ आंकड़ों का विश्लेषण तो किया ही जाए साथ ही उनकी व्याख्या भी की जाए तथा मृदा परीक्षण अंशांकन (soil test calibration) में सुधार लाया जाए । इसके फलस्वरूप "मृदा परीक्षण फसल अनुक्रिया सह–सम्बन्ध पर अखिल भारतीय समन्वित अनुसंधान परियोजना से सम्बंधित परीक्षणों का नियोजन, डिजाइनिंग और विश्लेषण" (Planning, designing and analysis of experiments relating to AICRP on Soil Test Crop Response Correlations) नामक एक परियोजना 1 मार्च, 2000 से भारतीय कृषि सांख्यिकी अनुसंधान संस्थान में शुरु की गई ।

इस रिपोर्ट में एस.टी.सी.आर. परियोजना की जरूरतों के आधार पर भिन्न–भिन्न डिजाइन बिन्दुओंDesign points) सहित (5x4x3), (4x4x3), (4x4x4) इत्यादि डिजाइनों की किस्म से अनेक डिजाइनों का प्रस्ताव रखा गया है । अनुक्रिया अन्तरापृष्ठ (response surface) पद्धति पर आधारित एक विश्लेषणात्मक विधि विकसित की गई है । इस विधि में यदि मृदा परीक्षण मान उपलब्ध हों तो किसी एक खास स्थान के लिए नाईट्रोजन, फासफोरस और पोटैशियम उर्वरक पोषकों के इष्टतम मान निकाले जा सकते हैं । विभिन्न सहयोगी केन्द्रों के आंकड़ों का विश्लेषण करते समय यह देखा गया कि सभी मामलों में जहां अनुक्रिया अन्तरापृष्ठ पद्धति से पल्याण बिन्दु (saddle point) के रूप में एक स्तब्ध बिन्दु (stationary point) बना यानि यह न तो अधिकतम था और न ही न्यूनतम था । इन मामलों में स्तब्ध बिन्दु के परिवेश(vicinity) में अनुक्रिया अन्तरापृष्ठ की संभावना का पता लगाया गया है । लक्षित उपज विधि के माध्यम से उर्वरक पोषकों नाईट्रोजन, फास्फोरस और पोटैशियम के इष्टतम मानों को अनुक्रिया अन्तरापृष्ठ पद्धति के परिप्रेक्ष्य में सत्यापित किया गया ।

हम, डा. एस.डी. शर्मा, निदेशक, भारतीय कृषि सांख्यिकी अनुसंधान संस्थान, नई दिल्ली के अत्यंत आभारी हैं कि उन्होंने इस परियोजना में गहरी दिलचस्पी लेते हुए लगातार हमारा उत्साहवर्धन तो किया ही साथ ही सुझाव देने के साथ–साथ हमें सभी सुविधाएं भी उपलब्ध की हैं । हम, डा. वी. के. गुप्ता, संयुक्त निदेशक, भा.कृ.सां.अ.सं. एवं पूर्व प्रधान, परीक्षण अभिकल्पना प्रभाग का भी हार्दिक धन्यवाद अदा करते हैं कि उन्होंने इस रिपोर्ट में प्रस्तावित नए डिजाइनों के विकास में अपना बहुमूल्य योगदान दिया है और पूरी परियोजना के दौरान वे लगातार हमारे प्रेरणा स्रोत बने रहे और बहुमूल्य सुझाव दिए ।

हम, डा. रवीन्द्र श्रीवास्तव, प्रधान वैज्ञानिक, परीक्षण अभिकल्पना के बड़े ऋणी हैं जिन्होंने रिपोर्ट की गुणवत्ता में सुधार लाने के लिए सृजनात्मक सुझाव दिए और बहुमूल्य टिप्पणियां की । हम, बाह्य रेफरी के बहुमूल्य सुझावों की भी सराहना करते हैं ।

हम, श्री उदयवीर सिंह, तकनीकी अधिकारी, टी–5 का भी हार्दिक आभार व्यक्त करते हैं जिन्होने इस रिपोर्ट को तैयार करने के दौरान पुरे लगन और निष्ठा से कार्य किया और अपना अमूल्य योगदान दिया । आंकड़ों के संकलन में डा. एस.एम.जी. सरन, वैज्ञानिक ने बहुमूल्य सहायता की इसके लिए हम उनका हार्दिक आभार व्यक्त करते हैं ।

अन्त में हम श्री ए.पी. सिंह , प्रभारी हिन्दी अनुभाग के अत्यन्त ही आभारी है कि उन्होंने आरम्भ के कुछ पृष्ठों का अनुवाद अत्यन्त ही सरल एवं सुबोध भाषा में किया ।

लेखकगण

PREFACE

All India Coordinated research project on Soil Test Crop Response Correlation was launched by ICAR during 1967-68 to develop soil test calibration for condition of intensive agriculture with high yielding varieties of crops. Presently there are 16 centres in different agro climatic zones of the country. Over the last 35 years a large volume of data have been generated under the project. It was observed that the recommendations based on the Fertilizer Adjustment Equations are not consistent over the years for a crop at a particular centre. Moreover, the optimal values of the nutrients as derived by the method of multiple regression is not successful every time. Therefore, it was necessary to review the overall aspects of the design adopted, determination of the optimal values, and the conditions necessary for carrying out the statistical analysis.

The Project Coordinator AICRP on Soil Test crop Response Correlations, Indian Institute of Soil Science, Bhopal highlighted these problems in a discussion with the Scientists of Division of Design of Experiments, IASRI, New Delhi and it was mutually agreed that a project would be taken up at IASRI, to explore the possibility of solving these problems and to develop new designs and the analysis of data, their interpretation and improvement in soil test calibration. Consequently, a project entitled "Planning, Designing and analysis of experiments relating to AICRP on Soil test Crop Response Correlations" was initiated at IASRI w.e.f. 1st March 2000.

In this report, a number of designs have been proposed from designs of type (5 x 4 x 3), (4 x 4 x 3), (4 x 4 x 4) etc. with different designs points, based on the requirements of STCR project. An analytical technique has been developed based on Response surface methodology. In this method, the optimal values of Nitrogen, Phosphorus and Potassium fertilizer nutrients could be derived for a particular site if its soil test values are available. While analyzing the data of different cooperating centres, it was observed that in almost all the cases the response surface methodology produced the stationary point as saddle point i.e. neither maxima nor minima. In such cases exploration of the response surface in the vicinity of the stationary point has been attempted. The optimal values of the fertilizer nutrients Nitrogen, Phosphorus and Potassium derived through Targeted Yield Approach were verified in the light of Response Surface Methodology.

We express our deep sense of gratitude to Dr. S.D. Sharma, Director, IASRI, New Delhi for his keen interest in the project, constant encouragement, suggestions and for the facilities provided. We are also thankful to Dr. V.K.Gupta, Joint director, IASRI and Ex-Head, Division of Design of Experiments, for his contributions in the development of new designs that are proposed in this report, his constant motivation and valuable suggestions during the entire period of the project.

We are greatly indebted to Dr. Ravindra Srivastava, Principal Scientist, Division of Design of experiments for offering constructive suggestions and valuable comments in improving the quality of the report. We also acknowledge the valuable comments of the external referee.

We sincerely acknowledge the efforts of Shri Udaivir Singh, Technical Officer T-5 for his untiring help and cooperation during the preparation of the report. The assistance of Dr. S.M.G. Saran, Technical Officer T-7 in compilation of data is also acknowledged.

AUTHORS

विषय–सूची

CONTENTS

Chapter -I

INTRODUCTION

The balanced application of fertilizer particularly the major nutrients, N P and K in optimum quantity, based on soil test and crop requirement is one of the most vital aspects for sustaining higher agricultural production. This requires the application of optimal and balanced quantity of fertilizers in right proportion through appropriate method and time of application for a specific soil-crop-climate situation. It ensures increased quantity of produce, maintenance of soil productivity and the most efficient and judicious use of applied fertilizers. Thus in this context the soil fertility evolution and refined fertilizer prescription for sustained agricultural production is of great importance to farming community. Hence, the soils have to be tested precisely for their available nutrient status for making fertilizer recommendations based on crop response and economic circumstances.

The determination of the amount of fertilizer that should be applied to a crop would be simple if a chemist could analyze the soil to measure the amount of available plant nutrients present in the soil and to calculate the amount of that nutrient which should be applied to correct the deficiencies. It is unfortunate that the determination of fertilizer requirements is not as simple. As every soil chemist knows, there are basic problems in interpreting soil test values in terms of nutrient availability to crops due to the interacting effects of other soil constituents, surface reactions, the changes that may occur in test values both laterally across farmers' fields and vertically down the soil profile and to all these factors may be added the uncertainties of weather, effects of crop variety, disease, pests etc. Any suggestion, therefore, that fertilizer requirement can be determined solely on the basis of a simple laboratory analysis of a few grams of soil, represents a vast oversimplification of a highly complex system. Nevertheless soil analysis can provide useful information on the effect that fertilizers are likely to have on yields, and it is important to use this information for the estimation of fertilizer requirements. Soil tests can provide a valuable piece of information and as such should be used in conjunction with such other information that is available for the estimation of fertilizer requirements.

1.1 All India Coordinated Research Project on Soil Test Crop Response Correlations

Soil test crop-response studies has been going on for a quite a long period of time both in India and abroad. With the introduction of high yielding varieties and intensification of multiple cropping under expanded irrigation facilities, the importance of balanced fertilizer use for increased crop production was well recognized by the Indian farmers.

Since the fertilizer recommendations for crops based on simple field trials did not give the expected yield response; a need arose for the refinement of fertilizer prescription for varying soil test values for economic crop production. Against this background, the All India Coordinated Research Project on Soil Test Crop Response Correlation was initiated during the year 1967-68.

1.2 Objectives of AICRP-STCR

The project has the following objectives.

(i) To develop relationships between soil test values and crop response to fertilizers in order to provide calibration for fertilizer recommendations based on soil testing.
(ii) To obtain a basis for making fertilizer recommendations for targeted yields.
(iii) To evaluate various soil test methods for their suitability under field conditions.

(iv) To evaluate the joint use of chemical fertilizers and organic manures for enhanced nutrient use efficiency.

(v) To derive a basis for making fertilizer recommendations for a whole cropping system on initial soil test values.

1.3 Cooperating Centres, location, soil type and agro-eco region

There were eight centers under the project to begin with. During 1970-71, five more centres were added. One centre (Raipur) was added during the year 1981-82. Currently, STCR project is having Sixteen cooperating centres. The location, year of start, their agro-eco region etc. are shown in Table 1.1

1.4 Statistical design and conduct of experiments under STCR

The main objective of STCR consists of developing a relationship between soil test and crop response to fertilizer in order to provide a calibration for balanced fertilizer recommendations based on soil testing. Since different levels of uncontrollable variables e.g. Soil fertility, cannot be expected to occur at one place, different sites have to be selected to represent different levels of soil fertility. In order to tide over the management problem conducting a field experiment at different sites differing from each other in the extent of uncontrolled variables, artificial fertility gradients in 4 adjoining plots are created by applying different amounts of fertilizers to a preceding non-experimental crop. Under the four large plots (strips) first strip receives no fertilizer, while second, third and fourth strips receives half, one and two times the standard dose (X) of N, P, and K respectively.

The standard dose (X) being: N_1=150 Kg/ha^{-1}, P_1=Phosphorus equivalent to the critical point in the P fixation studies of that field and K_1=enough to give 150 Kg/ha^{-1} of exchangeable K. Then a preparatory crop (or exhaust crop) has to be grown so that the fertilizers undergo reaction with the soil, plant and microbiological agencies. After the harvest of the preliminary crop, each of the strips is subdivided into 27 subplots, of which 6 are control plots and 21 receives various combinations of the levels of Nitrogen, Phosphorus, and Potassium, in a fractional factorial design.

During the experimentation, package of practices recommended for the test crop is followed for the experimental crop. The soil samples from all these plots are collected and analyzed for various soil characters. The yield and plant nutrient uptake are recorded on the harvest of crop.

1.5 Analytical approaches used by STCR

It is known that the yield of a crop is a function of several factors, which may be expressed as

$$\text{Yield} = f\,(\text{crop, soil, climate, management})$$

The authenticity and soundness of fertilizer recommendations will depend upon the thoroughness and quality of the background research. There are several approaches, which are followed worldwide over to derive the basis of judicious soil and fertilizer nutrient management. Some of them are: Soil analysis and correlation, soil fertility and survey, critical soil test levels, Mitscherlich's method (1909) and its modification by Mombiella et al.(1981), Bray's method (1948),foliar diagnosis, Colwell's method using simultaneous regression and orthogonal polynomials (1978), Ramamurthy's(1967) inductive approach (targeted yield) and integrated soil test crop response approach. Some other methods include, Linear response plateau models(LRP), Quadratic response plateau models(QRP) and QUEFTS(Quantitative Evaluation of Fertility of Tropical Soils).

Under the STCR project two approaches are used: multiple regression approach and Targeted yield approach(discussed in section 2,4)

Multiple regression is being used to calculate the dose of nutrient (s) required to obtain the maximum yield of crops under given set of experimental conditions. It can further be used to calculate the economic dose of fertilizer nutrients by incorporating a constant factor i.e. per unit cost of input (fertilizer) in the original equation. In this approach yield is regressed with soil nutrients, fertilizer nutrients, their quadratic terms and the interaction term of soil and fertilizer nutrients.

Conditions for application of the technique of multiple regression:
As per the manual on statistical computation (STCR publication, 1985), the following conditions are required to be fulfilled for deriving the optimum values of the nutrients.

(a) Soil test crop response calibration for economic yield of a crop is possible only when the response to added nutrients follow the law of diminishing returns. i.e. the signs of partial regression coefficients of linear, quadratic terms of nutrients and their interaction with available soil nutrients should in general be positive, negative and negative (+,-,-) respectively.

(b) The coefficient of determination (R^2) should be high.

(c) The partial regression coefficients should be statistically significant.

(d) The experiment should have sufficient design points i.e. the number of treatments should be at least two or more than the number of variables in the model.

1.6 Collaboration of AICRP- STCR with IASRI

The criterion mentioned in the previous section is seldom fulfilled under the STCR project data. In such cases the optimum values of the nutrients cannot be derived or even if they could be derived, are either too high or too low.

Keeping in view of the above problems and for better analysis of data, their interpretation and improvement in soil test calibration, the project coordinator AICRP on STCR, Indian Institute of Soil Science, Bhopal, formally approached IASRI, New Delhi for collaboration. As large amount of data have also been gathered under the project, the creation of a database under the project was also solicited. Consequently a project entitled "Planning, designing and analysis of experiments relating to AICRP on soil test crop response correlation" was under taken at IASRI with effect from 1st march 2000 with the following objectives:

1. To improve the existing methodology for analysis of data of ongoing STCR experiments.
2 To carry out planning and designing for the conduct of new set of experiments and subsequently to carry out the analysis of data.
3. To develop database for STCR experiments.

While analyzing the data of past STCR experiments at IASRI, it has been observed that the specific conditions, mentioned earlier, are seldom fulfilled. This is basically the problem of Regression and Response Surface Methodology and has to be tackled in the light of the same. Moreover in the model adopted by the STCR project, terms like Interaction (Fertilizer N x Fertilizer P) or SN^2, SP^2, SK^2 etc. have not been included. A proper response surface could only be fitted by carefully choosing the variables in the model and the set of meaningful treatment with sufficient design points. Besides this, certain other areas, which have to be looked into, are:

1. Whether the fertility gradient has been created in each experiment? Which is the basic necessity of the STCR project. This can be seen by assuming the four strips (0X, 1/2X, X

and 2X) as four replications and then performing the analysis of variance. If the replication (Strip) effect is not significant, then it can be said that there is no difference between the fertility gradients and therefore fertility gradient has not been created. In such cases the whole experimental field shall behave as a homogeneous field and the very purpose of creating artificial fertilizer gradients stands vitiated.

Another way is to include the replication as an independent variable in the model to see whether there is any significant difference between the strips.

2. It has been observed that there is considerable variation among the magnitude, sign and significance of the partial regression coefficients for a particular crop or a variety of a crop at the same site over the years. This means that the recommendation of fertilizer nutrients to the farmer will vary from year to year for the same crop. Efforts are to be made to understand the problem and for its possible solution, in the light of response surface methodology.

3 The treatment structure has to be reviewed. It is generally observed that at different centers the experiments are being conducted with different set of treatments without verifying the statistical prerequisites, which in turn makes the analysis difficult and the results unachievable. In order to streamline the treatment structures, it is necessary to consult a statistician before conducting any experiment. Haphazard way of choosing treatments makes the analysis difficult and does not serve the purpose. Attempts will be made to develop a suitable fractional factorial design, which can meet the objectives of the experiment. Of course this will require the combined effort of soil scientists and statisticians.

4. At present, when the optimal fertilizer doses are not derivable using the existing multiple regression model of the STCR project, then a fertilizer adjustment equation, as said earlier, for each nutrient is developed, which is based on the basic data of Nutrient requirement kg/q, Percent contribution of fertilizer from available soil nutrients and contribution from added fertilizer nutrients and then the optimum values are calculated for each nutrient. Since this method does not seem to have a sound statistical background, attempts will be made to arrive at a statistical solution based on response surface methodology.

Attempts will also be made to see whether it is possible to pool the fertilizer adjustment equations over the years. This aspect will be possible once the statistical solution to the Fertilizer Adjustment Equation is arrived at.

For the benefit of research workers and the scientists of the STCR project, a database in MS-ACCESS would be developed at IASRI. The experimental data received from different co-operating centers, would be fed into the database. This will put all the experiments conducted under the STCR project at a central place. Later we propose to place this at a central on-line sever so that all the scientists working in the project at different cooperating centres can access it through the WEB. This needs some time, proper infrastructure and mainly the cooperation of AICRP on STCR. This aspect would be taken up in a subsequent study.

Table 1.1 Experimental Sites, Agro -Eco region and Soil types of different cooperating centres of the STCR project

S.No.	Cooperating Centre	Date of Start	Experimental Site	No.	Agro- Eco Region	No.	Agro- Eco Subregion	Soil Type
1.	UAS, Bangalore	1.10.1970	Bangalore	8	Hot semi- arid	8.2	Hot Moist semi-arid	Medium to deep red loam
2.	OUAT, Bhubaneswar	1.9.1996	Bhubaneswar	12	Hot sub humid	12.2	Hot Moist sub humid	Medium to deep loamy red & red lateritic soil
3.	RAU, Bikaner	1.9.1996	Bikaner	2	Hot arid	2.1	Hot hyperarid	Shallow & deep sandy desert soils
4.	TNAU, Coimbatore	1.4.1967	Coimbatore	8	Hot semi-arid	8.1	Hot dry semi-arid	Medium deep to deep, loamy to clayey mixed red & black
5.	HAU, Hisar	1.4.1967	Hisar	2	Hot arid	2.3	Hot typic arid	Deep loamy desert soils
6.	APAU, Hyderabad	1.4.1967	Hyderabad	7	Hot semi-arid	7.2	Hot Moist semi-arid	Deep loamy and clayey mixed red &black
7.	JNKVV, Jabalpur	1.4.1967	Jabalpur	10	Hot sub humid	10.1	Hot dry sub humid	Medium black
8.	BCKV, Kalyani	21.11.1997	Kalyani	15	Hot semi-arid	15.1	Hot Moist sub humid	Deep loamy to clayey alluvial derived
9.	PAU, Ludhiana	1.4.1967	Ludhiana	4	Hot semi-arid	4.1	Hot Moist semi-arid	Deep loamy alluvial
10.	IARI, New Delhi	1.5.1967	New Delhi	4	Hot semi-arid	4.1	Hot semi-arid	Deep loamy alluvial derived

Table 1.1 (contd.) Experimental Sites, Agro -Eco region and Soil types of different Cooperating centres of the project

S.No.	Cooperating Centre	Date of Start	Experimental Site	No.	Agro- Eco Region	No.	Agro- Eco Subregion	Soil Type
11.	HPKV, Palampur	1.7.1970	Palampur	14	Warm sub-humid to humid with inclusion of perhumid	14.3	Warm humid to perhumid transitional	Podzolic
12.	GBPUA&T, Pantnagar	1.4.1970	Pantnagar	14	Warm sub-humid to humid with inclusion of perhumid	14.5	Warm humid/per humid	Medium to deep loamy tarai
13.	RAU, Pusa	1.12.1967	Pusa	13	Hot sub humid	13.1	Hot dry to moist Sub humid	Deep loamy alluvial derived
14.	MPKVV, Rahuri	28.10.1970	Rahuri	6	Hot semi-arid	6.1	Hot dry semi-arid	Shallow & medium loamy black
15.	IGKVV, Raipur	1.4.1981	Raipur	11	Hot/Moist/dry sub humid transitional	----	------	Deep loamy to clayey red & yellow
16	KAU, Vellanikkara	1.11.1996	Vellanikkara	19	Moist humid-per humid	19.2	Hot moist sub humid to humid transitional	Deep loamy to clayey red & lateritic soils

Chapter -II

REVIEW OF LITERATURE

2.1 Early work done on Soil-Test Crop Response

The yield response to application of most nutrients follows the law of diminishing returns. Each added fertilizer increment produces a progressively smaller yield increase, finally reaching an asymptote. The economic benefit of fertilization is a function of yield response in relation to fertilizer cost. The law of diminishing returns can be approximated by a curvilinear equation i.e. Mitscherlich equation (1909)

$$\log A - \log(A-Y) = CX$$

$$\text{or, in the form } Y = A(1 - e^{-CX}) \tag{2.1}$$

where Y is yield expressed on a relative basis as obtained in proportion to a limiting factor, X., “A” is the maximum yield, and "C" is a constant describing the shape of the curve (generally between 0.1 and 1, the higher the value the sooner the curve reaches maximum). Thus as the value of X increases, Y increases but at ever diminishing amounts.

The first approach towards the establishment of a soil test calibration was attempted by Bray (1948) which is a modification of Mitscherlich equation and known as Mitscherlich-Bray model as follows:

$$(A-Y)/A = \exp(b_1 x + b_2 t) \tag{2.2}$$

In this method, the yield is converted to relative yield, which is then correlated with soil test and fertilizer rate by the equation.

Where, A is the maximum yield, Y is the relative yield, x the fertilizer rate and t the soil test value. This method suffers from the drawback that in order to have a reasonable estimate of fertilizer requirements, the maximum yield has to be some desirable proportion of the yield (e.g. 95%) and the maximum is approached only as fertilizer rate approaches infinity.

The Mitscherlich-Bray equation was modified by Mombiela et al (1981)

$$Y = A\{1 - e^{-C[X+f(T)]}\} \tag{2.3}$$

Where, Y is a predicted yield obtained by application of X units of Nutrient (fertilizer), say P, to a soil with a P soil test value T. The parameter A is defined as maximum yield and C is proportionality constant related to the efficiency of soil and fertilizer P. The function f(T) relates to an amount of plant available P in the soil. Colwell(1974) suggested a method of calculating optimal fertilizer P by the following equation:

$$P_R = (1/C)\log(CA/p(1+R)) - bT \tag{2.4}$$

Where, p =price of fertilizer/price of crop, R=marginal rate of return(or interest rate), and other terms are as previously defined under the modified Mitscherlich equation.

A number of different yield functions have been proposed and used in the past, representing the relationship between crop yield and fertilizer application. Heady, Pesek and Brown (1955), Heady (1961), Abraham and Rao (1966) etc. have studied the suitability of a number of such relationships.

Heady et al. (1955) favoured the model.

$$Y_{ij}=A_i + B_i X_{ij}^{1/2} + C_i X_{ij} + D_i X_{ij}^{3/2} + \ldots + \varepsilon \qquad (2.5)$$

where A_i , B_i , C_i etc. are the parameters to be estimated, ε is the random error distributed as $N\sim(0,\sigma^2)$.

While Abraham and Rao preferred the model,

$$Y_{ij}=A_i+B_iX_{ij}+C_i X_{ij}^2 + \ldots + \varepsilon \qquad (2.6)$$

because of their simplicity in comparison to the traditional exponential growth function.

$$Y_{ij}=\alpha_i+ \beta_i \exp (\gamma_i X_{ij}) \qquad (2.7)$$

where α_i , β_i and γ_i are site parameters. These authors showed that the polynomials (2.5) & (2.6) give on an average a better regression fit of yield data. Also the polynomials have an additional advantage that they can accommodate a maximum yield, which the exponential models cannot.

Colwell (1967) developed a method wherein he used orthogonal polynomials to fit the data of n sites of a region at each of which a Randomized fertilizer experiment has been carried out with same r treatments (rates of fertilizer applications). He described the calibration equation as below:

$$Y=P_0\xi_0+P_1\xi_1+P_2\xi_2+P_3\xi_3+\ldots+\varepsilon \qquad (2.8)$$

where Y is the yield, ξ_0 , ξ_1 , ξ_2 and so on are orthogonal polynomials of fertilizer application rates and P_0 ,P_1 , P_2 and so on. are site parameters and ε as defined earlier. The regression of the form given above were fitted to the data of each site and coefficients for each site were then used as dependent variables to solve simultaneous regression of the form

$$p_{ki} = q_{ki}+ r_{ki} + T_i^{1/2} + s_{ki} T_i +\ldots+ \varepsilon' . \; ; \; k = 0, 1, 2,\ldots,(r-1) \; ; \; i = 1, 2,\ldots, n. \qquad (2.9)$$

where, T_i is the soil test measurements of the i^{th} site and k corresponds to the order of the polynomial in (2.8). The coefficients q_{ki} , r_{ki} and s_{ki} may be regarded as the regional parameters that provide a generalization of (2.8) by a function relating yield to fertilizer rate and soil test values. With appropriate substitution from (2.9) for the coefficients of p_{ki} in (2.8) and the expansion of the orthogonal polynomials, a generalized function may be obtained in the form of polynomials of soil test T_i and fertilizer rate X_i , in the square root scale, namely,

$$Y_{ij} = (\alpha_0 + \alpha_1T_i^{1/2} + \alpha_2 T_i)+(\beta_0 +\beta_1T_i^{1/2} +\beta_2T_i)X_{ij}^{1/2} + (\gamma_0 +\gamma_1T_i^{1/2} +\gamma_2T_i) X_{ij} + +(\delta_0+\delta_1T_i^{1/2}+\delta_2T_i)X_{ij}^{3/2} + \ldots + \varepsilon \qquad (2.10)$$

Alternatively, an average regional yield function

$$Y_i=a+b X_i^{1/2}+c X_i + d X_i^{3/2} +\ldots + \varepsilon \qquad (2.11)$$

may be obtained without soil test regression, by averaging the coefficients of (2.8) over sites and again by expanding and collecting terms. In both cases the coefficients may be regarded as regional parameters of generalized yield function.

Alternative to the derivation of (2.10)or (2.11) from(2.8) and (2.9), these equations may be estimated directly by a least square fit of regression to the yield, fertilizer and soil test data. It can be shown that the coefficients obtained by this direct method are identical with those derived from equations (2.8) and (2.9) for the same data. Colwell found square root scale to be somewhat better fit to the data as compared to the corresponding quadratic expression in natural scale. Yield response, profit and fertilizer requirements can be calculated by appropriate substitution in equation (2.10) and (2.11). Mead and Pike (1975) have given an exhaustive review of various response surface models.

Colwell (1978) brought out a comprehensive report based on his studies on soil test – crop response, titled "Computation for studies of soil fertility and fertilizer requirement". The work on soil test – crop response studies had been taken up elsewhere also, to name a few, the government soil testing agencies of Netherlands and U.S.A. in the last forty years conducted thousands of field experiments with different crops and on different types of soils under various climatic conditions.

With regard to choosing a model, Colwell (1978) noted that the model can be chosen for their:

(a) Computational convenience

(b) Statistical estimation of functions from data and

(c) The calculation of optimal rates.

Keeping this in view, the polynomial models are popular because:

1. They are easily fitted to data using standard multiple regression procedure

2. They can be made flexible enough to describe most smooth trends and rigid enough to smooth out aberrations or "errors" in data by appropriate choice of scale and degree

3. They are implicit in many standard methods of statistical analysis of variance in the form of orthogonal polynomial trends and

4. They can easily accommodate interaction effects.

2.2 The Indian scenario

Consequent upon the introduction of high yielding varieties, the importance of fertilizer application for higher crop production was very well recognized by the farmers. With the fast expanding soil testing advisory service in India, the Indian Council of Agricultural Research felt the need to generate information on soil test crop response calibration and fertilizer recommendation based on soil test values. In the first phase, work on soil test crop response correlation in the country was carried out at the Indian Agricultural Research Institute, New Delhi under field and pot culture conditions using limited number of soils collected from less than 20 locations in the country using the then existing tall varieties of wheat and paddy in the early sixties.

In order to provide a refinement in the scientific basis in fertilizer use suited for the modern agricultural technology, consequent upon Green Revolution, the second phase of soil test–crop response work in the country was initiated under All India Co-ordinated Research Project on Soil Test–Crop Response Correlation by the Indian Council of Agricultural Research from 1967 onwards initially at eight centres. In 1970-71 five more centres were sanctioned. At present there are seventeen centres across the country.

2.3 Methodology as adopted by STCR project

Main objective of STCR project is to develop a relationship between soil test and crop response to fertilizer, in order to provide a calibration for fertilizer recommendation based on soil testing. Since different levels of uncontrollable variables (e.g. soil fertility) cannot be expected to occur at one place, different sites have to be selected to represent different levels of soil fertility. In this present approach all the needed variation in soil fertility level is obtained not by selecting soils at different locations but deliberately creating it in one and the same field experiment in order to ensure homogeneity in the soil population studied, management practices adopted and climatic conditions prevailing. This is achieved by selecting a large area for the experiment in which there will be some variation in soil fertility level.

The chosen field is divided into four-strips lengthwise. While the first strip receives no fertilizer, second, third and fourth strips half, one and two times the standard dose (X) of N, P and K respectively. The standard dose (X) is:N_1 = 150 Kg./ha, P_1 = Phosphorus equivalent to the critical point in the P fixation studies of that field and K_1 = enough to give 150 Kg/ha. of exchangeable K.

Then a preparatory crop (or exhaust crop) has to be grown so that the fertilizers undergo reactions with the soil, plant and microbiological agencies. After the harvest of the preliminary crop, the field is ready for laying out the experiment with test crop for soil test- crop response correlation studies. Next the main experiment is conducted by selecting 21 treatments(a sub-set of treatment combinations from a 5 x 4 x 3 factorial experiment design). For this each one of the strips is subdivided into subplots of which 6 are control plots and 21 receives various combinations of the levels of Nitrogen(N), Phosphorus(P) and Potassium(K), in a fractional factorial design. The soil samples from all these plots under the experiment are to be collected from different soil layers. The package of cultural practices recommended for the test crop is followed for the experimental crop. The yield and uptake of the nutrients on harvest are recorded. After the harvest of the crop, soil values are measured. The resulting data is then subjected to multiple regression, taking the yield as dependent variable and the linear and quadratic terms of N, P and K and the interaction of N, P and K with the available soil Nitrogen, Phosphorus and Potash respectively, as independent variables.

The general soil test- crop response model for yield can be given in terms of soil and fertilizer variables as:

$$Y = a + b_1\,SN + b_2\,SP + b_3\,SK + b_4\,FN + b_5\,FN^2 + b_6\,FP + b_7\,FP^2 + b_8\,FK + b_9\,FK^2 + \\ + b_{10}\,(FN \times SN) + b_{11}\,(FP \times SP) + b_{12}\,(FK \times SK) + \varepsilon \qquad (2.12)$$

where, SN, SP and SK are soil available nutrients and FN, FP and FK are added fertilizer nutrients and ε is the error term which is assumed to be independently and identically distributed normally with zero mean and constant variance σ^2.

For soil test calibration, the multiple regression equation that has a high predictability ($R^2 > 0.67$) is used for making both yield prediction and optimization of chemical fertilizer requirements (Annual report, AICRP on STCR, 1993-98,pp-9). This equation is differentiated with respect to the nutrient, which behaved with the law of diminishing returns. The derivative will give the desired optimum fertilizer dose for varying soil test values of a nutrient for maximum yield. Inclusion of economic parameters will enable calculation of soil test based fertilizer dose for maximum profit and any desired rate of return on the investment made on fertilizers. The method of multiple regression for obtaining the optimal values of the nutrients is not always successful as the coefficients of linear, quadratic and interaction effects should have positive, negative and negative signs respectively for each of N, P and K which is not so in general. More over the R^2 value is also not so high. So to derive the fertilizer prescriptions, the method given by Truog (1960) was adopted, which although not statistically sound but is a mathematical derivation of certain indices. The basic data of the indices were generated by calculating the Nutrient requirement, Soil use efficiency and Fertilizer use efficiencies obtained from the nutrient uptake values of N, P and K. Then these values were fed into separate formula for obtaining separate equations for N, P and K respectively. Based on soil test values of a particular a site, the corresponding doses of N, P and K are calculated from these equations. Then follow up trials is conducted with these doses. Although the results of the follow up trials show good results but the coefficients of the parameters of the equations for generating the fertilizer doses vary widely from year to year. Different centres conduct experiments by choosing the number of treatments from the set defined earlier and could take any of the treatment combinations of their choice. Over the years, numbers of experiments were conducted at various centers of the AICRP on Soil Test Crop Response Project by the application of various designs with different treatment combinations. We now discuss the Targeted yield approach in the following section.

2.4 Targeted Yield Equations or Fertilizer Adjustment Equations

Targeted yield concept

Among the various methods of fertilizer recommendation, the one based on yield targeting is unique in the sense that this method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve if recommended agronomic practices are followed in raising the crop. The essential basic data required for formulating fertilizer recommendation for targeted yield are :

(i) nutrient requirement in kg/q of produce, grain or other economic produce
(ii) the percent contribution from the soil available nutrients and
(iii) the percent contribution from the applied fertilizer nutrients(Ramamoorthy et al. 1967).

The above mentioned three parameters are calculated as follows:

(i) Nutrient Requirement of Nitrogen, Phosphorus and Potassium for grain Production (NR)

$$\text{Kg of nutrient/ q of grain} = \frac{\text{total uptake of nutrient (kg)}}{\text{grain yield (q)}}$$

Percent contribution of nutrient from soil

$$\text{Percent contribution from soil (CS)} = \frac{\text{total uptake in control plots (kg ha}^{-1}) \times 100}{\text{Soil test values of nutrient in control plots (kg ha}^{-1})}$$

Percent contribution of nutrient from fertilizer

Contribution from fertilizer (CF) = (total uptake of nutrients in treated plots) – (soil test values of fertilizer nutrients in fertilizer treated plots × CS)

$$\text{Percent contribution from Fertilizer} = \frac{\text{CF}}{\text{fertilizer dose (kg ha}^{-1})} \times 100$$

Calculation of fertilizer dose

The above basic data are transformed into workable adjustment equation as follows:

$$\text{Fertilizer dose} = \frac{\text{Nutrient requirement in kg/q of grain}}{\text{\% CF}} \times 100 \times T - \frac{\text{\% CS}}{\text{\% CF}} \times \text{Soil test value}$$

$$= \text{a constant} \times \text{yield target(q ha}^{-1}) - \text{b constant} \times \text{soil test value(kg/ha}^{-1})$$

where T is the targeted yield

Targeted yield concept strikes a balance between 'fertilizing the crop' and 'fertilizing the soil'. The procedure provides a scientific basis for balanced fertilization and balance between applied nutrients and soil available nutrients. In the targeted yield approach, it is assumed that there is a linear relationship between grain yield and nutrient uptake by the crop, as for obtaining a particular yield, a definite amount of nutrients are taken up by the plants. Once this requirement is known for a given yield level, the fertilizer needs can be estimated taking into consideration the contribution from soil available nutrients.

The basic data comprising of NR (Nutrient Requirement), CF(Contribution of fertilizer) and CS(Contribution of soil) etc. have been derived for Maruteru(1994), Rabi Rice and is given in the appendix-I The subsequent fertilizer adjustment equations are also given separately for each gradient and over all the gradients.

2.5 Modified Colwell approach

Lahiri et al (1998) applied a modification to the Colwell's approach (discussed under section 2.1) in a study conducted at IASRI, New Delhi. In this approach, step wise multiple regression (backward elimination) method was applied in two stages. Let a district be divided into 'v' zones, 'b' blocks in each zone and 'm' villages in each block. Thus we have (v × b × m) sites or say 'n' sites for each district. At each site an experiment has been conducted using randomised block design, with the same set of treatments. Also, at each of these sites, s soil test measurements have been carried out. Then our problem is to relate these s soil tests to the yield data obtained by conducting the experiment at each site and testing the statistical significance of their relationship. The yield data from each of the site may be represented by a polynomial function of the fertilizer rate.

$$Y_{ij} = b_{0j} + b_{1j} X_{i1} + b_{2j} X_{i2} + b_{3j} X_{i3} + b_{4j} X_{i1}^2 + b_{5j} X_{i2}^2 + b_{6j} X_{i3}^2 + b_{7j} X_{i1} X_{i2} + b_{8j} X_{i1} X_{i3} + b_{9j} X_{i2} X_{i3} + \varepsilon_{ij} \qquad (2.13)$$

Where 'i' denotes the fertilizer treatment (i = 1,2,…,p) and 'j' denotes the site (j = 1,2,…,n), b's are regression co-efficients of linear, quadratic and interaction effects of fertilizer nutrients X_{i1} ,X_{i2} and X_{i3} respectively and ε_{ij}'s are randomly distributed with zero mean and variance σ^2. The whole set up of 'n' experiments can be written as simultaneous set of regression

$$Y = X\beta + \varepsilon \qquad (2.14)$$

where Y is a matrix of order (p x n) (row corresponds to fertilizer treatments and columns to sites), X is a (p x r) matrix of polynomial terms of the fertilizer treatments and β is a matrix of regression co-efficients which may be regarded as site parameters, representing linear and quadratic trends of yield response to fertilizers.β is estimated by the usual least square procedure.

$$\hat{\beta} = (X'X)^{-1} X'Y \qquad (2.15)$$

The site parameters of matrix $\hat{\beta}$ can as such be treated as function of the 's' site measurements (soil test values), the relationship being represented also by the simultaneous regression

$$\beta' = T'D \qquad (2.16)$$

where **T′** is the n x (s+1) matrix of the soil test variables for the n sites.

$$T = \begin{bmatrix} 1 \ldots 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1 \\ t_{11} t_{12} \ldots\ldots\ldots\ldots\ldots\ldots t_{1n} \\ t_{21} t_{22} \ldots\ldots\ldots\ldots\ldots\ldots t_{2n} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ t_{s1} t_{s2} \ldots\ldots\ldots\ldots\ldots\ldots t_{sn} \end{bmatrix} \qquad (2.17)$$

D is the matrix of regression co-efficients estimated by

$$D = (T'T)^{-1} TB' \qquad (2.18)$$

From the relationships of (2.14) and (2.16), yield may be expressed as a function of fertilizer treatments and soil tests as

$$Y = X'D'T \qquad (2.19)$$

The equation (2.19) may be expanded, rearranged and written in the form as follows:-

$$Y_j = \sum_{m=0}^{s} a_m t_m + \sum_{m=o}^{s} b_m t_m X_{j1} + \sum_{m=o}^{s} c_m t_m X_{j2} + .------+ \sum_{m=o}^{s} k_m t_m X_{j2} X_{j3} \qquad (2.20)$$

where Y_j is yield estimated for a particular site with the soil test values t_1, t_2,--- t_s and X_j 's are the fertilizer polynomial terms.

The above equation (2.20) was worked out taking the linear and quadratic terms of applied fertilizer and that of soil test values. The regression analysis was carried out by the method of stepwise multiple regression (backward elimination method). This method is only possible if the number of sites is more, so as to give greater error degrees of freedom for the analysis.

Chapter -III

ANALYTICAL TECHNIQUES DEVELOPED

3.0 Introduction

We have discussed earlier that in the AICRP on STCR, the main objective is to establish a relationship between Soil Test Values, the added fertilizer doses and the yield of the crop. This relationship is then used for obtaining balanced fertilizer doses for given soil test values. To achieve this, one has to take the help of Response Surface methodology. In order to understand the mechanism of the system, we need to do certain preliminary analysis. Therefore, in this chapter, we take an experiment, which was conducted earlier in STCR project and subject it to various analyses using established statistical tools. Also we use here various regression diagnostics to study the presence of outliers

A method, which was developed under this project, to get site-specific optimal values of fertilizer nutrients, if the soil test values of that site are known, has also been discussed.

As we know, that in order to avoid multi-location trials, which involves cost factor, four strips are laid out in STCR experiments. It is believed that by conducting a test experiment by growing an exhaust crop, the fertility gradient is established in the 4 strips named as OX, 0.5X, X and 2X.

