OPTIMISATION TECHNIQUES IN LONG TERM FERTILISER TRIALS: RICE-RICE SYSTEM

By

JESMA V A

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THESIS

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DECLARATION

I hereby declare that the thesis entitled "**Optimisation techniques in long term fertiliser trials: rice-rice system**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Place: Vellanikkara

Date: 08·08·19

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CERTIFICATE

Certified that the thesis entitled **"Optimisation techniques in long term fertiliser trials: rice-rice system"** is a record of work done independently by **Ms. Jesma V A** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of the advisory committee of **Ms. Jesma V A (2017-19-004)**, a candidate for the degree of **Master of Science in Agricultural Statistics**, with major field in **Agricultural Statistics**, agree that the thesis entitled **"Optimisation techniques in long term fertiliser trials: rice-rice system"** may be submitted by **Ms Jesma V A**, in partial fulfillment of the requirement for the degree.

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CHAPTER 1

INTRODUCTION

Long term experiments are those which are repeated on the same set of experimental units year after year, where the sequence of treatments or crops or both are pre-planned. The main aim of such experiments is to study the long-term field effects of given treatments and crops on soil fertility and on economic returns. Long term field experiments also play a vital role in understanding the effect of plant-soil-climate interactions on crop yield (Army and Kemper, 1991).

Fertiliser is defined as any organic or inorganic material of natural or synthetic origin that is added to a soil to supply one or more plant nutrients essential to the growth of plants. It is one of the major factors contributing to improved agricultural production. Over the years, its consumption has been increasing exponentially on soil and environment under intensive cropping. This had led to the need for long term continuous studies at the fixed rates to monitor the changes in nutrient dynamics which gives valuable information regarding the sustainability of intensive agriculture that cannot be obtained from short term experiments (Lal, 1994).

The world's first long term field experiment was pioneered under the leadership of J. B. Lawes and J. H. Gilbert between 1843-1856 at Rothamsted, England. These started as agronomic experiments aiming at determining the nutrient requirement of agricultural crops. In India, the green revolution commenced in the early 1960s that led to an increase in food grain production with the introduction of high yielding varieties (HYV). However, the substantial removal of nutrients from the soil by HYVs and use of fertiliser in large amount made it essential to examine the sustainability of modern intensive cropping based on high external inputs of fertiliser, agro-chemicals and high yielding cultivars under irrigated condition. Hence, in September 1970, Indian Council of Agricultural Research launched the All India Coordinated Research Project (AICRP) on Long Term Fertiliser Experiments (LTFE) at eleven centers based on the Rothamsted

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model. The work carried out at these eleven centres were reviewed and recognizing the significance of the information generated from the LTFE centres, six more centres were sanctioned during 1995-1996. AICRP on 'Long Term Fertiliser Experiments' to study changes in soil quality, crop productivity and sustainability' was started at Regional Agricultural Research Station, Pattambi during 1997 *rabi* season with rice-rice intensive cropping. These experiments were aimed to monitor the changes in soil properties and yield responses and soil environment due to continuous application of plant nutrient inputs through fertiliser and organic sources, which in turn helped to synthesis tactics and policies for national use and management of fertilisers leading to improved soil quality and minimized environment degradation.

The key objective of any agricultural experiment is to provide comparative efficiency of treatments. The experiments are carried out in pre-planned design and are analysed. The simple analysis of variance cannot give an accurate measure of the superiority of a treatment year after year or from place to place or both *i.e.*, it excludes time as a factor accounting for treatment responses.

In long term experiment, interest is to see the stability of individual treatments under different environmental conditions. Hence, to draw a valid inference from the experiment, repeated measurements are taken on the same plot for a number of years with the same treatments and cultural practices. Hence, such experiments help in obtaining a general conclusion with regard to sustainability and consistency of treatments as well as the interaction between them. Moreover, the yield of any crop in long term fertiliser experiments is a function of controllable and uncontrollable factors, such as previous crop yield, plot wise residuals, amount of soil nutrient and weather factors. To study crop and such factor interaction, several techniques are formulated to analyse long term fertiliser experiments.

The applicability of various statistical tools in different context are discussed in this study. Pooled analysis applying analysis of groups of experiments formulated by Yates and Cochran (1939) helps to study the consistency of treatment responses from season to season or from year to year, as well as to evaluate average response of treatment. Split plot analysis gives better estimate of changes in yield over the years. Crop weather relationship can be brought forth with the help of correlation analysis. The relative contribution of plant nutrients on crop yield can be quantified using non-linear regression. Repeated measures ANOVA and Kruskal Wallis H test can justify for dynamics of soil characters over years. The yield prediction model through multiple linear regression using principal components of the original weather variables as regressors can account for the presence of multi collinearity in the data and improve the predictability. Response curves using time as an independent variable can exhibit how treatments respond to time in terms of linear, quadratic and cubic model. A comparative study of the methods can help in identifying the best statistical tool for analysis of LTFE. Hence, this study can serve as a guide for analysis in further research in connection to LTFE.

Coupling with the principal aim of the experiment the present study titled 'Optimization techniques in long term fertiliser trials: rice-rice system' has been carried out with the following objectives:

1. To study the cumulative effect of weather factors and plant nutrients on crop production
2. To study the dynamics of soil characters in relation to fertiliser treatment
3. Suggest appropriate statistical optimization tools with respect to yield and its forecast

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

A critical review of literature is necessary for any scientific investigation. A proper understanding of the problem is required through assessment of the current status of the problem. In line with the objectives of the problem, the review of literature is presented below. These are divided into following sections:

2.1 Analysis of long-term fertiliser experiments
2.2 Influence of weather parameters on crop yield
2.3 Influence of soil parameters on crop yield
2.4 Analytical techniques in LTFE

2.1 Analysis of long-term fertiliser experiments

Patterson and Lowe (1970) calculated serial plot correlation from 12 experiments on arable crops for yields of 4, 6 and 8 years apart. They found that these were positive with an average value of 0.2. They concluded that the bias in the estimation of error and loss of efficiency in the estimation of treatment effects were due to the negligence of plot correlations. By eliminating two separate components of error mainly, plot error and plot x year error, the bias in variance can be wholly or partly eliminated.

Biswas *et al.* (1990) found that the analysis of long-term trial data on tea by ANOVA of individual year was valid but the combined analysis over years wasn't due to heterogeneity in variance-covariance matrix. This was due to successive years plots yield correlation, the magnitude of which is generally dependent upon the time lag. Among the various methods, they concluded that the rank method was found to offer accurate inference in testing the significance of treatment and treatment X year effects and better practical interpretation of the results in conformity with the results based on individual year's analysis.

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Vats *et al.* (2002) applied analysis of covariance technique on the data of each crop in the cropping systems at Ludhiana (1981-96) and Bangalore (1987-97) centres under the Long-Term Fertiliser Experiments project of ICAR taking plot wise preceding crop yields/residuals or available soil nutrients; linear, quadratic, logarithmic and reciprocal relationships of soil parameters and combinations thereof as covariates. They concluded that plot wise residuals at Ludhiana and residuals as well as different relationships of available soil nutrients at Bangalore influenced the succeeding crops of wheat and ragi respectively by considerably reducing the coefficient of variation in different years at these places.

Sharma and Rajinder (2003) evaluated the effect of fertilisers in combination with organic manures on the productivity of cereal-based crop sequences. They also examined whether the yields exhibited trend over the years using linear regression model.

Manna *et al.* (2005) evaluated potential impact of productivity due to continuous cultivation of crops in rotation, fertiliser and manure application on yield trends, Soil Organic Carbon (SOC) storage, soil quality parameters and Sustainable Yield Index (SYI). Linear regression equation was fitted to study trend analysis and relationship between SYI and soil quality parameters. The analysis of yield trends revealed that significant yield decline was remarkable under unbalanced (N or NP) fertiliser application.

Rashid and Voroney (2005) proposed nitrogen fertiliser recommendations for corn grown on soils amended with oily food waste using linear regression model. Data were divided into three data subsets, representing the rate, time, and landscape position of oily food waste application and analysis of variance for the effect of N on corn crop yields and change in maximum economic rate of nitrogen (MERN) due to oily food waste (OFW) application were performed. Using quadratic response equations, MERN for all experiments was calculated.

Hejcman *et al.* (2013) analyzed yield and concentrations of elements in grain of spring barley in unfertilized control, mineral fertiliser application (N4P2K2 – 70, 60 and100 kg N, P and K per ha) and combinations of farmyard manure or poultry litter with mineral fertiliser (FMN4P2K2 and PLN4P2K2) treatments using one-way ANOVA. They concluded that there was a clear positive effect of fertiliser treatment on grain yield and concentrations of N, P and K in the grain, but no effect on concentrations of Ca and Mg and apart from Fe, concentrations of micro- and risk-elements in the grain were not significantly affected by applied treatments.

Liu *et al.* (2013) studied the impacts of climate changes, soil nutrients, variety types and management practices on rice yield Taihu region in East China. They defined each location-year combination as an environment. It was considered as random effects and nitrogen rates as fixed effects. Regression analysis was carried out for character responses when there was a significant main effect for nitrogen fertility treatment or interaction. Linear, quadratic, and cubic regression models were tested. The results showed that the average temperature showed an increasing trend, while the total precipitation and sunshine hours exhibited decreasing trends in the rice growing season. It was also found that the average rice yield in the Taihu region increased by 46.3 per cent.

Integrated analysis of long-term experiments by Wei *et al.* (2016) established that the application of chemical fertilisers in combination with organic fertiliser was found to be the most effective way to produce more yield, build up soil organic matter thereby enhance the sustainability of cropping systems.

Results from studies on long term experiments in rice-wheat system conducted by Chaudhary *et al.* (2017) indicated that the selection of organic manure was important for long-term C sequestration as the stability of soil organic carbon differed based on the nature of organic manure added.

Saha *et al.* (2018) evaluated the long-term effects of integrated nutrient management (INM) in rice-wheat system for yield trends, sustainability, nutrient balance and soil fertility of the system. The yield slope and sustainability index under INM was seen considerably higher than 100% recommended fertiliser under INM.

2.2 Influence of weather parameters on crop yield

Shaw (1964) urged that weather index approach was a better analytical approach than multiple regression method to measure the impact of weather variables on crop yield.

Williams (1971) studied the relationships of wheat yield fluctuations to weather variations. They found that correlations of yields with weather variables were greatest in the driest areas, where only one weather variable was needed to explain 40% of the yield variance whereas in the most humid parts, at least three variables were needed.

Ravelo and Decker (1981) developed a model using weather data to estimate the yields of soybeans for varieties adapted to the central United States. An iterative regression analysis was used to relate soybean yields to environmental variables. The observed and estimated yields were statistically non-significant.

Campbell and Ferguson (1983) discussed the yield and quality of grains after the 12 years of long-term rotation study. The factors examined were the effect of rotation length, fallow-substitute crops, and N and P fertiliser. Using standard methods, Analyses of Variance, and regression analyses were carried out. They found that the trends in wheat yields were directly related to growing season rainfall.

Lu *et al.* (2001) quantified the relationship of calendar days after planting (DAP) and growing degree days after planting (GDD) to HI in taro and to compare their ability to explain seasonal variation in the linear increase of HI. Piecewise linear functions with HI based on DAP and GDD were fitted. They discovered that, for

GDD model, responses during the linear increase phase of HI more stable across years.

Pathak *et al.* (2003) studied the long-term trends of potential stimulated yields of rice and wheat in Indo-Gangetic plains. Linear regression analyses of weather parameters of last several years showed negative trends. They concluded that decrease in solar radiation and an increase in minimum temperature were the reasons for yield decline.

Okpliya (2003) revealed that pre-sowing rainfall had a positive effect on the rice yield as the entire life cycle of the crop grown partly depends on the soil moisture on the ground before the sowing is done.

Challinor *et al.* (2005) assessed the impact of high temperature on groundnut. They reported that weather strongly influences soil biological activity and grain yield of wheat and during the periods of high temperature near flowering can reduce yields of annual crops.

Girma *et al.* (2007) assessed if rainfall distribution coupled with previous year grain level and fertiliser response index improved the predictability of succeeding year fertiliser response index. Multiple linear regressions were used to determine the combined effect of these variables in explaining the variability in the fertiliser response index.

Kumar *et al.* (2017) examined the effect of climatic factor on yield during different stages of wheat using regression analysis. They discovered that relative humidity(morning) had a significant contribution towards yield variability.

Oguntunde *et al.* (2018) quantified the relationship between weather parameters and rice yield using multiple linear regression, principal component and support vector machine analyses. The climate variable of highest influence on rice yield was solar radiation and was predominant in the vegetative, booting, flowering, and grain filling stages.

2.3 Influence of soil parameters on crop yield

Bundy (2003) examined the effects of long-term nitrogen (N) fertilization on productivity and soil fertility parameters in a 45-year N rate experiment with continuous corn. In a randomized complete block design with four replications, initial treatments consisting of three N rates were arranged and ensuing N and lime treatments were merged into the experimental design using a split-plot treatment combination. They concluded that there was no indication of a decline in productivity after 45 years of N fertiliser use in continuous corn production.

Setia and Sharma (2005) investigated the available, water soluble and heat soluble sulphur (S) contents in maize-wheat sequence which was continuously cropped for 22 years. Using S status in different soil layers as independent variables, regression equations were fitted to predict S uptake by wheat. Simple linear regression analysis was used to compute the relationship between applied fertiliser and forms of S and stepwise multiple regression analysis was used to work out the relationship between S uptake and forms of S in different soil layers.

Studies done by Hati *et al.* (2007) indicated that the application of balanced rate of fertilisers in combination with organic manure could sequester soil organic carbon in the surface layer and also improve the soil physical environment and sustain higher crop productivity under soyabean-wheat-maize crop rotation.

Jagadamma *et al.* (2008) evaluated the effects of management practices on soil properties to explain field-level changeability in crop production using data from an experiment with five N rates and two cropping systems. The univariate analysis indicated that at least one treatment effect influenced 14 soil properties significantly. Principal Component Analysis (PCA) was used to remove multicollinearity among the correlated soil parameters. Finally, the multiple regression analysis was performed between PCA derived soil properties and corn and soybean yields.

Bhardwaj *et al.* (2011) examined the long-term changes (>20 years) in soil quality and productivity when incorporated with ecological management principles. Soil Quality Index (SQI) was derived using PCA. They concluded that use of multivariate approach for soil quality evaluation can be more effective than univariate analysis or single parameter assessment.

Thierfelder *et al.* (2013) evaluated the effects of conservation agriculture on soil parameters and maize yield for eight cropping seasons. They showed that maize grain yields increased significantly over time under no-tillage with the retention of crop residues on the surface compared with the traditional ridge and furrow system. The PCA biplot established that the maize yield was weakly interrelated to soil carbon.

2.4 Analytical techniques in LTFE

Cerrato and Blackmer (1990) found that quadratic-plus-plateau model best described the yield responses for understanding the optimal rates of fertiliser application.

Lopez *et al.* (1996) conducted a study with wheat yield to determine the effects of tillage (TILL), crop rotation (ROT) and fertiliser in a rainfed Mediterranean region. They used split-split plot design with four replications where tillage system namely no tillage (NT) and conventional tillage (CT) were taken as main plot and crop rotation, with four different 2-year rotations with wheat-sunflower (WS), wheat-chickpea (WCP), wheat-faba bean (WFB), and wheat fallow (WF) and continuous wheat (CW) were considered as subplot. N fertiliser rates (0, 50,100 and 150 kg N/ha) applied to wheat only were the sub-subplots. They got a significant TILL × ROT interaction in the drought years.

Bhandari *et al.* (2002) determined trends (slopes) using simple linear regression analysis of grain yields over the years. To study the effects of treatment and year, analysis of variance across years was done. The interaction of treatment and years on yield was determined using IRRISTAT version 92(International Rice Research Institute, Philippines). For the initial and final 3 years of the experiment, rice and wheat yield response to different levels of N-P-K application were compared by doing simple linear regression analysis on each year's data of grain yield and N, P and K applied. The slopes and y-intercepts were compared at 5 per cent level of probability.

Singh and Jones (2002), discussed variance–covariance models for the analysis of the grain and straw yields of barley in a long-term fertiliser experiment. They concluded that the best fit was obtained by a model which had a constant covariance and heterogeneous variances.

Ernani *et al.* (2002) evaluated the effect of liming on corn yield and chemical characteristics of a Humic Hapludox (clayey, kaolinitic, goethitic, termic) under both conventional tillage (CT) and no-tillage (NT) systems. A split-plot design was considered where tillage systems was the main plots and lime rate was assigned to subplots. They found that liming increased yield by 66% and was higher with CT than with NT in 2 to 3 years.

Sena *et al.* (2002) used multivariate approach to distinguish the farm areas as a function of the soil management and determine which are the most important parameters to characterize them. PCA was used to visualize the effect of microbes and soil amendments through biplots and Hierarchical Cluster Analysis (HCA) was used to verify the assessment among the plots.

Maruti *et al.* (2005) studied the statistical modeling and optimization of fertiliser nutrients for rain fed crops. This was based on soil and weather parameters under dryland conditions and LTFE data for 12 seasons. Regression models were standardized for predicting yield through rainfall and land degradation. They concluded that among the major crops, sorghum yield had a higher coefficient of determination (R^2).

Malone *et al.* (2007) applied multivariate polynomial regression to 10 years of data of Nashua, Iowa to predict yearly crop yield, total drainage from the two-year corn–soybean cycle, flow-weighted nitrate concentration over the two-year corn–soybean cycle, and nitrate load over the two-year corn–soybean cycle. The regression equations described over 87, 85, 94, 76, and 95 per cent confidence interval in soybean yield, corn yield, subsurface drainage, nitrate concentration, and nitrate loss in subsurface drainage, respectively. The regression equations gave an account of nitrate leaching and offered a simple method to quantify potential N losses from corn-soybean rotations under the climate, soil, and management conditions of the Nashua field experiments.

Stanger and Lauer (2008) determined the corn grain yield response to six crop rotation sequences and four N rates for 35 years. To test the rotation effect, a randomized complete block in a split-plot design with two replications of 21 treatments was done. To study the long-term effects of various crop rotations and different N fertilization rates on grain yield, regression slopes of each year of corn within each rotation sequence were assessed. They reported that corn grain yields trends of 5-yr crop rotations were significantly better where no N was added and to eliminate this difference, additional N was required for the 2-year rotations.

Michel and Makowski (2013) demonstrated that linear, quadratic, cubic and dynamic linear models were powerful tools for analyzing wheat yield time series.

Pandey *et al.* (2016) developed models for forecasting rice yield for faziabad district (U.P) based on weather parameters of 21 years (1989-2010). Using stepwise multiple regression, best model for yield forecasting was selected with RMSE value of 0.73

Thangaswamy (2016) studied the pattern of nutrient uptake using nonlinear logistic growth model for optimization of quantity and timing of nutrient application through fertilisers. The statistical integrity of the curve was ensured using correlation analysis. They reported that the uptake pattern of the nutrients was quadratic (sigmoid) in nature.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

In this chapter, a brief description of materials and statistical methods employed in the analysis of data pertaining to various objectives of the study are discussed under the following headings.

3.1 Description of the study area
3.2 Nature and source of data
3.3 Presence of trend
3.4 Exploratory data analysis
3.5 Student's t test
3.6 Kruskal Wallis H test
3.7 Analysis of variance for individual experiment
3.8 Analysis of groups of experiments
3.9 Split plot analysis
3.10 Repeated measures ANOVA
3.11 Correlation analysis
3.12 Multiple regression analysis
3.13 Nonlinear regression
3.14 Principal component analysis
3.15 Response curves using polynomial regression

3.1 Description of the study area

The data used in the study entitled 'Optimisation techniques in long term fertiliser trials: rice – rice system' is taken from All India Coordinated Research Project on Long-Term Fertiliser Experiments (AICRP-LTFE) on rice, which was initiated at Regional Agricultural Research Station (RARS), Pattambi in 1997 to study the changes in soil quality, crop productivity and sustainability under long term fertiliser experiments in rice. The experiment was laid out in RARS, Pattambi using the variety Aiswarya in two planting seasons *viz., kharif* (Virippu) and *rabi*

(Mundakkan). The *kharif* season starts from July to October during the South-West monsoon and the *rabi* cropping season is from October to March (Winter).

3.1.1 Experimental details

The following are the details of the experiment and the layout of the experiment is given in Fig. 3.1

Number of replications: 4
Number of treatments : 12
Design : Randomized Complete Block Design (RCBD)
Plot size : 125 m^2

Following are the fertiliser treatments:

T_1 : 50 per cent NPK (as per POP recommendation of KAU)

T_2 : 100 per cent NPK (90 N : 45 P_2O_5 : 45 K_2O)

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + lime @ 600 kg/ha

T_5 : 100 per cent NPK*

T_6 : 100 per cent NP

T_7: 100 per cent N

T_8: 100 per cent NPK + FYM @ 5t/ha to the *kharif* rice only

T_9: 50 per cent NPK + FYM @ 5t/ha to the *kharif* rice only

N

T_{10}	T_6	T_{11}	T_8	T_1	T_4
T_5	T_9	T_{12}	T_7	T_2	T_3

R_1

T_{12}	T_8	T_9	T_{11}	T_7	T_3
T_4	T_1	T_6	T_{10}	T_2	T_5

R_2

T_{10}	T_3	T_8	T_{11}	T_1	T_5
T_7	T_4	T_{12}	T_2	T_9	T_6

R_3

T_7	T_{10}	T_9	T_2	T_{11}	T_3
T_{12}	T_5	T_8	T_4	T_1	T_6

R_4

Fig. 3.1 Layout of LTFE

T_{10}: 100 per cent NPK + *in situ* growing of *Sesbania aculeata,* as green manure crop for *kharif* rice only

T_{11}: 50 per cent NPK + *in situ* growing of *Sesbania aculeata,* as green manure crop for *kharif* rice only

T_{12}: Absolute control

Note:

* T_5 was initially 100 per cent NPK with Copper. But within two years after the start of LTFE, the copper requirement of the soil was met. Hence after two years copper application was stopped.

The twelve treatments listed above shall hereafter be notated as T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11} and T_{12}.

3.2 Nature and source of data

The data recorded on grain yield of rice crop in *kharif* and *rabi* seasons for twenty years from 1997- 2017 serves as the base of the study. The soil properties like soil available nitrogen, phosphorus & potassium and other parameters such as pH, EC, OC etc., and weather parameters like maximum temperature, minimum temperature, sunshine hours, rainfall, number of rainy days, relative humidity and wind velocity were collected for the same period during the pre-sowing and crop growing periods in both the seasons. Data analysis were performed using Statistical Package for Social Sciences (SPSS), version 22.0 software to achieve the objective of the study.

3.3 Testing the presence of trend in data

The first and foremost thing to consider after getting a time series data is to determine whether there is upward or downward trend present in the data. The general tendency of a time series data to increase or decrease over a long period of time is known as trend. To formally test the presence of linear trend, a linear regression model taking time as the independent variable and average yield as dependent variable can be fitted as given below:

$$y_t = \beta_0 + \beta_1 t + \varepsilon_t$$

where β_0 is the intercept of the trend equation,

β_1 is the slope of the trend equation,

t is the independent variable in the equation; t= 1, 2,..20

ε_t is the error term associated with the trend equation

$\varepsilon_t \sim IID\ N(0, \sigma^2)$

If the β_1 coefficient of time t is statistically significant, then we can conclude that there is presence of long-term linear trend.

3.4 Exploratory data analysis

3.4.1 Non-graphical methods

A preliminary investigation to the objectives of the study can be realized through descriptive statistics *viz.*, mean, standard deviation, skewness and kurtosis and coefficient of variation.

3.4.2 Graphical method- Box plot

Box plot is the standard technique for presenting the 5-number summary which consists of the minimum and maximum range values, the upper and lower quartiles, and the median (Potter, 2006). The box indicates the positions of the upper and lower quartiles; the interior indicates the area between the upper and lower quartiles *i.e.* inter quartile range, which consists of 50% of the distribution.

Whiskers are extended to either minimum and maximum values in the dataset, or to a multiple, such as 1.5, of the inter quartile range to remove extreme outliers (Frigge *et al.*, 1989) Any point outside this range denote an outlier.