3.1 An example

We take an example by analyzing the data of experiment, conducted at Maruteru, Hyderabad centre for Rice crop in the year 1994 in Rabi season. The fertilizer doses are 0, 50, 100, 150 kg/ha of Nitrogen; 0, 40, 80 kg/ha of Phosphorus and 0, 40, 80 kg/ha of Potassium. There were in all 30 treatments in each strip consisting of 27 fertilizer treatment combination and 3 controls. In order to see the changes in soil fertility over the gradients, analysis of variance was performed separately by taking the Soil Nitrogen (SN), Soil Phosphorus (SP) and Soil Potash (SK) as dependent variable over the treatment and Gradients (Replication). The results are as follows:

Table 3.1: Analysis of variance of data for the Maruteru centre

Year: 1994 Season: Rabi Crop: Rice
Total Number of treatments: 30 in each strip (27 fertilizer combinations + 3 Controls)

Dependent Variable: SN (Soil Nitrogen)

Source	DF	Sum of Squares	Mean Squares	F Value	Pr >F
Model	30	106298.86	3543.29	7.71	<0.0001
Error	89	40879.10	459.32		
Corrected Total	119	147177.97			

R-Square	Coeff Var	Root MSE	SN MEAN
0.7222	6.40	21.43	334.82

Source	DF	Sum of Squares	Mean Squares	F Value	Pr >F
Gradient	3	1189.90	396.63	0.86	0.4632
Treatment	27	105108.97	3892.92	8.48	< 0.0001
Error	89	40879.10	459.32		
Corrected Total	119	147177.97			

Dependent Variable: SP (Soil Phosphorus)

Source	DF	Sum of Squares	Mean Squares	F Value	Pr >F
Model	30	44138.71	1471.29	17.86	<0.0001
Error	89	7333.23	82.40		
Corrected Total	119	51471.94			

R-Square	Coeff. Var	Root MSE	SP MEAN
0.8575	16.72	9.08	54.30

Source	DF	Sum of Squares	Mean Squares	F Value	Pr >F
Gradient	3	32810.89	10936.96	132.74	< 0.0001
Treatment	27	11327.81	419.55	5.09	< 0.0001
Error	89	7333.23	82.40		
Corrected Total	119	147177.97			

Dependent Variable: SK (Soil Potassium)

Source	DF	Sum of Squares	Mean Squares	F Value	Pr >F
Model	30	189337.20	6311.24	5.94	<0.0001
Error	89	94490.67	1061.69		
Corrected Total	119	283827.87			

R-Square	Coeff Var	Root MSE	SP MEAN
0.6671	9.41	32.58	346.37

Source	DF	Sum of Squares	Mean Squares	F Value	Pr >F
Gradient	3	27988.33	9329.44	8.79	< 0.0001
Treatment	27	161348.87	5975.88	5.63	< 0.0001
Error	89	94490.67	1061.69		
Corrected Total	119	147177.97			

The above analysis shows that the fertility gradient was indeed created by the experiment in respect of Soil Phosphorus (SP) and Soil Potassium (SK) but not in respect of Soil Nitrogen (SN).

Now to get the optimal doses of fertilizer, it is necessary that we form a relationship between Yield as dependent variable and Soil Nutrients of Nitrogen (SN), Phosphorus (SP) and Potassium (SK) along with added fertilizer nutrients of Nitrogen (FN), Phosphorus (FP) and Potassium (FK) as independent variables. To achieve this we need to perform Multiple Regression analysis. For this we take a second degree model with Yield as dependent variable and linear, quadratic effects of Fertilizer Nitrogen (FN), Fertilizer Phosphorus (FP) and Fertilizer Potassium (FK), linear effects of soil Nitrogen (SN), Soil Phosphorus (SP), Soil Potassium (SK) and their interactions with fertilizer nutrients(FN,FP and FK) as independent variables. At present in the project of AICRP on STCR, the second degree model used for this purpose is as follows:

Model-I (12 variable model (STCR model))

$$Y= B_0 + B_1\,FN + B_2\,FP + B_3\,FK + B_4\,FN^2 + B_5\,FP^2 + B_6\,FK^2 + B_7\,SN + B_8\,SP + B_9\,SK + +B_{10}\,FN\times SN + B_{11}\,FP\times SP + B_{12}\,FK\times SK + \varepsilon$$

where, FN, FP etc have been defined earlier and ε is the random error which is assumed to be distributed as $\sim N(0,\sigma^2)$

Another model tried earlier by AICRP on STCR is as follows:

Model-IV (18 variable model)

$$Y= B_0 + B_1\,FN + B_2\,FP + B_3\,FK + B_4\,FN^2 + B_5\,FP^2 + B_6\,FK^2 + B_7\,SN + B_8\,SP + B_9\,SK + +B_{10}\,SN^2 + B_{11}\,SP^2 + B_{12}\,SK^2 + B_{13}\,FN\times SN + B_{14}\,FP\times SP + B_{15}\,FK\times SK + B_{16}\,FN\times FP + +B_{17}\,FN\times FK + +B_{18}\,FP\times FK + \varepsilon$$

where, FN, FP etc have been defined earlier and ε is the random error which is assumed to be distributed as $\sim N(0,\sigma^2)$

The interactions like (FN × SN) are reasonable but within soil interactions like (SN × SP) and quadratic effects like SN^2, SP^2 etc. are of less significance. Of course we have to take interactions of the type (FN × FP). These give 15 parameters to be estimated which are as follows:

Model-III(b) (15 variable model)

$$Y= B_0 + B_1\,FN + B_2\,FP + B_3\,FK + B_4\,FN^2 + B_5\,FP^2 + B_6\,FK^2 + B_7\,SN + B_8\,SP + B_9\,SK + +B_{10}\,FN\times SN + B_{11}\,FP\times SP + B_{12}\,FK\times SK + B_{13}\,FN\times FP + B_{14}\,FN\times FK + B_{15}\,FP\times FK + \varepsilon$$

In these models we can also take strips (replication) as a parameter. Inclusion of replication increases the R- Square value. Moreover the significance of the effect of the strip (replication) component would show whether the fertility gradient has been created or not. Since we have 30 treatment combinations, number of degrees of freedom for error would be sufficient.

For all the models stated above, we perform the Step-down (backward elimination) multiple regression for the 15/16 variable models. We first enter all the variables and then those variables whose effects are not found significant at a desired level of significance are automatically dropped from the model. This analysis was carried out with the help of SAS package PROC REG.

Table 3.2: Multiple regression method of analysis
Centre: Maruteru, Year: 1994, Crop: Rice, Season: Rabi
Model-III (includes FN×FP, FN×FK and FP×FK interactions)

All Variables entered

R-Square = 0.9089 Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	147463475	9830898	69.19	<.0001
Error	104	14777851	142095		
Corrected Total	119	162241326			

Table 3.3 Multiple Regression (All variables entered)

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	4190.10335*	1159.30610	1856227	13.06	0.0005
fn	13.59956	8.36951	375169	2.64	0.1072
fp	1.82340	5.65208	14788	0.10	0.7476
fk	16.23264*	9.74218	394497	2.78	0.0987
fn2	-0.15418	0.02452	5617495	39.53	<.0001
fp2	0.08056	0.04959	375094	2.64	0.1072
fk2	-0.10242*	0.04939	610964	4.30	0.0406
sn	-5.58622	3.49895	362191	2.55	0.1134
sp	1.75705	3.22322	42225	0.30	0.5868
sk	-1.81762	1.56006	192887	1.36	0.2466
fnsn	0.09570*	0.03000	1446279	10.18	0.0019
fpsp	-0.06507	0.06029	165511	1.16	0.2830
fksk	-0.00257	0.03186	927.14434	0.01	0.9358
fnfp	-0.03635	0.02716	254497	1.79	0.1837
fnfk	0.00314	0.02906	1655.12781	0.01	0.9143
fpfk	0.00084992	0.03990	64.46703	0.00	0.9830

Table 3.4: Remaining Variables after backward elimination process (Model-III)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	146915470	18364434	133.01	<.0001
Error	111	15325856	138071		
Corrected Total	119	162241326			

R-Square = 0.9055

Table 3.5 : Multiple Regression (Remaining Variables) after backward elimination(Model-III)

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	2755.60889	289.16690	12538331	90.81	<.0001
fn	24.39779	4.51747	4027289	29.17	<.0001
fk	16.08044	3.91996	2323452	16.83	<.0001
fn2	-0.13557	0.01820	7658020	55.46	<.0001
fp2	0.06341	0.02793	711536	5.15	0.0251
fk2	-0.10505	0.04755	673842	4.88	0.0292
sk	-2.31739	0.94738	826131	5.98	0.0160
fnsn	0.05236	0.01200	2629468	19.04	<.0001
fnfp	-0.04118	0.02198	484565	3.51	0.0636

Table 3.6: ANOVA when replication is added as a variable in Model-III (16 variables)

All Variables Entered

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	148037298	9252331	67.09	<.0001
Error	103	14204028	137903		
Corrected Total	119	162241326			

R-Square = 0.9125

Table 3.7: Multiple Regression Model-III + replication (All variables entered)

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	4229.20123	1142.24019	1890498	13.71	0.0003
rep	-120.09994	58.87632	573824	4.16	0.0439
fn	12.53000	8.26180	317195	2.30	0.1324
fp	0.73375	5.59366	2372.89137	0.02	0.8959
fk	14.83111	9.62198	327637	2.38	0.1263
fn2	-0.14426	0.02464	4725520	34.27	<.0001
fp2	0.08409	0.04888	408157	2.96	0.0884
fk2	-0.10681	0.04871	663243	4.81	0.0306
sn	-5.43516	3.44776	342709	2.49	0.1180
sp	7.84537	4.35786	446946	3.24	0.0747
sk	-1.72956	1.53748	174512	1.27	0.2632
fnsn	0.09186	0.02961	1327078	9.62	0.0025
fpsp	-0.07059	0.05946	194368	1.41	0.2379
fksk	0.00082862	0.03143	95.84092	0.00	0.9790
fnfp	-0.03434	0.02677	226826	1.64	0.2025
fnfk	0.00570	0.02866	5460.15717	0.04	0.8427
fpfk	0.00427	0.03935	1623.82712	0.01	0.9138

Table 3.8: ANOVA of remaining variables after backward elimination process (Model-III + replication)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model Error	8 111	146970007 15271319	18371251 137579	133.53	<.0001
Corrected Total	119	162241326			

R-Square = 0.9059

Table: 3.9 Multiple Regression(remaining variables) after backward elimination process (Model –III)

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	2284.47601	125.78246	45382311	329.86	<.0001
rep	-77.25825	30.53624	880668	6.40	0.0128
fn	23.94818	4.48568	3921403	28.50	<.0001
fk	16.24373	3.91230	2371708	17.24	<.0001
fn2	-0.13080	0.01816	7137216	51.88	<.0001
fp2	0.05829	0.02780	604904	4.40	0.0383
fk2	-0.11494	0.04726	813790	5.92	0.0166
fnsn	0.04970	0.01207	2334635	16.97	<.0001
fnfp	-0.05078	0.02163	758435	5.51	0.0206

It is observed that although the backward elimination process in both the cases (15 and 16 Variables) returns almost similar variables, one can note that by including replication as a variable in the 16 variable model, R-square value is increased. Moreover it is observed that in the later case, since replication effect is significant, it shows that the fertility gradient has been established.

The optimal values of Nitrogen, Phosphorus and Potassium could be derived from these multiple regression equations by differentiating separately with respect to each nutrient and then solving the resulting equations (obtained by substituting the respective soil test values of SN, SP and SK in the equation of the site) . The process is cumbersome.

Going through all these pros and cons one would like to switch to Response Surface Methodology.

In the sequel we compare the derived optimal values of Nitrogen, Phosphorus and Potassium by the method of the Targeted yield equations (as followed by STCR project at present) and by the method of Response Surface for this experiment at Maruteru.

Targeted Yield Equation (over all the gradients(120 observations))

Parameter	N	P_2O_5	K_2O	Fertilizer Adjustment Equations	Target	Soil-test Values	Optimum Fertilizer doses
					(q/ha)	(kg/ha)	(kg/ha)
NR(kg/q) :	2.0696	1.1273	2.7009	FN=3.79*T-0.29 SN	57.23	350.0	119
CS :	0.1728	0.4100	0.1607	FP=2.68*T-2.13 SP		23.4	73
CF :	0.4777	0.4409	1.2073	FK=2.02*T-0.16 SK		336.0	72

The response surface methodology gives the following result:

Estimated Ridge of Maximum Response for Variable yield

Coded Radius	Estimated Response	Standard Error	Optimum Values for estimated response (kg/ha) FN	FP	FK
0.0	4816.166011	92.983229	75.000000	40.000000	40.000000
0.1	4959.066187	91.659901	82.306326	40.175470	40.885936
0.2	5089.543958	90.680606	89.555785	40.296774	41.909562
0.3	5207.759986	89.907002	96.728358	40.343527	43.096714
0.4	5313.925126	89.349541	103.796470	40.284766	44.477402
0.5	5408.319691	89.151290	110.722201	40.071809	46.084588
0.6	5491.321773	89.551571	117.453557	39.625232	47.950096
0.7	5563.451148	90.820730	123.918995	38.810728	50.094093
0.8	5625.443701	93.159009	130.016843	37.397431	52.500203
0.9	5678.388127	96.555567	135.590960	35.013582	55.062034
1.0	5723.945073	100.648392	140.401762	31.243843	57.511417

The two results of optimum values of fertilizer doses derived by Targeted yield equations and Response Surface methodology are given above. From above it is observed that the two methods seem to be matching though differing somewhere. Further study is needed to understand the mechanism of the difference between the two methods.

Here in brief we discuss Response Surface Methodology and then present a method, which has been developed at IASRI, New Delhi. In this the optimal values of nutrients could be derived with respect to soil test values of the site in question.

3.2 Response surface methodology

Fitting a Second Order Response Surface

Let us consider the fitting of a second order model in k variables of the form

$$Y = \beta_0 + \sum_{i=1}^{k}\beta_i x_i + \sum_{i=1}^{k}\beta_{ii} x^2_i + \sum_{i<j}\sum \beta_{ij} x_i x_j + \varepsilon \qquad \dots (3.1)$$

The number of terms in the model (3.1) is p' =(k+1)(k+2)/2, in our case we have taken k=3 i.e the three fertilizer nutrients FN, FP and FK and so the number of terms is 10 and the model becomes

$$Y= B_0 + B_1\, FN + B_2\, FP + B_3\, FK + B_4\, FN^2 + B_5\, FP^2 + B_6\, FK^2 + B_7\, FN\times FP + B_8\, FN\times FK + {} \\ +B_9\, FP\times FK + \varepsilon$$

The fitted model takes the form

$$\hat{Y} = b_0 + b_1\, FN + b_2\, FP + b_3\, FK + b_4\, FN^2 + b_5\, FP^2 + b_6\, FK^2 + b_7\, FN\times FP + b_8\, FN\times FK + {} \\ +b_9\, FP\times FK \qquad \dots (3.2)$$

After the fitted model is checked for adequacy of fit in the region defined by the coordinates of the design and is found to be adequate, the model is then used to locate the coordinates of the stationary point and to perform a canonical analysis of the response surface. If the stationary point is found to be inside the experimental region, then we describe the nature of the stationary point i.e. whether it is a maximum, a minimum, or a saddle point (minimax point, i.e. neither maximum nor minimum). If the stationary point is not inside the experimental region, then the search for maximum response is undertaken by Ridge analysis. In general, this method is used for finding the absolute maximum (minimum) of estimated response $\hat{Y}$ on concentric spheres of varying radii. For a detailed study the reader is referred to Khuri and Cornell (1987).

For the analysis by Response Surface methodology described above, the SAS package PROC RSREG has been used. Further in the above analysis, the soil variables SN, SP and SK has been taken as covariates to include them into the system.

3.3 Analytical technique developed

At present when the multiple regression equation does not provide the required optimal values of the fertilizer nutrients, the same are worked out through Fertilizer adjustment equations developed by STCR. The equations thus generated although provide good results at the follow up trials but are not statistically sound. Therefore, there is variation in the coefficients from year to year and so these cannot be pooled. In order to give a statistical backing to the whole process, a method has been worked out at IASRI to get the desired results by combining the method of fertilizer adjustment equations with that of response surface methodology.

The basic assumption in the targeted yield approach is that the plant nutrient uptake from the control plots and treated plots is same. Therefore it was felt that the doses of FN, FP and FK be worked out through Response Surface Methodology by exploring the response surface in the vicinity of stationery point. The stationery point is a point of a maximum, minimum or a saddle point (which neither maximum nor minimum). This method is applicable when the stationery point lies within the experimental region. If it is not within the experimental region, then also it is possible to find out the different combination of doses of FN, FP and FK with the help of canonical analysis of the response surface and ridge analysis.

EXAMPLE 3.3
For the illustration of the method and the corresponding results, we have chosen the same example of the data of one of the centers of the STCR project, namely, Maruteru (Rabi-Rice), 1994.
Multiple regression was fitted to the data, which is as follows (15 variables as taken earlier):

$$\begin{aligned} y = {} & 4190.1034 - 5.5862SN + 1.7570511SP - 1.817621SK + 13.599559FN^{*} \\ & + 1.8233963FP + 16.232643FK^{*} - 0.154184FN^{2\,**} + 0.0805624FP^{2\,*} \\ & - 0.102418FK^{2\,*} - 0.036346FNFP + 0.00314FNFK + 0.0008499FPFK \\ & + 0.0957009FNSN^{*} - 0.065072FPSP - 0.002574FKSK \end{aligned} \qquad R^2 = 0.9089$$

Where SN, SP, SK are soil available nutrients, FN, FP, FK are added fertilizers

By substituting the values of SN, SP, SK of a particular plot, corresponding to a particular treatment, we get a fitted response surface in FN, FP and FK with following results:

For given SN=350; SP=23.4; SK=336

	Eigen Value	Eigenvectors		
		FN	FP	FK
FN	0.0819615	-0.07672	0.0300211	0.9966006
FP	-0.10237	0.9970513	0.0006604	0.0767347
FK	-0.155631	0.0016455	0.999549	-0.029983

The co-ordinates of the stationary point:

FN	FP	FK
145.26043	30.493334	77.376379

The predicted yield at the stationary point: 5664.5034 kg/ha

As one Eigen Value is positive and two Eigen Values are negative, therefore, the stationary point is a saddle point indicating that there is neither Maxima nor Minimum. Also a situation can arise for a saddle point when two Eigen Values are positive and one is negative. If all are positive then it is called a minima and if all are negative then it is a maxima.

3.4 Exploration of the Response Surface in the vicinity of Stationery Point
The estimated response increases upon moving away from the stationary point along the W_i if corresponding λ_i is positive and decreases upon moving away from stationary point along the W_i if corresponding λ_i is negative. If the stationary point is minimax (saddle point) point, then it is desirable to explore the response surface in the vicinity of stationary point and determine the combinations of inputs for a given response. To achieve this, the W_i's corresponding to negative λ_i 's are set to zero. Now, the values of the W_i's corresponding positive λ_i 's are generated. To be clearer, in this case one of the λ_i 's denoted by λ_1 is positive. Then, a restricted canonical equation can be written as

$$Y_{des} = \hat{y}_0 + \lambda_1 W_1^2 \qquad (3.3)$$

where Y_{des} denotes the desired response. If $Y_{des} - \hat{y}_0$ is denoted by difference of the desired and predicted response, then

$$\text{Difference} = \lambda_1 W_1^2 \qquad (3.4)$$

$$\Rightarrow \quad \frac{W_1^2}{a^2} = 1$$

where a^2 = *Difference* / λ_1

This equation represents a straight line. W_1 should be so generated that it falls inside the interval (-*a, a*). Once the W_1 is generated, W_i ' s are known, we would like to express W_i in terms of x_i 's . This can be achieved by $x = MW + x_0$, where x_0 is the stationary point.

Let us assume that we get λ_1, λ_2 and λ_3 as 0.0819615, -0.10237 and -0.155631. As λ_2, λ_3 are negative, therefore, take $w_2 = w_3 = 0$. Let

M = {-0.07672 0.0300211 0.9966006,
0.9970513 0.0006604 0.0767347,
0.0016455 0.999549 -0.029983};

denotes the matrix of eigenvectors. Let the estimated response at the stationary points be 5664.5034 kg/ha. Let the desired response be Y_{des}=6000kg/ha. Therefore, let w_1, obtained from the equation is sqrt (difference/0.0819615)=AX1, say. To obtain various different sets of many values of w_1, generate a random variable, u, which follows uniform distribution and multiply this value with $2u-1$ such that w_1 lies within the interval, (-AX1, AX1). Now to get a combination of x_i's that produces the desired response, obtain $x = M*W + x_0$ with the help of the following SAS code:

```
PROC IML;
W=J(3,1,0);
Ydes=6000;
W2=0;
W3=0;
Dif=Ydes-5664.5034 ;
Ax1=Sqrt(dif/0.0819615);
u= uniform(0);
W1= ax1*(2*u-1); print w1;
w[1,] = w1;
w[2,] = 0;
w[3,] = 0;
 m = {-0.07672      0.0300211     0.9966006,
      0.9970513     0.0006604     0.0767347,
      0.0016455     0.999549      -0.029983};
xest = {145.26043, 30.493334, 77.376379};
x = m*w+xest;
print x;
run;
```

Results:

Desired Yield	FN	FP	FK
6000kg/ha	144.79605	36.528386	77.386339
	146.84785	39.8632775	77.342332
	144.75153	37.106991	77.387294
	141.9171	38.94317	77.448087
6100kg/ha	144.91531	34.978478	77.383781
	143.36787	55.089018	77.416971
	146.3448	46.400841	77.353121

This computer programme has been created for working in SAS package for checking the methodology. The technique is quite computer intensive. The development of a step-by-step procedure and the corresponding preparation of user-friendly software package are very necessary and will be taken up in a subsequent project.

3.5 Regression analysis

Various Multiple Regression models were tried including the one used by the AICRP on STCR.

Model-I (9 variable model)

$$Y = B_0 + B_1 FN + B_2 FP + B_3 FK + B_4 FN^2 + B_5 FP^2 + B_6 FK^2 + B_7 FN{\times}FP + B_8 FN{\times}FK + B_9 FP{\times}FK + \varepsilon \quad .....(3.5)$$

Model-II (12 variable model(STCR model))

$$Y = B_0 + B_1 FN + B_2 FP + B_3 FK + B_4 FN^2 + B_5 FP^2 + B_6 FK^2 + B_7 SN + B_8 SP + B_9 SK + B_{10} FN{\times}SN + B_{11} FP{\times}SP + B_{12} FK{\times}SK + \varepsilon \quad ..... (3.6)$$

Model-III(a) (15 variable model)

$$Y = B_0 + B_1 FN + B_2 FP + B_3 FK + B_4 FN^2 + B_5 FP^2 + B_6 FK^2 + B_7 SN + B_8 SP + B_9 SK + B_{10}SN^2 + B_{11}SP^2 + B_{12}SK^2 + B_{13}FN{\times}SN + B_{14}FP{\times}SP + B_{15}FK{\times}SK + \varepsilon \quad ..... (3.7a)$$

Model-III(b) (15 variable model)

$$Y = B_0 + B_1 FN + B_2 FP + B_3 FK + B_4 FN^2 + B_5 FP^2 + B_6 FK^2 + B_7 SN + B_8 SP + B_9 SK + B_{10} FN{\times}SN + B_{11} FP{\times}SP + B_{12} FK{\times}SK + B_{13} FN{\times}FP + B_{14} FN{\times}FK + B_{15} FP{\times}FK + \varepsilon \quad ..... (3.7b)$$

Model-IV (18 variable model)

$$Y = B_0 + B_1 FN + B_2 FP + B_3 FK + B_4 FN^2 + B_5 FP^2 + B_6 FK^2 + B_7 SN + B_8 SP + B_9 SK + B_{10} SN^2 + B_{11} SP^2 + B_{12} SK^2 + B_{13} FN{\times}SN + B_{14} FP{\times}SP + B_{15} FK{\times}SK + B_{16} FN{\times}FP + B_{17} FN{\times}FK + B_{18} FP{\times}FK + \varepsilon \quad ..... (3.8)$$

Where, FN, FP, FK are added fertilizer nutrients of Nitrogen, Phosphorus and Potassium respectively. SN, SP, SK are soil available nutrients of Nitrogen, Phosphorus and Potassium respectively, collected before the conduct of the main experiment and ε is the random error term which is distributed normally as $N\sim(0,\sigma^2)$.

Besides these models, another set of 10, 13, 16 and 19 models were tested by adding replication as one of the parameters to each of the above models.

The data of each experiment was subjected to multiple regression using backward elimination procedure with the help of PROC REG of the SAS package. The SAS code used is given in the appendix.

3.6 Regression diagnostics

Regression Diagnostics refers to the various methods that can be used effectively to flag observations that are dominating the regression. This also helps in detecting problems with either the model or data set. At present this is a very active field of research. Here we discuss few of them. For further study one can refer to Belsley, Kuh and Welsch(1980) and Cook and Weisberg(1982) which gives a fairly thorough coverage of the theory and methods of diagnostic techniques.

Regression model is fitted using least square technique for estimating parameters. The optimality properties of these estimates are described in an ideal setting, which is not often realized in practice. It has been observed that regressions based on different subsets of data produce very different results, raising questions of model stability. Frequently we do not have 'good' data in the sense that errors are non-normal or the variance is non-homogeneous. The data may contain outliers or extremes, which are not easily detectable but highly influential, as the least square estimation procedure tends to pull the estimated regression response towards outlying observations. The variable pool may not contain the right variables in the proper functional forms and we may have included variables with a high degree of multi-collinearity. Presence of multi-collinearity in data causes serious problems in estimation, prediction and interpretation. Moreover the estimated regression may be unrealistic in magnitude and sign. In the sequel we discuss here some of the techniques of regression diagnostics.

3.6.1 Residual analysis

Analysis of regression residuals, or some transformation of the residuals, is very useful for detecting inadequacies in the model or problems in the data. The true error in the regression model are assumed to be normally and independently distributed random variables with zero mean and common variance $\in \sim N(\mathbf{0}, \boldsymbol{I}\sigma^2)$. The observed residuals, however are not independent and do not have common variance, even when the $\boldsymbol{I}\sigma^2$ assumption is valid. Under the usual least squares assumptions,

$e = Y - \hat{Y} = Y - X\hat{\beta} = Y - (X(X'X)^{-1}X')Y = Y - PY = (I - P)Y$ has a multivariate normal distribution with E(e) = 0 and Var(e) = (I-P) σ^2 . Where $P = (X(X'X)^{-1}X')$ is an n x n matrix determined entirely by the X's. This matrix plays a particularly important role in regression analysis. It is a symmetric matrix ($P' = P$) and also idempotent (PP= P) and is therefore a projection matrix**.** The diagonal elements of Var(e) are not equal, so the observed residuals do not have common variance; the off-diagonal elements are not zero, so they are not independent.

The heterogeneous variances in the observed residuals are easily corrected by standardizing each residual. The variances of the residuals are estimated by diagonal elements of (I-P)s^2**.** Dividing each residual by its standard deviation gives a standardized residual, denoted with r_i ,

$$r_i = \frac{e_i}{s\sqrt{(1-v_{ii})}} , \qquad (3.9)$$

Where v_{ii} is the i^{th} diagonal element of P. All the standardized residuals (with σ in place of S in the denominator) have unit variance.

Another form suggested by Belsley, Kuh and Welsch (1980) is to standardize each residual with an estimate of its standard deviation that is independent of the residual. The variance labeled $s^2_{(i)}$, where the subscript in parentheses indicates that the i^{th} observation has been omitted for the estimate of σ^2 . This is **Studentized residual**, denoted by $\mathbf{r_i^*}$**.**

$$r_i^* = \frac{e_i}{s_{(i)}\sqrt{(1-v_{ii})}} . \qquad (3.10)$$

Each Studentized residual is distributed as Student's t with (n-p′-1) degrees of freedom when normality of ∈ holds. These Studentized residuals are easily obtained by using the option RSTUDENT in PROG REG for regression provided by SAS Institute.

Although these residuals have been used extensively to study the validity of the regression models, the heterogeneous variances of the observed residuals and the lack of independence among all types of residuals complicate interpretation of their behavior. For example an outlier may go undetected by inflating the residuals of all other observations and may itself have a relatively small residual.

In spite of the problems associated with their use, the observed, standardized Studentized residuals have proven useful for detecting model inadequacies and outliers. For most of the cases the three types behave similarly and lead to similar conclusions. The primary advantage of Studentized residuals over the standardized residuals is their closer connection to the t-distribution. This allows the use of Student's t as a convenient criterion for judging whether the residuals are inordinately large.

3.6.2 Plot of e versus $\hat{\mathbf{Y}}$

The plot of residuals against the fitted values of the dependent variable is particularly useful. A random scattering of points above and below the line **e = 0** with nearly all the data points being within the band defined by $e = \pm 2s$

3.7 Influence Statistics

The reference values for the influence statistics are as follows:

- $\mathbf{v_{ii}}$, elements of ***P*** (called HAT DIAG in PROC REG): Average value is p'/n. A point is potentially influential if $v_{ii} \geq 2p' / n$. Where p' is the number of variables in the model and n is the number of observations.
- Cook's *D* : Cutoff value for Cook's *D* is 4 / n if the relationship to DFFITS is used.
- DFFITS: Absolute values greater than $2\sqrt{p'/n}$ indicate influence on $\hat{\mathbf{Y}}$.
- $DFBETAS_j$: Absolute values greater than $2/\sqrt{n}$ indicate influence on $\hat{\beta}_j$.
- COVRATIO : Values outside the interval $1 \pm 3p' / n$ indicate a major effect on the generalized variance.

The data of Maruteru, as detailed earlier, was subjected to the above regression diagnostics and the results have been discussed in Chapter VI.

3.8 Extent of data

When the project was started, data in hand was only a few experiments of Hyderabad centre. After the commencement of the project, a tentative schedule(proforma) for recording the ancillary information of the conducted experiment along with yield data and other particulars of interest, was prepared and sent to the respective in-charge of various centres including the Project Co-ordinator. Initially data from eight centres viz. Kalyani (W.B.), Vellanikkara (Kerala). Jabalpur (M.P.), Barrackpore (W.B.), Palampur (H.P.), Ludhiana (Punjab), Raipur (Chhattisgarh) and Coimbatore (T.N.) has been received. The data received pertain to years from 1996 to 1998 only. We required data for at least past five years. After the annual workshop of the AICRP on STCR held at at BCKVV, Kalyani, from 30th January 2002 to 2nd February, 2002, further data could be gathered from the annual reports of some of the centres. At other centres the data in the annual report were of use for calculating the basic data for fertilizer adjustment equations and not sufficient for performing regression analysis or response surface methodology. However the data gradually trickled in due to the intervention of the Project Coordinator of AICRP on STCR till late December 2002. The position of data is given in the appendix.
In this project we have chosen experiments from some of the centres, where the analysis could be carried out for Multiple regression, Response surface and for developing the Targeted yield equations. At other centres the sets of data were not complete and there was very short time left for the clarification and correction of the discrepancies. The details of the chosen experiments are as follows:

S.No.	Centre	Crop/variety	Year	Season
1.	Bhubaneswar(Orissa)	Rice(Konark)	1998	kharif
2.	Bhubaneswar(Orissa)	Rice(Lalat)	1999	kharif
3.	Bhubaneswar(Orissa)	Rice(Konark)	2000	kharif
4.	Hisar(Haryana)	Wheat (542)	1993	Rabi
5.	Hisar(Haryana)	Wheat (896)	1995	Rabi
6.	Hisar(Haryana)	Wheat(cvsonak)	1997	Rabi
7.	Kalyani(West Bengal)	Wheat	1999	Rabi
8.	Kalyani(West Bengal)	BoroRice	2000	Kharif
9.	Kalyani(West Bengal)	Rape	1998	Rabi
10.	Hyderabad(Andhra Pradesh)	Sunflower	1993	Rabi
11.	Hyderabad(Andhra Pradesh)	Rice	1994	Rabi
12.	Hyderabad(Andhra Pradesh)	groundnut	1997	Rabi

Besides these experiments, we have taken up some experiments for studies specific to the experiments. They are:

S.No.	Centre	Crop/variety	Year	Season
1.	Maruteru(Andhra Pradesh)	Rice	!993	Rabi
2.	Maruteru(Andhra Pradesh)	Rice	1994	Rabi
3.	Ludhiana(Punjab)	Wheat	1997	Rabi
4.	Coimbatore(Tamil Nadu)	Onion	1998	Rabi

Chapter -IV

DESIGNING OF STCR EXPERIMENTS

4.1 Introduction

The experiments under AICRP on Soil Test Crop Response Correlation (STCR) are to be conducted on a soil with a wide range of soil fertility in terms of available nitrogen (N), phosphorus (P) and potassium (K). For getting the wide ranges of soil fertility, normally the fertility gradients are created in the previous season. For the fertility gradient experiment, the area is divided into four equal strips. On each strip the four different fertilizer treatments viz. 0 X, 0.5X, X and 2X are applied. Here X is the recommended dose of N, P and K. It is followed by sowing of an exhaust crop, preferably a crop that is not going to be taken as a test crop in the next season. The demarcation of the strips are maintained after the harvest of the exhaust crop so as to facilitate the laying out of the soil test crop response correlation experiment in the next season.

To meet the objectives, the selection of the levels of the chemical fertilizers and the fraction of the total factorial treatment combinations is to be made in an objective fashion. The different treatment structures as explained by Ramamoorthy et. al (1967) in various co-operating centres are given in Table 5.1. Throughout this chapter we shall denote the levels of a factor at s_i levels with 0, 1,…, s_I-1. Zero '0' generally denotes the no application of that particular factor.

Table 4.1: Treatment structures experimented in the STCR

S.No.	Nutrient Levels			No. of treatments	Treatment Combinations
	N	P	K		
1	5	4	3	22	000, 201, 220, 221, 222, 332, 000, 300, 322, 331, 422, 431, 100, 210, 211, 330, 421, 110, 111, 200, 311, 432
2	5	3	4	31	000, 423, 322, 101, 311, 201, 221, 303, 211, 323, 112, 210, 203, 300, 110, 223, 302, 301, 000, 422, 313, 220, 212, 111, 200, 421, 411, 410, 100, 213, 222
3	4	4	2	16	000, 030, 011, 021, 101, 131, 110, 120, 201, 231, 210, 220, 300, 330, 311, 321
4	5	4	3	22	000, 011, 100, 110, 111, 200, 201, 210, 211, 220, 221, 222, 300, 330, 311, 331, 322, 332, 421, 422, 431, 432
5	4	3	2	24	000, 001, 010, 011, 020, 021, 100, 101, 110, 111, 120, 121, 200, 201, 210, 211, 220, 221, 300, 301, 310, 311, 320, 321
6	5	4	4	14	000, 111, 211, 221, 222, 311, 322, 331, 332, 333, 422, 431, 432, 433
7	5	5	5	15	000, 001, 010, 011, 100, 101, 110, 111, 222, 223, 224, 232, 242, 322, 422
8	5	5	5	14	000, 032, 132, 232, 302, 312, 322, 330, 331, 332, 333, 334, 342, 432
9	5	5	5	14	000, 033, 133, 233, 303, 313, 323, 330, 331, 332, 333, 334, 343, 433
10	4	4	4	11	000, 022, 122, 202, 212, 222, 232, 220, 221, 223, 322

There are many more variations of the treatment structures that are being used for field experimentation for the project. It is well known that in an experiment where it is desired to build a relationship between the response and levels of the input factors, it is desired that the number of treatment combinations tried should be more than the number of parameters estimated in the model. It is generally believed that quadratic response surface is a good fit in fertilizer trials. Thus, if we want to fit a complete quadratic response surface, we need more than 28 design points as we have 6 input factors namely, soil nitrogen (SN), soil phosphorus (SP), Soil potassium (K), added nitrogen (FN), phosphorus (P) and potassium (K) respectively. In this situation, the quadratic terms of SN, SP, SK and cross product terms like FN×SP, FN×SK, FP×SN, FP×SK, FK×SN FK×SP, SN×SP, SN×SK and SP×SK may not play very important role. Therefore, we require at least 17 distinct points for fitting the response surface and some points are to be replicated to estimate the pure error. The most common treatment structure is 21 design points in case of $5 \times 4 \times 3$ factorial and 7 absolute treatment combinations i.e. per strip there are 28 design points. The design points are given at serial number 1 in Table 4.1. We have to use these design points in our further discussions; therefore, we number these points and present in Table 4.2.

Table 4.2: Design being used at present by STCR (Design points given below + 7 controls; Total 28 design points)

Design Point	N	P	K
1.	0	1	1
2.	1	0	0
3.	1	1	0
4.	1	1	1
5.	2	0	0
6.	2	1	0
7.	2	2	0
8.	2	0	1
9.	2	1	1
10.	2	2	1
11.	2	2	2
12.	3	0	0
13.	3	3	0
14.	3	1	1
15.	3	3	1
16.	3	2	2
17.	3	3	2
18.	4	2	1
19.	4	3	1
20.	4	2	2
21.	4	3	2

Some of the centers also use a 5 × 4 × 3 design in 32 plots per strip. These design points are given in Table 4.3.

Table 4.3: Design points given below (DESIGN 1 – Design points 13, 15, 17) + * points + 8 control; Total 32 points

1.	0	1	1
2.	1	0	0
3.	1	1	0
4.	1	1	1
5.	2	0	0
6.	2	1	0
7.	2	2	0
8.	2	0	1
9.	2	1	1
10.	2	2	1
11.	2	2	2
12.	3	0	0
13. *	3	0	1
14. *	3	1	0
15.	3	1	1
16. *	3	2	0
17. *	3	2	1
18.	3	2	2
19. *	4	1	1
20. *	4	1	2
21.	4	2	1
22.	4	2	2
23.	4	3	1
24.	4	3	2

A discussion with the subject matter specialists, revealed that besides fitting of a restricted quadratic response surface, the following points should be kept in mind in the choice of a treatment structure. The design or the treatment structure should enable to study the (i) response due to N, P, and K, (ii) accumulation behaviour of N, P, and K (iii) dilution behaviour of N, P, and K and should include (iv) treatment combination corresponding to balanced fertilizer dose of N, P, and K and (v) a treatment combination corresponding to highest level of N, P, and K. The designs discussed in Tables 4.2 and 4.3, do not answer some of these questions. Therefore, in the present investigation an attempt has been made to develop the designs/ treatment structure taking into account the above points. These designs are discussed in the section 2.

4.2 Proposed Designs

In this section, we shall describe, the designs obtained for (5×4×3),(4×4×4), (4×4×3) and (4×3×3) factorials. These designs were developed under the active support and guidance of Dr. V.K.Gupta, Head, Division of Design of Experiments and presented during the meeting with subject matter specialists, DDG(NRM) and Project Co-ordinator held at IASRI, New Delhi on April 16, 2002. The presentation was made by Dr. V.K.Gupta. although all the designs discussed above shall be given, but the design for 5×4×3 factorial will be discussed in detail.

Table 4.4: DESIGN PROPOSED(5×4×3):
The design points given below + 4 control; Total 28 design points

Design Points	N	P	K
1.	0	2	1
2.	1	2	1
3.	2	2	1
4.	3	2	1
5.	4	2	1
6.	3	0	1
7.	3	1	1
8.	3	3	1
9.	3	2	0
10.	3	2	2
11.	0	3	2
12.	1	3	2
13.	2	3	2
14.	3	3	2
15.	4	3	2
16.	4	0	2
17.	4	1	2
18.	4	2	2
19.	4	3	0
20.	4	3	1
21.	2	1	1
22.	4	0	0
23.	0	3	0
24.	0	0	2
In place of 22, 23, and 24 one may also try the following			
22.	4	1	1
23.	1	3	1
24.	1	1	2

In the sequel we give the comparison of the proposed design with the design given in Table 4.3.

Table 4.5: COMPARISON

STCR DESIGN				DESIGN PROPOSED			
S.No.	N	P	K	S.No.	N	P	K
1.	0	1	1	1.	0	0	2
2.	1	0	0	2.	0	2	1
3.	1	1	0	3.	0	3	0
4.	1	1	1	4.	0	3	2
5.	2	0	0	5.	1	2	1
6.	2	1	0	6.	1	3	2
7.	2	1	1	7.	2	1	1
8.	2	2	1	8.	2	2	1
9.	2	2	0	9.	2	3	2

10.	2	0	1	10.	3	3	2
11.	2	2	2	11.	3	3	1
12.	3	2	2	12.	3	2	2
13.	3	0	1	13.	3	0	1
14.	3	2	1	14.	3	2	1
15.	3	1	1	15.	3	1	1
16.	3	2	0	16.	3	2	0
17.	3	1	0	17.	4	3	0
18.	3	0	0	18.	4	0	0
19.	4	1	1	19.	4	0	2
20.	4	1	2	20.	4	1	2
21.	4	2	1	21.	4	2	1
22.	4	2	2	22.	4	2	2
23.	4	3	1	23.	4	3	1
24.	4	3	2	24.	4	3	2

- **For the design in Table 4.2**
  It is not possible to get response to N and P. However, response to K can be obtained at levels 2 of N and P and levels 3 of N and P. This design does not include the balanced fertilizer dose. However, the highest levels on N, P, and K are included as a design point.

- **For the design in Table 4.3**
  It is possible to get the response to N at levels 1 of P and K (and not at optimum levels of P and K that are 2 and 1 respectively).
  Similarly, the response to K can be obtained at levels 2 of both N and P and at optimum levels 3 of N and 2 of P.
  However, it is not possible to obtain the response of P at any levels of N and K.

- **In the proposed design given in Table 4.4, however, the scenario is different**.