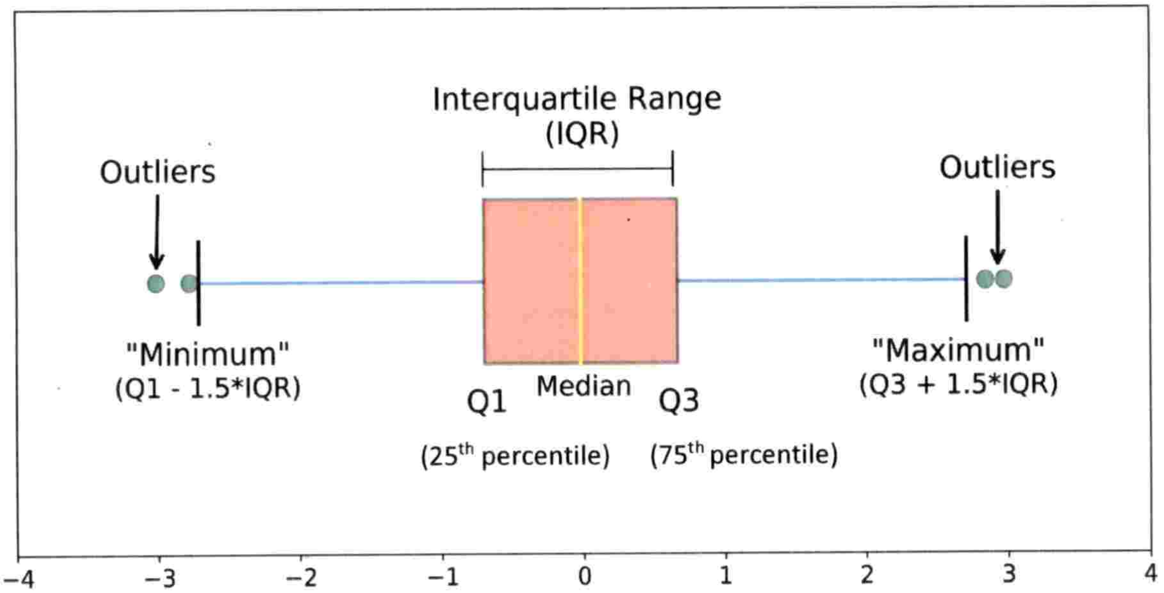

Fig 3.2 Box plot

3.5 Student's t test

Student's t test was proposed and first used by W.S. Gosset in 1908. Suppose we want to test H_0: $\mu=\mu_0$ on the basis of a small random sample $x_1, x_2, \ldots, x_n$ of size n ($n \leq 30$) from a normal population $N(\mu,\sigma^2)$ with σ^2 unknown for α level of significance. For testing H_0, student's t statistic is

$$t = \frac{\sqrt{n}(\bar{x} - \mu_0)}{s}, -\infty < t < \infty$$

where, $s = \sqrt{\frac{\Sigma_i (x_i - \bar{x})^2}{(n-1)}}$ for $i=1, 2, \ldots, n$.

Let two independent small samples of size n_1 and n_2 be $x_{11}, x_{12}, \ldots, x_{1n1}$ and $x_{21}, x_{22}, \ldots, x_{2n2}$ respectively. The test statistic for testing H_0: $\mu_1=\mu_2$ is

Case i: $\sigma_1^2 = \sigma_2^2 = \sigma^2$ (unknown)

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

Where $\bar{x}_1, \bar{x}_2$ are the sample means

$s = \sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{(n_1+n_2-2)}}$ where s_1^2 and s_2^2 are the variances of the first and second sample respectively.

The test statistic has $(n_1 + n_2 - 2)$ *d.f.*

Case ii: $\sigma_1^2 \neq \sigma_2^2$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

The calculated value of t is compared with t^*

$$t^* = \frac{\frac{s_1^2}{n_1}t_{(\alpha,n_1-1)} + \frac{s_2^2}{n_2}t_{(\alpha,n_2-1)}}{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

3.6 Analysis of variance for individual experiment

Individual experiment done in a year for both *kharif* and *rabi* seasons were analysed by performing Analysis of Variance (ANOVA) in RBD (Fisher,1926). The method suggested by Duncan (1955), popularly known as Duncan's Multiple Range Test (DMRT), is used to compare treatment means if the treatments are significantly different.

3.7 Analysis of Groups of Experiments

In a long-term experiment, the same treatments are repeated year after year to study the vulnerability of treatment effects to factors such as climate and soil conditions. These experiments help to obtain a general conclusion with regard to suitability and consistency of treatments and the extent of interaction present between the treatments and other factors represented by the trial. Hence a joint analysis of the set of trials is necessary. The usual analysis of replicated data cannot be done as the error variance in different years may not be homogenous. Hence mere pooling will lead to wrong interpretations. To tackle this, Yates and Cochran (1938) suggested analysis of groups of experiments.

Basically, the results of a set of replicated trials can be categorized into four:

i. Experimental errors are homogenous, and interaction is absent
ii. Experimental errors are homogenous, and interaction is present
iii. Experimental errors are heterogeneous, and interaction is absent
iv. Experimental errors are heterogenous, and interaction is present

Hence the first thing to do in combining results of a set of replicated experiments is to check whether the experimental errors are homogenous and if the treatment responses are consistent. Test for homogeneity of variance is done by Bartlett's test.

Bartlett's test for homogeneity of variance

Let the n error mean squares be $s_1^2, s_2^2, \dots, s_n^2$ based on k degrees of freedom. The pooled estimate $\bar{s}^2$ is given by

$$\bar{s}^2 = \frac{1}{n}\sum_{1}^{n} s_r^2$$

$$\chi'^2 = k(nlog\bar{s}^2 - \textstyle\sum_1^n log\, s_r^2)$$

$$C = 1 + \frac{n+1}{3nk}$$

The value $\frac{\chi'^2}{C}$ is compared with the critical value of χ^2 at *(n-1)* degrees of freedom. If $\chi'^2$is non-significant, it means that the experimental errors are of same order that is, the error variances are homogenous.

Case 1: Homogenous error variance

If the Bartlett's test is non-significant, we can conclude that the error variance is homogenous. Then we can perform combined analysis by arranging the treatment means for each year or season in a two-way table. A pooled experimental error is obtained by a joint estimate of error variance. The interaction of treatment with seasonal effect is tested using the pooled error variance. If interaction is absent, the error sum of squares is pooled with sum of squares for interaction to obtain a more precise experimental error. Treatment means are compared with this pooled experimental error. The skeleton of pooled ANOVA is given in Table 3.1.

Table 3.1 Skeleton of pooled ANOVA

Source of Variation	Degrees of freedom
Treatments	(v-1)
Year	(s-1)
Treatment x Year	(v-1)(s-1)
Pooled error	s(v-1)(r-1)

Case 2: Heterogenous error variance

When the error variances are heterogenous, to test the treatment differences we must initially find out the presence or absence of interaction between the treatment and season. Test for significance of interaction is achieved with weighted analysis of variance.

Weighted analysis of variance

The treatment means are weighted with weights which are inversely proportional to the error variance. The weights are calculated as

$$W_i = \frac{r}{s_i^2}$$

Where r is the number of replications for each trial, s_i^2 is the error variance from each experiment. Using these weights, for each year the quantities $W_i P_i$, $W_i t_i$ are calculated where P_i are the year total and t_i are the means for each treatment during each year. The crude sum of squares (S_i^2) are calculated for each column.

Treatments	1998	1999	……….	2016	2017	$\sum W_i\, t_i$
T_1						
T_2						
. . .						
T_{12}						
W_i						
$W_i P_i$						G
S_i^2						

The various sum of squares in ANOVA are calculated

$$Total\ S.S = \sum W_i\, S_i^2 - C$$

$$C = \frac{G^2}{t \sum W_i}$$

$$S.S\ for\ years = \frac{1}{t}\sum(W_i {P_i}^2) - C$$

$$S.S\ for\ treatments = \frac{\sum(\sum W_i\, t_i)^2}{\sum W_i} - C$$

$$S.S\ for\ interaction = TSS - SS\ for\ years - SS for\ treatments$$

For testing the significance of interaction, sum of squares for interaction (I) is transformed into χ^2 using the formula

$$\chi^2 = \frac{(n-4)(n-2)}{n(n+t-2)}\,(\mathrm{I})$$

This χ^2 obtained is tested with $\frac{(p-1)(t-1)(n-4)}{(n+t-3)}$ degrees of freedom, p being the number of trials.

If the interaction is present, interaction sum of squares obtained from simple analysis of variance is used to compare the treatment means.

3.8 Split plot analysis

While conducting an experiment, some factors require larger experimental plot when compared to other factors. Sometimes our objective would be to test one factor more precisely in comparison to the other factors. In all such conditions, we adopt split plot design. The experimental units which are considered as sub-plot are nested inside the main plot. The factors which require more degree of precision are taken as sub plot.

The model for split plot experiment in randomized blocks is:

$$Y_{ijk} = \mu + r_i + m_j + e_{ij} + s_k + (ms)_{jk} + e_{ijk}$$

Where Y_{ijk} = the observation of i^{th} replication, j^{th} main-plot and k^{th} sub-plot.
μ = overall mean
r_i = i^{th} replication effect
m_j = j^{th} main plot treatment effect
e_{ij} = main plot error or error (a)
s_k = k^{th} sub plot treatment effect
$(ms)_{jk}$ = interaction effect of main plot and subplot
e_{ijk} = error component for the sub plot or error(b)

In the present study, split plot analysis is done taking fertiliser treatments as main-plot treatment and year as sub-plot treatment so that even minute differences in the crop responses over several years by the application of same treatment throughout the years can be detected with more precision. The analysis of variance for m main plots and s sub plots is given in Table 3.2. Analysis is done for rice grain yield for three non-overlapping periods separately. For consistency of the results of the analysis, grain yield data is split into three periods having seven years data in first two periods (1998-2004) and (2005-2011) and six years data in period three (2012-2017).

Table 3.2: Analysis of variance for split-plot experiment in randomized blocks with factor A in main plots and factor B in sub plots

Source of Variation	Degrees of freedom	SS	MSS	F
Replication	r-1	RSS	RMS	RMS/EMS(a)
A	m-1	ASS	AMS	AMS/EMS(a)
Error(a)	(r-1) (m-1)	ESS (a)	EMS(a)	
B	s-1	BSS	BMS	BMS/EMS(b)
AB	(m-1) (s-1)	ABSS	ABMS	ABMS/EMS(b)
Error(b)	m(r-1) (s-1)	ESS(b)	EMS(b)	
Total	rms-1	TSS		

3.9 Repeated measures analysis

Repeated measures analysis is employed to multiple measurements which are obtained from the same experimental unit. These measurements may be obtained from a person or an animal or can be taken serially in time. This method appropriately accounts for the dependency among the measurements within the same experimental unit resulting in more precise results (Sullivan, 2008).

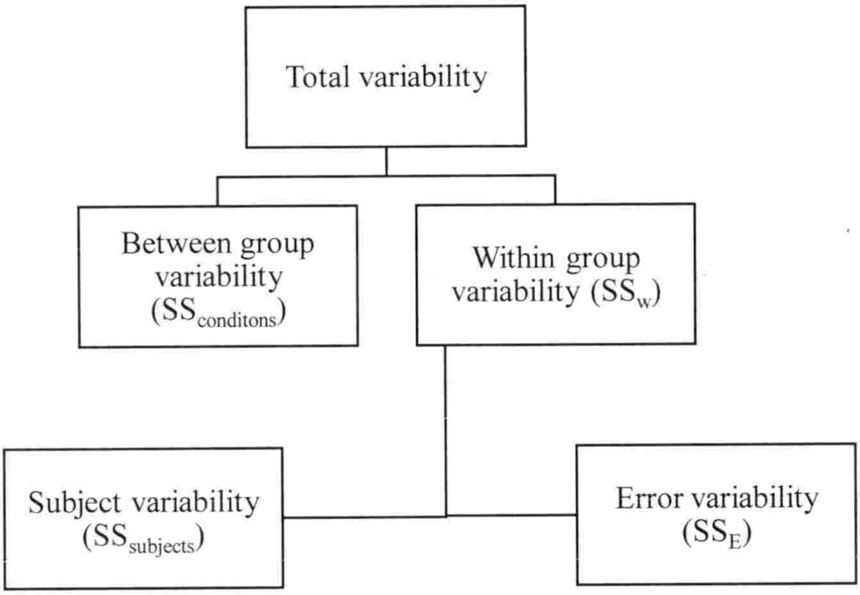

Fig 3.3 Partitioning of the variation in repeated meaures ANOVA

Repeated measures ANOVA is very similar to the independent sample ANOVA. The difference is that the repeated measures ANOVA further partitions the within group variablity and reduces the size of the error giving us a more precise result (Fig 3.3). This makes repeated ANOVA a more powerful test over independent sample ANOVA. The ANOVA for repeated measures data is given in Table 3.3.

Table 3.3 Repeated measures ANOVA

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F test
Conditions	k-1	$SS_{conditons}$	$MS_{conditons}$	$\frac{MSconditons}{MSerror}$
Subjects	n-1	$SS_{subjects}$	$MS_{subjects}$	$\frac{MSsubjects}{MSerror}$
Error	(k-1) (n-1)	SS_{error}	MS_{error}	

In the present study, conditions are the years (1998-2017), subjects are represented by the average yield values obtained from each treatment.

Effect Size ($\eta^2_{partial}$) for Repeated Measures ANOVA

The effect size for repeated measures ANOVA is represented by partial eta squared ($\eta^2_{partial}$).

$$\eta^2_{partial} = \frac{SS_{conditons}}{(SS_{conditons} + SS_{eror})}$$

$$= \frac{SS_{time}}{(SS_{time} + SS_{error})}$$

3.10 Correlation analysis

The influence of weather variables on crop yield was evaluated for the pre-sowing as well as for the four growth stages of rice using correlation analysis. The growth stages were identified with respect to days after sowing (DAS) of rice. The different periods considered were

i. Sowing to transplanting stage (0-15 DAS)
ii. Transplanting to active tillering stage (15-30 DAS)
iii. Active tillering to panicle initiation stage (30-45 DAS)
iv. Panicle initiation to flowering stage (45-75 DAS)

Correlation analysis measures the degree of association between two continuous variables. Correlation gives the interdependency of two variables. Pearson (1896) developed Pearson correlation coefficient (r) which measures the linear relationship between two variables. It is also known as product moment correlation. The value ranges from -1 to +1. It is given by the formula

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\ \sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

where n is the sample size

x_i and y_i are individual sample points

$\bar{x}$ and $\bar{y}$ are the sample means of x and y variables.

3.11 Kruskal-Wallis H test

The Kruskal-Wallis H test is a rank-based nonparametric test used to explain if k independent samples are from different populations. It is considered as the nonparametric alternative to the parametric one-way ANOVA.

The steps involved in Kruskal-Wallis H test is as follows. Considering the k samples as a single group, the data is sorted for all groups/samples giving first rank to the least observation, second rank to the next least observation and so on. The ranks in each group are then added up separately. The H statistic is calculated and compared with critical χ^2 at k-1 degrees of freedom.

$$H = \left[\frac{12}{N(N+1)}\sum_{j=1}^{k}\frac{R_j^2}{n_j}\right] - 3(N+1)$$

N = sum of sample sizes for all samples, k = number of samples, R_j = sum of ranks in the j^{th} sample, n_j = size of the j^{th} sample.

3.12 Multiple regression analysis

Regression analysis is the most extensively used statistical tool to analyse the functional relationship that exists among the study variables. A multiple regression model is expressed in terms of a dependent variable and one or more independent variables.

In general, a multiple linear regression with dependent variable **Y** and independent variables $X_1, X_2, \ldots, X_n$ can be expressed as

$$Y = \alpha + \beta X + \varepsilon$$

Where, α is the intercept term

$Y = [Y_1 \quad Y_2 \quad \cdots \quad Y_n]$ is a **1×n** vector of dependent variables

$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & & \vdots \\ X_{p1} & X_{p2} & \cdots & X_{pn} \end{bmatrix}$ is a **p×n** matrix of independent variables

$\beta = [\beta_1 \quad \beta_2 \quad \cdots \quad \beta_p]$ is a **1×p** vector of regression coefficients

$\varepsilon = [\varepsilon_1 \quad \varepsilon_2 \quad \cdots \quad \varepsilon_n]$ is a **1×n** vector of random error terms

and, $E(\varepsilon) = 0$

$$v(\varepsilon) = \sigma^2 I$$

$$\varepsilon \sim IID\ N(0, \sigma^2)$$

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

The regression coefficients are estimated using the method of least squares. In the present investigation, MLR is used to study the contribution of weather variables and plant nutrients to grain yield with respect to all treatments.

3.13 Second order polynomial model

Second order polynomial model was used to quantify the relative contribution of the uptake of plant nutrients N, P and K on the treatment responses for both seasons. The regression equation fitted for treatment responses takes the form:

$$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_1^2+b_5X_2^2+b_6X_3^2+b_7X_1X_2+b_8X_2X_3+b_9X_1X_3$$

Where b_i, i=1, 2, …, 9 are the partial regression coefficients

X_1, X_2, X_3 are the independent variables under study *viz.*, N uptake, P uptake and K uptake respectively.

3.14 Principal Component Analysis

Principal Component Analysis (PCA) is used for reducing the dimensionality of a large data set. In principal component analysis, a set of correlated variables are converted into a set of linearly uncorrelated variables known as principal components.

Let us consider the random variables X_1, X_2….X_p having a multivariate distribution with mean vector μ and dispersion matrix Σ assuming that the elements of μ and Σ are finite. Let the rank of Σ be p and the 'p' characteristics roots be λ_1, λ_2,….,λ_p such that $\lambda_1 > \lambda_2 > \ldots > \lambda_p$. Let there be n number of treatments which are repeated over p years. The observations, X_{ij} (i=1,2,…,n ; j=1,2,…,p) can be written in the form of n × p matrix. The various steps in PCA are as given below:

1. Standardization of the range of the original variables:

This is necessary so that each variable contribute equally to the analysis. Also, PCA is more sensitive to the variance of the original variable. Hence those variables with higher range will dominate the one with smaller range and this will lead to biased results. Therefore, transforming the original variables to a comparable scale can tackle this problem. Transforming Xij to standard score Z_{ij} as

$$Z_{ij} = \frac{(x_{ij}-\overline{X_j})}{s_j} \text{ (i=1, 2, ..., n; j= 1, 2, …, p)}$$

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Where $\overline{X}_j$ is the mean and s_j is the standard deviation of X_j. Z_{ij} is the standardized

2. Computation of variance- covariance matrix:

A variance- covariance matrix is a symmetric matrix of order p×p where p is the number of dimensions.

3. After computation of covariance matrix, eigen vectors and eigen values are calculated so that we can determine the principal components.

Principal components are linear combinations of the original variables formed in such a way that the new variables are uncorrelated and explains maximum information or variance about the original variables. The first principal component is constructed in such a manner that it accounts for maximum possible variance in the dataset.

The first principal component of observations Y_1 accounting for maximum variance can be written as:

$$Y_1 = a_{11}Z_1 + a_{21}Z_2 + a_{31}Z_3 + \ldots + a_{p1}Z_p$$

The second principal component is constructed orthogonal to the first principal component and accounts for the next largest variance. This is continued until a total of p principal components are obtained.

3.15 Response curves to yield using polynomial regression

Response curves serve as a measure of growth of a variable over a period of time with appropriate functional form. Polynomial regression model is helpful when the relationship of the response and the independent variables are curvilinear. In this study, first order response curve (straight line), second order response curve (parabola) and third order response curve (cubic) have been tried to establish the relationship between yield and time period. The best among the functional form is achieved based on model selection criterion.

The response curves used in the study are elaborated as:

- First order response curve (linear)

When data is expected to change by the same absolute amount in each time period, a first order polynomial model can be fitted to the data. It is usually called linear model and is represented by a straight line.

The equation of a fist order linear model is

$$Y_t = a + bt + e_t$$

Where a is the intercept

b is the regression co-efficient

e_t is the error term

$e_t \sim IID\ N(0, \sigma^2)$

- Second order response curve (Quadratic)

Quadratic function is usually fitted to the data which is curvilinear in nature. The equation for a quadratic model is

$Y_t = a + bt + ct^2 + e_t$

Where a is the Y intercept

b and c are regression coefficients

e_t is the error term

$e_t \sim IID\ N(0, \sigma^2)$

- Third order response curve (Cubic)

Cubic function is used when the data show alternate growth and decline over time.

The equation for cubic model is

$Y_t = a + bt + ct^2 + dt^3 + e_t$

Where a is the Y intercept

b, c and d are the regression coefficients

e_t is the error term

$e_t \sim IID\ N(0, \sigma^2)$

Model selection criteria

For selection of best model, the following criteria is used.

i) R^2
ii) Adjusted R^2
iii) Root Mean Square Error (RMSE)

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

Aiming at the objectives of the study titled "Optimisation techniques in long term fertiliser trials: rice-rice system", the data generated in different aspects were subjected to statistical methodologies explained in chapter 3. In this chapter, the salient findings of the research are discussed in detail under the headings

4.1 Testing presence of trend in data

4.2 Exploratory data analysis

4.3 Comparative performance of different treatments in *kharif* and *rabi* seasons

4.4 Testing the homogeneity of different treatments using Analysis of Variance

4.5 Pooled analysis of experiments over different years

4.6 Influence of weather variables and plant nutrients on rice yield

4.7 Dynamics of soil characteristics in relation to crop yield

4.8 Pre-harvest forecasting of crop yield

4.9 Response curves using polynomial regression

4.1 Testing presence of trend in data

The average rice yield with respect to all the treatments for 20 years for *kharif* and *rabi* seasons separately were tested for linear trend. The results of the same are depicted in Table 4.1 and Table 4.2

The linear regression model shows that the coefficient of time variable (β) is significant. Since the R^2 value is significant, it can be concluded that there is a long-term upward trend in the series of grain yield data for Aiswarya variety in k*harif* season (Fig. 4.1a).

Table 4.1 Linear regression model to test the presence of trend in *kharif* season

Model	Unstandardized coefficients		Standardized coefficients	t
	β	Std. Error	β	
(Constant)	1633.82	265.08		6.16
Time	105.55	22.13	0.75	4.77^{**}

*denotes significance at 1 per cent level of significance

In the case of grain yield in the *rabi* season, the coefficient (β) was not significant. Hence, it can be concluded that there was no long-term trend in the grain yield data for the Aiswarya variety in *rabi* season. As shown in Fig 4.1b, the trend equation was a poor fit to the data.

Table 4.2 Linear regression model to test the presence of trend in *rabi* season

Model	Unstandardized coefficients		Standardized coefficients	t
	β	Std. Error	β	
(Constant)	2845.57	165.78		17.17
Time	22.11	13.84	0.35	1.60

Time series of the *kharif* rice yield revealed an increasing trend at 1 per cent level of significance. In general, a significant trend is realized in a time series data of crop yield due to improvement of crop varieties, fertilisers and changes in cropping patterns and agricultural technology and practices. Kumar *et al*., (2004) reported similar findings in *kharif* rice production. Significant trend facades the short-term fluctuations which are most likely linked with year-to-year climatic variations. So, the time series of *kharif* rice yield is linearly detrended to understand the natural variability in yield over the years. (Fig 4.2)

To have an in-depth insight to the odd behaviour of crop yield data in *kharif season*, a detailed comparison was made with respect to year wise data in both the seasons (Fig 4.3 and 4.4). It showed that except in last three years of study, the crop yield was comparatively higher in *rabi* season. The yield in *kharif* season has considerable enhancement from 2015 onwards when compared to its previous years, and also with yield data in *rabi* season. Trend shows that year after year, drought is increasing in Kerala. This is substantiated by the increase in temperature and decrease in total rainfall as well as number of rainy days. Gopakumar (2011) has reported that there is an increase in annual mean temperature over decades and rise in uncertainties in rainfall. Furthermore, Kerala was totally drought hit during the year 2016. This can be attributed to the considerable decline in grain yield in *rabi* season.