- **For studying response to N**

Design points 1 - 5				**Design points 11 - 15**			
Point	**N**	P	K	Point	**N**	P	K
1.	**0**	2	1	11.	**0**	3	2
2.	**1**	2	1	12.	**1**	3	2
3.	**2**	2	1	13.	**2**	3	2
4.	**3**	2	1	14.	**3**	3	2
5.	**4**	2	1	15.	**4**	3	2

- **For studying response to P**

Design points 4, 6, 7, 8				**Design points 15, 16, 17, 18**			
Point	N	**P**	K	Point	N	**P**	K
4.	3	**2**	1	15.	4	**3**	2
6.	3	**0**	1	16.	4	**0**	2
7.	3	**1**	1	17.	4	**1**	2
8.	3	**3**	1	18.	4	**2**	2

- **For studying response to K**

Design points 4, 9, 10				Design points 15, 19, 20			
Point	N	P	**K**	Point	N	P	**K**
4.	3	2	**1**	15.	4	3	**2**
9.	3	2	**0**	19.	4	3	**0**
10.	3	2	**2**	20.	4	3	**1**

- **For studying accumulation behaviour of N, P, K**

Points	**N**	**P**	**K**		**N**	**P**	**K**
22.	4	0	0		4	1	1
23.	0	3	0	**or**	1	3	1
24.	0	0	2		1	1	2

- **For studying dilution behaviour of N, P, K**

Points	**N**	**P**	**K**
11.	0	3	2
16.	4	0	2
19.	4	3	0

- **Balanced fertilizer doses/Highest Doses**

Points	**N**	**P**	**K**
4.	3	2	1
15.	4	3	2

Comparison

Characteristic	**Design (Table 4.2)**	**Design (Table 4.3)**	**Proposed Design**
Response to N at optimum levels of P and K (2 and 1)	No	No (Possible only at levels 1 0f P and K)	Yes
Response to P at optimum levels of N and K (3 and 1)	No	No	Yes
Response to K at optimum levels of N and P (3 and 2)	No (Possible at levels 2 of N and P and levels 3 of N and P)	Yes	Yes
Accumulation behaviour	No	No	Yes
Dilution behaviour	No	No	Yes
Balanced dose	No	Yes	Yes
Highest dose	Yes	Yes	Yes

Note 4.1: It can be observed that the proposed design involves some of the design points that involve application of phosphorus and potassium at zero level of nitrogen. Some agronomists may have an objection to the inclusion of such points in the design. These points are, however, necessary to study the accumulation behaviour of P and K. If required, these points may be replaced by the points where the nitrogen is at lowest level other than zero. This, however, may not provide the accumulation behaviour of a particular input. If the accumulation behaviour of P and K are not of interest (as was felt by some of the subject matter specialists in meeting held at IASRI, New Delhi on April 16, 2002), then one may think of replacing these points by some

other combinations. The points 0 2 1 (point number 1 in Table 4.4) and 0 3 2 (point number 11 in Table 4.4) are required for obtaining the response of nitrogen. One may think of experimenting with non-zero levels of N, P and K. Of course absolute control 0 0 0 may be included in the experiment to study the relationship between the soil test values in the unfertilized plots and the corresponding crop yields.

In the sequel we give the designs for (4×4×4) , (4×4×3) and (4×3×3) experiments**.** The discussion in note 4.1 is also applicable to these designs**.**

Table 4.6: DESIGN PROPOSED (4×4×4):
The design points given below + 4 control; Total 28 design points

Design Points	N	P	K
1.	0	2	2
2.	1	2	2
3.	2	2	2
4.	3	2	2
5.	2	0	2
6.	2	1	2
7.	2	3	2
8.	2	2	0
9.	2	2	1
10.	2	2	3
11.	0	3	3
12.	1	3	3
13.	2	3	3
14.	3	3	3
15.	3	0	3
16.	3	1	3
17.	3	2	3
18.	3	3	0
19.	3	3	1
20.	3	3	2
21.	2	1	1
22.	3	0	0
23.	0	3	0
24.	0	0	3
In place of 22, 23, and 24 one may also try the following			
22.	3	1	1
23.	1	3	1
24.	1	1	3

Table 4.7: DESIGN PROPOSED (4×4×3):
The design points given below + 7 control; Total 28 design points

Design Points	N	P	K
1.	0	2	1
2.	1	2	1
3.	2	2	1
4.	3	2	1
5.	2	0	1
6.	2	1	1
7.	2	3	1
8.	2	2	0
9.	2	2	2
10.	0	3	2
11.	1	3	2
12.	2	3	2
13.	3	3	2
14.	3	0	2
15.	3	1	2
16.	3	2	2
17.	3	3	0
18.	3	3	1
19.	3	0	0
20.	0	3	0
21.	0	0	2
In place of 19, 20, and 21 one may also try the following			
19.	3	1	1
20.	1	3	1
21.	1	1	2

Table 4.8: DESIGN PROPOSED (4x3x3):
The design points given below + 4 control; Total 24 design points

Design Points	N	P	K
1.	0	1	1
2.	1	1	1
3.	2	1	1
4.	3	1	1
5.	2	0	1
6.	2	2	1
7.	2	1	0
8.	2	1	2
9.	0	2	2
10.	1	2	2
11.	2	2	2
12.	3	2	2
13.	3	2	0
14.	3	2	1
15.	3	0	2
16.	3	1	2
17.	1	1	2
18.	3	0	0
19.	0	2	0
20.	0	0	2
In place of 18, 19, and 20, one may also try the following			
18.	3	0	1
19.	3	1	0
20.	1	2	1

4.3: Designing with Organic Manure (OM) and Bio-fertilizers (BF)

In addition to the objectives mentioned in section 4.1, the experiment is also aimed at evolving basis for conjoint use of organic manures and fertilizers efficiently in providing integrated nutrient supply system. The inclusion of organic manure(s) (OM) and biofertilizers (BF) in the experiment shall be discussed in the sequel. We shall illustrate the designing with OM and BF for one case, i.e., 5×4×3 experiment. For other cases, it can be done similarly.

Suppose that OM with 4 levels as OM0, OM1, OM2, OM3 required to be introduced in the design. To get the treatment structure of the 5×4×3 (N×P×K) design with four levels of OM:

- Divide 24 treatment combinations into 4 groups named as A, B, C and D and control treatment is added once to each group.
- Each group thus has 7 treatment combinations.

The groups formed are shown below:

A	B	C	D
0 2 1	**2 1 1**	**3 2 1**	**4 2 1**
0 3 2	**2 2 1**	**3 1 1**	**3 3 1**
4 0 0	**3 0 1**	**3 2 0**	**3 2 2**
0 3 0	**1 3 2**	**2 3 2**	**3 3 2**
0 0 2	**4 3 0**	**4 1 2**	**4 3 2**
1 2 1	**4 0 2**	**4 3 1**	**4 2 2**
0 0 0	**0 0 0**	**0 0 0**	**0 0 0**

The OM levels denoted as OM0, OM1, OM2, OM3 are superimposed on the 4 strips as follows:

	I	II	III	IV
OM3	A	B	C	D
OM2	B	C	D	A
OM1	C	D	A	B
OM0	D	A	B	C

The main features of the above design are:

- This arrangement is a Latin Square type arrangement.
- All treatment combinations are tried on each level of OM. All treatment combinations are tried on all the strips.
- All the four groups viz. A, B, C, D, are appearing with every level of OM and also in all the strips precisely once.
- This design may be viewed alternatively as a reinforced resolvable block design with four replications (or resolvable groups). Each group is a complete replicate.
- The 4 levels of OM are the 4 replications or the 4 resolvable groups.
- There are four blocks within each replication. The four strips on each level of OM are the 4 blocks. In all there are 16 blocks.
- There are 6 treatment combinations in each block.
- Each block is reinforced with a control treatment.
- Thus the resolvable design has the following parameters:

Number of treatments, v = 24 + 1 (control), Number of replications = 4, Number of blocks per replication = 4, Total number of blocks = 16, Number of treatment combinations per block or the block size = 7, Replication of treatment combinations = 4, Replication of the control treatment = 16.

➢ How to Analyze the Data?

The analysis of the data generated can be presented in the following ANOVA:

Source	D.F.
Replications (OM)	3
Blocks within replication [Strips within levels of OM]	12
Treatments	24
Error	72
Total	**111**

Through this analysis one can identify the best level of OM. Analysis of covariance may also be carried out using SN, SP and SK as covariates.

The ANCOVA will be as follows:

Source	D.F.
Replication (OM)	3
Blocks within replication [Strips within levels of OM]	12
Treatments	24
SN	1
SP	1
SK	1
Error	69
Total	**111**

One may be interested in comparing the performance of treatment combinations at different levels of OM. For example, one may be interested to study whether or not the effect of balanced fertilizer dose is same at OM0 and OM3 levels of OM? For making such comparisons, contrast analysis would be useful. However, to make such comparisons possible, one needs to analyze the data differently. Instead of 25 treatment combinations (24 + one control), now one has to think of 25×4 = 100 treatment combinations obtained by taking the combinations of 25 treatments and 4 levels of OM. The data is then analyzed as per procedure of completely randomized designs and taking SN, SP and SK as covariates. This procedure ignores the effect of strips that seems appropriate, as SN, SP and SK have been included as covariates.

One may be interested in studying the effect of OM on the relationship of soil test values (SN, SP and SK) and added fertilizers FN, FP and FK. To study this, one may

- Fit the second order response surface to the 28 design points at each level of OM ignoring the effect of strips.
- The effect of strips may be ignored since we are taking soil parameters into consideration.

$$\begin{aligned} y = {} & \beta_0 + \beta_1 SN + \beta_2 SP + \beta_3 SK + \beta_4 FN + \beta_5 FP + \beta_6 FK + \beta_7 FN^2 \\ & + \beta_8 FP^2 + \beta_9 FK^2 + \beta_{10} FN \times FP + \beta_{11} FN \times FK + \beta_{12} FP \times FK \\ & + \beta_{13} FN \times SN + \beta_{14} FP \times SP + \beta_{15} FK \times SK + e \end{aligned}$$

- Test the homogeneity of the four regression equations.
- If the regression equations are not homogeneous, then separate recommendations may be made for each level of organic manure otherwise we can pool the data and fit only one response surface.
- If we are interested in giving recommendations on the given level of OM, then the effect of OM can also be incorporated into the model as:

$$\begin{aligned} y = {} & \beta_0 + \beta_1 SN + \beta_2 SP + \beta_3 SK + \beta_4 FN + \beta_5 FP + \beta_6 FK + \beta_7 FN^2 \\ & + \beta_8 FP^2 + \beta_9 FK^2 + \beta_{10} FN \times FP + \beta_{11} FN \times FK + \beta_{12} FP \times FK \\ & + \beta_{13} FN \times SN + \beta_{14} FP \times SP + \beta_{15} FK \times SK + \beta_{16} OM + e \end{aligned}$$

Here OM is taken as covariate. If the organic manure levels are quantitative in nature, then we may include the interaction terms of OM with and *FK* in the model. Since all the *25* distinct design points have been tried at each level FN, FP of OM, therefore, separate response curves may also be fitted for N, P and K at each level of OM. The homogeneity of the response curves for N, P, and K may also be tested over all levels of OM.

4.4 Discussion

In the meeting held at IASRI, New Delhi on April 16, 2002, it was felt that these experiments have been continuing since long. Therefore, now we should conduct experiments with N (3 levels), P (3 levels) and K (3 levels). The levels of N, P and K are to be decided based on the results of previous experiments. Three levels of organic manure are to be incorporated while deciding the treatment structure. The three levels should not include the zero application of the particular input. Absolute control treatments, however, can be incorporated in the design. An effort to finalize the design in discussion with the Project Co-ordinator and subject matter specialists is in progress.

Table 4.8 : Treatments Structures (as reported) experimented in the STCR at various centres

Sl.No.	Centre/crop/ variety/year	Nutrient Levels				No.of treatments	Treatments
		FYM	N	P	K		
1.	Kalyani/ Rice/IET-4094/1996	0	5	4	3	27	**Same combination in all strips** 011,100,110,111,200,201,210, 211,220,221,222,300,311,322, 330,331,332,421,422,431,432, 000 (7 times)
2.	Jabalpur/Sunflower/Modern/ 1997	4	5	4	3	30	**Strip-I** 0100,0200,0201,0210,0220,0221 0222,0311,0332,0422,1000,1300 1322,1331,1422,1431,2000,2100 2210,2211,2330,2421,3000,3110 3111,3200,3311,3432,0000,0000 **Strip-II** 0110,0111,0211,0300,0330,0322 0331,0421,0431,0432,1000,1100 1200,1220,1222,1330,2000,2111 2201,2221,2311,2332,3000,3210 3322,3331,3422,3431 **Strip -III** 0100,0200,0201,0210,0220,0221 0222,0311,0332,0422,1000,1110 1111,1221,1332,1432,2000,2220 2222,2322,2331,2431,3000,3201 3211,3300,3330,3421 **Strip -IV** 0110,0111,0211,0300,0322,0330 0331,0421,0431,0432,1000,1201 1210,1211,1311,1421,2000,2110 2200,2300,2422,2432,3000,3100 3220,3221,3222,3332

3.	Hyderabad	0	4	3	3	30	**Same combinations in all strips** 100,101,102,110,111,112,120 121,122,200,201,202,210,211 212,220,221,222,300,301,302 310,311,312,320,321,322,000 000,000
4.	Coimbatore (Ragi)	3	5	3	4	24	**Strip -I** 0000,0000,0000,0000,1000,1010 1110,2000,2011,2020,2100,2110 2120,2221,3001,3031,3111,3131 3221,3231,4120,4131,4220,4231 **Strip -II** 0000,0000,0000,0000,1001,1011 1111,2001,2011,2021,2101,2111 2120,2220,3000,3030,3100,3130 3221,3230,4120,4130,4220,4231 **Strip -III** 0000,0000,0000,0000,1001,1010 1111,2000,2010,2021,2100,2110 2121,2221,3000,3031,3111,3131 3220,3230,4121,4130,4221,4230 **Strip -IV** 0000,0000,0000,0000,1000,1011 1110,2001,2010,2020,2101,2111 2121,2220,3001,3030,3110,3130 3220,3231,4121,4131,4221,4230
5.	Coimbatore (Sorghum)	3	5	4	3	24	**Strip -I** 0000,0000,0001,0002,1002,1102 1112,2002,2012,2100,2110,2200 2210,2220,3001,3111,3220,3300 3311,3320,4210,4220,4311,4321 **Strip -II** 0000,0000,0001,0002,1000,1100 1111,2000,2011,2101,2111,2200 2212,2222,3000,3110,3221,3302 3310,3320,4212,4222,4310,4320 **Strip -III** 0000,0000,0001,0002,1001,1100 1110,2000,2010,2102,2112,2201 2210,2221,3002,3110,3220,3301 3310,3322,4210,4221,4312,4320 **Strip -IV** 0000,0000,0001,0002,1000,1101 1110,2001,2010,2100,2110,2202 2211,2220,3000,3112,3222,3300 3312,3321,4211,4220,4310,4322
6.	Ludhiana (Maize)	0	5	4	3	27	011,100,110,111,200,201,210 211,220,221,222,300,311,322 330,331,332,421,422,431,432 000 (6 times as control)

7.	Ludhiana (Wheat)	0	4	3	3	40	021,121,201,211,220,221,222 231,321,331 (This set of treatments is repeated 4 times in each strip)
8.	Palampur (Wheat)	4	5	4	3	30	**Strip -I** 0000,0000,0100,0200,0201,0210 0220,02210222,0311,0332,0422, 1000,13001322,1331,1422,1431, 2000,21002210,2211,2330,2422, 3000,3110,3111,3200,3311,3423 **Strip -II** 0000,0000,0110,0111,0211,0300 0322,03300331,0421,0431,0432, 1000,11001200,1220,1222,1300, 2000,21112201,2221,2311,2332, 3000,3210,3322,3331,3422,3431 **Strip -III** 0000,0000,0100,0200,0201,0210 0220,0221,0222,0311,0332,0422 1000,1110,1111,1221,1332,1432 2000,2220,2222,2322,2331,2431 3000,3201,3211,3300,3330,3421 **Strip -IV** 0000,0000,0110,0111,0211,0300 0322,0330,0331,0421,0431,0432 1000,1200,1210,1211,1311,1421 2000,2110,2200,2300,2422,2432 3000,3100,3220,3221,3222,3332
9.	Vellanikkara **Kerala** (Banana)	0	5	4	3	27	011,100,110,111,200,201,210 211,220,221,222,300,311,322 330,331,332,421,422,431,432 000 (6 times)
10.	Hisar Wheat-912	0	5	4	3	28	422,431,300,331,332,011,311 200,432,111,110,221,222,322 220,201,210,330,211,421,100 000(7 times)

Chapter-V

RESULTS AND DISCUSSION

It is well known that fertilizer is an important input in agricultural crop production. Besides being soil hazard in the long run, it is also cost intensive. Therefore its judicious use is very essential for any country. With a view to reduce the use of fertilizer nutrients, the AICRP on Soil Test Crop Response correlation was launched.
Having discussed the various problems associated with the analysis of these experiments in earlier chapters, the remedial measures were investigated.

We now give in the sequel, the results of the experiments conducted under STCR project, centre wise.

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At this centre, an experiment on paddy with variety as 'Konark' conducted over the years 1998, 1999 and 2000 in the Kharif season has been selected. The fertilizer doses are same in all the years. They are 0, 25, 50, 75 kg/ha of Nitrogen, 0, 20, 40, 60, 80 kg/ha of Phosphorus and 0, 20, 40 kg/ha of Potassium.

The data of the experiment conducted in the year 1998 was subjected to multiple regression analysis as explained earlier. A look at the table 5.1.1 shows that over 90% of the variability is explained by the models with 9, 12, 15 and 18 variables and looking at the table 5.1.2, in the backward elimination process, it is observed that models with 9 and 12 variables shows linear trend for fertilizer Phosphorus (FP) and Potash (FK) as significant variables and linear and quadratic trend for fertilizer Nitrogen (FN). In case of 15 and 18, the resulting significant variables although explains 97% of variability but only FK shows linear effect whereas there is quadratic effect of FP and FK. Other effects found significantly contributing are soil Nitrogen (SN), Quadratic effects of soil Phosphorus (SP) and soil Potash (SK) and the interactions between FN and SN, between FP and SP and between FN and FP.

From these it is observed that the linear, quadratic and interaction effects of FN, FP and FK are all not significant and the criteria of signs are not of the form "+, -, -," and therefore the optimum values cannot be derived from these equations. Similar is the case for the years 1999 and 2000.

Therefore, the data for the three years were subjected to analysis by Response surface methodology. In this case the stationary point is a saddle point (as discussed earlier). Therefore exploration of the response surface in the vicinity of the stationary point was attempted. In this case the variables SN, SP and SK have been taken as covariates. Optimum values have been calculated by taking into consideration the mean values of SN, SP and SK. In table 5.7, optimum fertilizer doses obtained by Targeted yield approach and Response surface approach have been compared. Maximum response achievable by Response surface methodology has been taken as Targeted yield for the crops at all the centres. This has been done to check the reliability of the Optimum doses calculated by the Targeted yield approach. From this table it is observed that for the year 1998, a maximum response of 40.98 q ha^{-1} is achievable by taking FN as 70 kg ha^{-1}, FP as 58 kg ha^{-1} and FK as 23 kg ha^{-1}

respectively. The corresponding optimum values by Targeted yield approach are FN= 63, FP= 58 and FK= 35 kg ha^{-1}. These optimal values obtained by both the methods i.e. response surface and Targeted yield equation are moderately similar. The optimal values for the other two years i.e.1999 and 2000 also are also fairly similar. This gives credibility to the Targeted yield approach as has been verified by the Response surface methodology in the above case.

HYDERABAD

(1) At this centre, an experiment on Sunflower conducted in the year 1993-94 Rabi season has been selected**.** The fertilizer doses are 0, 40, 80, 120 kg/ha of Nitrogen; 0, 40, 80 kg/ha of Phosphorus and 0, 40 , 80 kg/ha of Potassium.

The experiment was subjected to multiple regression analysis as explained earlier. A look at the table 5.2.1 shows that over 76 to 80% of the variability is explained by the models with 9, 12, 15 and 18 variables and looking at the table 5.2.2, in the backward elimination process, it is observed that the model with 12 variables (STCR model) shows linear trend for fertilizer Nitrogen (FN) , quadratic trend for FN and FP and interaction (FP X SP) as significant variables . In case of 15 and 18, the resulting significant variables are similar. Other effects found significantly contributing are soil Phosphorus (SP), Soil Potash (FK) and quadratic effect of soil Phosphorus (SP) and the interactions between FN and FK. The Optimum value calculated from the model with 12 variables gives FN=111 kg/ ha and FP= 41kg/ha. The optimum value for FK is not derivable.

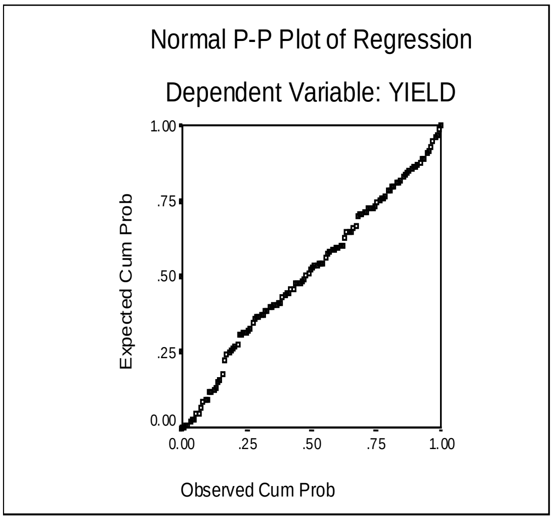
An interesting aspect is that by adding replication as a variable in the model with 15 variables, the R^2 value has increased to 83%. The replication effect is significant. Moreover the soil variables SN, SP and SK are also significant, thereby showing (table 5.2.3) the creation of fertility gradient (one of the feature of STCR project).

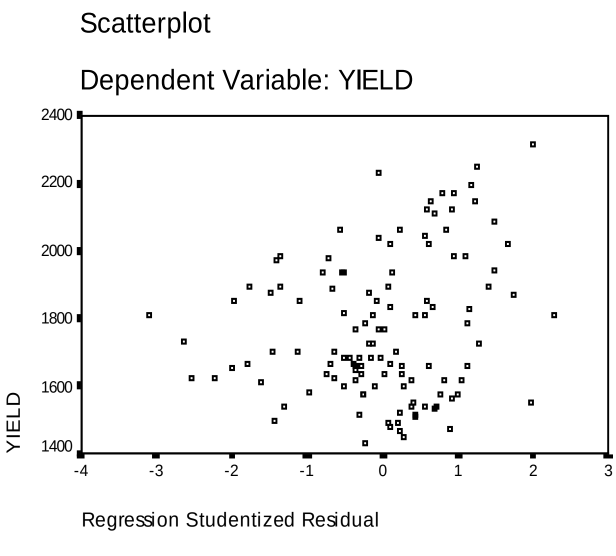
When the data was subjected to analysis by Response surface methodology it is observed that the stationary point is a saddle point (as discussed earlier). Therefore exploration of the response surface in the vicinity of the stationary point was attempted. In this case the variables SN, SP and SK have been taken as covariates. Optimum values have been calculated by taking into consideration the mean values of SN, SP and SK. In table 5.7, optimum fertilizer doses obtained by Targeted yield approach and Response surface approach have been compared. Maximum response achievable by Response surface methodology has been taken as Targeted yield for the crops at all the centres. This has been done to check the reliability of the Optimum doses calculated by the Targeted yield approach. From this table it is observed that for this experiment, a maximum response of 15.12 q ha^{-1} is achievable by taking FN as 100 kg ha^{-1}, FP as 41 kg ha^{-1} and FK as 14 kg ha^{-1} respectively. The corresponding optimum values by Targeted yield approach are FN= 106, FP= 79 and FK=57 kg ha^{-1}. These optimal values obtained by both the methods i.e. response surface and Targeted yield equation are moderately similar for FN but fairly different for FP and FK. The reason for this may be that in the reported data it is not mentioned whether the values of soil FP and FK are actual values of Phosphorus and Potash or they are in the form of P_2O_5 and K_2O.

(2) Another experiment which have been considered for this centre is an experiment on Groundnut conducted in the year 1997-98 in the Rabi season.

The fertilizer doses are 0, 15, 30, 60 kg/ha of Nitrogen; 0, 30, 60 kg/ha of Phosphorus and 0, 30 , 60 kg/ha of Potassium. There were in all 30 treatments in each strip consisting of 26 fertilizer treatment combination and 4 controls

The experiment was subjected to multiple regression analysis as explained earlier. A look at the table 5.2.6 shows that over 86 to 97% of the variability is explained by the models with 9, 12, 15 and 18 variables and looking at the table 5.2.7, in the backward elimination process, it is observed that in the model with 9 variables, the effects found significant were FN, FP, FK, FN^2 and interaction FN × FP (R^2=85%). For 12 variables (STCR model), the variables FN, FN^2 ,SP and interactions FN ×SN, FP ×SP, and FK × SK are significant(R^2 =94.88%) In case of 15 and 18, the resulting significant variables are similar (R^2 = 95%) i.e the quadratic terms of FN, FP and FK are significant, excepting the fact that with 18 variables, the interactions FN × FP, FN × FK and FP × FK are also significant. The signs of the different effects do not follow the desired '+, -, -' form and even if some of the optimal values which could be derived, the process is very cumbersome. However a test of Normal Probability plot below shows that the data are normally distributed





The scatter plot also shows fairy uniform pattern of spread although some outliers are observed which goes beyond the (+2,-2) interval. Here also it is observed (table 5.2.8) that by adding replication as a variable in the all the models, there is an increase in R^2 values. More over the value of R^2 is further increased by using the variables FN×FP, FN×FK and FP×FK in place of SN^2 SP^2 and SK^2 respectively for the model (table 5.2.11)with15 and16(with replication) variables. The replication effect is significant in all the models (models with 10, 13, 16 and 19 variables). Thereby showing the creation of fertility gradient (one of the feature of STCR project). The soil variables SN, SP and the interactions FN×SN and FP×SP are significant. Again the optimal doses are derivable but one has to solve a number of equations

When the data was subjected to analysis by Response surface methodology it is observed that the stationary point is a saddle point (as discussed earlier). Therefore exploration of the response surface in the vicinity of the stationary point was attempted. In this case the variables SN, SP and SK have been taken as covariates. Optimum values have been calculated by taking into consideration the mean values of SN, SP and SK. In table 5.7, optimum fertilizer doses obtained by Targeted yield approach and Response surface approach have been compared. Maximum response achievable by Response surface methodology has been taken as Targeted yield for the crops at all the centres. This has been done to check the reliability of the Optimum doses calculated by the Targeted yield approach. From this table it is observed that for this experiment, a maximum response of 20.48 q ha^{-1} is achievable by taking FN as 29 kg ha^{-1}, FP as 39 kg ha^{-1} and FK as 35 kg ha^{-1} respectively by Response surface methodology. The corresponding optimum values by Targeted yield approach are FN= 28, FP= 47 and FK= 83 kg ha^{-1}. These optimal values obtained by both the methods i.e. response surface and Targeted yield equation are moderately similar for FN and FP but fairly different for FK.

(3) The third experiment at this centre chosen was on Rice in the Rabi season conducted at the centre Maruteru. This experiment has been investigated for other aspects and discussed in detail in Chapter-III.

The fertilizer doses are 0, 50, 100, 150 kg/ha of Nitrogen; 0, 40, 80 kg/ha of Phosphorus and 0, 40 , 80 kg/ha of Potassium. There were in all 30 treatments in each strip consisting of 27 fertilizer treatment combination and 3 controls
Out of all models tested for regression, most of them had variables like FP, FK, FN^2, FP^2 ,FK^2 and interactions FN×SN, FP×SP etc significant(Tables 5.2.12 to 5.2.15). The variable FN was found significant only for the models with 9, 10, 12, 15, 18 and 19 variables. R^2 value for all the models was around 90%. The replication effect was found significant in all the four models i.e. with variables 10,13,16 and 19. This shows that fertility gradient has been created. Optimal values are derivable from the models with 18,10, 13,16 and 19 variables.

Regression Diagnostics

To apply regression diagnostics, first of all we observe the scatter plot between Yield and Standardized residuals along with the Normal probability plot which are shown below.

Scatter plot and Normal probability plot of Maruteru Rabi Rice 1994 Experiment conducted by STCR (Total Number of Observations=120)

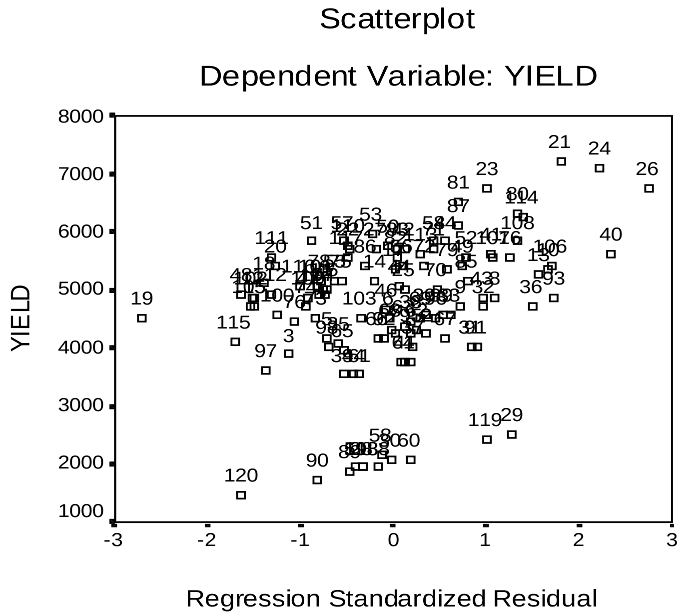


Fig: 5.1(a) Scatter plot of Yield Vs Standardized Residual
No. of Observations: 120(all)

Note: observation number 19 on the far left and observation numbers, 21,24, 26 and 40 on extreme right are outside -2 to +2 range. These are outliers.

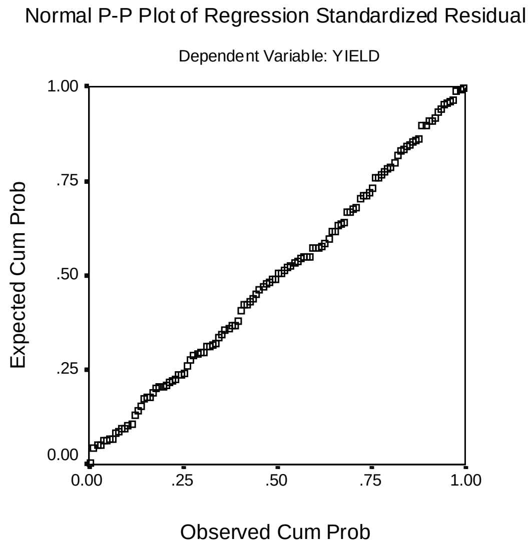
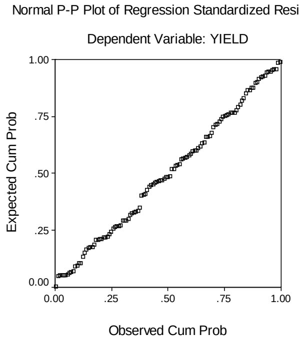


Fig: 5.1(b) The normal P-P shown above does not have much irregularity or breaks

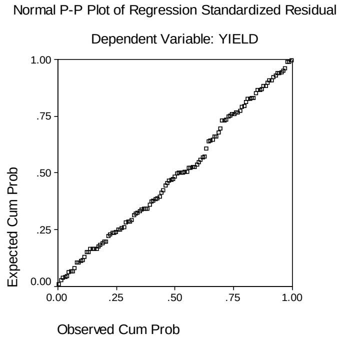
It is observed from the scatter plot of Standardized residuals(6.1a) above that the observations numbers 19, 21,24,26 and 40 are lying beyond the (+2,-2) range and hence they seem to be outliers. Therefore we delete these observations one by one and see if there is any change in the pattern.

Normal P-P Plot of Regression Standardized Residual

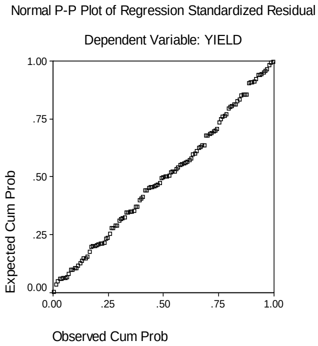
Deleted observation 19



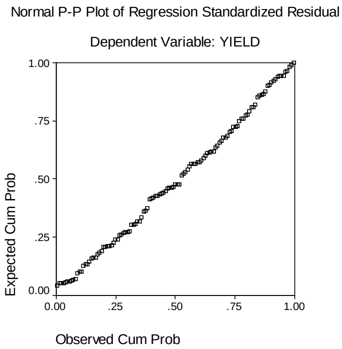
Deleted observation 21



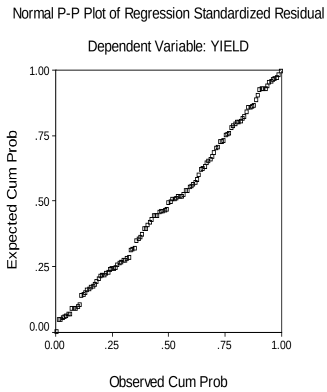
Deleted observation 24



Deleted observation 26



Deleted observation 40



Deleted observations 19,21,24,26 &40

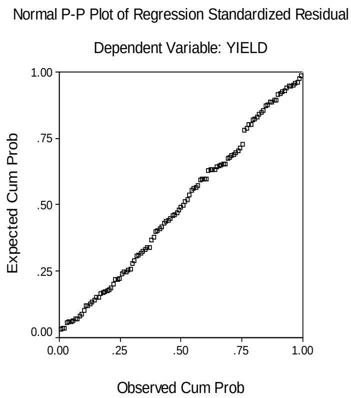
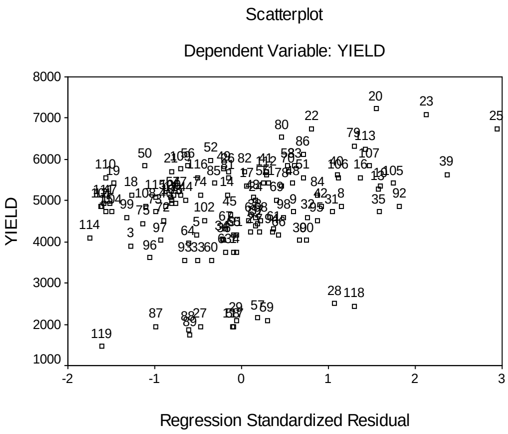


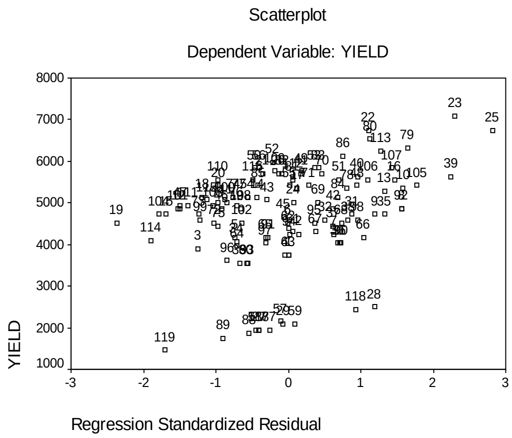
Fig: 5.2 Changes in Normal probability plots after deletion of observations

Plot of Standardized Residuals and Yield for different deleted observations

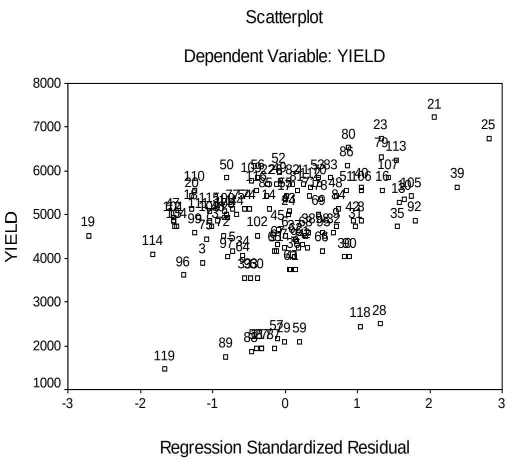
Deleted Observation number19



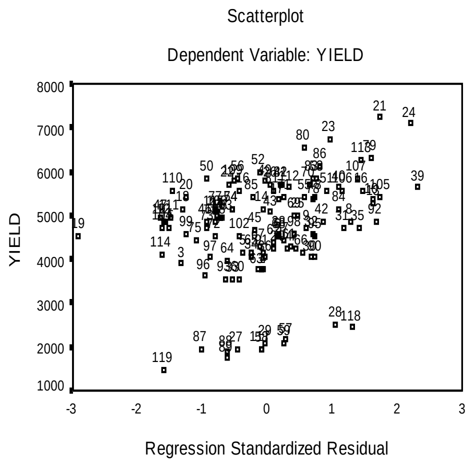
Deleted Observation number21



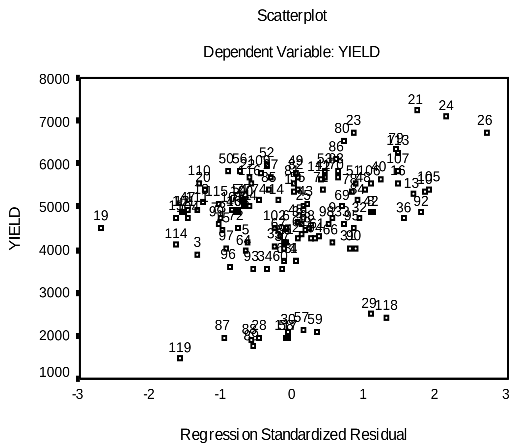
Deleted Observation number24



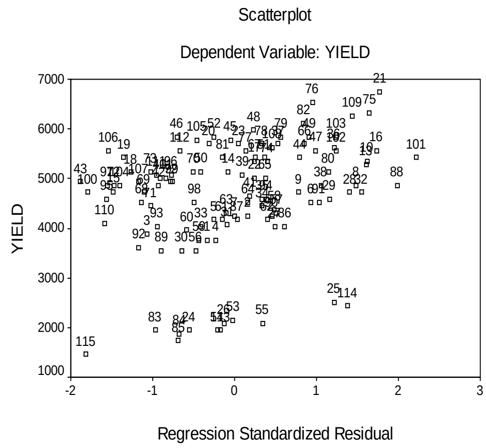
Deleted Observation number26



Deleted Observation number 40



Deleted Observation numbers19,21,24,26,40



The above plots of standardized residual shows no change in the status of outliers. Only it is observed that Observation number 19 is influenced by other observations as in each deletion it moves further out of range. Also it is observed that observation number 21 comes within the range of (+2,-2) standardized residual, when observation 19 is deleted.

It is also observed that all these outliers, except observation number 40, lies in the Strip 0X on which no fertilizer was added in the previous season and comparatively higher yield is observed in plot numbers 21(72.28 Qh^{-1}) , 24(70.89 Q h^{-1}), 26(67.42 Qh^{-1}) and 40 (56.30 Qh^{-1}) in Strip 0X. By putting average yield values from corresponding treatments in other strips did not alter the status of the plots or of analysis. Although we cannot pin point the outlier, but it seems that there is some problem in the recording of actual data, which is generally one of the problems of outlier detection.

Our next step is to apply various regression diagnostics and calculate the parameters of influence statistics like Hat Diagonal, COVRATIO, DFFITS, $DFBETAS_{j,}$ and Cook's D. Critical values of these influence statistics have been calculated and presented in the table 5(a) given overleaf. A summary of influence statistics is given in table 5(b). From the table 5(b) we see that besides the outliers mentioned above, there are a few more outliers such as 10, 88, 93,106, 108, 111 and 115 but they are not as prominent as the earlier observations 19,21,24,26 and 40. From table 5(a) which gives influential Statistics with critical values, it is observed that under DFFITS column, the observation number 19 has a negative sign always whenever an observation is deleted. From the sign on the DFFITS measures, we can conclude that by adding observation19 decreases the magnitude of $\hat{y}$. From the original output statistics for all observations (not shown here because of space) it has been observed that for observation number 19, the individual DFFITS(DFBETAS) which show negative sign are Intercept,FN,FP^2, FK^2 , SN, FN×SN, FP×SP and FK×SK and thereby their magnitude of regression coefficient are decreased. This is also evident from the table, which gives final regression equations after backward elimination. It is seen that the regression coefficients for FP^2, SN and FN×SN have decreased. Also by deletion of observation 19, the R^2 value increases from0.9055 to 0.9145.

Similarly by deleting observations 26 and 40, the R^2 value of the resulting equation increases in both the cases from 0.9055 to 0.9129 and 0.9125 respectively.

When these three observations are deleted, the R^2 value increases to 0.9240 and the number of significant regression equations, after backward elimination, increases to 9 from 8. Therefore, it is felt that the three observations 19, 26 and 40 are superfluous and should be omitted.

The process of regression diagnostics should be attempted with great caution as an observation which looks innocent may be ‘masked’ by another. For simple experiments with less observation one can go ahead with Regression diagnostics but in experiments of Soil test crop response project, which has more than 100 observations for each experiment, one must be cautious in dealing with data.