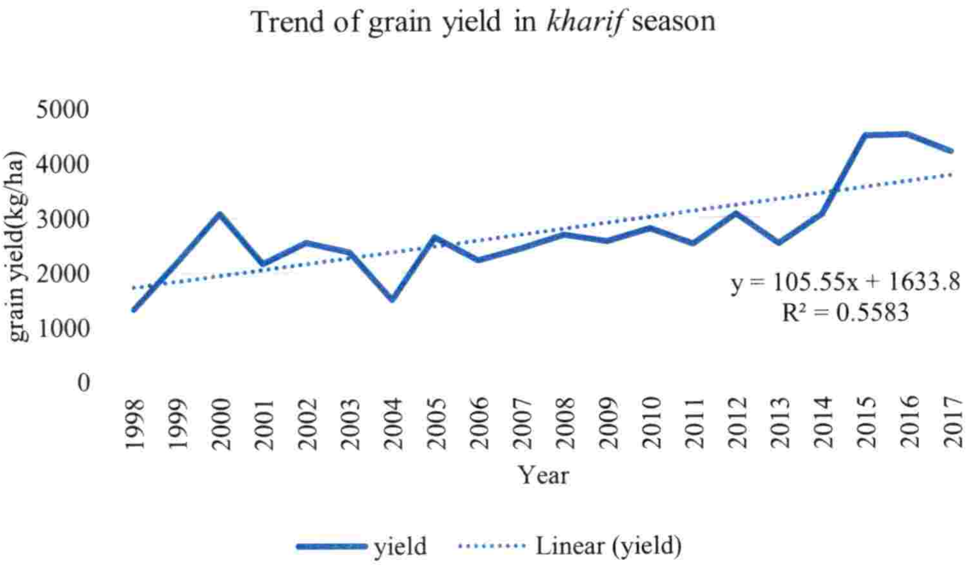

Fig 4.1a Trend of rice yield in k*harif* season

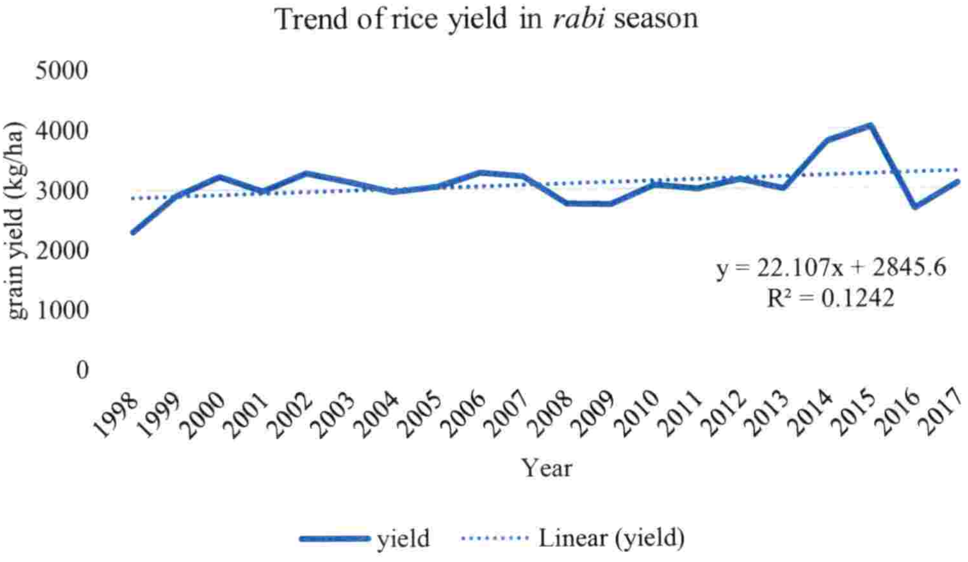

Fig 4.1b Trend of rice yield in r*abi* season

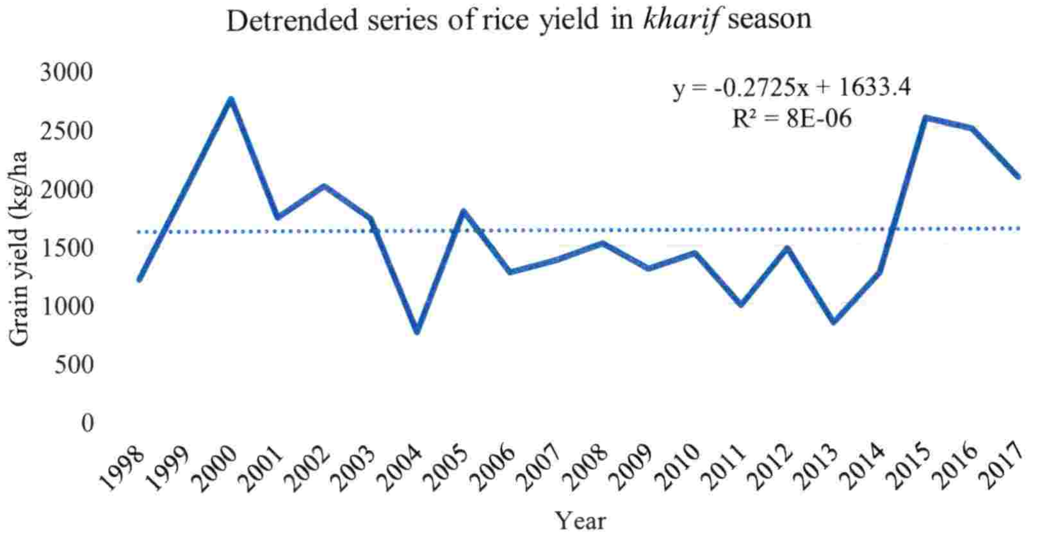

Fig 4.2 Detrended series of rice yield in *kharif* season

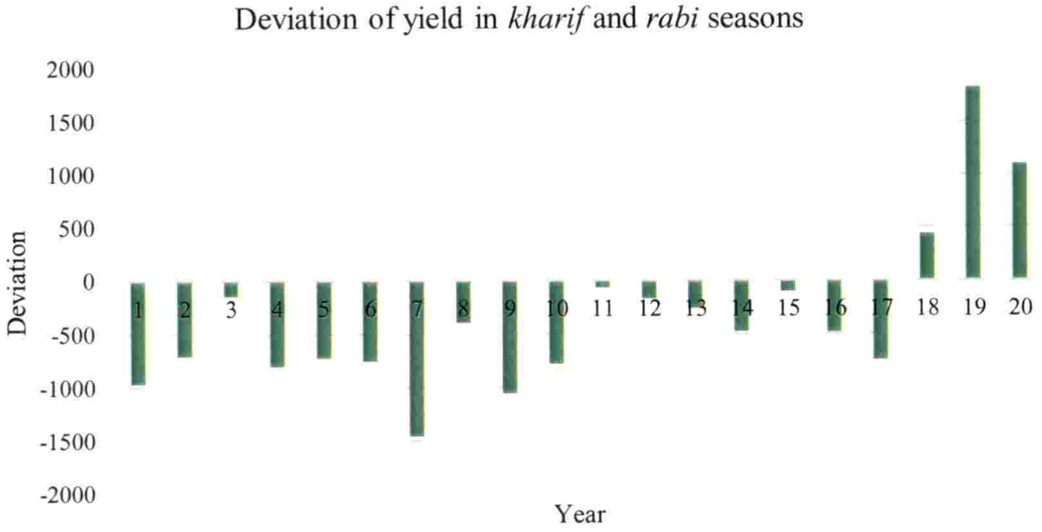

Fig 4.3 Deviation of yield in *kharif* and *rabi* seasons

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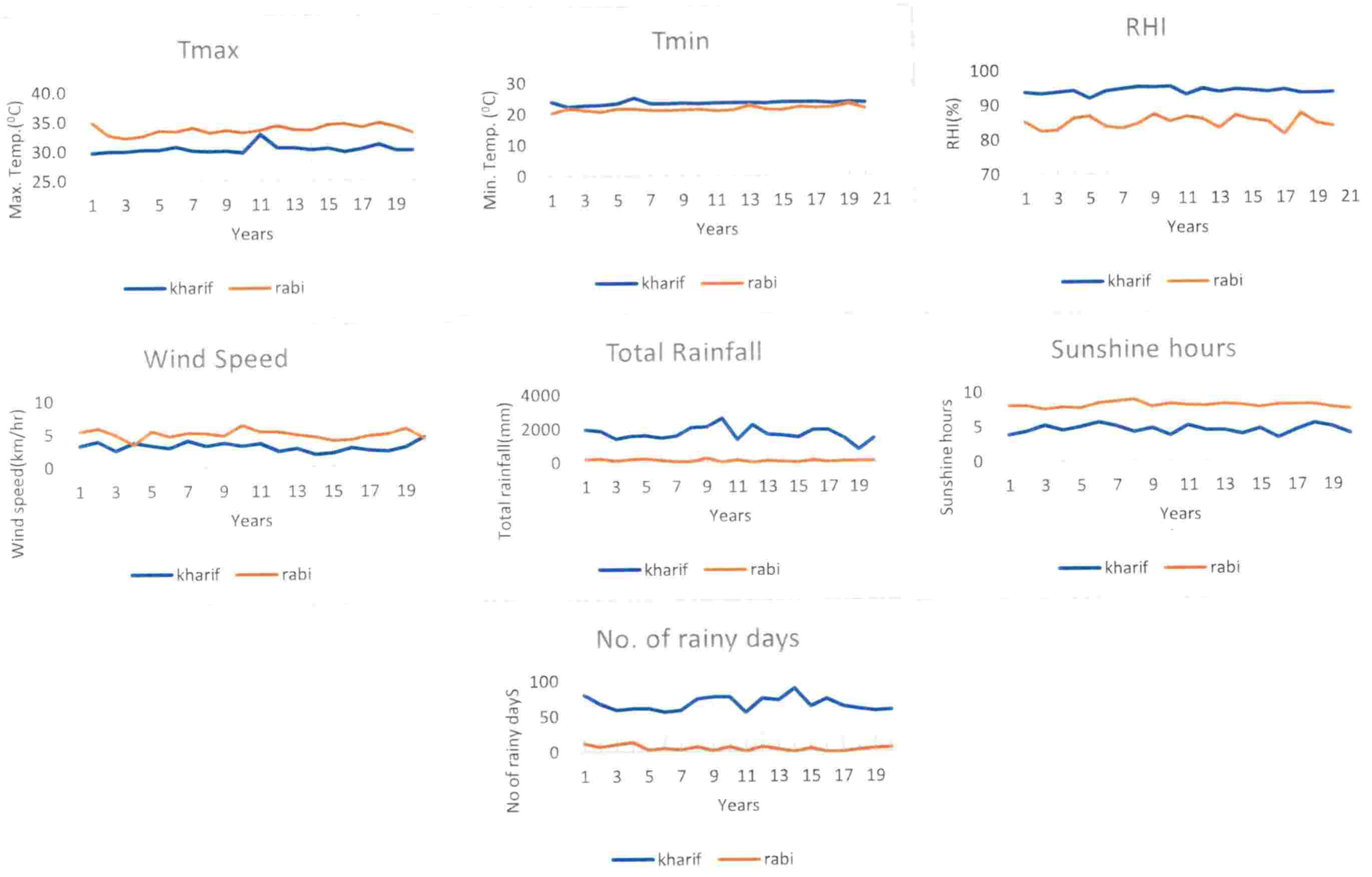

Fig 4.4 Comparison of weather variables in *kharif* and *rabi* seasons during whole growth period of rice

4.2 Exploratory data Analysis

A preliminary insight to the objectives of the study could be realized through exploratory and descriptive data analysis.

4.2.1 Descriptive analysis

An idea about the overall performance of the crop exposed under different treatments in the long term fertiliser experiment can be obtained with the help of summary statistics. The results are depicted in Table 4.3 and Table 4.4 for *kharif* and *rabi* respectively. Comparison of mean yield and CV values in *kharif* and *rabi* seasons is shown in Fig 4.5 and Fig 4.6 respectively

During *kharif* season, the highest mean grain yield of 3498.78 kg ha^{-1} was produced under treatment T_8. This was followed by T_{10} and T_9 with mean yield of 3315.64 kg ha^{-1} and 3001.12 kg ha^{-1} respectively. The least mean yield was obtained for T_{12} (1941.60 kg ha^{-1}). Since the coefficient of skewness (γ_1) was greater than 0 with respect to all the treatment yields, it can be concluded that the data was positively skewed. Higher yield values clustered above the average value for the last three years made the distribution right tailed. The coefficient of kurtosis (γ_2) was more than 0 for the yield distribution of all treatments and so they were leptokurtic in nature. The most consistent treatment among all was T_7 with a Coefficient of Variation (C.V.) of 27.51 per cent.

Relatively higher mean yield response under the treatments were observed in *rabi* season when compared to *Kharif* season. Treatment T_8 showed highest mean yield of 3844.72 kg ha^{-1} followed by T_{10} and T_9 with mean yield 3587.50kg ha^{-1} and 3355.67 kg ha^{-1}. In this case also the lowest mean yield was for T_{12}(2208.29 kgha^{-1}). The yield distribution with respect to all the treatments except T_7 and T_8 were positively skewed whereas T_7 and T_8 were negatively skewed. The yield distribution of all treatments except T_7 was leptokurtic in nature. The distribution of T_7 seemed to be platykurtic as a result of wide spread values of yield *i.e.,* with higher values of S.D. As against the result of T_7 in *kharif* season which was ranked one with respect to consistency in yield, it became most inconsistent in *rabi*. The most consistent treatment in *rabi* season was T_8 with a CV of 11.81 per cent.