Chapter-V

RESULTS AND DISCUSSION

It is well known that fertilizer is an important input in agricultural crop production. Besides being soil hazard in the long run, it is also cost intensive. Therefore its judicious use is very essential for any country. With a view to reduce the use of fertilizer nutrients, the AICRP on Soil Test Crop Response correlation was launched.
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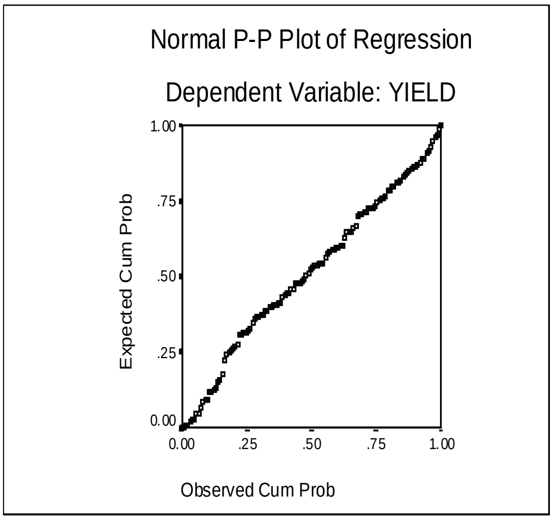
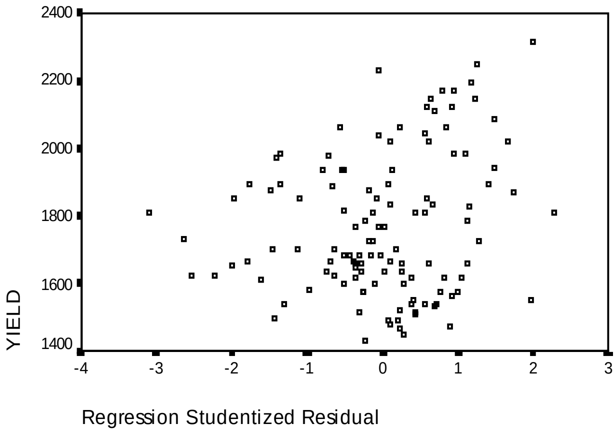
(2) Another experiment which have been considered for this centre is an experiment on Groundnut conducted in the year 1997-98 in the Rabi season.
The fertilizer doses are 0, 15, 30, 60 kg/ha of Nitrogen; 0, 30, 60 kg/ha of Phosphorus and 0, 30 , 60 kg/ha of Potassium. There were in all 30 treatments in each strip consisting of 26 fertilizer treatment combination and 4 controls
The experiment was subjected to multiple regression analysis as explained earlier. A look at the table 5.2.6 shows that over 86 to 97% of the variability is explained by the models with 9, 12, 15 and 18 variables and looking at the table 5.2.7, in the backward elimination process, it is observed that in the model with 9 variables, the effects found significant were FN, FP, FK, FN^2 and interaction FN × FP (R^2=85%). For 12 variables (STCR model), the variables FN, FN^2 ,SP and interactions FN ×SN, FP ×SP, and FK × SK are significant(R^2 =94.88%) In case of 15 and 18, the resulting significant variables are similar (R^2 = 95%) i.e the quadratic terms of FN, FP and FK are significant, excepting the fact that with 18 variables, the interactions FN × FP, FN × FK and FP × FK are also significant. The signs of the different effects do not follow the desired '+, -, -' form and even if some of the optimal values which could be derived, the process is very cumbersome. However a test of Normal Probability plot below shows that the data are normally distributed



Scatterplot

Dependent Variable: YIELD



The scatter plot also shows fairy uniform pattern of spread although some outliers are observed which goes beyond the (+2,-2) interval. Here also it is observed (table 5.2.8) that by adding replication as a variable in the all the models, there is an increase in R^2 values. More over the value of R^2 is further increased by using the variables FN×FP, FN×FK and FP×FK in place of SN^2 SP^2 and SK^2 respectively for the model (table 5.2.11)with15 and16(with replication) variables. The replication effect is significant in all the models (models with 10, 13, 16 and 19 variables). Thereby showing the creation of fertility gradient (one of the feature of STCR project). The soil variables SN, SP and the interactions FN×SN and FP×SP are significant. Again the optimal doses are derivable but one has to solve a number of equations

When the data was subjected to analysis by Response surface methodology it is observed that the stationary point is a saddle point (as discussed earlier). Therefore exploration of the response surface in the vicinity of the stationary point was attempted. In this case the variables SN, SP and SK have been taken as covariates. Optimum values have been calculated by taking into consideration the mean values of SN, SP and SK. In table 5.7, optimum fertilizer doses obtained by Targeted yield approach and Response surface approach have been compared. Maximum response achievable by Response surface methodology has been taken as Targeted yield for the crops at all the centres. This has been done to check the reliability of the Optimum doses calculated by the Targeted yield approach. From this table it is observed that for this experiment, a maximum response of 20.48 q ha^{-1} is achievable by taking FN as 29 kg ha^{-1}, FP as 39 kg ha^{-1} and FK as 35 kg ha^{-1} respectively by Response surface methodology. The corresponding optimum values by Targeted yield approach are FN= 28, FP= 47 and FK= 83 kg ha^{-1}. These optimal values obtained by both the methods i.e. response surface and Targeted yield equation are moderately similar for FN and FP but fairly different for FK.

(3) The third experiment at this centre chosen was on Rice in the Rabi season conducted at the centre Maruteru. This experiment has been investigated for other aspects and discussed in detail in Chapter-III.

The fertilizer doses are 0, 50, 100, 150 kg/ha of Nitrogen; 0, 40, 80 kg/ha of Phosphorus and 0, 40 , 80 kg/ha of Potassium. There were in all 30 treatments in each strip consisting of 27 fertilizer treatment combination and 3 controls
Out of all models tested for regression, most of them had variables like FP, FK, FN^2, FP^2 ,FK^2 and interactions FN×SN, FP×SP etc significant(Tables 5.2.12 to 5.2.15). The variable FN was found significant only for the models with 9, 10, 12, 15, 18 and 19 variables. R^2 value for all the models was around 90%. The replication effect was found significant in all the four models i.e. with variables 10,13,16 and 19. This shows that fertility gradient has been created. Optimal values are derivable from the models with 18,10, 13,16 and 19 variables.

Regression Diagnostics
To apply regression diagnostics, first of all we observe the scatter plot between Yield and Standardized residuals along with the Normal probability plot which are shown below.

Scatter plot and Normal probability plot of Maruteru Rabi Rice 1994 Experiment conducted by STCR (Total Number of Observations=120)

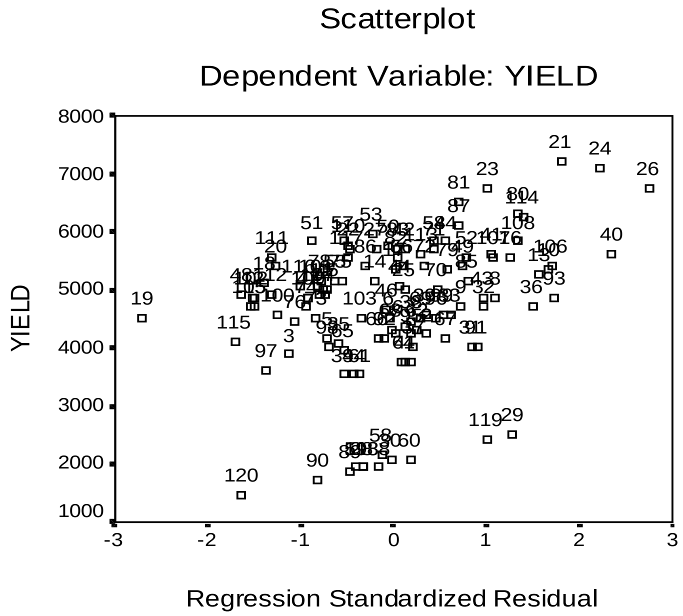


Fig: 5.1(a) Scatter plot of Yield Vs Standardized Residual
No. of Observations: 120(all)

Note: observation number 19 on the far left and observation numbers, 21,24, 26 and 40 on extreme right are outside -2 to +2 range. These are outliers.

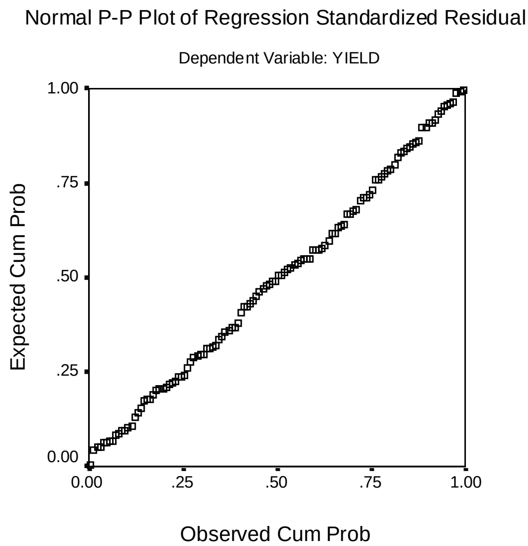
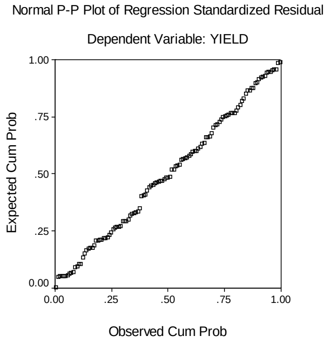


Fig: 5.1(b) The normal P-P shown above does not have much irregularity or breaks

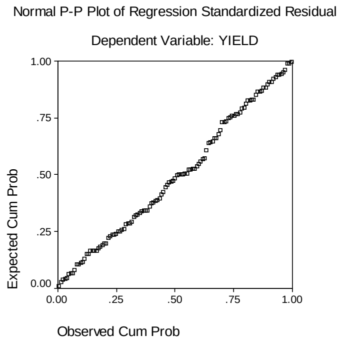
It is observed from the scatter plot of Standardized residuals(6.1a) above that the observations numbers 19, 21,24,26 and 40 are lying beyond the (+2,-2) range and hence they seem to be outliers. Therefore we delete these observations one by one and see if there is any change in the pattern.

Normal P-P Plot of Regression Standardized Residual

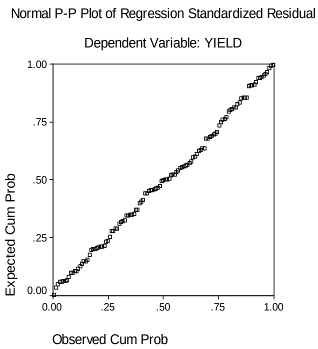
Deleted observation 19



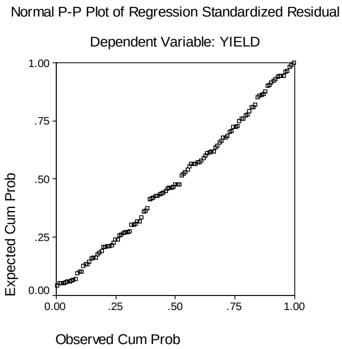
Deleted observation 21



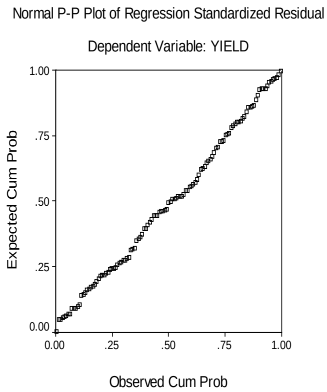
Deleted observation 24



Deleted observation 26



Deleted observation 40



Deleted observations 19,21,24,26 &40

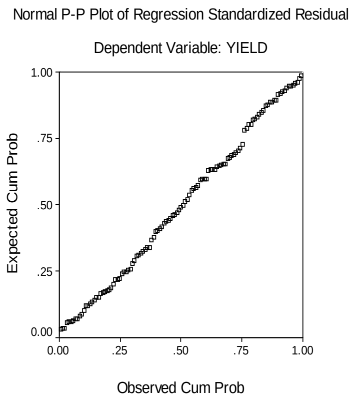
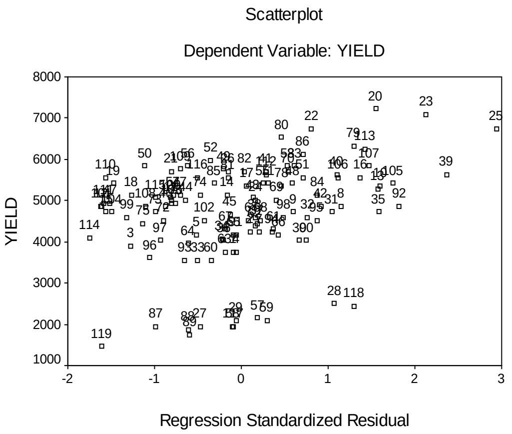


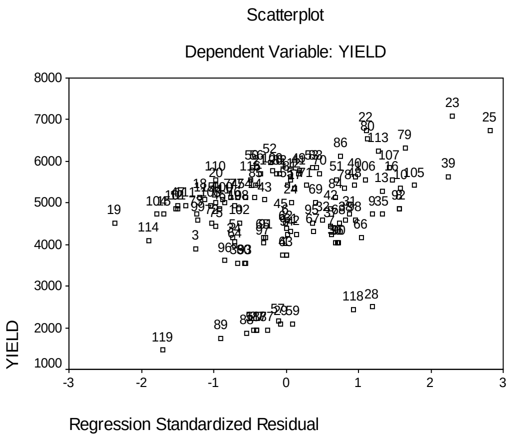
Fig: 5.2 Changes in Normal probability plots after deletion of observations

Plot of Standardized Residuals and Yield for different deleted observations

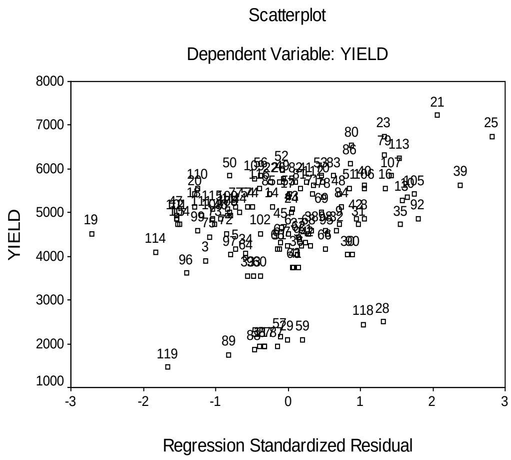
Deleted Observation number19



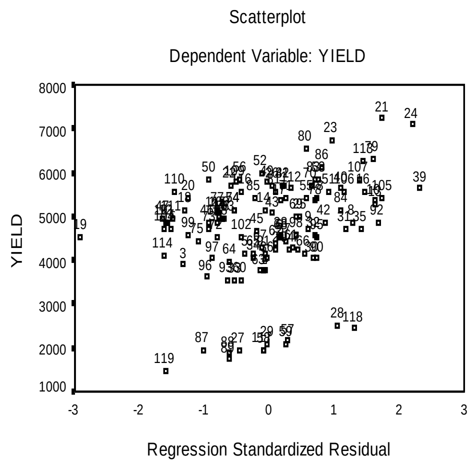
Deleted Observation number21



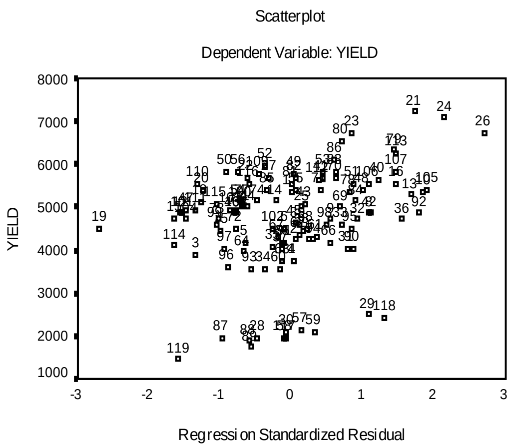
Deleted Observation number24



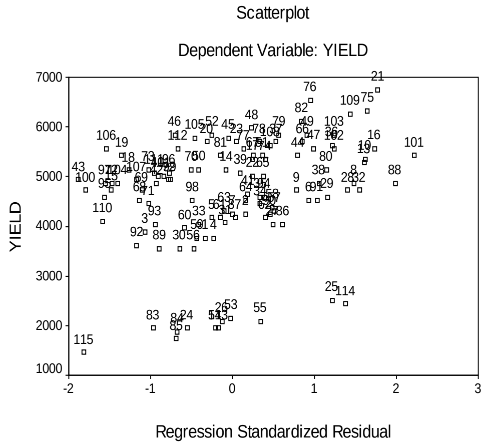
Deleted Observation number26



Deleted Observation number 40



Deleted Observation numbers19,21,24,26,40



The above plots of standardized residual shows no change in the status of outliers. Only it is observed that Observation number 19 is influenced by other observations as in each deletion it moves further out of range. Also it is observed that observation number 21 comes within the range of (+2,-2) standardized residual, when observation 19 is deleted.

It is also observed that all these outliers, except observation number 40, lies in the Strip 0X on which no fertilizer was added in the previous season and comparatively higher yield is observed in plot numbers 21(72.28 Qh^{-1}) , 24(70.89 Q h^{-1}), 26(67.42 Qh^{-1}) and 40 (56.30 Qh^{-1}) in Strip 0X. By putting average yield values from corresponding treatments in other strips did not alter the status of the plots or of analysis. Although we cannot pin point the outlier, but it seems that there is some problem in the recording of actual data, which is generally one of the problems of outlier detection.

Our next step is to apply various regression diagnostics and calculate the parameters of influence statistics like Hat Diagonal, COVRATIO, DFFITS, $DFBETAS_j$, and Cook's D. Critical values of these influence statistics have been calculated and presented in the table 5(a) given overleaf. A summary of influence statistics is given in table 5(b). From the table 5(b) we see that besides the outliers mentioned above, there are a few more outliers such as 10, 88, 93,106, 108, 111 and 115 but they are not as prominent as the earlier observations 19,21,24,26 and 40. From table 5(a) which gives influential Statistics with critical values, it is observed that under DFFITS column, the observation number 19 has a negative sign always whenever an observation is deleted. From the sign on the DFFITS measures, we can conclude that by adding observation19 decreases the magnitude of $\hat{y}$. From the original output statistics for all observations (not shown here because of space) it has been observed that for observation number 19, the individual DFFITS(DFBETAS) which show negative sign are Intercept,FN,FP^2, FK^2 , SN, FN×SN, FP×SP and FK×SK and thereby their magnitude of regression coefficient are decreased. This is also evident from the table, which gives final regression equations after backward elimination. It is seen that the regression coefficients for FP^2, SN and FN×SN have decreased. Also by deletion of observation 19, the R^2 value increases from0.9055 to 0.9145.

Similarly by deleting observations 26 and 40, the R^2 value of the resulting equation increases in both the cases from 0.9055 to 0.9129 and 0.9125 respectively.

When these three observations are deleted, the R^2 value increases to 0.9240 and the number of significant regression equations, after backward elimination, increases to 9 from 8. Therefore, it is felt that the three observations 19, 26 and 40 are superfluous and should be omitted.

The process of regression diagnostics should be attempted with great caution as an observation which looks innocent may be ‘masked’ by another. For simple experiments with less observation one can go ahead with Regression diagnostics but in experiments of Soil test crop response project, which has more than 100 observations for each experiment, one must be cautious in dealing with data.

Table: 5 (a) Influential statistics with critical values Maruteru Rabi Rice 1994

Deleted Number (Original)	Change in other Outlier Number	New outlier	Student Residual at (104 d.f.)	Hat Diag H p' / n	Cov Ratio $1 \pm 3p' / n$	DFFITS $2\sqrt{(p' / n)}$	DFBETAS $2/\sqrt{n}$ FN	FP	FK	Cook's D $4 / n$
Critical value			± 2	0.125(120)	1.375-.625	0.7071(120)	0.1826	0.1826	0.1826	0.033
19	20(21)		1.9875	0.2538	0.8529	1.1591	-0.2634	-0.1905	0.3051	0.082
	23(24)		2.2921	0.1367	0.6062	0.9119	-0.3631	0.2231	0.0192	0.050
	25(26)		3.1426	0.1526	0.3144	1.3335	0.0668	-0.2180	0.2030	0.102
	39(40)		2.3749	0.1262	0.5655	0.9027	-0.2015	-0.2183	0.1771	0.049
		105 (106)	2.0779	0.1387	0.6991	0.8338	0.0068	-0.1491	0.2785	0.042
21	19(19)		-2.8087	0.1582	0.4220	-1.2172	0.0008	0.2756	0.0835	0.087
	23(24)		2.6302	0.1540	0.4835	1.1222	-0.4672	0.2271	0.0811	0.074
	25(26)		2.9392	0.1524	0.3756	1.2464	0.0714	-0.2052	0.1783	0.090
	39(40)		2.5469	0.1238	0.4969	0.9530	0.2091	-0.2214	0.1984	0.050
		105 (106)	2.1693	0.1422	0.6622	0.8832	-0.0112	-0.1697	0.3091	0.047
24	19(19)		-2.9503	0.1542	0.3728	-1.2598	-0.0219	0.2678	0.1203	0.092
	21(21)		2.5295	0.2653	0.6011	1.5200	-0.3921	-0.1923	0.4020	0.137
	25(26)		2.9806	1.520	0.3623	1.2620	0.0669	-0.2162	0.1892	0.092
	39(40)		2.5225	0.1287	0.5060	0.9434	-0.2108	-0.2171	0.1944	0.053
		105 (106)	2.0294	0.1387	0.7204	0.8142	-0.0062	-0.1463	0.2717	0.040
26	19(19)		-3.1172	0.1547	0.3225	-1.3338	-0.0261	0.2805	0.1325	0.103
	21(21)		2.1278	0.2506	0.7785	1.2303	-0.2837	0.1868	0.3285	0.091
	24(24)		2.2967	0.1366	0.6043	0.9137	-0.3644	0.2271	0.0189	0.050
	39(40)		2.4327	0.1244	0.5415	0.9171	0.2029	-0.2018	0.1805	0.050
		105 (106)	1.9686	0.1394	0.7479	0.7924	0.0053	-0.1384	0.2594	0.038
40	19(19)		-2.8196	0.1575	0.4176	-1.2193	-0.0402	0.2747	0.1013	0.087
	21(21)		2.2020	0.2503	0.7416	1.2723	-0.2895	-0.1987	0.3446	0.098
	24(24)		2.2888	0.1366	0.6075	0.9103	0.3619	-0.2251	0.0196	0.050
	26(26)		2.8967	0.1537	0.3899	1.2342	0.0512	-0.1972	0.1738	0.089
		105 (106)	2.1854	0.1413	0.6546	0.8864	0.0175	-0.1688	0.3015	0.047
19,21,24, 26,40,(all 5 outliers)		101 (106)	2.5807	0.1460	0.4811	1.0672	-0.0082	-0.2044	0.3736	0.067

Table: 5 (b) Summary of influential statistics to detect outliers

Maruteru Rabi Rice 1994

Observation Number Critical values →	Studentized Residual (> ± 2)	HAT DIAG H (> 0.1250)	COVRATIO (1.375 - 0.625)	DFFITS (> ± 0.7071)	DFBETAS (> 0.1826)				Cook's D (> 0.0333)
					INTERCEPT	FN	FP	FK	
10	–	√	–	+ √	–	√	√	–	√
19	√	√	√	- √	–	–	√	–	√
21	√	√	–	+ √	–	√	√	√	√
24	√	√	–	+ √	–	√	√	–	√
26	√	√	√	+ √	–	–	√	√	√
40	√	–	√	+ √	√	√	√	√	√
88	–	√	√	- √	√	√	–	–	√
93	–	√	–	+ √	–	–	–	–	√
106	–	√	–	+ √	√	–	–	√	√
108	–	√	–	+ √	–	–	√	√	√
111	–	√	–	- √	–	√	√	–	√
115	–	√	–	- √	√	–	–	√	√

Note: ' √ ' Represents the values which are greater than the critical values (which are given in parentheses)

' – ' Represents the values which are less than the critical values

Table: 5(c) Final Regression equations after backward elimination

Maruteru Rice Rabi 1994

Original regression equation (120 observations)

Y= 2755.60889 + 24.39779 FN + 16.08044 FK -0.13557 FN^2 +0.06341FP^2-0.10505FK^2 -2.31739 SK -0.04118 FN×FP +0.05236 FN×SN R^2=0.9055

Regression equation after deleting observation 19

Y= 4338.76309 + 13.97894 FN +14.83166 FK-0.14964 FN^2 +0.07655 FP^2 -0.09463 FK^2-5.40397SN-2.31602 SK -0.05312 FN×FP+ 0.09546 FN×SN R^2 = 0.9145

Regression equation after deleting observation 21

Y=2626.09926+27.55086FN+16.64638FK-0.14974FN^2 -0.11556FK^2-1.80080 SK + 0.04653 FN×SN R^2 = 0.9013

Regression equation after deleting observation 24

Y= 2742.28406+26.74566 FN +16.32247 FK -0.13406 FN^2 +0.06873 FP^2 -0.11096 FK^2-2.29138 SK-0.04564 FN×FP +0.04529 FN×SN R^2 = 0.9069

Regression equation after deleting observation 26

Y= 4130.60071+13.86550FN +14.31508FK-0.15797 FN^2 +0.06680 FP^2 -0.08650 FK^2 -5.33959SN-2.70065 SK-0.05014 FN×FP+0.09723 FN×SN R^2 = 0.9129

Regression equation after deleting observation 40

Y= 4507.81242+ 13.30066FN+16.99820FK-0.14828FN^2 +0.06844FP^2 -0.11071FK^2 -5.59125SN-2.70065 SK-0.03776FN×FP +0.09486FN×SN R^2 = 0.9125

Regression equation after deleting observation all the above 5 Observations

Y= 4475.42287 + 20.79627 FN + 16.99820FK-0.15421 FN^2 +0.07300 FP^2 -0.08936 FK^2 -4.93321 SN-3.20131 SK-0.05610 FN×FP +0.07761 FN×SN + 0.03962 FK×SK

R^2 = 0.9125

LUDHIANA

An experiment on Wheat crop(variety PBW- 343) conducted at Punjab Agricultural University, Ludhiana in 1997 under the soil test crop response correlation project was take up, as this experiment was different from others, The experiment consisted of 10 treatment combinations of N, P and K selected from a 5×4×3 factorial experiment. This set of 10 treatments was replicated four times in each of the four strips (as mentioned earlier) in a randomized way. In all there were four strips. Therefore each strip contained a set of 10 treatments, which is repeated four times in the same strip, thereby giving 40 plots or observations.

We analyzed this experiment as follows: The data of individual strips (4 in all) were analyzed separately as Randomized block design with four replications. The error variances of the four experiments were tested by Bartlett's test and were found to be homogeneous. Next a pooled analysis was performed for the four sites as per the following ANOVA:

Analysis of Variance

Source	**d.f.**	**sum of sq.**	**Mean sq.**	**F**	**pr >F**
Strips	3	1371.71502	457.23834	37.63**	<.0001
Treatment	9	10458.37335	1162.04148	95.63**	<.0001
Rep (Strips)	12	393.71485	32.80957	2.70*	0.0032
StripsXTreat.	27	788.29057	29.19595	2.40*	0.0008
Error	108	1312.31980	12.15111	----	
Total	159	14324.41359			

R^2	**C.V.**	**Yield Mean (Kg./Ha.)**	**Max.Yield(Kg./Ha.)**
0.9083	6.65	52.39	57.03(treat.no.10)

In this analysis, the effects of Strips and Treatment were found to be highly significant .while the effect of Replication (Strips) and (Strips * Treatment) were only significant .

As the replications (strips) are significant, then each set of ten treatments can be taken as a different site. In that case, we would have 16 sites (4×4) instead of the regular 4 sites (strips). Since the strips are highly significant, it shows that the fertility gradient has been established, which is one of the aims of the STCR experiment.

The method applied at IASRI was adopted for further analysis. The following model is generally used by the STCR project:

$$Y = b_0 + b_1 FN + b_2 FP + b_3 FK + b_4 FN^2 + b_5 FP^2 + b_6 FK^2 + b_7 SN + b_8 SP + b_9 SK + b_{10} FN \times SN + b_{11} FP \times SP + b_{12} FK \times SK + \varepsilon$$

Where, b_i' s are the regression coefficients, FN, FP and FK are applied fertilizer doses of Nitrogen, Phosphorus and Potash, SN, SP and SK are available soil fertilizers for Nitrogen, Phosphorus and potash respectively. ε is the random error which is assumed ~ $N(0, \sigma^2)$

Since the numbers of distinct design points are only 10 in this case, the Response Surface for above model could not be fitted. Thus as per our assumption, we have an experiment with a set of 10 treatment combinations of N, P and K conducted at 16 sites. Therefore, considering the number of design points available, a multiple regression equation (backward elimination) was fitted to the whole data consisting of 160 observations taking 'yield' as dependent variable as per the following model:

$$Y = b_0 + b_1\,FN + b_2\,FP + b_3\,FK + b_4\,FN^2 + b_5\,FP^2 + b_6\,FK^2 + b_7\,(FN \times FP) + \varepsilon \quad ... \quad (1)$$

Where, FN, FP, FK are the applied fertilizer doses of N, P and K, b_i's are the regression coefficients and ε the random error assumed ~ $N(0, \sigma^2)$

The effects of (FN × FK) and (FP × FK) were omitted from the model as these were found to be combinations of the other effects. The R^2 – value was found to be 74%. Although the R^2 value was high but the significant effects were, only N and N^2.
A number of other models have been tried like with parameters,[N,P,K,.(N×P) and N^2],[N,P,(N×P)], [N,P,N^2] etc. But R^2 value is of the order of 74% only when N^2 is there in the model. Moreover the linear effect of K is also not significant Therefore it appears that the contribution of K is negligible and therefore could not be estimated. The final model selected was:

$$Y = b_0 + b_1\,FN + b_2\,FP + b_3\,FN^2 + b_4\,FN \times FP + \varepsilon \quad \ldots(2)$$

Next taking each b_i as dependent variable and the set of available soil test values of Nitrogen and Phosphorus (designated as SN and SP respectively) as independent variables a multiple regression was fitted using the following models:

$$b_1 = a_{10} + a_{11}\,SN + a_{12}\,SN^2 + e_1$$
$$b_2 = a_{20} + a_{21}\,SP + a_{22}\,SP^2 + e_2$$
$$b_3 = a_{30} + a_{31}\,SN + a_{32}\,SN^2 + e_3$$
$$b_4 = a_{40} + a_{41}\,SN + a_{42}\,SN^2 + a_{43}\,SP + a_{44}\,SP^2 + e_4$$

These values of b_i's were substituted in the original regression equation (1).
The new equation takes the following form:

$$Y=b_0+(a_{10}+a_{11}SN+a_{12}SN^2)FN+(a_{20}+a_{21}SP+a_{22}SP^2)FP+(a_{30}+a_{31}SN+a_{32}SN^2)FN^2$$
$$+(a_{40}+a_{41}SN+a_{42}SN^2+a_{43}SP+a_{44}SP^2)\,FN\times FP + \varepsilon' \quad ... (3)$$

By substituting the soil values of SN and SP of a particular site in the above equation and after simplification, the equation reduces to the following form:

$$Y = c_0 + c_1\,FN + c_2\,FP + c_3\,FN^2 + c_4\,FN \times FP + \varepsilon \quad ... \quad (4)$$

Then by differentiating the above equation with respect to FN and FP respectively and equating resulting equations to zero, the optimal values of N and P can be obtained for that particular site.

Also a Response Surface was fitted to the data by taking Soil N, P_2O_5 and K_2O and Replication as Co-variates and followed by canonical analysis, to get the optimal values of N and P.

Results and interpretations

From table L.1 it can be observed that the response of wheat up to N_{120} over P_{60} K_{30} (28.38), up to P_{60} over N_{120} K_{30} (2.90) and up to K_{30} over N_{120} P_{60} (1.90) is high. Moreover the response of N_{120} is highest in gradient II, that of P_{60} is highest in gradient I and that of K_{30} is highest in gradient III. The optimum dose is in the vicinity of N_{120} P_{60} K_{30}.

The optimum value of the nutrients obtained (Table L.3) by applying multiple regression for the STCR model were N=134 and P= 57 with R^2 value of 79% and N=125,P=24 with R^2 value of 81% when replication was introduced as a variable.

The optimum values of the nutrients obtained by IASRI approach were N=121 and P= 57 with R^2 value of 62%.

Since it was not possible to fit a complete response surface to the data because of lesser number of distinct design points, as an illustration, 10 more treatment combinations were chosen from the 5×4×3 combinations and were superimposed in each gradient and replicated twice. So now each gradient contains 20 treatments replicated twice. The covariates taken in this model were SN, SP, SK and Replication. The optimum values of the nutrients obtained by this method (table L.2) were N= 115, P= 33 and K=10 kg/ha.

So it is suggested that this particular experiment should have been undertaken with at least 20 distinct treatment combinations replicated twice in each gradient instead of 10 treatments, replicating four times in each gradient, since resources were available.

From the above it can be concluded that each experiment should be conducted by choosing a proper set of treatment combinations and sufficient number of design points so that a complete response surface could be fitted.

Table L.1: Response of Wheat (Q/ha.) to N,P,K at graded levels of application under different gradients (Ludhiana 1997)

Gradient	Response to N Over P_{60} K_{30}			Response to P Over N_{120} K_{30}			Response to K Over N_{120} P_{60}	
	N_{30}	N_{120}	N_{160}	P_{30}	P_{60}	P_{90}	K_{30}	K_{60}
I	19.46	29.42	30.13	4.94	4.61	4.80	-0.38	0.12
II	26.88	34.61	31.49	-3.51	2.69	2.13	2.31	-0.88
III	21.79	26.42	22.73	-0.67	2.17	-0.91	4.80	4.03
IV	21.28	23.07	27.07	-3.30	-0.99	-0.49	0.87	-0.25
Overall	22.35	28.38	25.36	-0.63	2.90	1.38	1.90	0.76

Table L.2: Optimal values of N, P and K(kg/ha) obtained by fitting of response surface for different gradients (Covariates: Rep, SN, SP and SK)

Nutrients	**Gradients**				
	I	**II**	**III**	**IV**	**Overall**
N	90	128	126	107	115
P	22	19	64	56	33
K	31	10	55	39	10
R^2	0.87	0.91	0.86	0.83	0.79
C.V.	8.64	6.88	6.03	6.89	8.68

Gradients	**I**	**II**	**III**	**IV**	**Overall**
Predicted yield ($q\ ha^{-1}$) at Stationary point (Saddle point)	47.70	55.22	61.24	54.64	54.76

Table L.3: Multiple regression equations and the derived optimal values

Multiple regression equation (backward elimination) for the STCR model is as follows (all effects are significant).

$$Y= -2.9298 + 0.35988\ FN - 0.00153\ FN^2 + .000863\ FNFP + 0.40022SP - 0.00267SP^2 + 0.17482\ SK - 0.0002969\ SK^2 - 0.001571\ FPSP \qquad R^2 = 0.79$$

For a particular site with soil test values (kg/ha): SN = 88, SP= 73.5 and SK = 330

The derived optimal Values of Nutrients (kg/ha): N= 134, P=57

Multiple regression equation (backward elimination) for the above STCR model including replication as a variable is as follows (all effects are significant).

$$Y= 7.0709 + 2.7325\ REP + 0.3387\ FN - 0.00154\ FN^2 + +0.00083FNFP + +0.40022SP - 0.00267SP^2 + 0.17482\ SK - 0.0002969\ SK^2 - 0.001571FPSP \qquad R^2 = 0.81$$

For a Particular site with Soil Test Values (kg/ha):SN = 75, SP= 66.8 and SK = 370

The derived optimal Values of Nutrients (kg/ha): N= 125, P=24

Multiple regression equation (backward elimination) for the IASRI model is as follows

For a Particular site with Soil Test Values (kg/ha):

SN = 75, SP= 66.8 and SK = 370

$$Y= 1.41988 + + 0.24396\ FN + 0.51806\ FP - 0.00428\ FNFP \qquad R^2 = 0.62$$

The derived optimal Values of Nutrients(kg/ha): N= 121, P=57

Table L.4: Estimated ridge of maximum response for yield optimum values (kg ha^{-1})

Coded Radius	**Estimated Response**	**Standard Error**	**FN**	**FP**	**FK**
0.0	52.1999	1.6286	80.00	45.00	30.00
0.1	53.1937	1.4823	87.81	44.06	30.18
0.2	53.9693	1.3000	95.66	43.29	30.48
0.3	54.5299	1.0875	103.56	43.00	31.09
0.4	54.8917	0.8670	111.28	44.74	32.52
0.5	55.1337	0.7232	117.02	50.62	34.27
0.6	55.3587	0.6551	120.80	56.95	35.15
0.7	55.5988	0.6126	123.83	62.70	35.63
0.8	55.8615	0.5843	126.53	68.06	35.93
0.9	56.1493	0.5741	129.04	73.18	36.15
1.0	**56.4636**	**0.5928**	**131.44**	**78.14**	**36.32**

KALYANI

At this centre, an experiment on Rape crop, conducted in the year 1998 in the Rabi season has been selected. The fertilizer doses are 0, 50, 75,100 and 125 kg/ha of Nitrogen, 0, 25, 50, 75 kg/ha of Phosphorus and 0, 25, 50 kg/ha of Potassium. The design used is 5×4×3 fractional factorial and number of fertilizer treatment combinations are 21 with 7 controls making a total of 28 treatments.

The data was subjected to multiple regression analysis as explained earlier. A look at the table 5.3.1 shows that, excepting the model with 9 variables (only added fertilizer treatments), over 87% of the variability is explained by the models with 12, 15 and 18 variables and looking at the table 5.3.2, in the backward elimination process, it is observed that in all the models, linear and quadratic trend for fertilizer Phosphorus (FP) is prominent. Whereas in table 5.3.3 it is observed that (when replication is used as a variable) even the model with 9 variables (plus replication) the R-square value is more than 86%. Also in the remaining variables, after backward elimination (Table 5.3.4), quadratic trend of Nitrogen is observed. Although, optimal values of Nitrogen and Phosphorus could be derived but the same for Potassium is not possible.

Therefore, the data for the year was subjected to analysis by Response surface methodology. In this case the stationary point is a saddle point, which is neither maximum nor minimum. Therefore exploration of the response surface in the vicinity of the stationary point was attempted. In this case the variables SN, SP and SK have been taken as covariates. Optimum values have been calculated by taking into consideration the mean values of SN, SP and SK. In table 5.7, optimum fertilizer doses obtained by Targeted yield approach and Response surface approach have been compared for all the centres. Maximum response achievable by Response surface methodology has been taken as the Targeted yield for the crops at all the centres. This has been done to check the reliability of the Optimum doses calculated by the Targeted yield approach. For this centre, a look at the table 5.7 shows that for achieving a maximum response of 12.38 q ha^{-1}, the required optimal fertilizer doses of FN, FP and FK are 119 kg ha^{-1}, 47 kg ha^{-1} and 34 kg ha^{-1} respectively as derived by the Response surface methodology. The corresponding optimum values by Targeted yield approach are FN= 109, FP= 58 and FK= 39 kg ha^{-1}. This shows that the Targeted yield approach and the Response surface methodology give somewhat similar results.

COIMBATORE

An experiment on Onion conducted in the year 1998 in the Rabi season has been selected. The fertilizer doses are 0, 30, 60, 90 and 120 kg/ha of Nitrogen, 0, 30, 60, 90 kg/ha of Phosphorus and 0, 30, 60 kg/ha of Potassium. A fractional factorial design 5×4×3 was used and number of fertilizer treatment combinations was 20 with 4 controls making a total of 24 treatments.

A look at the table 5.4.1 (multiple regression) shows that over 80% of the variability is explained by the models with 9, 12, 15 and 18 variables and looking at the table 6.4.2, in the backward elimination process, it is observed that in all the models, linear and quadratic trends for fertilizer Nitrogen (FN) and fertilizer Phosphorus (FP) are significant. Also the interactions FN×SN and FP×SP are found to be significant in all the models. Here it is observed in all the models Potassium (FK) has no role to play. From table 5.4.3 it is observed that the use of replication as a variable, the R-square value, as reported earlier, goes than 87 % in all the models. Also after backward elimination, in the remaining variables, (Table 5.4.4), similar trend is observed. Here it is also observed that the derivation of optimal values are only possible for fertilizer Nitrogen and Phosphorus.

In this case also the RSM shows that the stationary point is a saddle point (as discussed earlier). The exploration of the response surface in the vicinity of the stationary point shows that to get a response of 181.34 q ha^{-1}, the optimal values of FN, FP and FK required are 110, 68 and 36 kg ha^{-1} respectively. The corresponding optimum values by Targeted yield approach are FN= 111, FP= 68 and FK= 56 kg ha^{-1} for the same achievable target. This gives credibility to the Targeted yield approach as has been verified by the Response surface methodology in the above cases.

HISAR

At this centre, we have chosen two experiments on Wheat crop. The first one was conducted in the year 1993-94 with variety WH-542 and the second was conducted with variety WH-896. The fertilizer doses for both the years were 0, 50, 100, 150 and 200 kg/ha of Nitrogen, 0, 30, 60, 90 kg/ha of Phosphorus and 0, 30, 60 kg/ha of Potassium. A fractional factorial design 5×4×3 was used and number of fertilizer treatment combinations was 21 with 9 controls making a total of 30 treatments.

After subjecting the data to multiple regression analysis, a look at the table 5.5.1 for the year 1993-94, shows that over 90 % of the variability is explained by the models with 9, 12, 15 and 18 variables and looking at the table 5.5.2, in the backward elimination process, it is observed that in all the models, linear and quadratic trends for fertilizer Nitrogen (FN) and fertilizer Phosphorus (FP), the linear trends of soil variables SN, SP, SK and also the interactions FN×SN and FP×SP are found to be significant in all the models. Here we observe that the criteria for deriving optimal fertilizer doses when the law of diminishing returns operates i.e. the coefficients of linear, quadratic and interaction terms should be positive(+), Negative(-), Negative(-) is fulfilled. Therefore the optimal values of Fertilizer Nitrogen and Fertilizer Phosphorus are derivable. From table 5.5.3 it is observed that by inclusion of replication as a variable, R-square value becomes more than 99 % in all the models. Also in the remaining variables, after backward elimination (Table 6.5.4), similar trend is observed. Although, optimal values of Nitrogen and Phosphorus could be derived but the same for Potassium is not possible.