Relative performance of different treatments in *kharif* and *rabi* seasons

During the whole study period, under T_1 during *kharif* season the maximum yield was 4451.00 kgha^{-1}and minimum yield was 1195.25 kgha^{-1} whereas, during *rabi* season the maximum yield was 3864.17 kgha^{-1}and minimum yield was 2248.25 kgha^{-1}. The mean yield for *kharif* and *rabi* seasons were found to be 2549.42 kgha^{-1}and 2973.97 kgha^{-1}respectively.

During *kharif* season T_2 gave a maximum yield of 4760.00 kgha^{-1}and minimum yield of 1071.55 kgha^{-1}whereas, during *rabi* season the maximum yield was 4107.50 kgha^{-1}and minimum yield was 2286.36 kgha^{-1}. The mean yield for *kharif* and *rabi* seasons were found to be 2871.51 kgha^{-1}and 3225.71 kgha^{-1}respectively.

For T_3 during *kharif* season mean yield obtained was 2959.05 kgha^{-1}with maximum yield 5425.00 kgha^{-1}and minimum yield 1152.66 kgha^{-1}. However, during *rabi* season the mean yield was found to be 3368.43 kgha^{-1} with maximum yield of 4817.92 kgha^{-1} and minimum yield of 2328.68 kgha^{-1}respectively.

Under T_4 during *kharif* season the yield response ranged from 1757.55 kgha^{-1} to 4788.00 kgha^{-1}and in *rabi* season the range was from 2394.33 kgha^{-1} to 4417.92 kgha^{-1}. The average yield during *kharif* and *rabi* was found to be 2801.36 kgha^{-1}and3161.66 kgha^{-1} respectively.

The mean response of T_5 during *kharif* was 2886.19 kgha^{-1}and the yield ranged from 788.52 to 4921.00 kgha^{-1}. While during *rabi* season the mean response was found to be 3262.08 kgha^{-1} and the yield ranged from 2260.96kgha^{-1} to 4383.75 kgha^{-1}respectively.

Table 4.3 Treatment-wise summary statistics of grain yield(kg/ha) during *kharif* season

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Mean	2549.42	2871.51	2959.05	2801.36	2886.19	2575.49	2376.13	3498.78	3001.12	3315.64	2863.16	1941.60
Std. deviation	896.40	942.98	1113.97	924.00	991.30	774.84	653.64	1098.33	1031.58	1077.23	1056.91	697.50
Skewness	1.05	0.49	0.89	1.02	0.42	0.82	0.52	0.51	0.56	0.40	0.95	1.15
Std. error of skewness	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Kurtosis	0.73	0.64	0.49	0.73	1.07	1.12	0.19	0.58	0.14	0.44	0.61	1.07
Std. error of kurtosis	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Minimum	1195.25	1071.55	1152.66	1457.55	785.52	1223.11	1312.76	1588.12	1295.68	1329.83	1316.70	987.00
Maximum	4451.00	4760.00	5425.00	4788.00	4921.00	4432.00	3888.00	5931.00	5055.00	5672.00	5396.00	3645.00
CV(%)	35.16	32.84	37.65	32.98	34.35	30.09	27.51	31.39	34.37	32.49	36.91	35.92

Table 4.4 Treatment-wise summary statistics of grain yield (kg/ha) during *rabi* season

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Mean	2973.97	3225.71	3368.43	3161.66	3262.08	2994.48	2776.58	3844.72	3355.67	3587.50	3243.38	2208.29
Std. deviation	380.50	388.98	580.68	462.86	420.13	477.71	534.22	453.98	488.68	526.90	475.18	358.42
Skewness	0.05	0.11	0.87	0.74	0.52	1.19	-0.32	-0.12	0.27	0.32	0.29	0.77
Std. error of skewness	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Kurtosis	0.66	1.84	1.80	2.07	2.99	2.21	-1.32	3.28	2.00	1.20	0.85	1.42
Std. error of kurtosis	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Minimum	2248.25	2286.36	2328.68	2394.33	2260.96	2318.12	1955.00	2631.43	2201.68	2506.53	2280.01	1538.09
Maximum	3864.17	4107.50	4817.92	4417.92	4383.75	4342.08	3599.84	4884.17	4473.00	4820.75	4245.75	3157.92
CV(%)	12.79	12.06	17.24	14.64	12.88	15.95	19.24	11.81	14.56	14.69	14.65	16.23

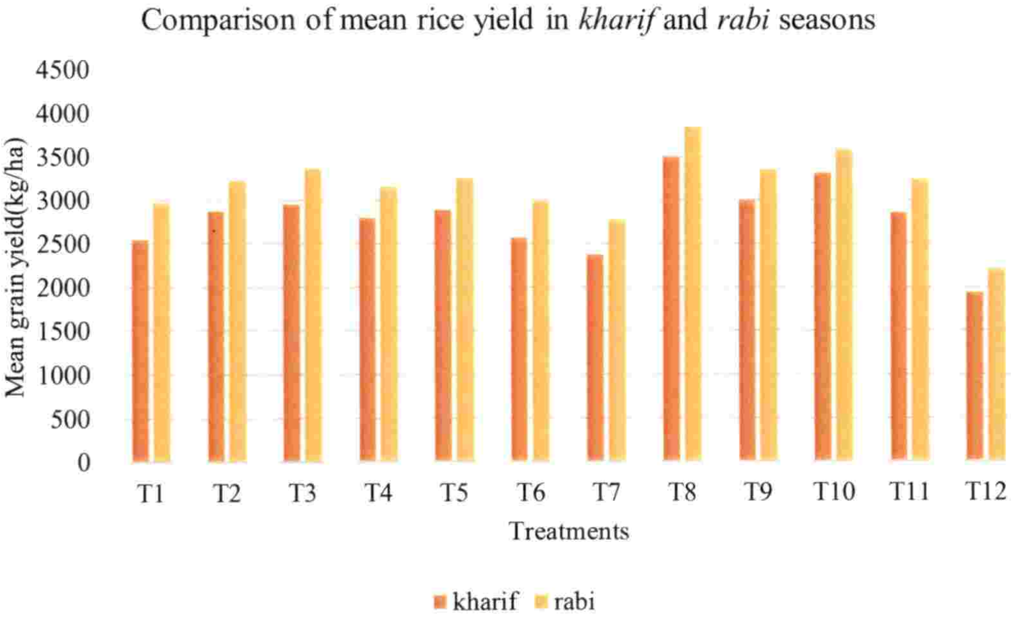
Comparison of mean rice yield in *kharif* and *rabi* seasons

Fig 4.5 Comparison of mean rice yield in *kharif* and *rabi* seasons

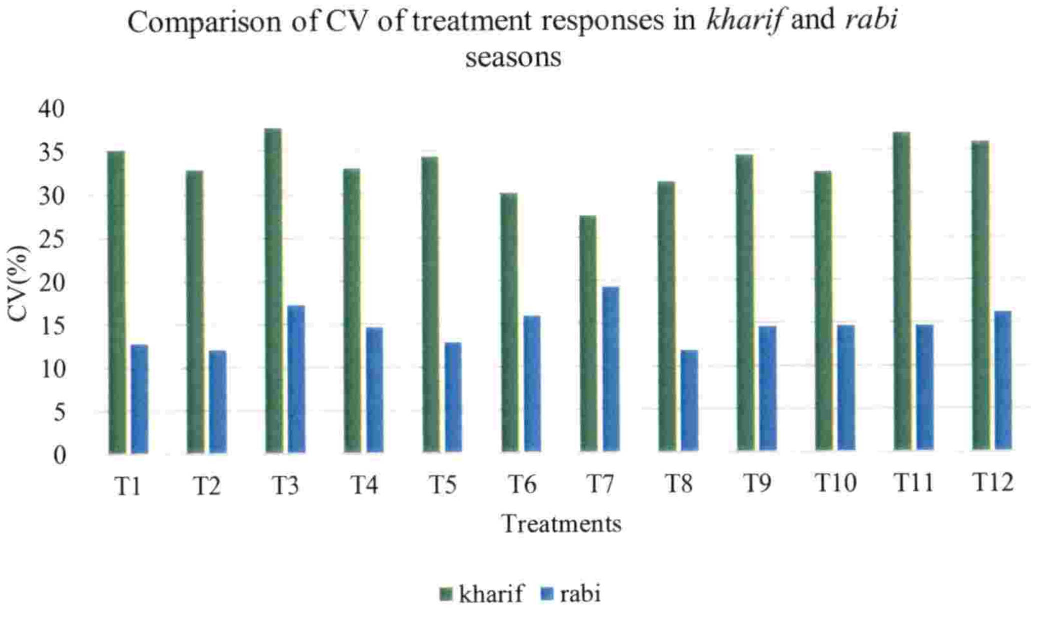
Comparison of CV of treatment responses in *kharif* and *rabi* seasons

Fig 4.6 Comparison of CV of treatment responses in *kharif* and *rabi* seasons

The mean yield response of T_6 during *kharif* was found to be 2376.13 kgha^{-1}and over the years it ranged from 1223.11 to 4432.00 kgha^{-1}. Whereas, during *rabi* season mean yield response was estimated to be 2994.70 kgha^{-1} and over the years it ranged from 2318.72 kgha^{-1} to 4342.08 kgha^{-1}respectively.

The yield response of T_7 during *kharif* ranged from1312.76 kgha^{-1} to 3888.00 kgha^{-1}. The average yield response under T_7 was found to be 2376.13 kgha^{-1}. While in *rabi* season, the yield response ranged from 1955.00 to 3599.84 kgha^{-1} and the average yield was found to be 2776.58 kgha^{-1}.

Under T_8 during *kharif* season the maximum and minimum yield obtained were 5931.00 kgha^{-1} and 1588.12 kgha^{-1}respectively. The mean yield obtained was found to be 3498.78 kgha^{-1}. While in the case of *rabi* season the maximum and minimum yield obtained were 4884.17 kgha^{-1} and 2631.43 kgha^{-1}respectively. The average yield obtained was 3844.72 kgha^{-1}. This treatment had the highest yield response.

The treatment T_9 during *kharif* season gave yield responses which ranged from 1295.68 to 5055.00 kgha^{-1}. The average yield obtained was 3001.12 kgha^{-1}. However, during *rabi* season the yield response ranged from 2201.68 kgha^{-1} to 4473.00 kgha^{-1}and average yield was found to be 3355.67 kgha^{-1}.

The yield response of T_{10} during *kharif* season ranged from 1329.83 kgha^{-1} to 5672.00 kgha^{-1}. The average yield was found to be 3315.64 kgha^{-1}. Whereas, during *rabi* season the yield response ranged from 2506.53 kgha^{-1} to 4820.75 kgha^{-1}and the average yield response was 3587.50 kgha^{-1}.

The mean yield response of T_{11} was found to be 2863.16 kgha^{-1}and over the years it ranged from 1316.70 kgha^{-1} to 5396.00 kgha^{-1}. While in *rabi* season the mean yield, response was found to be 3243.38 kgha^{-1}and over the years it ranged from 2280.01 to 4245.75 kgha^{-1}.

Under T_{12} during *kharif* season the minimum and maximum yield responses were found to be 987.00 kgha^{-1} and 3645.00 kgha^{-1} respectively with an average value of 1941.60 kgha^{-1}. While in *rabi* season the minimum and maximum yield responses were 1538.09 kgha^{-1} and 3157.92 kgha^{-1} respectively with an average yield response of 2208.29 kgha^{-1}.

Higher yield and more consistent treatment responses were produced in *rabi* season when compared to *kharif* season. In both the seasons, T_8 was the most superior treatment. Yield data recorded over the period 1998-2017 for both *kharif* and *rabi* seasons clearly validated the superiority of integrated use of FYM and green manuring with chemical fertilisers, which provided greater stability in crop production as compared to 100% NPK. This could be linked with the benefits of organics, which apart from N, P and K supply also improves microbial activities, thereby supplying macro and micro-nutrients such as S, Zn, Cu and B, which are not supplied by inorganic fertilisers. Similar findings were reported by Yadav *et al.* (2000).

4.2.2 Graphical method- Box Plot

Box plot graphically explains the distribution plot of the treatments built on the maximum value, minimum value, first quartile (Q_1), median (Q_2), and third quartile of the data.

The treatment-wise box plot for *kharif* season grain yield (Fig 4.7) gives a comparative performance of the treatments. Box plot of none of the treatments in the two seasons are placed in between the whiskers. This means that the given set of treatments have a skewed distribution. Since the mean is greater than median it can be concluded that the distribution is positively skewed. Almost for every treatment there are extreme outliers present beyond the upper whisker. These values pull the mean towards the right, making it positively skewed.

The treatment wise box plot for *rabi* season is depicted in Fig 4.8. *Rabi* season had noticeably higher yield points. The position of median line for *kharif* season is explanatory to state that there was clustering of yield values below the average value. The notion of consistency is quite apparent for *rabi* season in Fig 4.9 as the whiskers were closer to the quartiles in this season when compared to *kharif* season.

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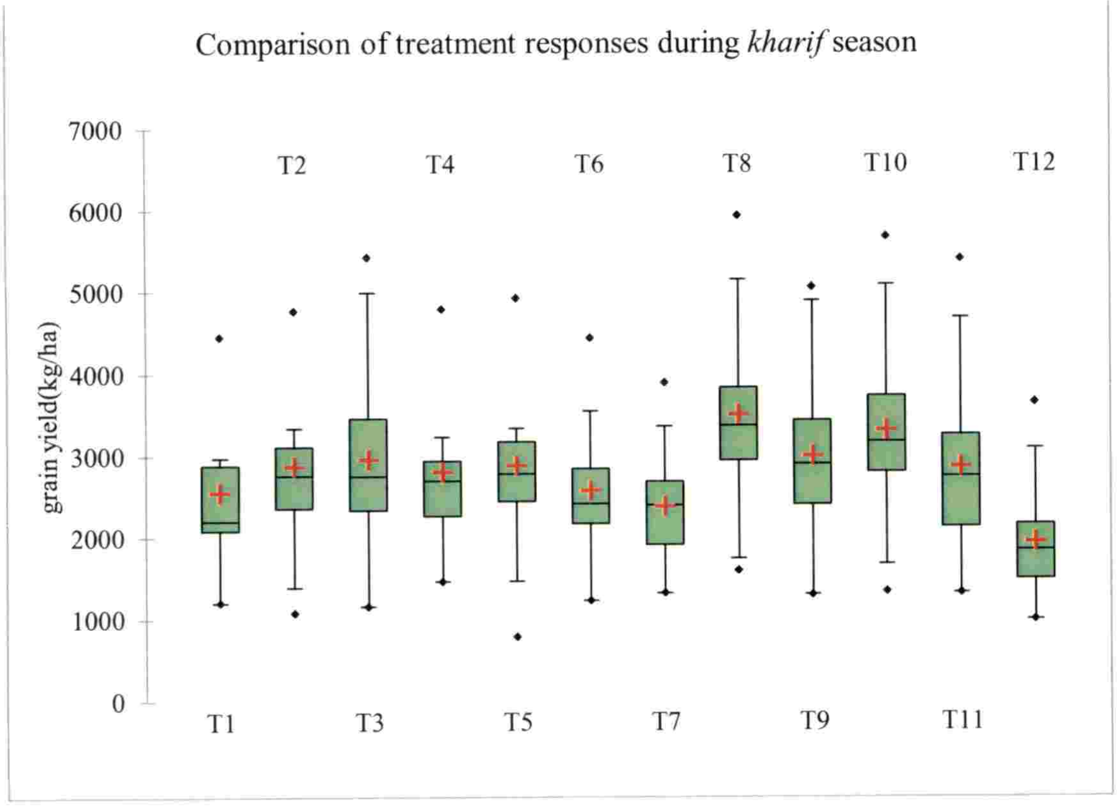

Fig. 4.7 Comparison of treatment responses during *kharif* season

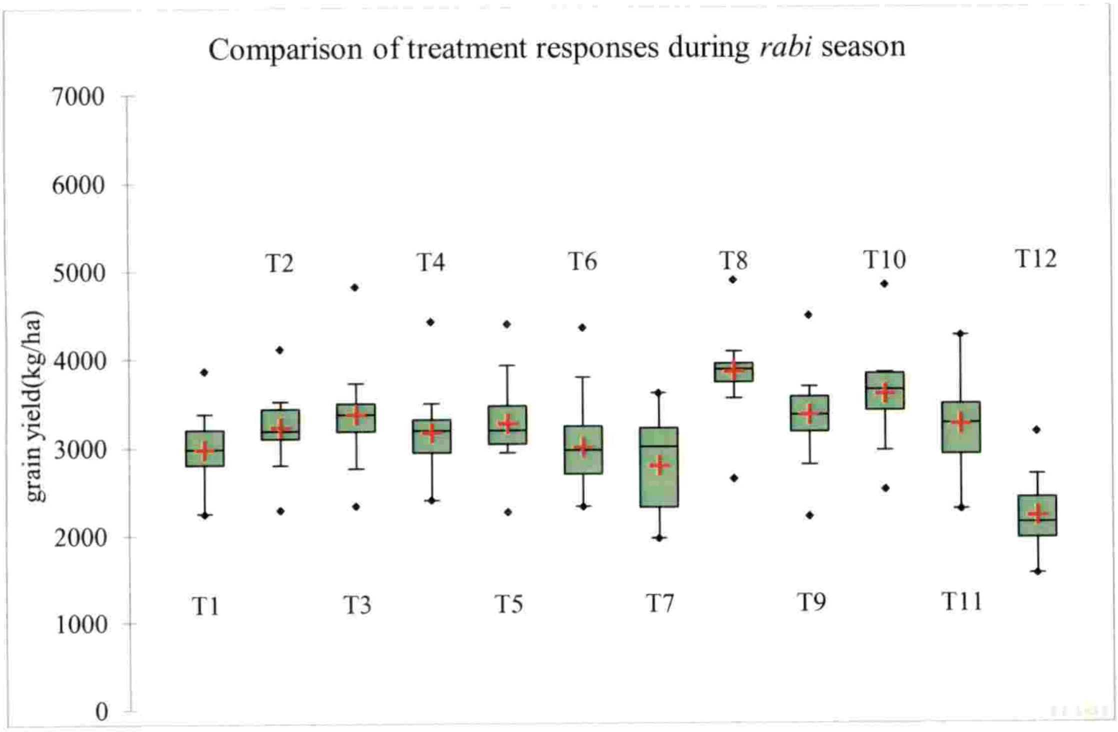

Fig. 4.8 Comparison of treatment responses during *rabi* season

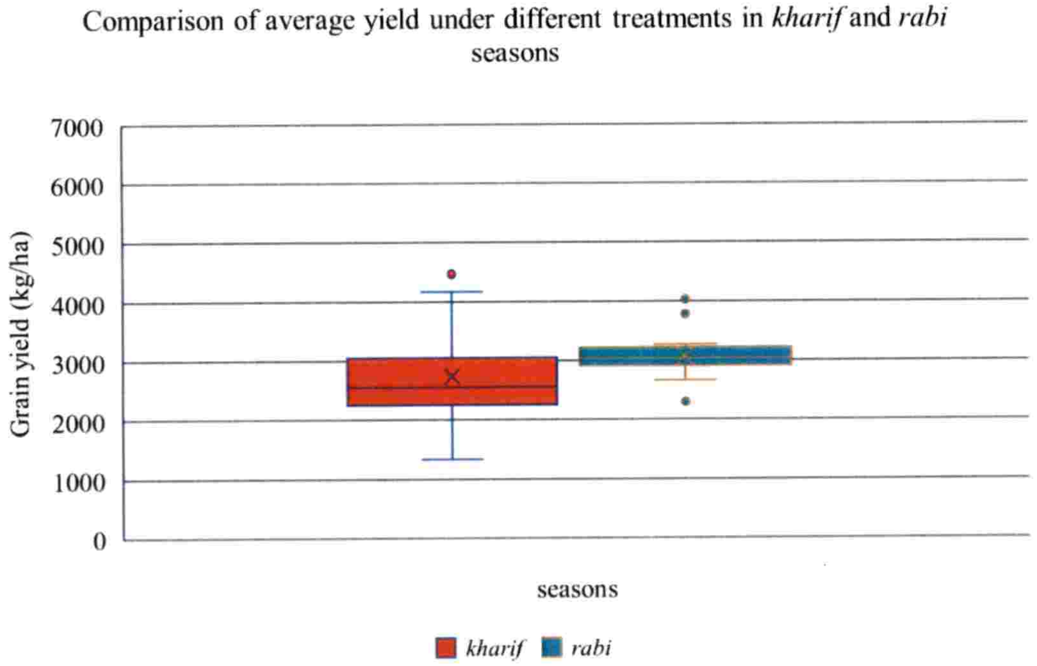

Fig. 4.9 Comparison of average yield under different treatments in *kharif* and *rabi* seasons

4.3 Comparative Performance of different treatments in *kharif* and *rabi* seasons

The relative performance of different treatments with respect to grain yield were compared, applying independent sample t test and the results are depicted in Table 4.5. It revealed that grain yield in response of treatment T_7 were significantly different in two seasons. Hence it was evident that all the treatments except T_7 performed alike over the two seasons in a year. T_7 was reported to be the most imbalanced treatment susceptible to even minute changes of weather variables and other factors.

Table 4.5 Comparison of treatments with respect to grain yield in *kharif* and *rabi* seasons

Treatment	t statistic	p value
T_1	-1.95	0.06
T_2	-1.46	0.13
T_3	-1.56	0.16
T_4	-1.56	0.13
T_5	-2.06	0.13
T_6	-2.12	0.05
T_7	-1.30	0.04*
T_8	-1.39	0.21
T_9	-1.01	0.18
T_{10}	-1.47	0.32
T_{11}	-1.52	0.15
T_{12}	-1.95	0.14

* Significance at 5 per cent level

4.4 Testing the homogeneity of different treatments using Analysis of Variance

As the experiment was laid out using RBD in each year, the underlying homogeneity of treatments were tested using two-way ANOVA.

The results of analysis of variance of individual RBD for each year is presented in Appendix II and III for *kharif* and *rabi* seasons respectively. Except in 1998 and 2006 during *kharif* season and in 1998 during *rabi* season the treatments were found to be significantly different. The mean square error obtained from each ANOVA is depicted in Table 4.6.

Table 4.6 Mean square Error variance obtained from ANOVA for different years

Year	*Kharif*	*Rabi*
1998	108848.53	93659.69
1999	69,655.69	109357.18
2000	81,107.17	53403.68
2001	79,245.48	73536.64
2002	149,339.30	99442.96
2003	23,081.35	10261.02
2004	27,077.56	48111.33
2005	22,388.00	27138.35
2006	138,916.78	42162.22
2007	3,487.90	1360.38
2008	4,347.60	5697.55
2009	33,638.03	63295.84
2010	118,632.22	44060.74
2011	174,203.11	5887.84
2012	917.07	2295.84
2013	11,901.54	4522.04
2014	14,799.21	7625.52
2015	6,479.68	12974.23
2016	22,588.78	346971.81
2017	41,166.86	46587.54

4.5 Pooled Analysis of experiments over different years

4.5.1 Groups of experiments

The pooled analysis of individual two-way ANOVA for different years were carried out separately for two seasons to summarize the effect of treatment effects which was repeated over 20 years. As mentioned in chapter 3, the results from set of trails could be categorized into four different types *viz.*, Homogenous experimental error with no interaction, homogenous experimental error with interaction, heterogenous experimental error with no interaction and heterogenous experimental error with interaction. So, the first thing to do before combining the results of a set of repeated experiments is to check whether the errors are homogenous or heterogenous and if the treatment responses have interaction present or not. Since the experimental error differs from year to year, Bartlett's test was performed to test the homogeneity of error variance.

During *kharif* season, χ^2 value obtained at 19 degrees of freedom was 192.43, which was found to be significant at 5 per cent level of significance. Since the error variances were heterogenous, weighted analysis of variance was performed. The interaction was found to be significant at 5 per cent level of significance. Therefore, treatment mean squares was tested using interaction mean squares obtained from unweighted analysis of variance (Table 4.7).

Table 4.7 Unweighted analysis of variance for *kharif* season

Source of Variation	*df*	MS	F value
Year	19	486024.42	1.29
Treatment	11	14147223.98	37.77**
Year x Treatment	209	374543.74	
Pooled error	660	56591.09	
Total	959		

** Significant at 1 per cent level

During *rabi* season, the errors were heterogenous and interaction was significant. The unweighted analysis of variance is depicted in Table 4.8.

Table 4.8 Unweighted analysis of variance for *rabi* season

Source of Variation	*df*	MS	F value
Year	19	186496.67	0.63
Treatment	11	1973186.40	6.67**
Year x Treatment	209	295740.93	
Pooled error	660	54,917.62	
Total	959		

** Significant at 1 per cent level

An effective modern agricultural experiment is the experiment laid down in the same year at a number of places or carried out at the same place independently over a number of years. If the experiments are conducted in diverse locations having different agroclimatic conditions, there may arise cases of heterogeneous error variances. The precision of the estimates of treatment effects in such experiments can be enhanced by having a pooled analysis of the experiments.