The analysis by Response surface methodology, again, in this case shows the stationary point as a saddle point. In table 5.7, optimum fertilizer doses obtained by Targeted yield approach and Response surface approach have been compared. Maximum response achievable by Response surface methodology has been taken as Targeted yield for the crops at all the centres. From this table 5.6.7 it is observed that for the year 1993-94, a maximum response of 60.97 q ha^{-1} is achievable by taking FN as 180 kg ha^{-1}, FP as 70 kg ha^{-1} and FK as 24 kg ha^{-1} respectively. The corresponding optimum values by Targeted yield approach are FN= 153, FP= 67 and FK= 52 kg ha^{-1}. We find some difference in the two methods here at this centre and most likely reason for this is selection of treatments for maximum response procedure of targeted yield equations. From tables 5.5.6 to 5.5.10 , which are the results of the experiment conducted in the year 1995-96, we observe similar trends as mentioned in the 1993-94 experiment and therefore are not discussed separately.

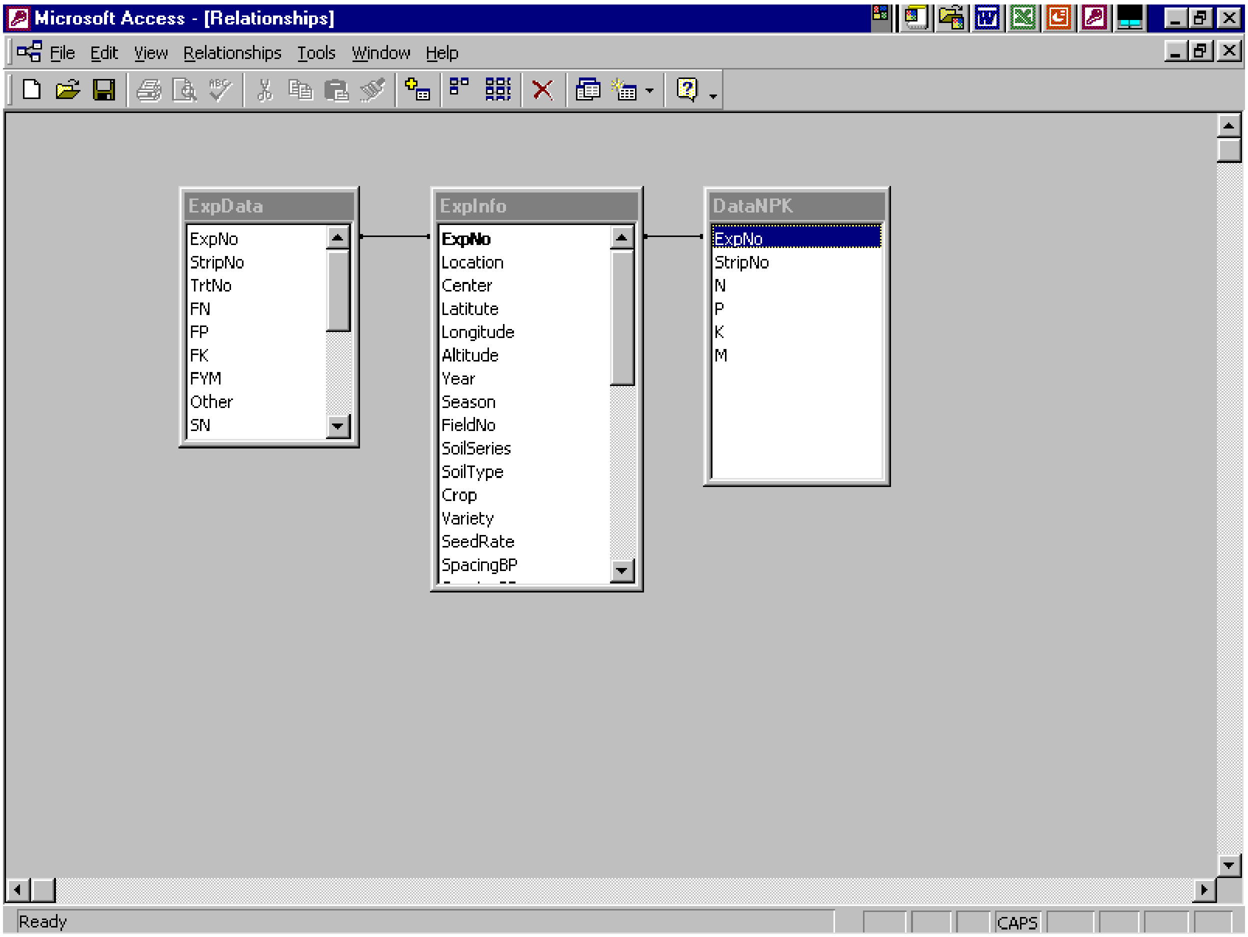
Chapter- VI

DATABASE FOR STCR EXPERIMENTS

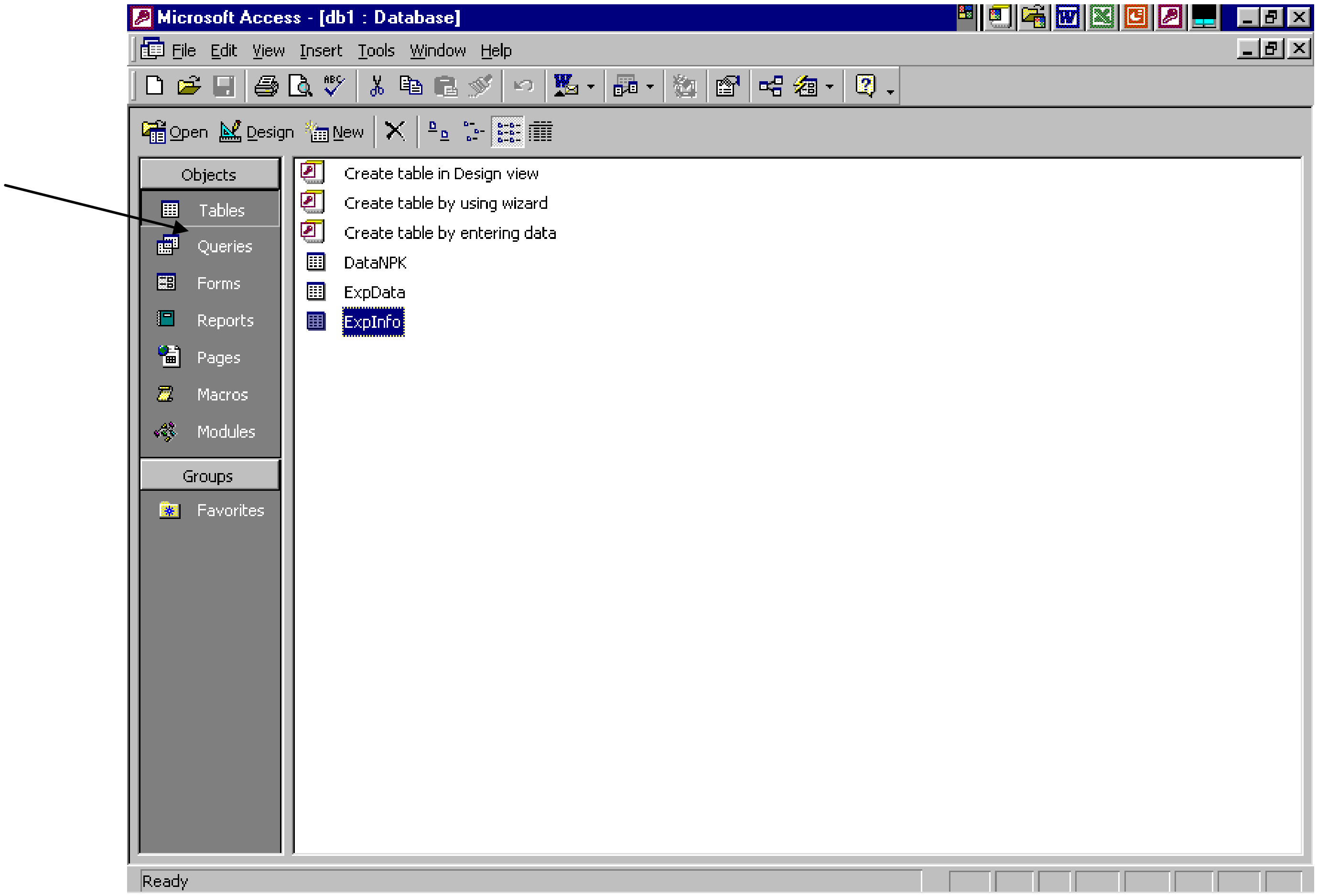
For the benefit of research workers and the scientists of the STCR project, a preliminary database in MS-ACCESS has been developed at IASRI. The experimental data received from a few co-operating centers, has been fed into the database to check its operation. In future, experimental data to be received from different cooperating centres would be fed into this database which will put all the experiments conducted under the STCR project at a central place. Later we propose to place this in IASRI website so that all the scientists working in the project at different cooperating centres can access it through the WEB. This needs some time, proper infrastructure and mainly the cooperation of all the cooperating centres. Therefore it is proposed that for maintaining a database for STCR experiments, an externally funded project would be launched which will provide proper infrastructure and manpower to develop the database..

For the present database, three tables has been created as ExpInfo (Table containing the information of experiment), ExpData (Containing the information on the data of experiment) and DataNPK (information about the treatment structure).

Screen showing the relation ship between three tables

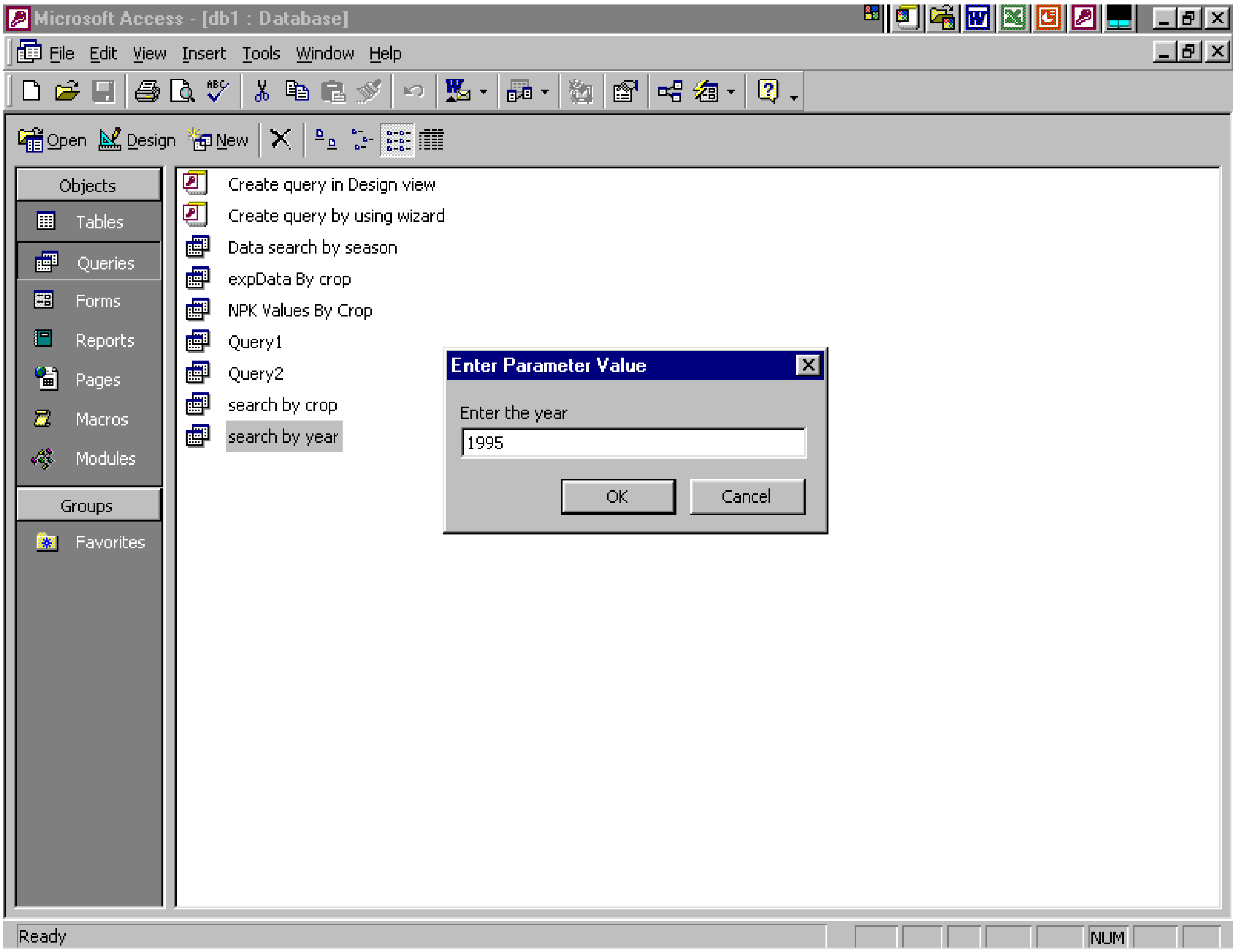


Here after clicking the queries as indicated by arrow the data about the experiment can be retrieved. Various queries are already designed.

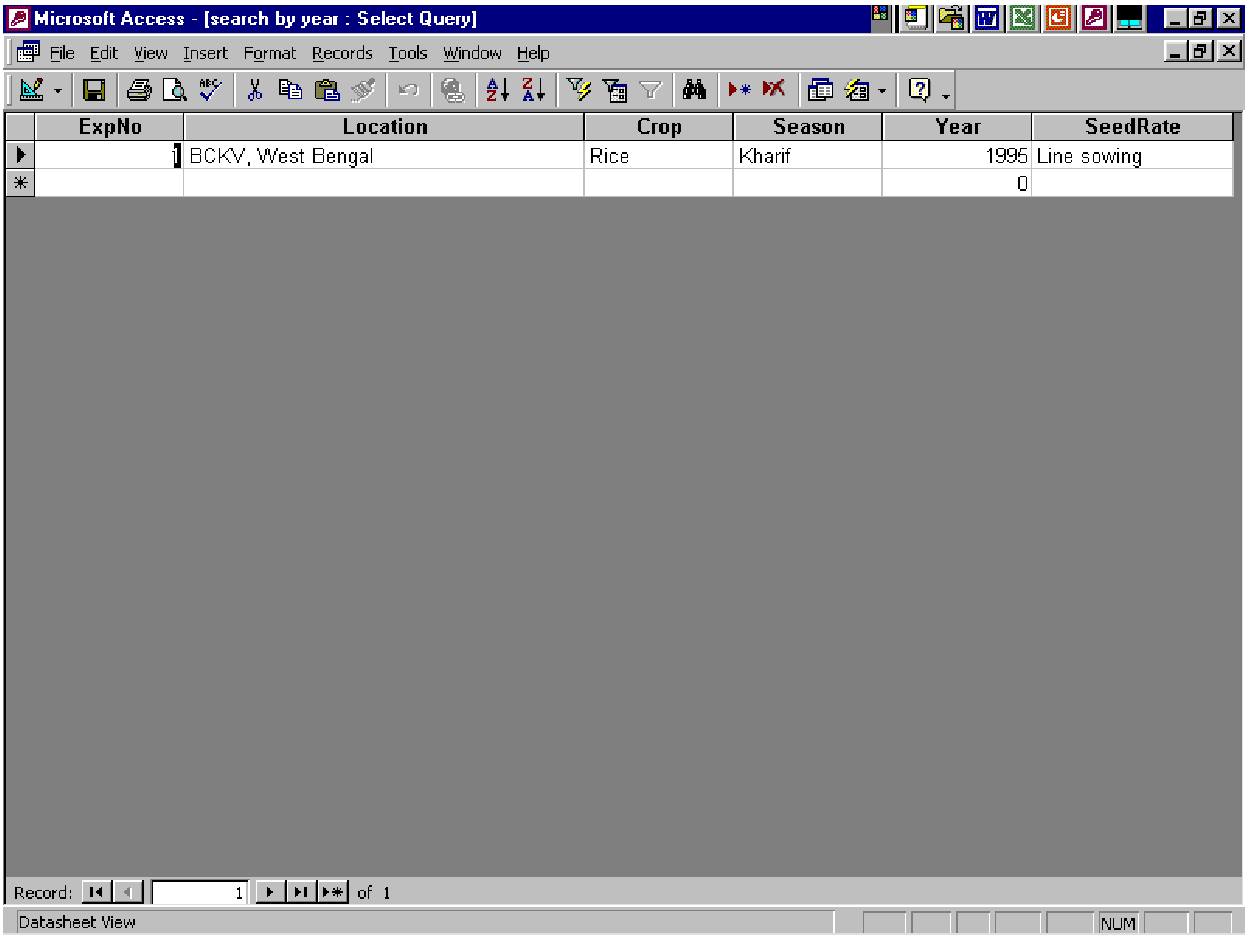


Searches on various basis can be done. For example:

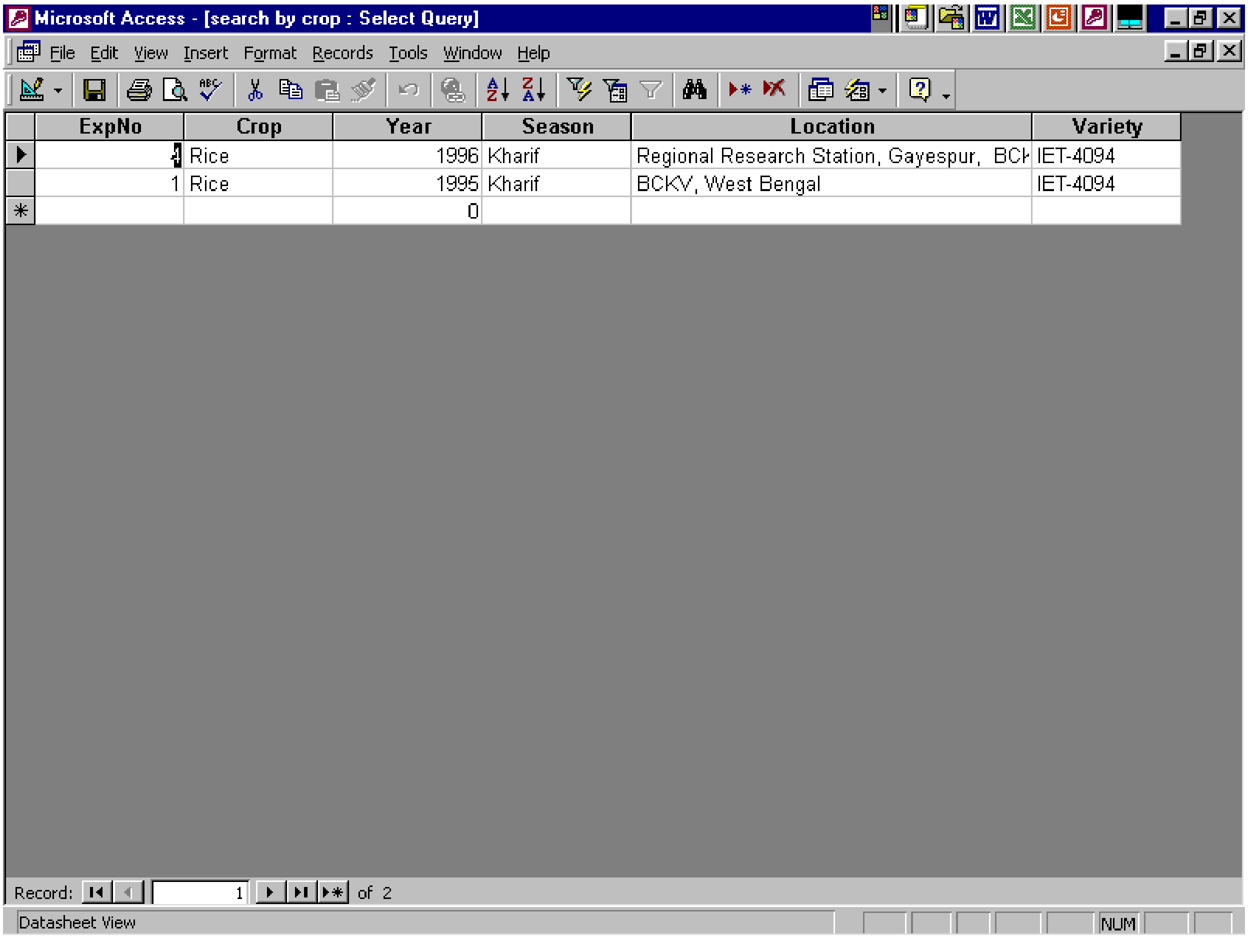
If we want to search the experiments which are conducted in the year 1995.
This can be searched through database by query **"search by year"** with dummy data as below



Following output will be generated.



Search By Crop
Likewise various experiments conducted on specific crop can be searched by running the query **“search by crop”**. Here experiments are searched by crop “Rice” and result is as below



ExpNo	Crop	Year	Season	Location	Variety
4	Rice	1996	Kharif	Regional Research Station, Gayespur, BCK	IET-4094
1	Rice	1995	Kharif	BCKV, West Bengal	IET-4094
		0			

Experimental data regarding various experiments can be searched by crop and season from ExpData table. This gives the following output:

Here we see Experiment Number, Treatment No. Nitrogen Fertilizer doses, Phosphorus Fertilizer doses, Potassium fertilizer doses, Soil available Nitrogen, Phosphorus and Potassium, Grain yield and host of other information about experiments

Microsoft Access - [ExpData By Season and crop : Select Query]

ExpNo	TrtNo	FN	FP	FK	SN	SP	SK
1	16	15	60	0	240	33.5	36
1	30	0	0	0	242	25.5	31
1	3	0	0	60	241	23.2	35
1	4	0	30	0	235	29.5	33
1	5	0	30	30	220	31.2	34
1	6	0	30	60	220	32.4	33
1	7	0	60	0	239	36.5	31
1	8	0	60	30	228	36.7	35
1	9	0	60	60	235	38.9	36
1	10	15	0	0	220	28.5	30
1	11	15	0	30	218	25.4	30
1	12	15	0	60	228	24.5	34
1	13	15	30	0	235	24.8	35
1	1	0	0	0	220	24.9	31
1	15	15	30	60	225	31.4	37
1	30	0	0	0	230	17.5	31
1	17	15	60	30	222	34.2	39
1	18	15	60	60	230	36.2	39
1	19	30	0	0	220	34.4	35
1	20	30	0	30	278	35.1	36
1	21	30	0	60	250	35.7	37
1	22	30	30	0	247	36.5	35
1	23	30	30	30	254	36.5	37
1	24	30	30	60	242	34	36
1	25	30	60	0	263	35.5	35
1	26	30	60	30	242	38.1	36

Record: 1 of 120

Datasheet View

These data can be subjected to analysis by SAS and SPSS packages directly.

Similarly, various queries can be thought of and can be designed using MS Access as per the need of the user.

TABLES

Table 5.1.1 : Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1998

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error
Intercept	2103.84595	50.31420	-2197.74275	682.54206	-2228.77164	5778.99510	-120.80415	5584.17236
fn	5.35190	5.04078	9.12115	9.90485	-1.31199	10.90774	-4.19969	10.51809
fp	9.93661	4.36936	-1.15451	3.12698	-2.03116	3.03627	2.95264	3.20845
fk	12.71041	7.84978	8.07315	14.94661	15.84625	18.42116	16.08370	17.83399
fn^2	0.06506	0.09410	0.12940	0.02905	0.12418	0.02851	-0.00138	0.04818
fp^2	-0.06342	0.07854	-0.00200	0.02311	-0.00469	0.02267	-0.11739	0.03857
fk^2	-0.20280	0.20907	-0.16343	0.08189	-0.15483	0.07909	-0.19476	0.10092
sn	-------	-------	37.66482	6.18995	154.23751	109.29830	113.07796	106.94426
sp	-------	-------	-45.21108	11.48897	41.94265	47.39644	47.26447	45.61922
sk	-------	-------	-1.00398	10.46500	-191.20187	150.72924	-178.81034	144.48752
sn^2	-------	-------	-------	-------	-0.42417	0.36195	-0.28110	0.35404
sp^2	-------	-------	-------	-------	-1.49387	0.83601	-1.74719	0.80724
sk^2	-------	-------	-------	-------	0.98900	0.74006	0.95555	0.70918
fn*sn	-------	-------	-0.01090	0.06756	0.06459	0.07500	0.06408	0.07153
fp*sp	-------	-------	0.39462	0.10754	0.43401	0.10417	0.42838	0.09918
fk*sk	-------	-------	0.06877	0.15285	-0.02013	0.18489	-0.01339	0.17696
fn*fp	0.15486	0.14572	-------	-------	-------	-------	0.22044	0.07262
fn*fk	0.09372	0.14250	-------	-------	-------	-------	0.10462	0.06894
fp*fk	-0.03010	0.20390	-------	-------	-------	-------	-0.10235	0.10011
R^2	0.9026		0.9741		0.9768		0.9796	

Table: 5.1.2 Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1998

Model	Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2085.28878	45.59517	162340991	2091.68	<.0001
	fn	7.46991	3.69509	317186	4.09	0.0457
	fp	8.32184	1.46118	2517473	32.44	<.0001
	fk	8.39841	2.56110	834592	10.75	0.0014
	fn2	0.15691	0.04780	836301	10.78	0.0014
	R^2 = 0.8994					
II	Intercept	-2312.94255	526.65401	399795	19.29	<.0001
	fn	7.53193	2.05720	277855	13.40	0.0004
	fk	14.52385	3.41757	374359	18.06	<.0001
	fn2	0.12715	0.02687	464091	22.39	<.0001
	fk2	-0.15745	0.07928	81764	3.94	0.0497
	sn	37.55461	4.95891	1188813	57.35	<.0001
	sp	-43.97069	8.41526	565914	27.30	<.0001
	fpsp	0.35424	0.02742	3458995	166.87	<.0001
	R^2 = 0.9739					
III	Intercept	-2269.16199	493.68112	413451	21.13	<.0001
	fk	14.11420	3.27016	364553	18.63	<.0001
	fn2	0.12518	0.02563	466919	23.86	<.0001
	fk2	-0.14945	0.07656	74567	3.81	0.0536
	sn	32.95247	3.87453	1415549	72.33	<.0001
	sp2	-0.71028	0.11962	690028	35.26	<.0001
	fnsn	0.05285	0.01338	305391	15.61	0.0001
	fpsp	0.35163	0.02672	3388720	173.16	<.0001
	R^2 = 0.9753					
IV	Intercept	-2355.90198	473.00562	445331	24.81	<.0001
	fk	13.61671	3.13346	338997	18.88	<.0001
	fp2	-0.10654	0.02819	256303	14.28	0.0003
	fk2	-0.17727	0.07398	103086	5.74	0.0184
	sn	29.45527	4.58035	742387	41.36	<.0001
	sp2	-1.07425	0.16016	807595	44.99	<.0001
	sk2	0.09242	0.04445	77604	4.32	0.0401
	fnsn	0.04962	0.01228	293299	16.34	0.0001
	fpsp	0.46996	0.05672	1232296	68.65	<.0001
	fnfp	0.20585	0.03538	607653	33.85	<.0001
	R^2 = 0.9778					

Table 5.1.3 : **Parameter estimates along with standard errors for response surface models using different number of variables (models include replication)**

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1998

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	1641.85488	49.74558	-801.52358	1303.62495	-1371.01740	7821.35721	1888.00985	7516.26217
Replication	184.79643	15.17350	130.90781	104.24835	24.76415	151.22083	57.96281	144.35031
fn	5.35190	3.22414	9.29396	9.87707	-1.51775	11.03522	-4.73317	10.64905
fp	9.93661	2.79469	-2.22480	3.23231	-2.18441	3.19205	2.63189	3.32052
fk	12.71041	5.02081	5.94472	14.99933	16.58612	19.05850	17.88745	18.46956
fn^2	0.06506	0.06018	0.13024	0.02897	0.12374	0.02878	-0.00372	0.04875
fp^2	-0.06342	0.05023	0.00343	0.02345	-0.00402	0.02314	-0.11654	0.03881
fk^2	-0.20280	0.13372	-0.15326	0.08206	-0.15347	0.07993	-0.19076	0.10187
sn	----------	----------	31.15851	8.05850	155.11555	109.98731	115.28458	107.57028
sp	----------	--------	-50.04361	12.08477	41.54672	47.69983	46.24783	45.89623
sk	----------	----------	-7.67322	11.70850	-208.26740	183.87939	-219.03171	176.35218
sn^2	----------	----------	----------	----------	-0.42826	0.36465	-0.29107	0.35651
sp^2	----------	----------	----------	----------	-1.50964	0.84578	-1.78393	0.81605
sk^2	----------	----------	----------	----------	1.06462	0.87549	1.13409	0.83976
fn*sn	----------	----------	----------	----------	----------	----------	0.06853	0.07270
fp*sp	----------	----------	----------	----------	----------	----------	0.43902	0.10309
fk*sk	----------	----------	----------	----------	----------	----------	-0.02884	0.18188
fn*fp	0.15486	0.09321	-0.00943	0.06738	0.06646	0.07623	0.22274	0.07318
fn*fk	0.09372	0.09114	0.42204	0.10943	0.43856	0.10832	0.10599	0.06933
fp*fk	-0.03010	0.13041	0.09160	0.15349	-0.02658	0.18996	-0.10519	0.10081
R^2	0.9606		0.9745		0.9768		0.9796	

Table: 5.1.4 Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1998

Model	Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	1647.97757	49.66344	35623009	1101.11	<.0001
	rep	184.79643	15.20151	4780961	147.78	<.0001
	fn	7.79025	2.39115	343393	10.61	0.0015
	fp	6.71565	1.24459	941945	29.12	<.0001
	fk	7.91442	1.67152	725297	22.42	<.0001
	fn2	0.10403	0.04083	210068	6.49	0.0123
	fnfp	0.07228	0.03653	126646	3.91	0.0500
	R^2 = 0.9588					
II	Intercept	-2152.40417	524.51382	348047	16.84	<.0001
	fn	7.81062	2.02012	308973	14.95	0.0002
	fn2	0.12623	0.02671	461499	22.33	<.0001
	fk2	-0.15487	0.07806	81361	3.94	0.0499
	sn	36.62775	4.94327	1134742	54.90	<.0001
	sp	-44.84017	8.41424	586961	28.40	<.0001
	fpsp	0.34829	0.02755	3303785	159.85	<.0001
	fksk	0.14491	0.03377	380576	18.41	<.0001
	R^2 = 0.9740					
III	Intercept	-2269.16199	493.68112	413451	21.13	<.0001
	fk	14.11420	3.27016	364553	18.63	<.0001
	fn2	0.12518	0.02563	466919	23.86	<.0001
	fk2	-0.14945	0.07656	74567	3.81	0.0536
	sn	32.95247	3.87453	1415549	72.33	<.0001
	sp2	-0.71028	0.11962	690028	35.26	<.0001
	fnsn	0.05285	0.01338	305391	15.61	0.0001
	fpsp	0.35163	0.02672	3388720	173.16	<.000
	R^2 = 0.9753					
IV	Intercept	-2355.90198	473.00562	445331	24.81	<.0001
	fk	13.61671	3.13346	338997	18.88	<.0001
	fp2	-0.10654	0.02819	256303	14.28	0.0003
	fk2	-0.17727	0.07398	103086	5.74	0.0184
	sn	29.45527	4.58035	742387	41.36	<.0001
	sp2	-1.07425	0.16016	807595	44.99	<.0001
	sk2	0.09242	0.04445	77604	4.32	0.0401
	fnsn	0.04962	0.01228	293299	16.34	0.0001
	fpsp	0.46996	0.05672	1232296	68.65	<.0001
	fnfp	0.20585	0.03538	607653	33.85	<.0001
	R^2 =0.9778					

Table 5.1.5 : Estimated ridge of maximum yield

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1998

Average STV* of the Site: SN=147.87 Kg ; SP =26.72 Kg; SK=97.83Kg

Coded Radius	Estimated **yield**	Standard Error	Uncoded Factor Values FN	FP	FK
0.0	3143.606330	66.562771	37.500000	40.000000	20.000000
0.1	3225.819399	66.115593	40.702312	41.970421	20.335319
0.2	3310.949111	65.437225	43.931705	43.898631	20.658488
0.3	3399.007714	64.582448	47.182735	45.792379	20.971542
0.4	3490.004610	63.676834	50.451305	47.657658	21.276090
0.5	3583.947126	62.927154	53.734277	49.499166	21.573415
0.6	3680.841058	62.627026	57.029208	51.320631	21.864556
0.7	3780.691048	63.148020	60.334175	53.125050	22.150364
0.8	3883.500859	64.904319	63.647640	54.914856	22.431537
0.9	3989.273568	68.288497	66.968362	56.692042	22.708658
1.0	4098.011721	73.599067	70.295330	58.458258	22.982215

* **STV- Soil Test Value**

Table 5.1.6 : Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1999

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error
Intercept	2398.64608	51.76926	-963.27973	374.87570	-3307.97975	4745.99114	-2847.45544	4745.13883
fn	7.29797	5.18656	-19.60467	9.61552	-22.41375	25.62646	-26.12402	25.64255
fp	8.59660	4.49572	8.83645	2.33153	5.97360	4.06860	6.70185	4.09250
fk	11.68171	8.07679	10.08234	6.43459	-5.19061	13.17134	-1.10061	13.30775
fn^2	0.11731	0.09682	0.08843	0.02920	0.09656	0.03822	0.06852	0.04629
fp^2	0.00854	0.08081	0.01643	0.01994	0.00750	0.02219	-0.00111	0.03185
fk^2	-0.07928	0.21511	-0.12080	0.06445	-0.17180	0.07242	-0.08307	0.08689
sn	--------	--------	15.06504	3.32886	18.69820	71.99401	13.69406	71.97483
sp	--------	--------	1.70873	6.47478	22.33281	23.19912	23.13348	23.22677
sk	---------	---------	11.10649	2.92624	46.33871	24.90950	43.32657	24.91027
sn^2	---------	---------	--------	--------	-0.02062	0.24898	0.00010599	0.24909
sp^2	--------	--------	--------	--------	-0.52716	0.44566	-0.55454	0.44688
sk^2	--------	--------	---------	---------	-0.14055	0.11214	-0.12834	0.11223
fn*sn	0.02830	0.14994	---------	---------	0.16903	0.17573	0.18084	0.17556
fp*sp	0.03611	0.14662	--------	--------	0.09758	0.15212	0.09522	0.15258
fk*sk	-0.08620	0.20979	--------	--------	0.08274	0.12577	0.07241	0.12575
fn*fp	---------	---------	0.15270	0.06626	---------	---------	0.06622	0.04916
fn*fk	--------	--------	-0.05684	0.07151	--------	--------	-0.01710	0.04903
fp*fk	--------	--------	-0.04878	0.06334	--------	--------	-0.10853	0.06921
R^2	0.8876		0.9876		0.9887		0.9891	

Table 5.1.7 Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1999

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2404.76465	46.31781	215894182	2695.56	<.0001
	fn	8.90327	3.75365	450592	5.63	0.0195
	fp	8.75776	1.48434	2788125	34.81	<.0001
	fk	6.03265	2.60169	430622	5.38	0.0223
	fn^2	0.12365	0.04856	519289	6.48	0.0123
	R^2 = 0.8868					
II	Intercept	-1070.63946	250.21834	169815	18.31	<.0001
	fn	-13.86882	7.52388	31515	3.40	0.0682
	fp	8.11463	0.50591	2386275	257.27	<.0001
	fk	5.79270	2.39548	54238	5.85	0.0174
	fn^2	0.10252	0.02639	140011	15.10	0.0002
	fk^2	-0.14399	0.05303	68372	7.37	0.0078
	sn	17.10685	2.49832	434881	46.89	<.0001
	sk	9.59817	1.77729	270513	29.17	<.0001
	fnxsn	0.10947	0.05150	41916	4.52	0.0359
	R^2 = 0.9874					
III	Intercept	-2693.94301	575.05815	193248	21.95	<.0001
	fn	-17.75041	8.76483	36115	4.10	0.0455
	fn^2	0.09830	0.02660	120280	13.66	0.0004
	fk^2	-0.08978	0.03369	62531	7.10	0.0090
	sn	11.95563	2.96093	143566	16.30	0.0001
	sp	49.47431	12.54512	136953	15.55	0.0001
	sk	36.86771	12.07854	82040	9.32	0.0029
	sp^2	-1.07390	0.22653	197905	22.47	<.0001
	sk^2	-0.08422	0.05037	24614	2.80	0.0976
	fnxsn	0.14181	0.06054	48311	5.49	0.0211
	fpxsp	0.30112	0.03378	699559	79.44	<.0001
	R^2 = 0.9883					
IV	Intercept	-2433.31741	473.60883	227601	26.40	<.0001
	fn	-21.41012	7.93224	62815	7.29	0.0082
	fp	8.07323	0.67617	1229119	142.55	<.0001
	fn^2	0.05407	0.02758	33151	3.84	0.0527
	sn	12.99325	2.95891	166260	19.28	<.0001
	sk	44.85101	10.85156	147291	17.08	<.0001
	sk^2	-0.15389	0.04563	98086	11.38	0.0011
	fnxsn	0.15673	0.05445	71433	8.28	0.0049
	fkxsk	0.06040	0.02431	53207	6.17	0.0146
	fnxfp	0.08175	0.03172	57259	6.64	0.0114
	fpxfk	-0.14648	0.04934	75979	8.81	0.0037
	R^2 = 0.9885					

Table 5.1.9 Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1999

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F

I	Intercept	1829.54647	29.19511	46491594	3927.05	<.0001
	rep	228.06071	9.19581	7281637	615.07	<.0001
	fn	7.84231	1.54195	306237	25.87	<.0001
	fp	8.73036	0.57085	2769038	233.90	<.0001
	fk	10.68243	2.58167	202697	17.12	<.0001
	fn^2	0.13632	0.01976	563203	47.57	<.0001
	fk^2	-0.11698	0.05988	45187	3.82	0.0534
	R^2 = 0.9874					
II	Intercept	-1070.63946	250.21834	169815	18.31	<.0001
	fn	-13.86882	7.52388	31515	3.40	0.0682
	fp	8.11463	0.50591	2386275	257.27	<.0001
	fk	5.79270	2.39548	54238	5.85	0.0174
	fn^2	0.10252	0.02639	140011	15.10	0.0002
	fk^2	-0.14399	0.05303	68372	7.37	0.0078
	sn	17.10685	2.49832	434881	46.89	<.0001
	sk	9.59817	1.77729	270513	29.17	<.0001
	fnxsn	0.10947	0.05150	41916	4.52	0.0359
	R^2 = 0.9874					
III	Intercept	-2291.50713	472.29626	207301	23.54	<.0001
	fn	-18.44154	7.66631	50958	5.79	0.0180
	fp	8.07334	0.49241	2367275	268.82	<.0001
	fn^2	0.09664	0.02632	118717	13.48	0.0004
	fk^2	-0.14216	0.05936	50507	5.74	0.0185
	sn	13.08731	2.89179	180367	20.48	<.0001
	sk	41.73878	10.85132	130287	14.79	0.0002
	sk^2	-0.13872	0.04558	81566	9.26	0.0030
	fnxsn	0.14568	0.05369	64838	7.36	0.0078
	fkxsk	0.04625	0.02303	35520	4.03	0.0472
	R^2 = 0.9881					
IV	Intercept	-4050.77186	735.07595	251291	30.37	<.0001
	rep	-151.41751	52.87285	67866	8.20	0.0051
	fn	-26.87616	8.87289	75922	9.17	0.0031
	fn^2	0.05064	0.03012	23387	2.83	0.0959
	sn	17.86565	3.70389	192525	23.27	<.0001
	sp	54.04114	12.36796	157986	19.09	<.0001
	sk	44.61347	12.01400	114110	13.79	0.0003
	sp^2	-0.96510	0.22608	150794	18.22	<.0001
	sk^2	-0.09463	0.04896	30913	3.74	0.0561
	fnxsn	0.17517	0.05914	72588	8.77	0.0038
	fpxsp	0.22470	0.04925	172270	20.82	<.0001
	fnxfp	0.09597	0.03418	65236	7.88	0.0060
	fpxfk	-0.13261	0.03341	130388	15.76	0.0001
	R^2 = 0.9892					

Table 5.1.9 Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure
Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1999

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	1829.54647	29.19511	46491594	3927.05	<.0001
	rep	228.06071	9.19581	7281637	615.07	<.0001
	fn	7.84231	1.54195	306237	25.87	<.0001
	fp	8.73036	0.57085	2769038	233.90	<.0001
	fk	10.68243	2.58167	202697	17.12	<.0001
	fn^2	0.13632	0.01976	563203	47.57	<.0001
	fk^2	-0.11698	0.05988	45187	3.82	0.0534
	R^2 = 0.9874					
II	Intercept	-1070.63946	250.21834	169815	18.31	<.0001
	fn	-13.86882	7.52388	31515	3.40	0.0682
	fp	8.11463	0.50591	2386275	257.27	<.0001
	fk	5.79270	2.39548	54238	5.85	0.0174
	fn^2	0.10252	0.02639	140011	15.10	0.0002
	fk^2	-0.14399	0.05303	68372	7.37	0.0078
	sn	17.10685	2.49832	434881	46.89	<.0001
	sk	9.59817	1.77729	270513	29.17	<.0001
	fnxsn	0.10947	0.05150	41916	4.52	0.0359
	R^2 = 0.9874					
III	Intercept	-2291.50713	472.29626	207301	23.54	<.0001
	fn	-18.44154	7.66631	50958	5.79	0.0180
	fp	8.07334	0.49241	2367275	268.82	<.0001
	fn^2	0.09664	0.02632	118717	13.48	0.0004
	fk^2	-0.14216	0.05936	50507	5.74	0.0185
	sn	13.08731	2.89179	180367	20.48	<.0001
	sk	41.73878	10.85132	130287	14.79	0.0002
	sk^2	-0.13872	0.04558	81566	9.26	0.0030
	fnxsn	0.14568	0.05369	64838	7.36	0.0078
	fkxsk	0.04625	0.02303	35520	4.03	0.0472
	R^2 = 0.9881					
IV	Intercept	-4050.77186	735.07595	251291	30.37	<.0001
	rep	-151.41751	52.87285	67866	8.20	0.0051
	fn	-26.87616	8.87289	75922	9.17	0.0031
	fn^2	0.05064	0.03012	23387	2.83	0.0959
	sn	17.86565	3.70389	192525	23.27	<.0001
	sp	54.04114	12.36796	157986	19.09	<.0001
	sk	44.61347	12.01400	114110	13.79	0.0003
	sp^2	-0.96510	0.22608	150794	18.22	<.0001
	sk^2	-0.09463	0.04896	30913	3.74	0.0561
	fnxsn	0.17517	0.05914	72588	8.77	0.0038
	fpxsp	0.22470	0.04925	172270	20.82	<.0001
	fnxfp	0.09597	0.03418	65236	7.88	0.0060
	fpxfk	-0.13261	0.03341	130388	15.76	0.0001
	R^2 = 0.9892					

Table 5.1.10 Estimated ridge of maximum yield
Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 1999

Average STV* of the Site: SN= 157. 42 Kg; SP=33. 55 Kg; SK=109. 54 Kg

Coded Radius	Estimated yield	Standard Error	Uncoded Factor Values		
			fn	fp	fk
0.0	3321.498899	23.637714	37.500000	40.000000	20.000000
0.1	3378.876646	23.681125	40.468165	42.444345	19.981644
0.2	3439.287680	23.910252	43.527816	44.758488	19.936489
0.3	3502.809194	24.331266	46.662130	46.958681	19.871124
0.4	3569.503069	24.966935	49.857654	49.059390	19.790502
0.5	3639.419219	25.858413	53.103649	51.073249	19.698340
0.6	3712.598180	27.063183	56.391527	53.011168	19.597431
0.7	3789.073118	28.649513	59.714392	54.882520	19.489880
0.8	3868.871368	30.688604	63.066685	56.695338	19.377281
0.9	3952.015622	33.246474	66.443890	58.456507	19.260847
1.0	4038.524853	36.377771	69.842322	60.171938	19.141506

* **STV- Soil Test Value**

Table 5.1.11 : Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Bhubaneswar Crop: Paddy Year: Kharif 2000

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Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error
Intercept	2871.21669*	77.36596	1930.94112	1592.65048	-2655.21570	7995.36833	1672.22195	7772.81469
fn	20.63827*	7.72328	14.37558	22.51648	-23.78817	75.69921	-20.08764	74.56008
fp	9.97022	6.89032	-3.74100	10.30949	-3.16906	18.20276	2.96869	17.69390
fk	4.88214	12.06608	16.03722	23.83112	16.62854	48.64238	27.72245	47.85593
fn^2	-0.45531*	0.15166	-0.23861*	0.12099	-0.29871*	0.16405	-0.56052*	0.19361
fp^2	-0.18297	0.12431	0.11559	0.07345	0.11533	0.08184	-0.19238	0.12660
fk^2	0.21219	0.32236	0.42286*	0.24798	0.43462	0.27748	0.33549	0.33576
sn	-------	-------	-8.17558	13.60940	54.26162	122.15873	45.95277	119.51532
sp	-------	-------	22.95060	24.35525	16.43070	102.51585	46.24442	99.62992
sk	-------	-------	14.92981	10.29697	13.61061	87.87601	-2.03861	85.78530
sn^2	-------	-------	-------	-------	-0.20184	0.39662	-0.17126	0.38833
sp^2	-------	-------	-------	-------	0.06156	1.75083	-0.38179	1.69693
sk^2	-------	-------	-------	-------	0.00442	0.43089	0.07224	0.42052
fn*sn	-------	-------	0.11208	0.17959	0.35787	0.50115	0.27872	0.49136
fp*sp	-------	-------	-0.06048	0.32595	-0.06908	0.60865	0.09868	0.59283
fk*sk	-------	-------	-0.22280	0.24028	-0.22974	0.49334	-0.27908	0.47866
fn*fp	0.52543*	0.22919	-------	-------	-------	-------	0.55392*	0.21027
fn*fk	0.12570	0.22298	-------	-------	-------	-------	0.13875	0.20946
fp*fk	-0.16611	0.31038	-------	-------	-------	------	-0.18574	0.28578
R^2	**0.7614**		**0.8070**		**0.8077**		**0.8263**	

Table 5.1.12 Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 2000

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2893.71003	63.43730	378334206	2080.75	<.0001
	fn	26.78225	5.26500	4704919	25.88	<.0001
	fn^2	-0.33327	0.08626	2713872	14.93	0.0002
	fk^2	0.28127	0.09369	1638880	9.01	0.0033
	fnxfp	0.26018	0.06538	2879174	15.83	0.0001
	R^2 = 0.7558					
II	Intercept	1265.28766	291.86840	2816574	18.79	<.0001
	fn	24.53193	4.80707	3903184	26.04	<.0001
	fn^2	-0.14848	0.06434	798119	5.33	0.0230
	fp^2	0.06904	0.02463	1177020	7.85	0.0060
	fk^2	0.16103	0.08863	494710	3.30	0.0721
	sk	15.85680	2.88434	4529546	30.22	<.0001
	R^2 = 0.8006					
III	Intercept	927.88167	492.49260	543118	3.55	0.0624
	fk	35.05396	18.89109	526827	3.44	0.0663
	fn^2	-0.20777	0.08734	865887	5.66	0.0192
	fp^2	0.06987	0.02512	1183819	7.74	0.0064
	fk^2	0.47523	0.24157	592148	3.87	0.0518
	sk	19.45120	4.94881	2363741	15.45	0.0002
	fnxsn	0.15423	0.03607	2796980	18.28	<.0001
	fkxsk	-0.40843	0.19090	700386	4.58	0.0347
	R^2 = 0.8002					
IV	Intercept	2347.77052	251.38414	12051259	87.22	<.0001
	fn^2	-0.50775	0.10276	3373260	24.41	<.0001
	fp^2	-0.13777	0.05337	920551	6.66	0.0112
	fk^2	0.27100	0.08172	1519519	11.00	0.0013
	sp	48.43155	10.98369	2686317	19.44	<.0001
	sn^2	-0.03852	0.01848	600207	4.34	0.0396
	fnxsn	0.19322	0.03821	3533691	25.58	<.0001
	fnxfp	0.43599	0.11915	1849927	13.39	0.0004
	R^2 = 0.8196					

Table 5.1.13 Parameter estimates along with standard errors for response surface models using different number of variables (models include replication)

Centre: Bhubaneswar Crop: Paddy Year: Kharif 2000

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	2438.83276*	106.12984	-183.61741	2081.12434	-11514*	9013.69942	-11601*	8663.90633
Replication	172.95357*	32.37424	-261.19753	167.14327	-389.26513	193.02937	-439.97718	185.43250
fn	20.63827*	6.85329	14.23183	22.35444	-47.62612	75.45006	-46.28938	73.60385
fp	9.97022	6.11416	-4.58540	10.24947	-2.13294	17.92617	4.50160	17.28135
fk	4.88214	10.70690	23.76940	24.17127	-5.34799	49.10802	3.20454	47.83683
fn^2	-0.45531*	0.13458	-0.22773*	0.12032	-0.33043*	0.16226	-0.60969*	0.19010
fp^2	-0.18297	0.11030	0.12746*	0.07332	0.12931	0.08086	-0.19526	0.12356
fk^2	0.21219	0.28605	0.49931*	0.25101	0.46622*	0.27360	0.35681	0.32782
sn	-------	-------	-4.38629	13.72721	93.16501	121.79067	88.78428	118.03565
sp	-------	-------	46.54999	28.50820	21.30987	100.94563	53.38618	97.28551
sk	-------	-------	30.41159*	14.23564	107.24115	98.17768	103.32608	94.77401
sn^2	-------	-------	-------	-------	-0.30316	0.39366	-0.28182	0.38186
sp^2	-------	-------	-------	-------	0.47490	1.73566	0.05995	1.66664
sk^2	-------	-------	-------	-------	-0.34537	0.45827	-0.32110	0.44265
fn*sn	-------	-------	-------	-------	-------	-------	0.40913	0.48271
fp*sp	-------	-------	-------	-------	-------	-------	-0.13113	0.58665
fk*sk	-------	-------	-------	-------	-------	-------	-0.14416	0.47062
fn*fp	0.52543*	0.20337	0.09336	0.17869	0.47967	0.49702	0.58193*	0.20556
fn*fk	0.12570	0.19786	-0.17515	0.33182	-0.28171	0.60837	0.14809	0.20447
fp*fk	-0.16611	0.27542	-0.36966	0.25639	-0.10838	0.48936	-0.18617	0.27893
R^2	**0.8140**		**0.8117**		**0.8156**		**0.8363**	

Table 5.1.14 Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Bhubaneswar Crop: Paddy (Konark) Year: Kharif 2000

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2461.32610	98.07090	90723708	629.88	<.0001
	rep	172.95357	32.07505	4187811	29.08	<.0001
	fn	26.78225	4.68600	4704919	32.67	<.0001
	fn^2	-0.33327	0.07678	2713872	18.84	<.0001
	fk2	0.28127	0.08339	1638880	11.38	0.0010
	fnxfp	0.26018	0.05819	2879174	19.99	<.0001
	R^2 = 0.8083					
II	Intercept	1265.28766	291.86840	2816574	18.79	<.0001
	fn	24.53193	4.80707	3903184	26.04	<.0001
	fn^2	-0.14848	0.06434	798119	5.33	0.0230
	fp^2	0.06904	0.02463	1177020	7.85	0.0060
	fk^2	0.16103	0.08863	494710	3.30	0.0721
	sk	15.85680	2.88434	4529546	30.22	<.0001
	R^2 = 0.8006					
III	Intercept	-4942.37941	2088.55048	850219	5.60	0.0198
	rep	-191.60711	78.82696	897061	5.91	0.0168
	fn^2	-0.17866	0.08287	705727	4.65	0.0334
	fp_2	0.05813	0.02671	718809	4.73	0.0318
	sk	126.78973	36.53602	1828412	12.04	0.0008
	sk^2	-0.43455	0.14742	1319152	8.69	0.0039
	fnxsn	0.13895	0.03452	2459508	16.20	0.0001
	R^2 = 0.7999					
IV	Intercept	-6066.31160	1970.14039	1245583	9.48	0.0027
	rep	-399.55640	105.39683	1888073	14.37	0.0003
	fn^2	-0.45261	0.10205	2584190	19.67	<.0001
	fp^2	-0.20288	0.06646	1224339	9.32	0.0029
	sp	51.02541	18.28155	1023446	7.79	0.0063
	sk	132.23219	34.03036	1983622	15.10	0.0002
	sk^2	-0.46554	0.13737	1508931	11.49	0.0010
	fnxsn	0.10797	0.03300	1405938	10.70	0.0015
	fnxfp	0.50989	0.12317	2251510	17.14	<.0001
	R^2 = 0.8301					

Table 5.1.15 Estimated ridge of maximum yield
Centre: Bhubaneswar Crop: Paddy Year: Kharif 2000

Average STV* of the Site: SN=165.60 Kg; SP =34.51 Kg; SK=108.43 Kg

Coded Radius	Estimated yield	Standard Error	Uncoded Factor Values fn	fp	fk
0.0	4042.991388	108.100649	37.500000	40.000000	20.000000
0.1	4106.848796	108.511274	39.649687	42.937445	20.726906
0.2	4169.894423	108.246806	41.739753	45.893769	21.484196
0.3	4232.153786	107.312996	43.791428	48.847513	22.274088
0.4	4293.646673	105.771137	45.813970	51.785945	23.100238
0.5	4354.392096	103.728883	47.811141	54.699359	23.967389
0.6	4414.410649	101.339839	49.783659	57.578767	24.881332
0.7	4473.726072	98.806429	51.730173	60.414695	25.848989
0.8	4532.366681	96.382841	53.647631	63.196377	26.878537
0.9	4590.366895	94.374524	55.531324	65.911084	27.979530
1.0	4647.769038	93.129945	57.374766	68.543499	29.162958

* **STV- Soil Test Value**

Table 5.2.1: **Parameter estimates along with standard errors for response surface models using different number of variables**
Centre: Hyderabad Crop: Sunflower Year: Rabi- 1993

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error
Intercept	740.67470	52.47508	572.48037	387.90244	-646.45073	1720.40134	-832.04654	1734.08631
fn	13.50872	1.28110	8.75395	3.63183	5.79765	6.37837	6.78457	6.50202
fp	1.96191	1.64270	0.63621	2.01861	0.47315	1.99573	0.23788	2.01400
fk	0.14721	1.62007	-3.19157	3.26921	-4.45835	3.23642	-4.86907	3.26148
fn^2	-0.05922	0.00898	-0.05220	0.01334	-0.04926	0.01505	-0.04553	0.01546
fp^2	-0.02139	0.01744	-0.01674	0.01639	-0.01885	0.01618	-0.01706	0.01629
fk^2	0.00059	0.01713	0.00247	0.01619	0.00258	0.01591	0.00257	0.01598
sn	---------	---------	-0.11809	1.48203	1.43932	13.07375	1.64074	13.17814
sp	---------	---------	0.84786	3.05122	31.02999	12.00071	28.05288	12.46520
sk	---------	---------	0.75573	0.55014	4.23370	4.48280	5.24615	4.57094
sn^2	---------	---------	-------	-------	-0.00391	0.02830	-0.00404	0.02857
sp^2	---------	---------	-------	-------	-0.48237	0.19048	-0.42905	0.19636
sk^2	---------	---------	-------	-------	-0.00462	0.00609	-0.00623	0.00622
fn*sn	---------	---------	0.01017	0.01653	0.01945	0.02874	0.01596	0.02922
fp*sp	---------	---------	0.03067	0.04942	0.04171	0.04906	0.05515	0.05792
fk*sk	---------	---------	0.00676	0.00870	0.01031	0.00861	0.01425	0.00910
fn*fp	-0.00192	0.00996	-------	------	-------	-------	-0.00328	0.01073
fn*fk	-0.00682	0.01002	-------	-------	-------	-------	-0.01418	0.01017
fp*fk	0.00495	0.01193	-------	-------	-------	------	-0.00207	0.01153
R^2	0.7339		0.7766		0.7921		0.7965	

Table 5.2.2 Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Hyderabad Crop: Sunflower Year: Rabi- 1993

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	770.28409	36.98861	8244270	433.68	<.0001
	fn	13.32749	1.21251	2296762	120.82	<.0001
	fn2	-0.06019	0.00866	918225	48.30	<.0001
	R^2 = 0.7264					
II	Intercept	439.39668	115.82435	237897	14.39	0.0002
	fn	10.45566	1.46677	839945	50.81	<.0001
	fn2	-0.04320	0.01018	297437	17.99	<.0001
	fp2	-0.01752	0.01056	45533	2.75	0.0997
	sk	1.09486	0.37759	138981	8.41	0.0045
	fpsp	0.05244	0.02745	60307	3.65	0.0586
	R^2 = 0.7682					
III	Intercept	-71.49933	225.06627	1616.64053	0.10	0.7513
	fn	9.99236	1.48698	723361	45.16	<.0001
	fn2	-0.04054	0.01064	232485	14.51	0.0002
	sp	28.84053	11.43482	101901	6.36	0.0130
	sk	1.27353	0.42063	146839	9.17	0.0030
	sp2	-0.40656	0.17763	83919	5.24	0.0239
	R^2 = 0.7754					
IV	Intercept	-62.56971	222.91849	1237.44008	0.08	0.7795
	fn	10.15944	1.47533	744815	47.42	<.0001
	fn2	-0.04015	0.01054	227910	14.51	0.0002
	sp	26.96939	11.37018	88368	5.63	0.0194
	sk	1.31211	0.41707	155462	9.90	0.0021
	sp2	-0.36341	0.17750	65840	4.19	0.0429
	fnfk	-0.00824	0.00456	51275	3.26	0.0735
	R^2 = 0.7817					

Table 5.2.3 : Parameter estimates along with standard errors for response surface models using different number of Variables (models include replication)

Centre: Hyderabad Crop: Sunflower Year: Rabi- 1993

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	582.19884	52.42237	436.27424	344.43589	-2698.43970	1560.04346	-3042.73491	1560.99622
Replication	61.12290	10.02634	56.62947	10.26889	57.91092	10.40707	59.88060	10.46087
fn	13.50248	1.11137	8.65258	3.21661	0.65715	5.69535	0.93710	5.76233
fp	1.79037	1.42534	1.82449	1.80074	1.41101	1.76648	1.13336	1.76356
fk	0.81929	1.40975	-1.80617	2.90628	-3.02989	2.86312	-3.44876	2.85546
fn2	-0.05872	0.00779	-0.04264	0.01195	-0.04178	0.01333	-0.03880	0.01353
fp2	-0.02216	0.01513	-0.01901	0.01452	-0.01817	0.01425	-0.01580	0.01421
fk2	-0.00148	0.01486	0.00226	0.01434	0.00425	0.01402	0.00413	0.01394
sn	-------	-------	-0.62763	1.31582	15.64988	11.79888	17.21692	11.81167
sp	-------	-------	0.32069	2.70403	19.94071	10.75990	17.31945	11.03265
sk	-------	-------	1.14185	0.49224	6.65188	3.97360	7.71073	4.00995
sn2	-------	-------	0.00731	0.01465	-0.03530	0.02557	-0.03870	0.02564
sp2	-------	-------	-0.00901	0.04436	-0.30011	0.17100	-0.23338	0.17465
sk2	-------	-------	0.00354	0.00773	-0.00749	0.00539	-0.00920	0.00545
fnsn	-------	-------	-------	-------	0.03715	0.02552	0.03657	0.02574
fpsp	-------	-------	-------	-------	0.00530	0.04372	-0.00205	0.05149
fksk	-------	-------	-------	-------	0.00627	0.00762	0.01065	0.00797
fnfp	0.00053	0.00865	-------	-------	-------	-------	0.00297	0.00942
fnfk	-0.01104	0.00872	-------	-------	-------	-------	-0.01838	0.00890
fpfk	0.00203	0.01036	-------	-------	-------	-------	0.00214	0.01008
R^2	0.8015		0.8264		0.8401	0.8467		

Table 5.2.4 Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Hyderabad Crop: Sunflower Year: Rabi- 1993

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	619.15909	40.52048	3373550	233.48	<.0001
	rep	60.45000	9.81455	548130	37.94	<.0001
	fn	13.32749	1.05708	2296762	158.96	<.0001
	fn2	-0.06019	0.00755	918225	63.55	<.0001
	R^2 = 0.7938					
II	Intercept	255.05988	94.89420	91374	7.22	0.0083
	rep	57.38223	9.21173	490781	38.80	<.0001
	fn	10.15584	1.24594	840336	66.44	<.0001
	fn2	-0.04007	0.00855	278047	21.98	<.0001
	sk	1.25386	0.29958	221561	17.52	<.0001
	R^2 = 0.8211					
III	Intercept	-1732.52994	914.11610	44361	3.59	0.0607
	rep	58.16108	9.86426	429321	34.76	<.0001
	fn2	-0.04891	0.01128	232142	18.80	<.0001
	sn	15.75487	7.29658	57575	4.66	0.0330
	sp	19.48615	10.48351	42666	3.45	0.0657
	sk	1.34103	0.37314	159505	12.92	0.0005
	sn2	-0.03678	0.01404	84749	6.86	0.0100
	sp2	-0.30427	0.16440	42300	3.43	0.0669
	fnsn	0.04458	0.00597	687690	55.69	<.0001
	R^2 = 0.8314					
IV	Intercept	-2045.57038	904.43439	62473	5.12	0.0256
	rep	61.38241	9.59695	499623	40.91	<.0001
	fn2	-0.04651	0.01110	214490	17.56	<.0001
	sn	20.39637	6.88401	107212	8.78	0.0037
	sk	1.38200	0.33130	212517	17.40	<.0001
	sn2	-0.04580	0.01305	150407	12.32	0.0006
	fnsn	0.04451	0.00583	711815	58.28	<.0001
	fnfk	-0.00756	0.00390	45883	3.76	0.0551
	R^2 = 0.8317					

Table 5.2.5 : Estimated ridge of maximum yield

Centre: Hyderabad Crop: Sunflower Year: Rabi - 1993

Average STV* of the Site: SN=259.43 Kg; SP=30.71 Kg; SK= 370.77Kg

Coded Radius	Estimated yield	Standard Error	Uncoded Factor Values fn	fp	fk
0.0	1352.907834	33.536170	60.000000	40.000000	40.000000
0.1	1380.655736	33.323255	65.982142	40.107061	39.710795
0.2	1405.250713	32.858784	71.938680	40.232173	39.226367
0.3	1426.747707	32.169029	77.840959	40.378932	38.454097
0.4	1445.242206	31.333335	83.627629	40.549439	37.246746
0.5	1460.906359	30.474620	89.169257	40.739280	35.384819
0.6	1474.047466	29.719423	94.226235	40.927584	32.617471
0.7	1485.154702	29.133644	98.497247	41.073003	28.857061
0.8	1494.834558	28.739894	101.844439	41.139193	24.363533
0.9	1503.635231	28.634233	104.402053	41.122844	19.542772
1.0	1511.941638	29.015876	106.402736	41.041936	14.663650

* **STV- Soil Test Value**

Table 5.2.6 : Parameter estimates along with standard errors for response surface models using different number of variables
Centre: Hyderabad Crop: Groundnut Year: Rabi 1997- 98

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	1514.49542	18.22951	1452.67797	129.52802	2848.48921	972.40612	1957.75290	737.28950
fn	4.39738	2.35580	-8.41342	5.51750	-4.41815	5.73632	-5.56166	4.27842
fp	3.85008	1.17790	5.04775	0.81576	5.95437	0.91015	5.35547	0.69638
fk	0.84568	1.17790	-3.38522	2.54446	1.38416	3.47276	1.82972	2.98264
fn2	0.18969	0.07288	0.16389	0.04582	0.17620	0.05293	0.17653	0.03958
fp2	-0.02600	0.01822	-0.01674	0.01131	-0.02592	0.01189	-0.01971	0.00874
fk2	0.00580	0.01822	0.01237	0.01217	0.01451	0.01217	0.01160	0.00940
sn	------	-------	-0.49033	0.45219	2.54460	4.31438	-2.18743	3.22743
sp	-------	-------	7.91547	0.73519	4.39700	2.51299	8.67728	1.89281
sk	-------	-------	-0.16356	0.33048	-10.91783	5.14106	-2.39805	3.93268
sn2	-------	-------	-------	-------	-0.00522	0.00870	0.00401	0.00651
sp2	-------	-------	-------	-------	0.05289	0.03640	0.01357	0.02703
sk2	-------	-------	-------	-------	0.01631	0.00780	0.00369	0.00594
fnsn	-------	-------	0.06098	0.02354	0.04134	0.02540	0.03074	0.01895
fpsp	-------	-------	-0.06039	0.01762	-0.07414	0.02069	-0.09520	0.01538
fksk	-------	-------	0.01045	0.00771	-0.00367	0.01052	-0.00444	0.00963
fnfp	0.06764	0.02473	-------	-------	-------	-------	0.10412	0.01161
fnfk	0.03611	0.02473	-------	-------	-------	-------	0.03887	0.01485
fpfk	-0.01153	0.01237	-------	-------	-------	-------	-0.01167	0.00630
R^2	**0.8613**		**0.9522**		**0.9552**		**0.9768**	

Table 5.2.7 Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Hyderabad Crop: Groundnut Year: Rabi 1997- 98

Models	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	1514.59058	16.27260	57558160	8663.17	<.0001
	fn	5.48555	2.28574	38266	5.76	0.0180
	fp	1.94547	0.44789	125354	18.87	<.0001
	fk	1.39032	0.30597	137187	20.65	<.0001
	fn2	0.18962	0.07287	44992	6.77	0.0105
	fnfp	0.06759	0.02438	51064	7.69	0.0065
	R^2 = 0.8552					
II	Intercept	1280.20559	22.23305	7864059	3315.60	<.0001
	fp	4.04634	0.59888	108275	45.65	<.0001
	fn2	0.16599	0.04406	33667	14.19	0.0003
	sp	7.96976	0.72492	286681	120.87	<.0001
	fnsn	0.02619	0.00544	54934	23.16	<.0001
	fpsp	-0.05982	0.01693	29609	12.48	0.0006
	fksk	0.00298	0.00050144	83556	35.23	<.0001
	R^2 = 0.9488					
III	Intercept	2939.94133	604.93954	52349	23.62	<.0001
	fp	5.46819	0.80021	103499	46.70	<.0001
	fn2	0.17095	0.04327	34587	15.60	0.0001
	fp2	-0.02668	0.01135	12253	5.53	0.0205
	fk2	0.01577	0.00362	42038	18.97	<.0001
	sp	8.02111	0.71245	280942	126.75	<.0001
	sk	-9.90238	3.59996	16770	7.57	0.0070
	sk2	0.01468	0.00534	16773	7.57	0.0070
	fnsn	0.02485	0.00573	41727	18.83	<.0001
	fpsp	-0.05779	0.01679	26249	11.84	0.0008
	R^2 = 0.9534					
IV	Intercept	1272.53139	15.90160	7422029	6404.06	<.0001
	fn	-3.79885	2.17765	3526.89999	3.04	0.0839
	fp	5.16264	0.57570	93200	80.42	<.0001
	fn2	0.16194	0.03136	30910	26.67	<.0001
	fp2	-0.01961	0.00781	7311.65508	6.31	0.0135
	fk2	0.01543	0.00355	21949	18.94	<.0001
	sp	9.38610	0.53810	352626	304.26	<.0001
	fnsn	0.02541	0.00898	9291.19676	8.02	0.0055
	fpsp	-0.08988	0.01274	57691	49.78	<.0001
	fnfp	0.10452	0.01082	108064	93.24	<.0001
	fnfk	0.03977	0.01018	17667	15.24	0.0002
	fpfk	-0.01074	0.00507	5199.62381	4.49	0.0365
	R^2 = 0.9761					

Table 5.2.8: Parameter estimates along with standard errors for response surface models using different number of variables (models include replication)
Centre: Hyderabad Crop: Groundnut Year: Rabi 1997- 98

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	1367.34542	13.19164	1619.58398	129.42285	3289.79612	870.72347	2252.72018	721.31271
Replication	58.86000	3.55043	36.34740	9.45716	50.56648	9.57102	23.47708	8.39142
fn	4.39738	1.26113	-10.65695	5.22611	-6.68884	5.13083	-6.74952	4.16247
fp	3.85008	0.63056	4.78196	0.77095	6.36235	0.81489	5.59520	0.67940
fk	0.84568	0.63056	-2.37030	2.40952	3.12470	3.11277	3.10328	2.92234
fn^2	0.18969	0.03901	0.15162	0.04324	0.17561	0.04718	0.17481	0.03831
fp^2	-0.02600	0.00975	-0.01411	0.01067	-0.02356	0.01061	-0.01921	0.00846
fk^2	0.00580	0.00975	0.01416	0.01146	0.01644	0.01086	0.01390	0.00913
sn	-------	-------	-0.92500	0.44040	2.39623	3.84552	-1.70394	3.12836
sp	-------	-------	3.80950	1.27286	-5.97135	2.97795	3.37499	2.63584
sk	-------	-------	-0.31405	0.31353	-12.43197	4.59119	-4.03555	3.85088
sn2	-------	-------	-------	-------	-0.00586	0.00775	0.00260	0.00632
sp2	-------	-------	-------	-------	0.12488	0.03519	0.05095	0.02938
sk2	-------	-------	-------	-------	0.01834	0.00697	0.00608	0.00581
fn*sn	-------	-------	0.07648	0.02252	0.05614	0.02281	0.03994	0.01863
fp*sp	-------	-------	-0.04171	0.01728	-0.06978	0.01846	-0.08985	0.01501
fk*sk	-------	-------	0.00787	0.00729	-0.00818	0.00942	-0.00836	0.00942
fn*fp	0.06764	0.01324	-------	-------	-------	-------	0.08961	0.01237
fn*fk	0.03611	0.01324	-------	-------	-------	-------	0.03885	0.01437
fp*fk	-0.01153	0.00662	-------	-------	-------	-------	-0.00939	0.00615
R^2	**0.9606**		**0.9581**		**0.9647**		**0.9785**	

Table 5.2.9 Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Hyderabad Crop: Groundnut Year: Rabi 1997- 98

Models	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	1366.64120	13.09980	20458588	10883.80	<.0001
	rep	58.86000	3.53999	519675	276.46	<.0001
	fn	4.35043	1.25496	22589	12.02	0.0008
	fp	3.82660	0.62748	69908	37.19	<.0001
	fk	1.17823	0.29111	30793	16.38	<.0001
	fn2	0.19022	0.03889	44972	23.92	<.0001
	fp2	-0.02587	0.00972	13311	7.08	0.0090
	fnfp	0.06803	0.01318	50050	26.63	<.0001
	fnfk	0.03650	0.01318	14410	7.67	0.0066
	fpfk	-0.01133	0.00659	5553	2.95	0.0885
	R^2 = 0.9605					
II	Intercept	1553.93200	100.23961	493339	240.32	<.0001
	rep	36.66289	9.20108	32594	15.88	0.0001
	fn	-12.59307	4.88357	13651	6.65	0.0112
	fp	4.00154	0.56717	102184	49.78	<.0001
	fn2	0.14857	0.04237	25242	12.30	0.0007
	fk2	0.01971	0.00280	102002	49.69	<.0001
	sn	-1.06743	0.42018	13249	6.45	0.0125
	sp	3.83163	1.24061	19582	9.54	0.0025
	fnsn	0.08440	0.02124	32402	15.78	0.0001
	fpsp	-0.04409	0.01676	14203	6.92	0.0098
	R^2 = 0.9568					
III	Intercept	3294.19380	547.93082	64718	36.14	<.0001
	rep	46.35348	9.09190	46541	25.99	<.0001
	fp	6.56269	0.79086	123294	68.86	<.0001
	fn2	0.19351	0.03943	43119	24.08	<.0001
	fp2	-0.02584	0.01020	11496	6.42	0.0127
	fk2	0.01935	0.00335	59900	33.45	<.0001
	sp	-4.96817	2.89385	5277.37104	2.95	0.0889
	sk	-10.98829	3.24231	20565	11.49	0.0010
	sp2	0.11934	0.03467	21215	11.85	0.0008
	sk2	0.01603	0.00480	19933	11.13	0.0012
	fnsn	0.02570	0.00530	42027	23.47	<.0001
	fpsp	-0.07331	0.01771	30681	17.14	<.000
	R^2 = 0.9630					
IV	Intercept	1538.59282	71.10050	517695	468.28	<.0001
	rep	29.88696	5.54109	32162	29.09	<.0001
	fn	-9.50767	3.63444	7565.60746	6.84	0.0102
	fp	5.67328	0.59888	99213	89.74	<.0001
	fn2	0.16626	0.03139	31007	28.05	<.0001
	fp2	-0.01673	0.00771	5201.52535	4.70	0.0323
	fk2	0.01645	0.00346	24916	22.54	<.0001
	sn	-0.67354	0.31262	5131.73450	4.64	0.0335
	sp2	0.08764	0.01141	65225	59.00	<.0001
	fnsn	0.05352	0.01603	12317	11.14	0.0012
	fpsp	-0.09284	0.01446	45562	41.21	<.0001
	fnfp	0.08481	0.01063	70402	63.68	<.0001
	fnfk	0.03681	0.00994	15152	13.71	0.0003
	fpfk	-0.00841	0.00496	3171.05335	2.87	0.0933
	R^2 = 0.9776					

Table 5.2.10 Estimated ridge of maximum yield

Centre: Hyderabad Crop: Groundnut Year: 199

Average STV* of the Site: SN=240.45 **Kg; SP=** 33.56 **Kg; SK=** 346.84 **Kg**

Coded Radius	Estimated yield	Standard Error	Uncoded Factor Values fn	fp	fk
0.0	1782.147131	20.418236	15.000000	30.000000	30.000000
0.1	1804.682032	20.297740	16.352773	31.168540	30.560830
0.2	1828.101016	20.060524	17.720389	32.271697	31.112352
0.3	1852.413794	19.724917	19.099955	33.319481	31.656058
0.4	1877.628104	19.321658	20.489238	34.320079	32.193171
0.5	1903.750175	18.896744	21.886496	35.280219	32.724694
0.6	1930.785065	18.514376	23.290361	36.205458	33.251453
0.7	1958.736921	18.258641	24.699744	37.100410	33.774129
0.8	1987.609173	18.231424	26.113772	37.968935	34.293291
0.9	2017.404676	18.543523	27.531741	38.814277	34.809410
1.0	2048.125826	19.298247	28.953074	39.639181	35.322885

* **STV- Soil Test Value**

Table 5.2.11 Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure (With New Variables FNFP,FNFK AND FPFK)

CENTRE: HYDERABAD CROP: GROUNDNUT YEAR :RABI 1997-98

Models	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
III(b)	Intercept	1272.53139	15.90160	7422029	6404.06	<.0001
	fn	-3.79885	2.17765	3526.89999	3.04	0.0839
	fp	5.16264	0.57570	93200	80.42	<.0001
	fn2	0.16194	0.03136	30910	26.67	<.0001
	fp2	-0.01961	0.00781	7311.65508	6.31	0.0135
	fk2	0.01543	0.00355	21949	18.94	<.0001
	sp	9.38610	0.53810	352626	304.26	<.0001
	fnsn	0.02541	0.00898	9291.19676	8.02	0.0055
	fpsp	-0.08988	0.01274	57691	49.78	<.0001
	fnfp	0.10452	0.01082	108064	93.24	<.0001
	fnfk	0.03977	0.01018	17667	15.24	0.0002
	fpfk	-0.01074	0.00507	5199.62381	4.49	0.0365
	R^2 = 0.9761					
III(b) (with repl.)	Intercept	1418.35789	76.08580	388946	347.51	<.0001
	rep	14.92075	7.20201	4803.94971	4.29	0.0407
	fn	-8.79548	3.66917	6431.42552	5.75	0.0183
	fp	4.96704	0.57275	84175	75.21	<.0001
	fn2	0.15109	0.03144	25849	23.09	<.0001
	fp2	-0.01752	0.00776	5710.45413	5.10	0.0259
	fk2	0.01582	0.00349	22975	20.53	<.0001
	sn	-0.59052	0.31713	3880.65470	3.47	0.0654
	sp	7.65813	1.01454	63772	56.98	<.0001
	fnsn	0.05016	0.01623	10688	9.55	0.0026
	fpsp	-0.07972	0.01340	39582	35.36	<.0001
	fnfp	0.09646	0.01127	82050	73.31	<.0001
	fnfk	0.03942	0.01001	17360	15.51	0.0001
	fpfk	-0.00988	0.00500	4380.67609	3.91	0.0505
	R^2 = 0.9773					

Table 5.2.12: Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Maruteru Crop- Rice Year: Rabi-1994

Models	I		II		III		IV	
Parameters	**Parameter estimates**	**Standard Error**	**Parameter estimates**	**Standard Error**	**Parameters**	**Parameter estimates**	**Standard Error**	**Parameter estimates**
Intercept	2078.66367	112.84644	4383.69316	1123.63222	3950.42727	4208.73738	4504.03759	4285.60049
fn	37.62341	3.59514	13.24265	8.25451	18.57427	16.93481	19.92983	17.41864
fp	4.48754	5.24455	-1.38651	4.87251	-1.35307	5.00862	1.55522	5.80591
fk	14.24206	5.24455	16.19023	9.13836	15.73285	9.25376	16.06610	9.90542
fn^2	-0.10337	0.02246	-0.16713	0.02132	-0.16084	0.02473	-0.14950	0.02741
fp^2	0.03002	0.05242	0.08381	0.04917	0.08636	0.04988	0.08262	0.05042
fk^2	-0.10214	0.05242	-0.10385	0.04872	-0.10874	0.04960	-0.10641	0.05031
sn	-------	-------	-5.91646	3.46565	-11.44090	25.59362	-13.80866	26.12447
sp	-------	-------	2.47080	3.08442	-1.68374	9.27613	-1.02230	9.40755
sk	-------	-------	-2.17531	1.43987	4.78253	8.59600	3.05738	8.83704
sn2	-------	-------	-------	-------	0.01107	0.04394	0.01530	0.04493
sp2	-------	-------	-------	-------	0.03962	0.08853	0.02821	0.09039
sk2	-------	-------	-------	-------	-0.00998	0.01225	-0.00695	0.01264
fn*sn	-------	-------	0.10080	0.02950	0.08107	0.05885	0.07344	0.06033
fp*sp	-------	-------	-0.07306	0.05941	-0.07623	0.06569	-0.06901	0.06708
fk*sk	-------	-------	-0.00089557	0.02533	0.00154	0.02576	-0.00184	0.03248
fn*fp	-0.06859	0.02821	-------	-------	-------	-------	-0.03329	0.02822
fn*fk	0.02478	0.02821	-------	-------	-------	-------	0.00544	0.02975
fp*fk	-0.01725	0.03670	-------	-------	-------	-------	0.00194	0.04077
R^2	**0.8849**		**0.9073**		**0.9081**		**0.9094**	

Table 5.2.13 : Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Maruteru Crop- Rice Year: Rabi-1994

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2068.62792	111.06128	58000383	346.93	<.0001
	fn	37.10933	3.31136	20996443	125.59	<.0001
	fp	5.90616	2.96646	662714	3.96	0.0489
	fk	15.90472	4.31469	2271668	13.59	0.0004
	fn2	-0.09668	0.02012	3861774	23.10	<.0001
	fk2	-0.10110	0.05200	631997	3.78	0.0543
	fnfp	-0.06608	0.02777	947064	5.66	0.0190
	R^2 = 0.8836					
II	Intercept	2715.26393	264.96819	14905620	105.01	<.0001
	fn	25.60463	4.53412	4526527	31.89	<.0001
	fk	16.37605	3.97232	2412361	17.00	<.0001
	fn2	-0.15027	0.01717	10875233	76.62	<.0001
	fk2	-0.10846	0.04816	719786	5.07	0.0263
	sk	-2.09864	0.85347	858254	6.05	0.0155
	fnsn	0.05273	0.01213	2684877	18.92	<.0001
	R^2 = 0.9011					
III	Intercept	2361.19458	140.07155	40166211	284.16	<.0001
	fn	25.57679	4.51483	4536346	32.09	<.0001
	fk	16.41645	3.96379	2424562	17.15	<.0001
	fn2	-0.15003	0.01712	10851076	76.77	<.0001
	fk2	-0.10880	0.04804	725104	5.13	0.0254
	sk2	-0.00304	0.00119	925193	6.55	0.0118
	fnsn	0.05270	0.01210	2682671	18.98	<.0001
	R^2= 0.9016					
IV	Intercept	2369.62139	147.73532	35357554	257.27	<.0001
	fn	24.30554	4.49870	4011719	29.19	<.0001
	fk	16.12431	3.91058	2336537	17.00	<.0001
	fn2	-0.13549	0.01816	7652706	55.68	<.0001
	fp2	0.06327	0.02786	708979	5.16	0.0251
	fk2	-0.10529	0.04742	677692	4.93	0.0284
	sk2	-0.00342	0.00134	896855	6.53	0.0120
	fnsn	0.05246	0.01197	2640779	19.21	<.0001
	fnfp	-0.03964	0.02201	445567	3.24	0.0745
	R^2= 0.9060					

Table 5.2.14: Parameter estimates along with standard errors for response surface models using different number of Variables (models include replication)

Centre: Maruteru Crop- Rice Year: Rabi-1994

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	2312.04700	136.34159	4438.04982	1106.40188	4354.36440	4146.44114	4914.73600	4224.55148
Replication	-93.35333	32.58865	-122.66207	58.35131	-123.52856	59.01695	-121.94818	59.67559
fn	37.62341	3.48287	12.05322	8.14538	18.80344	16.66643	20.53019	17.15358
fp	4.48754	5.08077	-2.25110	4.81408	-2.30226	4.94995	0.38190	5.74549
fk	14.24206	5.08077	14.41097	9.03550	13.91691	9.14814	14.65878	9.77755
fn^2	-0.10337	0.02176	-0.15537	0.02172	-0.14782	0.02512	-0.13804	0.02757
fp^2	0.03002	0.05078	0.08728	0.04843	0.08964	0.04911	0.08609	0.04967
fk^2	-0.10214	0.05078	-0.10898	0.04803	-0.11431	0.04888	-0.11134	0.04960
sn	-------	-------	-5.76489	3.41233	-13.86675	25.21412	-16.55538	25.75826
sp	-------	-------	8.56396	4.19771	5.01924	9.67433	5.55517	9.80632
sk	-------	-------	-2.12495	1.41760	4.88814	8.45974	3.33556	8.70236
sn^2	-------	-------	-------	-------	0.01553	0.04330	0.02036	0.04431
sp^2	-------	-------	-------	-------	0.03419	0.08717	0.02458	0.08902
sk^2	-------	-------	-------	-------	-0.01005	0.01206	-0.00720	0.01245
fn*sn	-------	-------	0.09671	0.02911	0.07202	0.05808	0.06371	0.05959
fp*sp	-------	-------	-0.07757	0.05853	-0.07934	0.06467	-0.07361	0.06609
fk*sk	-------	-------	0.00479	0.02508	0.00748	0.02551	0.00159	0.03202
fn*fp	-0.06859	0.02733	-------	-------	-------	-------	-0.03142	0.02781
fn*fk	0.02478	0.02733	-------	-------	-------	-------	0.00830	0.02932
fp*fk	-0.01725	0.03555	-------	-------	-------	-------	0.00593	0.04019
R^2	**0.8930**		**0.9110**		**0.9119**		**0.9130**	

Table 5.2.15: Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Maruteru Crop- Rice Year: Rabi-1994

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2302.01125	134.63073	45902519	292.37	<.0001
	rep	-93.35333	32.35262	1307227	8.33	0.0047
	fn	37.10933	3.20897	20996443	133.73	<.0001
	fp	5.90616	2.87473	662714	4.22	0.0423
	fk	15.90472	4.18127	2271668	14.47	0.0002
	fn2	-0.09668	0.01949	3861774	24.60	<.0001
	fk2	-0.10110	0.05039	631997	4.03	0.0472
	fnfp	-0.06608	0.02691	947064	6.03	0.0156
	R^2= 0.8916					
II	Intercept	5489.29173	657.98108	9414055	69.60	<.0001
	rep	-127.35869	57.37587	666453	4.93	0.0285
	fk	16.23044	3.87577	2371999	17.54	<.0001
	fn2	-0.15944	0.02051	8176936	60.45	<.0001
	fp2	0.08340	0.03243	894804	6.62	0.0115
	fk2	-0.11166	0.04699	763768	5.65	0.0192
	sn	-9.70584	1.99334	3206829	23.71	<.0001
	sp	10.57695	3.93072	979370	7.24	0.0083
	sk	-1.84200	1.03681	426927	3.16	0.0784
	fnsn	0.13480	0.01180	17661474	130.57	<.0001
	R^2= 0.9091					
III	Intercept	5155.17043	578.09304	10734960	79.52	<.0001
	rep	-127.09327	57.30428	664020	4.92	0.0286
	fk	16.28110	3.87160	2387239	17.68	<.0001
	fn2	-0.15864	0.02048	8102635	60.02	<.0001
	fp2	0.08320	0.03240	890293	6.60	0.0116
	fk2	-0.11210	0.04691	770929	5.71	0.0186
	sn	-9.61496	1.98522	3166574	23.46	<.0001
	sp	10.52420	3.92763	969233	7.18	0.0085
	sk2	-0.00269	0.00147	456130	3.38	0.0688
	fnsn	0.13430	0.01174	17653392	130.77	<.0001
	fpsp	-0.10485	0.04733	662341	4.91	0.0288
	R^2= 0.9093					
IV	Intercept	2432.25543	151.08088	35027117	259.18	<.0001
	rep	-55.57075	32.75439	389008	2.88	0.0926
	fn	24.70646	4.46736	4133557	30.59	<.0001
	fk	16.14938	3.87793	2343776	17.34	<.0001
	fn2	-0.13325	0.01805	7361943	54.47	<.0001
	fp2	0.06197	0.02763	679692	5.03	0.0269
	fk2	-0.10747	0.04704	705520	5.22	0.0242
	sk2	-0.00249	0.00144	405195	3.00	0.0862
	fnsn	0.04997	0.01196	2359065	17.46	<.0001
	fnfp	-0.04288	0.02191	517433	3.83	0.0529
	R^2 = 0.9084					

Table 5.2.16 : Estimated ridge of maximum yield
Centre: Maruteru (Hyderabad) Crop: Rice Year: 1994

Average STV* of the Site: SN= 334.82 Kg; SP= 54.30 Kg; SK=346.37 Kg

Coded Radius	Estimated Yield	Standard Error	Uncoded Factor Values fn	fp	fk
0.0	4816.166011	92.983229	75.000000	40.000000	40.000000
0.1	4959.066187	91.659901	82.306326	40.175470	40.885936
0.2	5089.543958	90.680606	89.555785	40.296774	41.909562
0.3	5207.759986	89.907002	96.728358	40.343527	43.096714
0.4	5313.925126	89.349541	103.796470	40.284766	44.477402
0.5	5408.319691	89.151290	110.722201	40.071809	46.084588
0.6	5491.321773	89.551571	117.453557	39.625232	47.950096
0.7	5563.451148	90.820730	123.918995	38.810728	50.094093
0.8	5625.443701	93.159009	130.016843	37.397431	52.500203
0.9	5678.388127	96.555567	135.590960	35.013582	55.062034
1.0	5723.945073	100.648392	140.401762	31.243843	57.511417

* **STV- Soil Test Value**

Table 5.3.1: Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Kalyani Crop: Rape Year: Rabi 1998

Models	I		II		III		IV	
Parameters	**Parameter estimates**	**Standard Error**	**Parameter estimates**	**Standard Error**	**Parameters**	**Parameter estimates**	**Standard Error**	**Parameter estimates**
Intercept	343.80097	47.58357	-347.82375	248.56684	26.93311	995.37689	60.69267	1037.95129
fn	7.05765	2.21874	5.89325	3.71692	7.17790	3.74138	7.33274	3.83392
fp	7.43661	4.01841	9.16856	2.49668	9.81957	2.50608	10.31630	2.82640
fk	0.83494	6.89677	4.90971	4.06540	5.20279	4.05996	3.55462	5.28043
fn^2	-0.02136	0.02343	-0.01420	0.01101	-0.01405	0.01101	-0.01817	0.01498
fp^2	-0.03190	0.06568	-0.05227	0.02975	-0.06192	0.03033	-0.03854	0.04326
fk^2	-0.01210	0.12503	-0.00833	0.05724	-0.02369	0.05751	-0.03083	0.08037
sn	-------	-------	1.09830	1.16664	-1.42477	8.38998	-1.70749	8.72944
sp	-------	-------	10.66345	3.60289	33.74077	10.68614	33.90575	10.81718
sk	-------	-------	0.79134	0.55115	-2.62186	1.98025	-2.50393	2.01267
sn^2	-------	-------	-------	-------	0.00711	0.01628	0.00743	0.01691
sp^2	-------	-------	-------	-------	-0.45803	0.19187	-0.45556	0.19458
sk^2	-------	-------	-------	-------	0.00617	0.00361	0.00592	0.00366
fn*sn	-------	-------	0.00268	0.01343	-0.00337	0.01356	-0.00324	0.01383
fp*sp	------	------	-0.07201	0.06003	-0.06024	0.06012	-0.05917	0.06106
fk*sk	-------	-------	-0.01090	0.01175	-0.00788	0.01166	-0.00824	0.01179
fn*fp	-0.00809	0.05089	-------	-------	-------	-------	-0.01777	0.03280
fn*fk	0.04193	0.09729	-------	-------	-------	-------	0.04960	0.06227
fp*fk	-0.03853	0.09600	-------	-------	-------	-------	-0.04493	0.06236
R^2	**0.6674**		**0.8702**		**0.8776**		**0.8789**	

Table 5.3.2: Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure
Centre: Kalyani Crop: Rape Year: Rabi 1998

Model	Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	351.09283	42.76633	4253061	67.40	<.0001
	fn	5.40743	0.70910	3669728	58.15	<.0001
	fp	9.18525	3.03397	578393	9.17	0.0031
	fp2	-0.07132	0.03998	200863	3.18	0.0772
	R2 = 0.6608					
II	Intercept	-398.74846	163.24555	157672	5.97	0.0162
	fn	5.34067	0.46114	3544530	134.13	<.0001
	fp	11.63473	2.12843	789652	29.88	<.0001
	fp2	-0.07738	0.02615	231483	8.76	0.0038
	sn	1.77373	0.73593	153512	5.81	0.0177
	sp	14.08767	2.46787	861143	32.59	<.0001
	fpsp	-0.08948	0.04431	107767	4.08	0.0460
	R2 = 0.8619					
III	Intercept	-149.03267	66.58413	130669	5.01	0.0273
	fn	5.16203	0.45745	3321205	127.33	<.0001
	fp	11.61397	2.11353	787583	30.20	<.0001
	fp2	-0.07227	0.02577	205096	7.86	0.0060
	sp	32.90673	5.81538	835151	32.02	<.0001
	sp2	-0.31151	0.11553	189618	7.27	0.0082
	fpsp	-0.10374	0.04343	148837	5.71	0.0187
	R2 = 0.8637					
IV	Intercept	-149.03267	66.58413	130669	5.01	0.0273
	fn	5.16203	0.45745	3321205	127.33	<.0001
	fp	11.61397	2.11353	787583	30.20	<.0001
	fp2	-0.07227	0.02577	205096	7.86	0.0060
	sp	32.90673	5.81538	835151	32.02	<.0001
	sp2	-0.31151	0.11553	189618	7.27	0.0082
	fpsp	-0.10374	0.04343	148837	5.71	0.0187
	R2 = 0.8637					

Table 5.3.3 : Parameter estimates along with standard errors for response surface models using different number of Variables (models include replication)
Centre: Kalyani Crop: Rape Year: Rabi 1998

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	-79.98630	45.89924	-312.46419	245.82168	60.62145	993.93133	121.96456	1037.32088
Replication	169.19298	13.77231	165.60829	85.17398	114.62808	98.26403	116.61069	100.22594
fn	6.93728	1.41184	6.17856	3.66874	6.92234	3.74079	7.16608	3.82933
fp	8.15385	2.55761	8.93886	2.46517	9.66445	2.50492	10.33922	2.82111
fk	-0.10652	4.38914	4.48692	4.01538	4.91059	4.06009	2.80735	5.30941
fn^2	-0.02057	0.01491	-0.01429	0.01086	-0.01369	0.01100	-0.01846	0.01495
fp^2	-0.02649	0.04179	-0.05017	0.02936	-0.06045	0.03029	-0.03710	0.04320
fk^2	-0.01542	0.07956	-0.00741	0.05645	-0.02070	0.05746	-0.03557	0.08032
sn	------	------	0.96573	1.15261	-1.51117	8.37459	-2.03143	8.71734
sp	------	------	3.96929	4.94769	22.75775	14.22710	22.65144	14.49603
sk	------	------	-0.38990	0.81520	-3.04905	2.01018	-2.93727	2.04309
sn^2	------	------	-------	-------	0.00704	0.01625	0.00786	0.01688
sp^2	------	------	-------	-------	-0.34689	0.21391	-0.34298	0.21698
sk^2	------	------	------	------	0.00568	0.00363	0.00544	0.00368
fn*sn	------	------	0.00199	0.01325	-0.00202	0.01358	-0.00189	0.01385
fp*sp	------	------	-0.06878	0.05923	-0.05970	0.06001	-0.05833	0.06095
fk*sk	------	------	-0.00889	0.01163	-0.00728	0.01165	-0.00760	0.01178
fn*fp	-0.01838	0.03239	-------	-------	------	-------	-0.02081	0.03284
fn*fk	0.05897	0.06192	-------	-------	-------	-------	0.05518	0.06234
fp*fk	-0.04761	0.06109	------	------	------	------	-0.03832	0.06250
R^2	0.8667		0.8750		0.8794	0.8807		

Table 5.3.4: Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Kalyani Crop: Rape Year: Rabi 1998

Model	Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	-76.45960	44.39470	76431	2.97	0.0880
	rep	168.90123	13.56883	3992523	154.95	<.0001
	fn	6.95271	1.23839	812193	31.52	<.0001
	fp	7.95343	2.08385	375356	14.57	0.0002
	fn2	-0.01966	0.01167	73158	2.84	0.0950
	fp2	-0.05393	0.02795	95934	3.72	0.0564
	fnfk	0.02132	0.01217	79136	3.07	0.0826
	R2 = 0.8653					
II	Intercept	-146.77631	55.22253	179377	7.06	0.0091
	rep	198.62906	19.08184	2751273	108.35	<.0001
	fn	5.39013	0.45055	3634120	143.12	<.0001
	fp	11.13507	2.06996	734765	28.94	<.0001
	fp2	-0.07069	0.02540	196766	7.75	0.0064
	fpsp	-0.08846	0.04050	121106	4.77	0.0312
	R2 = 0.8660					
III	Intercept	-149.03267	66.58413	130669	5.01	0.0273
	fn	5.16203	0.45745	3321205	127.33	<.0001
	fp	11.61397	2.11353	787583	30.20	<.0001
	fp2	-0.07227	0.02577	205096	7.86	0.0060
	sp	32.90673	5.81538	835151	32.02	<.0001
	sp2	-0.31151	0.11553	189618	7.27	0.0082
	fpsp	-0.10374	0.04343	148837	5.71	0.0187
	R2 = 0.8637					
IV	Intercept	-149.03267	66.58413	130669	5.01	0.0273
	fn	5.16203	0.45745	3321205	127.33	<.0001
	fp	11.61397	2.11353	787583	30.20	<.0001
	fp2	-0.07227	0.02577	205096	7.86	0.0060
	sp	32.90673	5.81538	835151	32.02	<.0001
	sp2	-0.31151	0.11553	189618	7.27	0.0082
	fpsp	-0.10374	0.04343	148837	5.71	0.0187
	R2 = 0.8637					

Table 5.3.5: Estimated ridge of maximum yield
Centre: Kalyani Crop: Rape Year: Rabi 1998

Average STV* of the Site: SN= 252.88 Kg; SP= 21.39 Kg; SK= 237.06 Kg

Coded Radiu	Estimated Yield	Standard Error	Uncoded Factor Values fn	fp	fk
0.0	959.091901	40.222034	62.500000	37.500000	25.000000
0.1	992.574239	39.796506	68.169518	39.012873	25.299687
0.2	1024.629643	39.181230	73.854284	40.457513	25.696658
0.3	1055.305767	38.377886	79.552343	41.814449	26.204873
0.4	1084.661400	37.475157	85.259027	43.060089	26.839687
0.5	1112.768842	36.649472	90.965644	44.166779	27.617132
0.6	1139.716224	36.163232	96.658036	45.103711	28.552517
0.7	1165.609186	36.348545	102.315456	45.839161	29.658254
0.8	1190.571136	37.564163	107.910513	46.344265	30.941106
0.9	1214.741192	40.130065	113.411014	46.597832	32.399600
1.0	1238.269388	44.272421	118.783902	46.590747	34.022746

* **STV- Soil Test Value**

Table 5.4.1 : Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Coimbatore Crop: Onion Year: Kharif 1998

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error
Intercept	9671.87137	332.42879	221.64644	3361.13837	-32874.000	20684	-35431.0000	20460.000
fn	89.78812	21.90000	144.44157	44.61604	144.20536	44.70592	161.83035	45.03223
fp	35.54210	26.74540	50.54445	17.54069	48.72301	17.32145	9.86097	24.48064
fk	41.78605	28.96532	30.27220	53.80214	34.21688	54.50805	59.25698	55.52279
fn^2	-0.51638	0.30968	-0.22709	0.08876	-0.25863	0.08868	-0.60592	0.26810
fp^2	-0.76869	0.25968	-0.48976	0.15081	-0.47696	0.14883	-0.83662	0.22030
fk^2	-0.10443	0.50258	-0.15826	0.31041	-0.18399	0.30637	-0.07936	0.42892
sn	--------	--------	38.96059	21.51933	277.30729	195.31711	258.79753	193.18736
sp	--------	--------	-17.93141	34.03324	-45.92910	95.54974	-67.72576	94.94738
sk	---------	---------	5.88459	10.06137	69.56207	80.26440	102.36337	80.83089
sn^2	---------	---------	--------	--------	-0.59002	0.45479	-0.54364	0.44968
sp^2	--------	--------	--------	--------	0.33277	1.20005	0.47418	1.19523
sk^2	--------	--------	---------	---------	-0.09830	0.13970	-0.15246	0.14066
fn*sn	---------	--------	-0.33947	0.19956	-0.31435	0.19979	-0.27975	0.19984
fp*sp	--------	--------	0.54724	0.33650	0.55810	0.33350	0.53653	0.33093
fk*sk	--------	--------	-0.01256	0.18603	-0.02164	0.18927	-0.03758	0.18744
fn*fp	0.72290	0.49678	---------	---------	---------	---------	0.87803	0.42598
fn*fk	-0.20525	0.52386	--------	--------	--------	--------	-0.34725	0.44406
fp*fk	-0.02342	0.42628	--------	--------	--------	--------	0.00782	0.36033
R^2	0.8248		0.8757		0.8839		0.8912	

Table 5.4.2: Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Coimbatore Crop: Onion Year: Kharif 1998

Model	Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2404.76465	46.31781	215894182	2695.56	<.0001
	fn	8.90327	3.75365	450592	5.63	0.0195
	fp	8.75776	1.48434	2788125	34.81	<.0001
	fk	6.03265	2.60169	430622	5.38	0.0223
	fn2	0.12365	0.04856	519289	6.48	0.0123
	R^2= 0.8868					
II	Intercept	1255.16960	2103.54181	488280	0.36	0.5523
	fn	148.26011	37.88252	21005697	15.32	0.0002
	fp	51.00616	16.64173	12882920	9.39	0.0029
	fk	17.19944	7.14902	7937828	5.79	0.0183
	fn2	-0.22331	0.08503	9460078	6.90	0.0102
	fp2	-0.49031	0.14732	15191424	11.08	0.0013
	sn	39.17665	9.66233	22545341	16.44	0.0001
	fnsn	-0.35765	0.16654	6324484	4.61	0.0345
	fpsp	0.51435	0.29147	4270614	3.11	0.0811
	R^2= 0.8746					
III	Intercept	-21483	11753	4435984	3.34	0.0710
	fn	154.31179	37.40121	22601281	17.02	<.0001
	fp	48.17629	16.43770	11404875	8.59	0.0043
	fk	16.80601	7.03708	7572701	5.70	0.0191
	fn2	-0.23905	0.08404	10742272	8.09	0.0056
	fp2	-0.48405	0.14499	14798744	11.15	0.0012
	sn	255.65397	110.55564	7099855	5.35	0.0231
	sn2	-0.50938	0.25918	5128529	3.86	0.0526
	fnsn	-0.37113	0.16401	6798242	5.12	0.0262
	fpsp	0.57020	0.28820	5197363	3.91	0.0511
	R^2= 0.8800					
IV	Intercept	-21962	11626	4651011	3.57	0.0622
	fn	189.85173	33.61970	41560768	31.89	<.0001
	fk	19.00104	6.85704	10007440	7.68	0.0068
	fn2	-0.72569	0.15107	30073535	23.08	<.0001
	fp2	-0.76837	0.20998	17451515	13.39	0.0004
	sn	260.13379	109.35922	7374371	5.66	0.0196
	sn2	-0.52042	0.25638	5370212	4.12	0.0455
	fnsn	-0.37277	0.16077	7006602	5.38	0.0228
	fpsp	0.60763	0.27293	6459983	4.96	0.0286
	fnfp	0.88631	0.27533	13505475	10.36	0.0018
	R^2=0.8822					

Table 5.4.3 : Parameter estimates along with standard errors for response surface models using different number of Variables (models include replication)

Centre: Coimbatore Crop: Onion Year: Kharif 1998

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	8147.71512	395.86434	-930.73821	4260.01240	-32733	20826	-35172.000	20523.000
Replication	609.66250	109.40949	-291.92041	657.65775	-128.72182	744.92301	-578.00296	777.95215
fn	89.78812	18.85254	149.13182	46.06179	146.39335	46.72774	172.29671	47.30975
fp	35.54210	23.02368	50.36217	17.63094	48.72836	17.42747	6.76850	24.90247
fk	41.78605	24.93469	25.47247	55.13504	31.04413	57.83359	48.64010	57.48924
fn^2	-0.51638	0.26659	-0.23127	0.08969	-0.26029	0.08974	-0.60928	0.26892
fp^2	-0.76869	0.22355	-0.48631	0.15174	-0.47618	0.14981	-0.85312	0.22205
fk^2	-0.10443	0.43264	-0.16414	0.31220	-0.18522	0.30833	-0.01901	0.43777
sn	-------	-------	42.42323	22.98823	282.31779	198.64001	280.54614	195.95054
sp	-------	-------	-8.01231	40.85265	-37.44050	107.95836	-32.37659	106.44897
sk	-------	-------	8.91511	12.19971	63.13070	88.91962	77.04402	87.93853
sn^2	-------	-------	-------	-------	-0.59836	0.46011	-0.57903	0.45350
sp^2	-------	-------	-------	-------	0.28512	1.23847	0.30103	1.22117
sk^2	-------	-------	-------	-------	-0.08466	0.16120	-0.09767	0.15918
fn*sn	-------	-------	-0.35990	0.20575	-0.32381	0.20832	-0.32509	0.20951
fp*sp	-------	-------	0.53817	0.33875	0.55149	0.33771	0.51126	0.33364
fk*sk	-------	--------	0.00793	0.19255	-0.00873	0.20457	0.02160	0.20416
fn*fp	0.72290	0.42765	-------	-------	-------	-------	0.93324	0.43363
fn*fk	-0.20525	0.45097	-------	-------	-------	-------	-0.44338	0.46377
fp*fk	-0.02342	0.36696	-------	-------	-------	-------	0.00059366	0.36152
R^2	**0.8717**		**0.8760**		**0.8839**		**0.8920**	

Table 5.4.4: Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Coimbatore Crop: Onion Year: Kharif 1998

Model	Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	1829.54647	29.19511	46491594	3927.05	<.0001
	rep	228.06071	9.19581	7281637	615.07	<.0001
	fn	7.84231	1.54195	306237	25.87	<.0001
	fp	8.73036	0.57085	2769038	233.90	<.0001
	fk	10.68243	2.58167	202697	17.12	<.0001
	fn2	0.13632	0.01976	563203	47.57	<.0001
	fk2	-0.11698	0.05988	45187	3.82	0.0534
	R^2= **0.9874**					
II	Intercept	1255.16960	2103.54181	488280	0.36	0.5523
	fn	148.26011	37.88252	21005697	15.32	0.0002
	fp	51.00616	16.64173	12882920	9.39	0.0029
	fk	17.19944	7.14902	7937828	5.79	0.0183
	fn2	-0.22331	0.08503	9460078	6.90	0.0102
	fp2	-0.49031	0.14732	15191424	11.08	0.0013
	sn	39.17665	9.66233	22545341	16.44	0.0001
	fnsn	-0.35765	0.16654	6324484	4.61	0.0345
	fpsp	0.51435	0.29147	4270614	3.11	0.0811
	R^2= **0.8746**					
III	Intercept	-21483	11753	4435984	3.34	0.0710
	fn	154.31179	37.40121	22601281	17.02	<.0001
	fp	48.17629	16.43770	11404875	8.59	0.0043
	fk	16.80601	7.03708	7572701	5.70	0.0191
	fn2	-0.23905	0.08404	10742272	8.09	0.0056
	fp2	-0.48405	0.14499	14798744	11.15	0.0012
	sn	255.65397	110.55564	7099855	5.35	0.0231
	sn2	-0.50938	0.25918	5128529	3.86	0.0526
	fnsn	-0.37113	0.16401	6798242	5.12	0.0262
	fpsp	0.57020	0.28820	5197363	3.91	0.0511
	R^2=**0.8800**					
IV	Intercept	-21962	11626	4651011	3.57	0.0622
	fn	189.85173	33.61970	41560768	31.89	<.0001
	fk	19.00104	6.85704	10007440	7.68	0.0068
	fn2	-0.72569	0.15107	30073535	23.08	<.0001
	fp2	-0.76837	0.20998	17451515	13.39	0.0004
	sn	260.13379	109.35922	7374371	5.66	0.0196
	sn2	-0.52042	0.25638	5370212	4.12	0.0455
	fnsn	-0.37277	0.16077	7006602	5.38	0.0228
	fpsp	0.60763	0.27293	6459983	4.96	0.0286
	fnfp	0.88631	0.27533	13505475	10.36	0.0018
	R^2=**0.8822**					

Table 5.4.5 : Estimated ridge of maximum yield

Centre: Coimbatore Crop: Onion Year: Kharif 1998

Average STV* of the Site: SN=216.01Kg; SP= 32.39 Kg; SK= 270.15Kg

Coded Radius	Estimated Response	Standard Error	Uncoded Factor Values		
			fn	fp	fk
0.0	16012	310.533314	60.000000	45.000000	30.000000
0.1	16342	317.470890	65.804823	45.633220	30.630712
0.2	16638	320.626028	71.458712	46.838119	31.293382
0.3	16904	319.532193	76.916227	48.536876	31.974977
0.4	17142	315.310475	82.163855	50.631653	32.663661
0.5	17358	309.445952	87.211786	53.029752	33.350114
0.6	17551	303.394669	92.082417	55.655395	34.027225
0.7	17724	298.554359	96.801937	58.451323	34.689074
0.8	17879	296.323437	101.395931	61.375986	35.329751
0.9	18015	298.127011	105.887805	64.399877	35.942082
1.0	18134	305.374024	110.298817	67.502470	36.515969

* **STV- Soil Test Value**

Table 5.5.1 : Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Hisar Crop: Wheat Year: Rabi-1993-94

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error
Intercept	2439.64385	58.08713	648.23376	156.50099	-363.83481	717.10385	-377.17101	726.25693
fn	32.02411	2.32920	33.89944	1.73260	33.91798	1.76944	34.96536	1.99931
fp	21.33543	6.34733	28.76400	2.48277	28.91607	2.53137	27.44319	3.35095
fk	1.37267	6.71666	0.95261	4.21942	0.98006	4.23378	0.95432	4.52462
fn^2	-0.09936	0.01751	-0.08433	0.00402	-0.08286	0.00417	-0.09211	0.00831
fp^2	-0.21262	0.08671	-0.15534	0.02098	-0.15906	0.02146	-0.18758	0.04081
fk^2	-0.05730	0.12895	-0.03960	0.04081	-0.04910	0.04144	-0.06449	0.06052
sn	------	------	7.51056	1.63404	22.31978	10.17250	22.08820	10.33625
sp	------	------	29.00744	4.12444	13.69272	12.58847	14.02952	12.79377
sk	------	------	0.51785	0.25295	0.94089	1.17575	1.11229	1.18991
sn^2	------	------	------	------	-0.04786	0.03253	-0.04654	0.03303
sp^2	------	------	------	------	0.29985	0.29291	0.27621	0.29653
sk^2	------	------	------	------	-0.00051974	0.00148	-0.00075248	0.00150
fn*sn	------	------	-0.02231	0.01162	-0.02439	0.01198	-0.02569	0.01210
fp*sp	------	------	-0.32602	0.07407	-0.31740	0.07523	-0.31121	0.07596
fk*sk	------	------	0.00193	0.01031	0.00281	0.01041	0.00349	0.01051
fn*fp	0.04813	0.07706	------	------	------	------	0.02993	0.03605
fn*fk	0.00163	0.07438	------	------	------	------	0.00321	0.03493
fp*fk	0.02479	0.10056	------	------	------	------	0.00415	0.04791
R^2	**0.9456**		**0.9889**		**0.9892**		**0.9894**	

Table 5.5.2: **Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure**

Centre: Hisar Crop: Wheat Year: Rabi-1993-94

Model	Variable	Parameter Estimates	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2433.89778	56.20241	239239611	1875.40	<.0001
	fn	30.60213	1.65781	43468110	340.75	<.0001
	fp	23.55276	3.76863	4982587	39.06	<.0001
	fn2	-0.08489	0.00842	12972419	101.69	<.0001
	fp2	-0.16425	0.04116	2031084	15.92	0.0001
	R^2 = 0.9451					
II	Intercept	659.92883	154.66163	495937	18.21	<.0001
	fn	33.97010	1.70399	10825703	397.43	<.0001
	fp	28.48057	2.19811	4572957	167.88	<.0001
	fn2	-0.08501	0.00391	12883070	472.96	<.0001
	fp2	-0.15513	0.01914	1789668	65.70	<.0001
	sn	7.34116	1.59902	574145	21.08	<.0001
	sp	29.25642	4.07550	1403714	51.53	<.0001
	sk	0.54214	0.22154	163119	5.99	0.0160
	fnsn	-0.02214	0.01136	103428	3.80	0.0539
	fpsp	-0.32079	0.07016	569449	20.91	<.0001
	R^2 = 0.9888					
III	Intercept	659.92883	154.66163	495937	18.21	<.0001
	fn	33.97010	1.70399	10825703	397.43	<.0001
	fp	28.48057	2.19811	4572957	167.88	<.0001
	fn2	-0.08501	0.00391	12883070	472.96	<.0001
	fp2	-0.15513	0.01914	1789668	65.70	<.0001
	sn	7.34116	1.59902	574145	21.08	<.0001
	sp	29.25642	4.07550	1403714	51.53	<.0001
	sk	0.54214	0.22154	163119	5.99	0.0160
	fnsn	-0.02214	0.01136	103428	3.80	0.0539
	fpsp	-0.32079	0.07016	569449	20.91	<.0001
	R^2 = 0.9888					
IV	Intercept	659.92883	154.66163	495937	18.21	<.0001
	fn	33.97010	1.70399	10825703	397.43	<.0001
	fp	28.48057	2.19811	4572957	167.88	<.0001
	fn2	-0.08501	0.00391	12883070	472.96	<.0001
	fp2	-0.15513	0.01914	1789668	65.70	<.0001
	sn	7.34116	1.59902	574145	21.08	<.0001
	sp	29.25642	4.07550	1403714	51.53	<.0001
	sk	0.54214	0.22154	163119	5.99	0.0160
	fnsn	-0.02214	0.01136	103428	3.80	0.0539
	fpsp	-0.32079	0.07016	569449	20.91	<.0001
	R^2 = 0.9888					

Table 5.5.3: Parameter estimates along with standard errors for response surface models using different number of Variables (models include replication)

Centre: Hisar Crop: Wheat Year: Rabi-1993-94

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	1765.67718	47.24937	1074.95414	143.35722	985.04757	633.60528	1036.96075	633.12061
Replication	269.58667	14.87930	222.00872	31.58863	222.80781	33.17738	229.49825	33.04496
fn	32.02411	1.16823	34.57588	72.04672	34.49341	1.48525	36.01041	1.65717
fp	21.33543	3.18355	28.44670	61.82094	28.25399	2.12355	26.46565	2.76960
fk	1.37267	3.36879	3.80571	105.74216	3.82846	3.57313	3.64407	3.75485
fn^2	-0.09936	0.00878	-0.08548	8.35024	-0.08519	0.00351	-0.09763	0.00690
fp^2	-0.21262	0.04349	-0.15747	15.67407	-0.15600	0.01799	-0.19759	0.03372
fk^2	-0.05730	0.06468	-0.02770	30.51447	-0.02776	0.03487	-0.05913	0.04996
sn	-----	-----	3.72360	1.45906	6.00725	8.86378	4.68582	8.89233
sp	-----	-----	13.03545	4.10827	13.73398	10.54902	14.80402	10.56113
sk	-----	-----	0.09080	0.21852	-0.33924	1.00353	-0.13062	0.99837
sn^2	-----	-----	-----	-----	-0.00774	0.02791	-0.00312	0.02797
sp^2	-----	-----	-----	-----	-0.02771	0.25025	-0.07960	0.25007
sk^2	-----	-----	-----	-----	.00055900	0.00125	0.00025003	0.00125
fn*sn	-----	-----	-0.02758	0.48360	-0.02739	0.01005	-0.02944	0.01001
fp*sp	-----	-----	-0.27583	1.85640	-0.27248	0.06340	-0.26080	0.06312
fk*sk	-----	-----	-0.00761	0.25999	-0.00747	0.00885	-0.00721	0.00881
fn*fp	0.04813	0.03865	-----	-----	-----	-----	0.03831	0.02978
fn*fk	0.00163	0.03731	-----	-----	-----	-----	0.00358	0.02883
fp*fk	0.02479	0.05044	-----	-----	-----	-----	0.02428	0.03965
R^2	**0.9864**		**0.9924**		**0.9925**		**0.9928**	

Table 5.5.4: **Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure**

Centre: Hisar Crop: Wheat Year: Rabi-1993-94

Model	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	1767.48275	46.53037	46674873	1442.90	<.0001
	rep	269.58667	14.68511	10901546	337.01	<.0001
	fn	31.89192	1.08244	28080065	868.07	<.0001
	fp	21.28940	2.25021	2895524	89.51	<.0001
	fn2	-0.09841	0.00837	4468575	138.14	<.0001
	fp2	-0.20752	0.03105	1445148	44.68	<.0001
	fnfp	0.04738	0.02531	113346	3.50	0.0638
	R^2 = 0.9863					
II	Intercept	1084.10409	140.40827	1109357	59.62	<.0001
	rep	220.19862	28.47884	1112499	59.78	<.0001
	fn	34.78862	1.40415	11422530	613.83	<.0001
	fp	28.88367	1.81504	4712449	253.24	<.0001
	fn2	-0.08549	0.00323	13022955	699.83	<.0001
	fp2	-0.16006	0.01582	1904439	102.34	<.0001
	sn	3.85922	1.38486	144511	7.77	0.0063
	sp	13.51415	3.99630	212802	11.44	0.0010
	fnsn	-0.02906	0.00936	179433	9.64	0.0024
	fpsp	-0.29208	0.05809	470369	25.28	<.0001
	R^2 = 0.9923					
III	Intercept	1084.10409	140.40827	1109357	59.62	<.0001
	rep	220.19862	28.47884	1112499	59.78	<.0001
	fn	34.78862	1.40415	11422530	613.83	<.0001
	fp	28.88367	1.81504	4712449	253.24	<.0001
	fn2	-0.08549	0.00323	13022955	699.83	<.0001
	fp2	-0.16006	0.01582	1904439	102.34	<.0001
	sn	3.85922	1.38486	144511	7.77	0.0063
	sp	13.51415	3.99630	212802	11.44	0.0010
	fnsn	-0.02906	0.00936	179433	9.64	0.0024
	fpsp	-0.29208	0.05809	470369	25.28	<.0001
	R^2 = 0.9923					
IV	Intercept	1098.06797	138.48378	1135455	62.87	<.0001
	rep	224.92344	28.14704	1153223	63.86	<.0001
	fn	35.99033	1.49864	10415684	576.74	<.0001
	fp	26.86803	2.03285	3154788	174.69	<.0001
	fn2	-0.09680	0.00629	4277551	236.86	<.0001
	fp2	-0.19652	0.02343	1270406	70.34	<.0001
	sn	3.82432	1.36438	141888	7.86	0.0060
	sp	12.78537	3.95241	188978	10.46	0.0016
	fnsn	-0.03002	0.00923	191043	10.58	0.0015
	fpsp	-0.28379	0.05737	441933	24.47	<.0001
	fnfp	0.03965	0.01902	78449	4.34	0.0395
	R^2 = 0.9926					

Table: 5.5.5 Estimated ridge of maximum yield
Centre: Hisar Crop: Wheat Year: Rabi-1993-94

Average STV* of the Site: SN= 137.70 Kg; SP:= 20.27 Kg; SK= 331.67 Kg

Coded Radius	Estimated Yield	Standard Error	Uncoded Factor Values fn	fp	fk
0.0	5401.438046	48.958948	100.000000	45.000000	30.000000
0.1	5541.459641	49.458616	109.681823	46.121442	29.931752
0.2	5664.193615	49.675660	119.194678	47.517234	29.843218
0.3	5770.091672	49.680028	128.477221	49.226726	29.727582
0.4	5859.703752	49.640775	137.455329	51.285349	29.574792
0.5	5933.681962	49.776325	146.046431	53.717754	29.369190
0.6	5992.772459	50.311884	154.168179	56.529955	29.084374
0.7	6037.793964	51.458929	161.748949	59.702232	28.670758
0.8	6069.611599	53.448771	168.731725	63.181600	28.021306
0.9	6089.140597	56.707448	175.045837	66.854655	26.861083
1.0	6097.528577	62.536906	180.420476	70.381790	24.378396

* **STV- Soil Test Value**

Table 5.5.6 : Parameter estimates along with standard errors for response surface models using different number of variables

Centre: Hisar Crop: Wheat Year: Rabi-1995-96

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameter estimates	Standard Error
Intercept	2609.20927	61.44498	550.70568	340.99890	-861.08405	1459.85183	-615.34151	1459.73674
fn	22.20269	2.46384	25.15121	3.84737	24.50073	3.99011	26.74772	4.35697
fp	9.78231	6.71425	17.83929	5.00121	18.01759	5.06157	13.06778	6.71118
fk	-0.54060	7.10493	3.04739	8.36058	3.27001	8.48048	5.45507	9.04856
fn^2	-0.08527	0.01852	-0.05231	0.00733	-0.05218	0.00741	-0.07907	0.01524
fp^2	-0.17625	0.09172	-0.10057	0.03915	-0.09910	0.04016	-0.17294	0.07361
fk^2	-0.03918	0.13641	0.00344	0.07452	0.00384	0.07571	-0.01996	0.10892
sn	------	------	9.42531	3.00847	23.35858	17.31709	22.41667	17.32096
sp	------	------	9.93505	9.57965	3.31233	25.67774	12.85430	25.91846
sk	------	------	1.84231	0.64425	5.05444	4.90218	3.97383	4.90026
sn^2	------	------	------	------	-0.05196	0.06462	-0.05325	0.06472
sp^2	------	------	------	------	0.22854	0.66603	0.02686	0.66868
sk^2	------	------	------	------	-0.00458	0.00698	-0.00296	0.00698
fn*sn	------	------	-0.04917	0.02672	------	------	-0.04285	0.02815
fp*sp	------	------	-0.18351	0.19183	------	------	-0.18754	0.19651
fk*sk	------	------	-0.00995	0.01964	------	------	-0.01382	0.01982
fn*fp	0.09168	0.08152	------	------	-0.04504	0.02779	0.09043	0.06645
fn*fk	0.02115	0.07868	------	------	-0.19183	0.19552	0.00669	0.06356
fp*fk	-0.00400	0.10637	------	------	-0.01114	0.01988	-0.01352	0.08639
R^2	**0.8566**		**0.9133**		**0.9141**		**0.9178**	

Table 5.5.7: Parameter estimates along with standard errors for remaining significant variables in different models using backward elimination procedure

Centre: Hisar Crop: Wheat Year: Rabi-1995-96

Models	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2608.67908	60.04529	269360370	1887.48	<.0001
	fn	22.35977	2.27356	13802931	96.72	<.0001
	fp	8.57187	4.72634	469409	3.29	0.0724
	fn2	-0.08610	0.01759	3420667	23.97	<.0001
	fp2	-0.18764	0.06521	1181501	8.28	0.0048
	fnfp	0.10662	0.05316	574060	4.02	0.0473
	R^2 = 0.8564					
II	Intercept	400.48579	286.12311	175001	1.96	0.1644
	fn	27.78781	2.98121	7760574	86.88	<.0001
	fp	15.28842	3.16018	2090612	23.40	<.0001
	fn2	-0.05208	0.00710	4809284	53.84	<.0001
	fp2	-0.10401	0.03453	810581	9.07	0.0032
	sn	11.90713	2.28767	2419900	27.09	<.0001
	sk	1.74286	0.44865	1347992	15.09	0.0002
	fnsn	-0.06936	0.01971	1106494	12.39	0.0006
	R^2= 0.9117					
III	Intercept	400.48579	286.12311	175001	1.96	0.1644
	fn	27.78781	2.98121	7760574	86.88	<.0001
	fp	15.28842	3.16018	2090612	23.40	<.0001
	fn2	-0.05208	0.00710	4809284	53.84	<.0001
	fp2	-0.10401	0.03453	810581	9.07	0.0032
	sn	11.90713	2.28767	2419900	27.09	<.0001
	sk	1.74286	0.44865	1347992	15.09	0.0002
	fnsn	-0.06936	0.01971	1106494	12.39	0.0006
	R^2= 0.9117					
IV	Intercept	463.22853	283.73028	231422	2.67	0.1054
	fn	29.99271	3.12858	7979251	91.90	<.0001
	fp	11.13683	3.71242	781329	9.00	0.0033
	fn2	-0.07687	0.01394	2641525	30.42	<.0001
	fp2	-0.18225	0.05105	1106551	12.75	0.0005
	sn	11.34111	2.27212	2163090	24.91	<.0001
	sk	1.81951	0.44388	1458806	16.80	<.0001
	fnsn	-0.06798	0.01944	1061799	12.23	0.0007
	fnfp	0.08610	0.04187	367199	4.23	0.0421
	R^2= 0.9150					

Table 5.5.8 : Parameter estimates along with standard errors for response surface models using different number of Variables (models include replication)

Centre: Hisar Crop: Wheat Year: Rabi-1995-96

Models	I		II		III		IV	
Parameters	Parameter estimates	Standard Error	Parameter estimates	Standard Error	Parameters	Parameter estimates	Standard Error	Parameter estimates
Intercept	2106.21760	79.22432	1080.12197	384.55986	558.91430	1444.90592	721.66312	1443.80168
Replication	201.19667	24.94852	199.80134	73.68695	329.77353	94.22274	319.20895	93.99047
fn	22.20269	1.95880	26.23035	3.75914	27.27608	3.87243	29.17069	4.20705
fp	9.78231	5.33795	17.73758	4.85921	18.43925	4.80971	13.77184	6.38976
fk	-0.54060	5.64855	3.46033	8.12437	1.75336	8.06761	3.99082	8.62145
fn^2	-0.08527	0.01472	-0.05527	0.00720	-0.05762	0.00721	-0.08168	0.01452
fp^2	-0.17625	0.07292	-0.09970	0.03804	-0.09801	0.03815	-0.16245	0.07012
fk^2	-0.03918	0.10845	-0.00986	0.07257	0.00519	0.07192	-0.00661	0.10372
sn	------	------	6.34353	3.13615	11.10272	16.81881	10.93101	16.82610
sp	------	------	-4.98806	10.81283	-78.06065	33.69782	-66.99108	34.07426
sk	------	------	0.68705	0.75718	4.76924	4.65750	3.77766	4.66347
sn^2	------	------	------	------	-0.02025	0.06205	-0.02357	0.06220
sp^2	------	------	------	------	1.75030	0.76769	1.52309	0.77395
sk^2	------	------	------	------	-0.00681	0.00666	-0.00523	0.00668
fn*sn	------	------	-0.05216	0.02598	-0.05633	0.02660	-0.05394	0.02698
fp*sp	------	------	-0.16726	0.18647	-0.19373	0.18574	-0.19194	0.18700
fk*sk	------	------	-0.00991	0.01908	-0.00867	0.01889	-0.01096	0.01888
fn*fp	0.09168	0.06481	------	------	------	------	0.08329	0.06327
fn*fk	0.02115	0.06255	------	------	------	------	0.00511	0.06048
fp*fk	-0.00400	0.08457	------	------	------	------	-0.02472	0.08227
R-square	**0.9102**		**0.9189**		**0.9232**	**0.9263**		

Table 5.5.9: Parameter estimates along with standard errors for remaining significant variables in different models(replication included) using backward elimination procedure

Centre: Hisar Crop: Wheat Year: Rabi-1995-96

Models	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
I	Intercept	2105.68741	77.71516	66246140	734.14	<.0001
	rep	201.19667	24.52712	6072015	67.29	<.0001
	fn	22.35977	1.80790	13802931	152.96	<.0001
	fp	8.57187	3.75830	469409	5.20	0.0244
	fn2	-0.08610	0.01398	3420667	37.91	<.0001
	fp2	-0.18764	0.05186	1181501	13.09	0.0004
	R^2= 0.9100					
II	Intercept	1163.06515	307.15597	1213198	14.34	0.0002
	rep	182.71970	38.80930	1875602	22.17	<.0001
	fn	29.10171	2.91775	8417467	99.48	<.0001
	fp	13.97009	3.08569	1734340	20.50	<.0001
	fn2	-0.05530	0.00697	5326685	62.95	<.0001
	fp2	-0.08978	0.03372	599743	7.09	0.0089
	sn	7.28744	2.67757	626774	7.41	0.0075
	fnsn	-0.07349	0.01919	1240481	14.66	0.0002
	R^2= 0.9164					
III	Intercept	1540.09135	347.93925	1596881	19.59	<.0001
	rep	307.11947	65.80474	1775362	21.78	<.0001
	fn	30.17055	2.91148	8752375	107.38	<.0001
	fp	14.48257	3.09088	1789428	21.95	<.0001
	fn2	-0.05789	0.00692	5706813	70.02	<.0001
	fp2	-0.09153	0.03364	603248	7.40	0.0076
	sn	7.50356	2.64475	656073	8.05	0.0054
	sp	-74.44938	30.16283	496552	6.09	0.0151
	sp2	1.48391	0.66640	404144	4.96	0.0280
	fnsn	-0.07765	0.01904	1355977	16.64	<.0001
	R^2= 0.9209					
IV	Intercept	1598.70978	343.76406	1709466	21.63	<.0001
	rep	300.86953	64.86946	1700271	21.51	<.0001
	fn	32.31304	3.04234	8916256	112.81	<.0001
	fp	10.18921	3.66376	611321	7.73	0.0064
	fn2	-0.08241	0.01350	2947393	37.29	<.0001
	fp2	-0.16811	0.04920	922735	11.67	0.0009
	sn	6.57193	2.64175	489151	6.19	0.0144
	sp	-64.75695	30.05764	366864	4.64	0.0334
	sp2	1.29731	0.66219	303359	3.84	0.0527
	fnsn	-0.07604	0.01876	1298179	16.42	<.0001
	fnfp	0.08566	0.04069	350331	4.43	0.0376
	R^2= 0.9240					

Table 5.5.10: Estimated ridge of maximum yield

Centre: Hisar Crop: Wheat Year: Rabi-1995-96

Average STV* of the Site: SN= 135.38 Kg; SP= 15.67 Kg;SK= 347.92 Kg

Coded Radius	Estimated Yield	Standard Error	Uncoded Factor Values fn	fp	fk
0.0	4464.553023	75.972117	100.000000	45.000000	30.000000
0.1	4554.311896	76.691646	109.786609	45.921675	29.950443
0.2	4630.522495	76.953861	119.312888	47.336433	29.929827
0.3	4694.099252	76.855313	128.452450	49.279369	29.954018
0.4	4746.057973	76.616326	137.090453	51.739089	30.047523
0.5	4787.432722	76.426167	145.154232	54.655602	30.250463
0.6	4819.194496	76.368770	152.624427	57.934481	30.635892
0.7	4842.214437	76.385943	159.513504	61.458784	31.355210
0.8	4857.316500	76.154537	165.791977	65.058313	32.758885
0.9	4865.533808	74.764141	171.160391	68.340143	35.580439
1.0	4868.643040	71.345309	174.922609	70.610266	40.163142

* **STV- Soil Test Value**

Table: 5.7 Comparison of optimum fertilizes doses by targeted yield approach and Response Surface Methodology

S.No.	Centre	Crop /Season/ Variety	Year	Mean Soil Test Value			Targeted Yield* (Kg/ ha^{-1})	Optimal Fertilizer Doses					
								Targeted Yield Approach			Response Surface Methodology		
				SN	SP	SK		FN	FP	FK	FN	FP	FK
1.	Bhubaneswar	Rice /Kharif / Konark	1998	147.87	26.72	97.83	4098	63	58	35	70	58	23
2.	---do-------	Rice /Kharif /Konark	1999	157.42	33.55	109.54	4038	56	56	33	70	60	19
3.	----do------	Rice / Kharif /Konark	2000	165.60	31.51	108.13	4648	68	66	42	57	68	29
4.	----do-----	Rice / Kharif /Lalat	1999	186.17	26.02	181.69	4911	117	52	41	114	41	31
5.	Hyderabad	Sunflower /Rabi /	1993	259.43	30.71	370.77	1511	106	79	57	106	41	14
6.	Hyderabad (Maruteru)	Rice /Rabi	1994	334.82	54.30	346.37	5723	119	73	72	140	31	58
7.	Hyderabad	Groundnut /Rabi -	1997	240.45	33.56	346.84	2048	28	47	83	29	39	35
8.	Hisar	Wheat /Rabi /542	1993	137.70	20.27	331.67	6097	153	67	52	180	70	24
9.	Hisar	Wheat /Rabi /896	1995	135.38	15.67	347.92	4808	159	66	46	175	71	40
10	Hisar	Wheat /Rabi /CVSonak	1997	135.07	18.21	400.43	5059	159	65	51	179	71	35
11.	Kalyani	Rape/Rabi	1998	252.88	21.31	237.06	1238	109	58	39	119	47	34
12.	Coimbatore	Onion/Rabi	1998	216.16	32.4	270.16	18134	111	68	56	110	68	36

* Targeted yield has been taken as the maximum response achievable by Response surface methodology. This has been done only to compare and verify the targeted yield approach.

SUMMARY

The balanced application of fertilizer nutrients particularly the major nutrients, N P and K in optimum quantity, based on soil test and crop requirement is one of the most vital aspects for sustaining higher agricultural production. This requires the application of optimally balanced quantity of fertilizers in right proportion through correct method and time of application for a specific soil-crop-climate situation. It ensures increased quantity of produce, maintenance of soil productivity and the most efficient and judicious use of applied fertilizers. Thus in this content the soil fertility evolution and refined fertilizer prescription for sustained agricultural production is of great importance to any country of the world in general and farming community in particular. Hence the soils have to be tested precisely for their available nutrient status for making fertilizer recommendation based on crop response and economic circumstances.

The determination of the amount of fertilizer that should be applied to a crop would be delightfully simple if a chemist could analyze the soil, and then use the analyses to measure the amount of plant nutrients in the soil and to calculate the amounts that should be applied to correct deficiencies. It is unfortunate that the determination of fertilizer requirements is not as simple as this. As every soil chemist knows, there are basic problems in interpreting soil test values in terms of nutrient availability to crops due to the interacting effects of other soil constituents, surface reactions, the changes that may occur in test values both laterally across farmers' fields and vertically down the soil profile, and to all these factors may be added the uncertainties of weather, effects of crop variety, disease, pests etc. Any suggestion therefore that fertilizer requirement can be determined solely on the basis of a simple laboratory analysis of a few grams of soil, represents a vast oversimplification of a highly complex system. Nevertheless soil analysis can provide useful information on the effect that fertilizers are likely to have on yields, and it is important to use this information for the estimation of fertilizer requirements. Soil tests can provide a valuable piece of information and as such should be used in conjunction with such other information that is available for the estimation of fertilizer requirements.

Soil test crop-response studies has been going on for a quite a long period of time both in India and abroad. the All India Coordinated Research Project on Soil Test Crop Response Correlation was initiated during the year 1967-68. Currently, STCR project is having seventeen cooperating centres.

Under the STCR project multiple regression approach is being used to calculate the dose of nutrient (s) required to obtain the maximum yield of crops under given set of experimental conditions. It can further be used to calculate the economic dose of fertilizer nutrients by incorporating a constant factor i.e. per unit cost of input (fertilizer) in the original equation. In this approach yield is regressed with soil nutrients, fertilizer nutrients, their quadratic terms and the interaction term of soil and fertilizer nutrients. For this the following criteria should be fulfilled.

(a) Soil test crop response calibration for economic yield of a crop is possible only when the response to added nutrients follow the law of diminishing returns. i.e. the signs of partial regression coefficients of linear, quadratic terms of nutrients and their interaction with available soil nutrients should in general be positive, negative and negative (+,–,–) respectively.
(b) The coefficient of determination (R^2) should be high.
(c) The partial regression coefficients should be statistically significant.

(d) The experiment should have sufficient design points i.e. the number of treatments should be at least two or more than the number of variables in the model.

The above criterions are seldom fulfilled under the STCR project data. In such cases the optimum values of the nutrients cannot be derived or if they could be derived, they are either too high or too low.
Keeping in view of the above problems and for better analysis of data, their interpretation and improvement in soil test calibration, the projector coordinator (STCR) Indian Institute of Soil Science, Bhopal, formally approached IASRI, New Delhi for collaboration. As large amount of data have also been gathered under the project, the creation of a database under the project was also solicited.
Consequently a project entitled Planning, designing and analysis of experiments relating to AICRP on soil test crop response correlation was under taken at IASRI w.e.f. 1st march 2000 with the following objectives:

1. To improve the existing methodology for analysis of data of ongoing STCR experiments.
2 To carry out planning, design for the conduct of new set of experiments and subsequently to carry out the analysis of data.
3. To develop a database for the project.

In this report, the first two chapters contain introduction and review of literature. In the third chapter Analytical techniques has been discussed along with a method, which has been developed at IASRI based on Response surface methodology has been discussed. In this method, the optimal values of N,P and K fertilizer nutrients can be derived if the soil test values for a particular site is available.
Chapter four deals with designs for future STCR experimentation. In this, a number of designs have been proposed with different designs points, based on the requirements of STCR project, from designs of type (5 x 4 x 3),(4 x 4 x 3), (4 x 4 x 4) etc.
Chapter five deals with results and discussion. Although we have received the data from a number of centres but due to pending query for discrepancies, only data of seven centres (totaling about 12 experiments) have been discussed in detail.
The common result is that in almost all the cases the response surface methodology produced the stationery point as saddle points i.e. neither maxima nor minima. In such cases exploration of the response surface in the vicinity of the stationery point has been attempted. The optimal values of the fertilizer nutrients N, P and K obtained by Response Surface Methodology, has been found to be closely related to that obtained by Targeted yield approach adopted by the STCR project. Thus one could advocate for the adoption of the Targeted yield approach as has been tested by sound statistical system of Response Surface Methodology. A number of models have been tried for all the experiments but the models with 15 variables and 18 variables have been mostly found to be better. One model with 15 variables, which includes the interactions (FN x FP), (FN x FK) and (FP x FK) also gives higher values of R-Square. In some cases it was possible to find the optimum values from the Multiple Regression equations.

Lastly, in Chapter six we have given the sketch of the database prepared for storing the STCR data. In this, number of queries can be prepared and the data can be retrieved.

सारांश

मृदा परीक्षण और फसल की जरूरत के आधार पर प्रमुख उर्वरक पोषकों यानि एन.पी. और के. की अनकूल मात्रा अर्थात संतुलित उपयोग कृषि के उच्च उत्पादन को अक्षुण बनाए रखने का सर्वाधिक महत्वपूर्ण पहलू है । इसके लिए जरूरी है कि किसी विशिष्ट मृदा फसल जलवायवीय दशाओं में उचित विधि और उचित समय पर उचित अनुपात में उर्वरकों की अनुकूल संतुलित मात्रा डाली जाए । ऐसा करने से उत्पाद अधिक मात्रा में मिलता है, मिट्टी की उर्वरता बनी रहती है और डाले गए उर्वरकों का कुशल और विवेकपूर्ण इस्तेमाल सुनिश्चित होता है । विश्व के किसी भी देश में आमतौर पर और खासकर कृषि समुदाय के लिए अक्षुण कृषि उत्पादन लेने के लिए मृदा की उर्वरता का विकास और परिष्कृत उर्वरक के निर्धारण की बड़ी भारी महत्व है इसलिए मिट्टी में उपलब्ध पोषक तत्व का स्तर जानने के लिए मिट्टी का परीक्षण सटीकता से करना होगा ताकि उर्वरकों की सिफारिश, फसल अनुकिया और आर्थिक परिस्थिति के आधार पर की जा सके ।

यदि कोई रसायनशास्त्री मिट्टी का विश्लेषण कर सके और तब उस विश्लेषण का इस्तेमाल मिट्टी में पादप पोषकों की मात्रा मापने के साथ–साथ सही कमी वाली मिट्टी में डाली जाने वाली मात्रा की गणना करता है तो किसी फसल में डाले जाने वाले उर्वरक की मात्रा का निर्धारण करना बहुत ही सरल होगा । यह बड़ा ही दुर्भाग्य पूर्ण है कि उर्वरकों की जरूरत का निर्धारण करना इतना सरल नही है जितना समझा जाता है । क्योंकि एक मृदा रसायनशास्त्री भली–भांति जानता है कि फसलों की पोषण उपलब्धता के परिप्रेक्ष्य में मृदा परीक्षण मानों की व्याख्या करने में समस्याएं आती हैं जिसका कारण है–मिट्टी के दूसरे अन्योन्यकिया संघटकों, अन्तरापृष्ठ किया, ऐसे परिवर्तनों का होना, जो परीक्षण मानों में दोनों ही प्रकार से यानि पार्श्व रूप से और उर्ध्व रूप से किसानो के खेतों की मिट्टी में होतें हैं और इनमें ऐसे सभी कारकों को भी जोड़ा जा सकता है जो मौसम की अनिश्चितता, फसल की किस्म, रोग, नाशी पीड़क इत्यादि से संबंधित हैं, इसलिए किसी एक उच्च रूप से जटिल प्रणाली के विस्तृत अति–सरलीकरण का प्रतिनिधित्व करने वाली कुछ ग्राम मिट्टी के साधारण प्रयोगशाला विश्लेषण के आधार पर ऐसा कोई भी सुझाव जो केवल उर्वरकों की जरूरत को निर्धरित कर सकता है मान्य होगा । फिर भी मिट्टी के विश्लेषण से उर्वरकों के ऐसे प्रभावों पर उपयोगी सूचना मिल सकती जो उपज पर पड़ सकते हैं, और सबसे महत्वपूर्ण यह है कि उर्वरक की जरूरत का आकलन करने के लिए इस सूचना का भरपूर उपयोग किया जा सतका है । मृदा परीक्षण बहुमूल्य सूचनाएं प्रदान करते हैं जिनका उपयोग ऐसी दूसरी सूचनाओं के साथ किया जा सकता है जो उर्वरकों की जरूरत का आकलन करने के लिए उपलब्ध हैं ।

भारत ही नही विदेशों में भी एक लम्बे अर्से से मृदा परीक्षण फसल अनुकिया पर अध्ययन चल रहे हैं । मृदा परीक्षण फसल अनुकिया सहसम्बन्ध पर एक अखिल भारतीय समन्वित अनुसंधान परियोजना सन् 1967–68 के दौरान शुरू की गई थी । इस समय मृदा परीक्षण फसल अनुकिया सहसम्बन्ध पर एक अखिल भारतीय समन्वित अनुसंधान परियोजना के 17 सहयोगी केन्द्र हैं ।

मृदा परीक्षण फसल अनुकिया सहसम्बन्ध पर एक अखिल भारतीय समन्वित अनुसंधान परियोजना के तहत किसी दी हुई परीक्षणात्मक दशाओं में फसलों की अधिकाधिक उपज प्राप्त करने के लिए जरूरी पोषकों की खुराक की गणना हेतु बहु समाश्रयण विधि का उपयोग किया जा सकता है । इसके अलावा इसका उपयोग, स्थिर कारकों जैसे–मूल समीकरण में प्रति

इकाई निवेश (उर्वरक) को शामिल कर उर्वरक पोषकों की किफायती खुराक की गणना करने के लिए भी किया जा सकता है । इस विधि में उपज को मृदा पोषक तत्वों, उर्वरक पोषकों, उनकी द्विघाती पद और मिट्टी एवं उर्वरक पोषकों के अन्योन्यक्रिया पदों के साथ समाश्रयित किया जाता है । इसके लिए निम्न मानदण्डों को पूरा किया जाना चहिए ।

(क) किसी फसल की लाभप्रद उपज का मृदा परीक्षण फसल अनुक्रिया अंशांकन केवल तभी संभव है जब डाले गए पोषकों की अनुक्रिया (ला आफ डिमिनीशंग रिटर्न) ह्रासमान लाभ के कानून का अनुसरण करे, यानि रैखिकता के आंशिक समाश्रयण गुणांकों (पार्शियल रिग्रेशन कोएफिशिएन्टस) के चिन्हों, पोषकों के द्विघातीय पदों, और उनकी उपलब्ध, मृदा पोषकों के साथ अनुक्रिया, आमतौर पर क्रमशः धनात्मक, ऋणात्मक और ऋणात्मक (+,−,−) होनी चाहिए ।

(ख) निर्धारण का गुणांक (R^2) उच्च होना चाहिए ।

(ग) आंशिक समाश्रयण गुणांक सांख्यिकी रूप से महत्वपूर्ण (सिग्निफिकेन्ट) होना चाहिए।

(घ) परीक्षण में पर्याप्त डिजाइन बिन्दु होने चाहिए यानि उपचारों की संख्या मॉडल में चरों की संख्या से कम से कम 2 या अधिक हों ।

मृदा परीक्षण फसल अनुक्रिया परियोजना के आंकड़ों में उक्त मानदण्ड कम ही पूरे होते हैं । ऐसे मामलों में पोषकों के इष्टतम मान या तो निकाले ही नहीं जा सकते या फिर निकाले जा सकते हैं तो ये या तो बहुत ज्यादा होते हैं या बहुत कम ।

उक्त समस्याओं को ध्यान में रखते हुए और आंकड़ों का बेहतर विश्लेषण करने के लिए, उनकी व्याख्या करने के लिए तथा मृदा परीक्षण अंशांकन में सुधार लाने के लिए परियोजना समन्वयक (मृदा परीक्षण फसल अनुक्रिया) भारतीय मृदा विज्ञान संस्थान, भोपाल औपचारिक रूप से भारतीय कृषि सांख्यिकी अनुसंधान संस्थान, नई दिल्ली के पास सहयोग की अपेक्षा से आए । क्योंकि इस परियोजना के तहत बड़ी संख्या में आंकड़े भी एकत्रित किए गए हैं इसलिए इस परियोजना में एक डाटा–बेस तैयार करने की भी जरुरत है ।
परिणाम स्वरुप "मृदा परीक्षण फसल अनुक्रिया सह–सम्बन्ध पर अखिल भारतीय समन्वित अनुसंधान परियोजना से सम्बंधित परीक्षणों का नियोजन, डिजाइनिंग और विश्लेषण नामक एक परियोजना 1 मार्च, 2000 से भारतीय कृषि सांख्यिकी अनुसंधान संस्थान में शुरु की गई । इस परियोजना के प्रमुख उद्‌देश्य निम्नानुसार हैं :

1. चल रहे एस.टी.सी.आर. परीक्षणों के आंकड़ों का विश्लेषण करने के लिए मौजूदा पद्धति में सुधार करना ।

2. परीक्षणों के नए सैट का नियोजन और डिजाइन तैयार करना और तदन्तर आंकड़ों का विश्लेषण करना ।

3. परियोजना के लिए डाटाबेस का विकास करना ।

इस रिपोर्ट में पहले 2 अध्याय प्रस्तावना और साहित्य समीक्षा से सम्बंधित है । तीसरे अध्याय में विश्लेषणात्मक तकनीकों पर विचार किया गया है इसके अलावा एक नई विधि, जो अनुक्रिया अन्तापृष्ठ पद्धति पर आधारित है, भारतीय कृषि सांख्यिकी अनुसंधान संस्थान में विकसित की गई है । इस विधि में नाइट्रोजन, फास्फोरस और पोटेशियम उर्वरक पोषकों के

इष्टतम मानों को निकाला जा सकता है बशर्ते कि उस स्थान के मृदा परीक्षण के मान उपलब्ध हों ।

अध्याय 4 में भावी एस.टी.सी.आर. परीक्षणों की डिजाइनों की व्याख्या की गई है । एस.टी.सी.आर. परियोजना की जरूरतों के आधार पर भिन्न–भिन्न डिजाइन बिन्दुओं सहित (5x4x3), (4x4x3),(4x4x4) इत्यादि डिजाइनों की किस्म से अनेक डिजाइनों का प्रस्ताव रखा गया है ।

अध्याय 5 में परिणामों और विचारों की व्याख्या की गई है । हांलाकि हमें अनेक केन्द्रो से आंकड़े प्राप्त हुए परन्तु उनमें विरोधाभास सम्बन्धी जानकारी के रहते केवल 7 केन्द्रों (कुल लगभग 12 परीक्षणों) के आंकड़ों पर विस्तार से विचार किया गया है ।

सामान्य परिणाम यह निकला है कि सभी मामलों में जहां अनुक्रिया अन्तरापृष्ठ पद्धति से पल्याण बिन्दु (सैडल प्वाइंट) के रूप में एक स्तब्ध बिन्दु (स्टेशनरी प्वाइंट) बना यानि यह न तो अधिकतम था और न ही न्यूनतम था । इन मामलों में अनुक्रिया अन्तरापृष्ठ पद्धति द्वारा प्राप्त उर्वरक पोषकों नाईट्रोजन, फासफोरस और पोटैशियम के इष्टतम मान उन मानों के काफी करीब पाए गए हैं जो एस.टी.सी.आर. परियोजना द्वारा अपनाई गई लक्ष्य विधि से प्राप्त हुए हैं । इस प्रकार कोई भी लक्षित उपज विधि की वकालत कर सकता है क्योंकि इसे अनुक्रिया अन्तरापृष्ठ पद्धति की एक ठोस सांख्यिकी प्रणाली द्वारा परीक्षित किया गया है । सभी परीक्षणों के लिए अनेक मॉडल अपनाए गए । परन्तु 15 और 18 चरों वाले मॉडल श्रेष्ठ पाए गए हैं । 15 चरों वाला एक मॉडल जिसमें (FN x FP), (FN x FK) और (FP x FK) अन्योन्यक्रियाएं शामिल हैं, से भी R-Square का उच्च मान प्राप्त होता है । कुछ मामलों में बहु समाश्रयण समीकरणों से इष्टतम मान प्राप्त करना संभव था ।

अन्ततः छठे अध्याय में एस.टी.सी.आर. आंकड़ों को एकत्रित करने के लिए तैयार किए गए डाटाबेस का चित्रण किया है । इसमें अनेक जानकारियां तैयार की जा सकती हैं और आंकड़ों को पुनः प्राप्त किया जा सकता है ।

APPENDIX-I

Table: Calculation of Basic Data for Targetted yield equations

Centre : MARUTERU(HYDERABAD) Year:1994Crop:Rice Season :Rabi

GRD	TRT	FN	FP	FK	YIELD	SN	UP-N	NR-N	CFN	CSN
1	2	3	4	5	6	7	8	9	10	11
								(Col 8*100) /col 6)	(col 8-av.CSN* col 7)/col 4	(col 8 /col 7)
1	1	50	0	0	3753	286	72.04	1.9185	0.5485	
1	2	50	0	40	4240	276	78.94	1.8608	0.7177	
1	3	50	0	80	3892	295	101.7	2.6105	1.1124	
1	4	50	40	0	3753	300	80.36	2.1396	0.6709	
1	5	50	40	40	4170	331	76.19	1.8249	0.4902	
1	6	50	40	80	4518	319	91.11	2.0164	0.8276	
1	7	50	80	0	4240	348	93.3	2.2005	0.7812	
1	8	50	80	40	4865	319	97.34	2	0.9516	
1	9	50	80	80	4726	300	69.79	1.4748	0.4589	
1	10	100	0	0	5352	322	81.01	1.5135	0.3081	
1	11	100	0	40	5004	335	81.82	1.6347	0.2959	
1	12	100	0	80	4865	322	84.03	1.7266	0.3381	
1	13	100	40	0	5282	322	100.1	1.8951	0.4991	
1	14	100	40	40	5143	324	91.49	1.7772	0.409	
1	15	100	40	80	4728	312	80.84	1.709	0.3217	
1	16	100	80	0	5560	376	97.28	1.7482	0.386	
1	17	100	80	40	5352	342	120.6	2.2515	0.672	
1	18	100	80	80	5128	386	87.38	1.7024	0.2714	
1	19	150	0	0	4518	375	97.48	2.1558	0.2597	
1	20	150	0	40	5421	362	100.4	1.8521	0.2932	
1	21	150	0	80	7228	420	165.3	2.2856	0.6649	
1	22	150	40	0	5699	429	114.8	2.0144	0.3196	
1	23	150	40	40	6742	442	156.3	2.3168	0.5821	
1	24	150	40	80	7089	420	140.6	1.9834	0.5009	
1	25	150	80	0	5004	319	111.3	2.2222	0.4099	
1	26	150	80	40	6742	342	141.4	2.0973	0.5873	
1	27	150	80	80	5699	350	116.5	2.0425	0.4123	
1	28	0	0	0	1946	285	56.96	2.9239	-	0.1996
1	29	0	0	0	2502	276	46.29	1.8465	-	0.1674
1	30	0	0	0	2085	291	46.04	2.2062	-	0.1581
2	1	50	0	0	4031	294	68.82	1.7068	0.4596	
2	2	50	0	40	4726	310	93.69	1.9805	0.9057	
2	3	50	0	80	4587	319	94.58	2.0602	0.8956	
2	4	50	40	0	3545	322	75.93	2.141	0.5143	
2	5	50	40	40	4070	348	75.53	1.855	0.4252	
2	6	50	40	80	4726	308	87.85	1.8578	0.7959	
2	7	50	80	0	4031	281	76.17	1.8879	0.6461	
2	8	50	80	40	4448	315	76.06	1.7086	0.5381	
2	9	50	80	80	4587	295	85.11	1.8552	0.7824	
2	10	100	0	0	5630	342	136.4	2.421	0.83	
2	11	100	0	40	5630	335	115.8	2.0551	0.6349	
2	12	100	0	80	5699	388	130.4	2.2864	0.6983	
2	13	100	40	0	4865	316	99.35	2.0411	0.5005	
2	14	100	40	40	5074	335	109.9	2.164	0.5759	
2	15	100	40	80	5004	346	100.4	2.0064	0.4647	
2	16	100	80	0	4657	340	105.3	2.2611	0.5231	
2	17	100	80	40	4865	356	98.91	2.0329	0.4342	
2	18	100	80	80	4935	388	86.62	1.7548	0.2613	
2	19	150	0	0	5421	342	125	2.3058	0.478	
2	20	150	0	40	5769	359	119.7	2.0749	0.425	

2	21	150	0	80	5838	376	112.1	1.9185	0.356	
2	22	150	40	0	5560	362	110	1.9784	0.3572	
2	23	150	40	40	5977	396	119.6	2.001	0.3859	
2	24	150	40	80	5838	331	111.7	1.9133	0.4007	
2	25	150	80	0	5143	374	104.1	2.0241	0.3054	
2	26	150	80	40	5421	314	99.93	1.8428	0.3397	
2	27	150	80	80	5838	385	118.1	2.0212	0.3866	
2	28	0	0	0	2155	314	52.73	2.4455	-	0.1678
2	29	0	0	0	1946	314	39.7	2.0401	-	0.1264
2	30	0	0	0	2085	300	39.91	1.9137	-	0.133
3	1	50	0	0	3545	320	78.3	2.2087	0.5685	
3	2	50	0	40	4309	318	102.6	2.3811	1.0608	
3	3	50	0	80	4379	310	98.13	2.2402	0.9957	
3	4	50	40	0	3753	281	84.37	2.2462	0.8101	
3	5	50	40	40	3962	300	98.28	2.4785	1.0289	
3	6	50	40	80	4170	315	89.52	2.1463	0.8081	
3	7	50	80	0	4170	310	106.3	2.5492	1.1597	
3	8	50	80	40	4309	300	106.3	2.4669	1.1909	
3	9	50	80	80	4518	308	105.6	2.3351	1.1499	
3	10	100	0	0	5004	340	104.8	2.0923	0.5171	
3	11	100	0	40	5699	364	150.7	2.6426	0.9387	
3	12	100	0	80	5421	322	130.5	2.4073	0.8031	
3	13	100	40	0	4518	335	124.1	2.7446	0.7179	
3	14	100	40	40	4726	308	118.7	2.5095	0.706	
3	15	100	40	80	5143	348	137.7	2.6755	0.8336	
3	16	100	80	0	4448	348	116.9	2.6281	0.6266	
3	17	100	80	40	4935	335	114.4	2.3181	0.6219	
3	18	100	80	80	5143	364	152.1	2.9574	0.9537	
3	19	150	0	0	5352	326	128.5	2.3991	0.5173	
3	20	150	0	40	6325	346	148.8	2.3526	0.6325	
3	21	150	0	80	6533	400	167.5	2.5624	0.7004	
3	22	150	40	0	5560	388	155.1	2.7896	0.6309	
3	23	150	40	40	5699	362	150.6	2.6408	0.6272	
3	24	150	40	80	5838	348	138.8	2.3758	0.5631	
3	25	150	80	0	5143	318	127.6	2.481	0.5203	
3	26	150	80	40	5421	364	118.8	2.1915	0.4138	
3	27	150	80	80	6116	374	140.2	2.2907	0.5454	
3	28	0	0	0	1946	239	55.04	2.8263	-	0.2301
3	29	0	0	0	1877	285	52.16	2.7757	-	0.1828
3	30	0	0	0	1738	310	49.39	2.8366	-	0.159
4	1	50	0	0	4031	295	74.98	1.8581	0.5784	
4	2	50	0	40	4170	310	82.82	1.9856	0.6897	
4	3	50	0	80	4865	307	93.81	1.9281	0.919	
4	4	50	40	0	3545	293	72.48	2.0423	0.5347	
4	5	50	40	40	4240	322	79.48	1.8726	0.5843	
4	6	50	40	80	4518	348	93.95	2.0784	0.7932	
4	7	50	80	0	3614	368	73.84	2.0421	0.3289	
4	8	50	80	40	4031	295	79.62	1.9747	0.6724	
4	9	50	80	80	4587	310	85.6	1.8661	0.7457	
4	10	100	0	0	4587	362	94.16	2.0514	0.3768	
4	11	100	0	40	5074	350	105.8	2.0832	0.5115	
4	12	100	0	80	4865	331	95.56	1.963	0.4391	
4	13	100	40	0	4516	326	91.58	2.0261	0.4069	
4	14	100	40	40	4935	325	102.3	2.0709	0.5155	
4	15	100	40	80	4726	348	87.95	1.8599	0.3366	
4	16	100	80	0	5421	348	106.4	1.9627	0.5216	
4	17	100	80	40	5560	324	117.4	2.1097	0.668	
4	18	100	80	80	5838	350	116.9	2.0007	0.6225	
4	19	150	0	0	4865	326	98.48	2.0226	0.3173	
4	20	150	0	40	5769	375	108	1.8721	0.3304	
4	21	150	0	80	5560	375	113.5	2.0414	0.367	
4	22	150	40	0	4935	396	95.28	1.9291	0.2232	

4	23	150	40	40	5630	363	113.3	2.0107	0.3775	
4	24	150	40	80	6255	368	124.1	1.984	0.445	
4	25	150	80	0	4101	320	81.93	1.9971	0.2135	
4	26	150	80	40	5074	342	111.3	2.1935	0.3866	
4	27	150	80	80	5560	364	111	1.9964	0.3618	
4	28	0	0	0	1946	310	40.57	2.0812	-	0.1306
4	29	0	0	0	2433	310	45.9	1.8866	-	0.1481
4	30	0	0	0	1460	300	34.1	2.3356	-	0.1137
						MEAN		2.1265	0.577	0.1597
						S.D.		0.301	0.2278	0.0322

Note: The basic data has been calculated for obtaining Nutrient requirement(NR), Contribution to fertilizers (CFN) and contribution to Soil(CSN) for Nitrogen only. For Phosphorus and Potassium the same method holds.

APPENDEX-II

Fertilizer Adjustment Equations for FN,FP and FK

CENTRE: MARUTERU CROP: RICE SEASON: RABI YEAR: 1994

GRADIENT OX

PARAMETER	N	P_2O_5	K_2O	FERTILISER ADJUSTMENT EQUATIONS	TARGET (Q/HA)	SOIL-TEST (KG/HA)	FERT-DOSE (KG/HA)
NR (KG/Q)	1.7503	1.1625	2.3820	FN=5.21*T-0.65 SN	80	394	159
CS	0.2194	0.5031	0.2019	FP=4.86*T-4.82 SP		58	111
CF	0.3361	0.2392	0.8305	FK=2.87*T-0.29 SK		415	108

RESPONSE YARDSTICK (KG/KG) : 7.73

GRADIENT 1/2 X

PARAMETER	N	P_2O_5	K_2O	FERTILISER ADJUSTMENT EQUATIONS	TARGET (Q/HA)	SOIL-TEST (KG/HA)	FERT-DOSE (KG/HA)
NR (KG/Q)	:1.7591	1.1786	2.4780	FN=4.07*T- 0.41 SN	80	374	172
CS	:0.1774	0.4256	0.1657	FP=2.87*T- 2.37 SP		62	83
CF	:0.4321	0.4113	1.1825	FK =2.10*T-0.17 SK		416	97

RESPONSE YARDSTICK (KG/KG) : 11.07

GRADIENT 1X

PARAMETER	N	P_2O_5	K_2O	FERTILISER ADJUSTMENT EQUATIONS	TARGET (Q/HA)	SOIL-TEST (KG/HA)	FERT-DOSE (KG/HA)
NR(KG/Q)	:1.8123	1.1658	2.4599	FN=3.37*T-0.29 SN	80	442	142
CS	:0.1549	0.4037	0.1536	FP=2.61*T-2.07 SP		58	89
CF	:0.5374	0.4465	1.3290	FK=1.85*T-0.14 SK		424	89

RESPONSE YARDSTICK (KG/KG) : 12.77

GRADIENT 2X

PARAMETER	N	P_2O_5	K_2O	FERTILISER ADJUSTMENT EQUATIONS	TARGET (Q/HA)	SOIL-TEST (KG/HA)	FERT-DOSE (KG/HA)
NR (KG/Q)	:1.7769	1.2009	2.4641	FN=3.49*T-0.30 SN	80	384	162
CS	:0.1554	0.3369	0.1486	FP=1.81*T-1.16 SP		53	83
CF	:0.5095	0.6639	1.3418	FK=1.84*T-0.13 SK		464	85

RESPONSE YARDSTICK (KG/KG) : 14.02

OVERALL GRADIENTS

PARAMETER	N	P_2O_5	K_2O	FERTILISER ADJUSTMENT EQUATIONS	TARGET (Q/HA)	SOIL-TEST (KG/HA)	FERT-DOSE (KG/HA)
NR(KG/Q)	:1.7789	1.1820	2.4427	FN=3.72*T-0.36 SN	80	442	138
CS	:0.1728	0.4100	0.1607	FP=2.68*T-2.13 SP		58	92
CF	:0.4777	0.4409	1.2073	FK=2.02*T-0.16 SK		424	94

RESPONSE YARDSTICK (KG/KG) : 11.87

Note:

FN- Fertilizer Nitrogen (added)
FP- Fertilizer Phosphorus(added)
FK- Fertilizer Potassium (added)
SN- Soil Available Nitrogen
SP- Soil Available Phosphorus
SK- Soil Available Potassium
T- Targeted Yield

APPENNDEX-III (SAS-PROGRAMME)

The following SAS programme has been developed from PROC REG , PROC RSREG, PROC GLM, PROC PLOT to carry out Regression, RSM and Graphic plots

```
data <file name>;
input cen yr sea rep trt fn fp fk oc sn sp sk yield un up uk ;
fn2 = fn*fn;
fn3=  fn2*fn;
fp2 = fp*fp;
fk2 = fk*fk;
sn2 = sn*sn;
sp2 = sp*sp;
sk2 = sk*sk;
fnsn = fn*sn;
fpsp = fp*sp;
fksk = fk*sk;
fnfp = fn*fp;
fnfk = fn*fk;
fpfk = fp*fk;
snsp = sn*sp;
snsk = sn*sk;
spsk = sp*sk;
cards ;

DATA

;
proc print;
run;
proc means;
var sn sp sk;
```

```
run;
proc glm ;
 class rep fn fp fk;
 model yield = rep fn fp fk fn*fp fn*fk fp*fk fn*fp*fk;
 means fn fp fk fn*fp fn*fk fp*fk;
 run;
 proc reg ;
 model yield = fn fp fk fn2 fp2 fk2 sn sp sk fnsn fpsp fksk/selection = backward;
 run;
 proc reg ;
 model yield = fn fp fk fn2 fp2 fk2 sn sp sk sn2 sp2 sk2 fnsn  fpsp fksk fnfp fnfk fpfk/selection = backward;
 run;
 proc reg ;
 model yield = rep fn fp fk fn2 fp2 fk2 sn sp sk sn2 sp2 sk2 fnsn fpsp fksk fnfp fnfk fpfk/selection =
 backward;
 run;
 proc reg ;
 model yield = fn fp fk fn2 fp2 fk2 sn sp sk sn2 sp2 sk2 fnsn fpsp fksk/selection = backward;
 run;
 proc reg ;
 model yield = rep fn fp fk fn2 fp2 fk2 sn sp sk sn2 sp2 sk2 fnsn fpsp fksk/selection = backward;
 run;
 proc reg ;
 model yield = fn fp fk fn2 fp2 fk2 fnfp fnfk fpfk/selection = backward;
 run;
 proc reg ;
 model yield = rep fn fp fk fn2 fp2 fk2 fnfp fnfk fpfk/selection = backward;
 run;
 proc reg ;
 model yield = sn sp sk sn2 sp2 sk2 snsp snsk spsk/selection = backward;
 run;
 proc reg ;
 model yield = rep sn sp sk sn2 sp2 sk2 snsp snsk spsk/selection =   backward;
 run;
```

```
proc reg ;
model yield = rep fn fp fk fn2 fp2 fk2 sn sp sk fnsn fpsp fksk/selection   = backward;
run;
proc reg ;
model yield =fn fp fk fn2 fp2 fk2 sn sp sk fnsn fpsp fksk/influence;
run;
proc reg ;
model yield =fn fp fk fn2 fp2 fk2 sn sp sk fnsn fpsp fksk/p r;
run;
proc reg ;
model yield =fn fp fk fn2 fp2 fk2 sn sp sk fnsn fpsp fksk/selection=backward;
run;
proc reg ;
model yield =fn fp fk fn2 fn3 fp2 fk2 sn sp sk fnsn fpsp  fksk/selection=backward;
run;

PROC GLM;
CLASS fn fp fk;
MODEL YIELD= REP fn fp fk;
OUTPUT OUT= MAR2 PREDICTED = YPRED RESIDUAL=Z;
PROC STANDARD STD=1.0;
VAR Z;
PROC RANK NORMAL=BLOM ;
VAR Z;
RANKS NSCORE;
PROC PRINT;
;
PROC PLOT;
PLOT Z*YPRED/ VREF=0 VPOS=19 HPOS=50;
PLOT Z*NSCORE/VREF=0 HREF=0 VPOS=19 HPOS=50;
RUN;
```

```
 PROC PLOT;
PLOT FN*YIELD/ VREF=0 VPOS=19 HPOS=50;
PLOT FP*YIELD/ VREF=0 VPOS=19 HPOS=50;
PLOT FK*YIELD/ VREF=0 VPOS=19 HPOS=50;
 RUN;

proc rsreg;
model yield = sn sp sk fn fp fk /covar=3 lackfit ;
ridge max outr=ridge;
run;
```

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