4.5.2 Split plot analysis

In order to assess the minute variations between grain yields under treatments applied over different years, split plot analysis was carried out taking actual treatments as main plot treatments and years as subplot treatments, and the results are depicted in Table 4.9a and Table 4.9b. It was observed that during *kharif* season, the effect of treatment, year and their interactions were significant at 1 per cent level of significance.

In *rabi* season, the effect of treatment, year and their interactions were significant during the second and third period. In the first period, the effect of treatment and year were significant, but the interaction effect between treatment and year was not significant. The absence of the year × treatment interaction might have resulted in non-significant trend in yield during r*abi* season.

When time was considered as subplot, the interaction effect of treatment and years over the study period was significant in both the seasons (Table 4.10a and

Table 4.10b), *i.e.*, the interdependency of treatments' effect over time was significant. Thus, it is evident that the variation in yield is not only due to treatment effect but also due to the responses from environmental factors over years. Due to the significance in the interaction effect, one cannot simply draw conclusion over the effectiveness of a particular treatment. Similar findings were reported in finger millet –hybrid maize-fodder cowpea cropping sequence by Sheela (2009).

Table 4.9a Assessment of the significance of year after year variation in rice yield during the *kharif* season using split plot analysis

Source of Variation	**Degrees of freedom (3rd period)**	**Period 1 (1998 to 2004)**		**Period 2 (2005 to 2011)**		**Period 3 (2012 to 2017)**	
		MSS	**Fcal.**	**MSS**	**Fcal.**	**MSS**	**Fcal.**
Replication	3	448741.30		112939.36		21578.84	
Treatment	11	37700986.68	677.88**	55178101.42	1265.23**	96415398.68	10760.13**
Error (a)	33	55616.14		43611.01		8960.43	
Year	6(5)	6510562.23	124.08**	640709.44	17.81**	12655824.95	1314.36**
Treatment ×Year	66(55)	537559.86	10.25**	323352.75	8.99**	927647.56	96.34**
Error (b)	216(180)	52472.55		35967.39		9628.89	
Total	335(287)						

** 1 per cent level of significance

Values within the parenthesis indicates degrees of freedom for third period

Table 4.9b Assessment of the significance of year after year variation in rice yield during the *rabi* season using split plot analysis

Source of Variation	Degrees of freedom (3rd period)	Period 1 (1998 to 2004)		Period 2 (2005 to 2011)		Period 3 (2012-2017)	
		MSS	Fcal.	MSS	Fcal.	MSS	Fcal.
Replication	3	58837.76		142308.53		312035.75	
Treatment	11	3011386.13	32.72**	5744132.71	244.44**	6498578.74	104.53^{**}
Error (a)	33	92028.30		23499.07		62168.66	
Year	6(5)	5990922.92	54.62**	2419220.06	85.95**	15001872.69	179.14^{**}
Treatment ×Year	66(55)	144002.39	1.31	180950.28	6.43**	210788.24	2.52^{**}
Error (b)	216(180)	109686.14		28147.68		83742.19	
TOTAL	335(287)						

** 1 per cent level of significance

Values within the parenthesis indicates degrees of freedom for third period

Table 4.10a Significance of the effect of time variable (20 years) on rice yield during the *kharif* season using split plot analysis

Source of Variation	Degrees of freedom	MSS	Fcal
Replication	3	78850.35	
Treatment	11	13570854.49	151.58**
Error (a)	33	89530.48	
Year	19	39309500.43	599.77**
Treatment ×Year	209	365267.33	5.57**
Error (b)	684	52472.55	
TOTAL	959		

** 1 per cent level of significance

Table 4.10b Significance of the effect of time variable (20 years) on rice yield during the *rabi* season using split plot analysis

Source of Variation	Degrees of freedom	MSS	Fcal
Replication	3	250953.58	
Treatment	11	13588179.02	216.97**
Error (a)	33	62627.82	
Year	19	7753633.63	107.29**
Treatment ×Year	209	245768.22	3.40**
Error (b)	684	72265.52	
TOTAL	959		

** 1 per cent level of significance

4.5.3 Repeated measures ANOVA

The term repeated measures refer to the multiple observations made on the same experimental unit. The unit in our case was the crop yield from multiple harvest taken over years from the same plot. Twelve treatments were repeated on the same experimental site for twenty years. Repeated measures ANOVA is widely used to control the unexplained variability among the experimental units. Repeated measures ANOVA was attempted to study the effect of time on the changes in yield over the years with respect to the same treatments.

During both the seasons, test of sphericity was significant at 1 per cent level, violating the assumption of homogeneity in variance. Hence Greenhouse-Geisser correction was employed in the ANOVA.

Table 4.11 Repeated measures ANOVA for 20 years of grain yield during *kharif* season

Source of variation	d.f	Mean Sum of Squares	F value	η_p^2
Years	4.65	160606810.23	289.70**	0.86
Error	218.57	554388.46		

**significant at 1 per cent level

Table 4.11 depicts the result of repeated measures ANOVA during *kharif* season. The effect of years on treatment responses was found to be significant at 1 per cent level of significance. The effect size was measured using partial eta squared (η_p^2) and was found to be 0.86, implying that time variable was responsible for 86 per cent of variability in grain yield, other non-error sources of variation being partialed out.

Table 4.12 Repeated measures ANOVA for 20 years of grain yield during *rabi* season

Source of variation	d.f.	Mean Sum of Squares	F value	η_p^2
Years	6.26	23525839.28	68.69**	0.59
Error	294.32	342472.586		

** $p < 0.01$

The result of repeated measures ANOVA during *rabi* season is shown in Table 4.12. The effect of years on treatment responses was found to be significant at 1 per cent level of significance. The effect size measured using partial eta squared (η_p^2) was found to be 0.59, implying that time variable was responsible for 59 per cent of variability in grain yield, other non-error sources of variation being partialed out

4.6 Influence of weather variables and plant nutrients on rice yield

Climate and plant nutrients are some major uncontrollable factors influencing yield of any crop. In this section an attempt has been made to study the influence of weather variables and plant nutrients on crop yield of Aiswarya rice variety.

4.6.1 Effect of weather variables at different stages of crop growth on treatment responses under twelve treatments during *kharif* and *rabi* seasons

The predominant weather conditions of a particular environment decide the performance of a crop. Among the crops, rice is a sensitive crop that depends highly on weather conditions. Amid the abiotic stresses, weather finds significant role in influencing the growth and yield of rice.

To study the influence of weather variables namely maximum temperature, minimum temperature, relative humidity, sunshine hours, rainfall, number of rainy days and wind velocity on crop yield, the whole crop growth period was divided into four stages namely sowing to transplanting stage, transplanting to active tillering stage, active tillering to panicle initiation stage and panicle initiation to flowering stage. In addition to this, the weather variables during the pre-sowing period (one month before sowing) for both the seasons were also observed. Correlation between weather variables and grain yield were worked out for both *kharif* and *rabi* seasons for the five phases separately.

In *kharif* season, the correlation coefficient between weather variables and grain yield during pre-sowing period are tabulated in Table 4.13. Treatments T_1, T_2, T_6, T_7 and T_{12} had no significant correlation with any of the weather variables. The rest of the treatments were having significant negative association with wind speed at 5 per cent level of significance having correlation coefficient ranging from 0.45 to 0.52. Remaining weather variables have not shown any significant effect with respect to the treatment responses.

The correlation coefficients between weather variables and grain yield during sowing to transplanting stage is given in Table 4.14. Wind speed had a significant negative association with grain yield under T_1, T_2, T_3, T_4, T_5, T_6, T_9, T_{10} and T_{11} at 5 per level of significance and with T_8 at 1 per cent level of significance. The rest of the weather variables didn't have any significant correlation with crop yield. Table 4.15 depicts the correlation coefficients between weather variables and grain yield during the transplanting to active tillering stage. Maximum temperature had significant positive correlation with responses of T_1, T_2, T_3, T_4, T_5, T_9, T_{11}, and T_{12} at 5 per cent level and for the responses of T_6 and T_7 at 1 per cent level significance. Minimum temperature had significant positive association with the yield due to T_{10} at 5 per cent level of significance. The results in Table 4.16 shows the correlation coefficients between weather variables and treatment responses during active tillering to panicle initiation stage. Minimum temperature had significant positive association with yield under T_8, T_9, T_{10} and T_{11} at 5 per cent level of significance. There was a significant negative correlation at 5 per cent level of significance for rainfall with the response due to T_7. Table 4.17 shows that during panicle initiation to flowering stage none of the weather variables had significant association with any treatment responses.

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Table 4.13 Influence of weather variables in pre-sowing period on crop yield during *kharif* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall
T1	-0.17	0.19	0.16	-0.38	0.24	-0.21
T2	-0.17	0.27	0.11	-0.43	0.22	-0.22
T3	-0.27	0.20	0.16	**-0.45***	0.26	-0.12
T4	-0.11	0.30	0.13	**-0.51***	0.27	-0.19
T5	-0.18	0.29	0.12	**-0.46***	0.26	-0.23
T6	-0.12	0.27	0.17	-0.37	0.36	-0.25
T7	0.01	0.19	0.07	-0.16	0.28	-0.29
T8	-0.22	0.31	0.15	**-0.45***	0.20	-0.11
T9	-0.21	0.32	0.11	**-0.50***	0.25	-0.19
T10	-0.28	0.32	0.18	**-0.47***	0.16	-0.07
T11	-0.21	0.27	0.13	**-0.53***	0.23	-0.13
T12	-0.16	0.22	0.18	-0.36	0.30	-0.14

*denotes significance at 5% level

Table 4.14 Influence of weather variables of sowing to transplanting period on crop yield during *kharif* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of Rainy Days
T1	0.05	-0.21	-0.38	**-0.46***	-0.14	-0.13	-0.25
T2	0.11	-0.11	-0.36	**-0.49***	-0.05	-0.21	-0.29
T3	0.08	-0.18	-0.41	**-0.53***	-0.08	-0.25	-0.36
T4	0.12	-0.09	-0.44	**-0.48***	-0.10	-0.20	-0.40
T5	0.12	-0.09	-0.37	**-0.53***	-0.05	-0.21	-0.30
T6	0.13	-0.15	-0.35	**-0.49***	-0.01	-0.18	-0.29
T7	0.06	-0.29	-0.34	-0.29	-0.04	-0.03	-0.10
T8	0.10	-0.05	-0.35	**-0.57****	-0.11	-0.20	-0.32
T9	0.15	-0.01	-0.36	**-0.56***	-0.05	-0.28	-0.38
T10	0.10	0.00	-0.33	**-0.54***	-0.09	-0.22	-0.32
T11	0.11	-0.03	-0.36	**-0.53***	-0.07	-0.30	-0.44
T12	0.04	-0.21	-0.39	-0.38	-0.12	-0.14	-0.31

*denotes significance at 5% level of significance

**denotes significance at 1% level of significance

Table 4.15 Influence of weather variables of transplanting to active tillering stage on crop yield during *kharif* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of Rainy Days
T1	**0.47***	0.25	-0.13	-0.12	0.07	-0.16	-0.18
T2	**0.53***	0.40	-0.10	-0.12	0.08	-0.20	-0.18
T3	**0.45***	0.35	-0.18	-0.12	0.06	-0.20	-0.17
T4	**0.46***	0.36	-0.21	-0.17	-0.02	-0.15	-0.12
T5	**0.55***	0.43	-0.10	-0.14	0.10	-0.21	-0.21
T6	**0.59****	0.44	-0.08	-0.17	0.18	-0.28	-0.25
T7	**0.65****	0.34	0.00	-0.05	0.29	-0.33	-0.31
T8	0.41	0.39	-0.15	-0.18	-0.03	-0.11	-0.14
T9	**0.47***	0.41	-0.12	-0.17	-0.03	-0.21	-0.14
T10	0.40	**0.45***	-0.13	-0.12	-0.03	-0.13	-0.15
T11	**0.45***	0.43	-0.25	-0.16	0.03	-0.24	-0.20
T12	**0.48***	0.33	-0.08	-0.07	0.04	-0.27	-0.16

*denotes significance at 5% level of significance **denotes significance at 1% level of significance

Table 4.16 Influence of weather variables of active tillering to panicle initiation stage on crop yield during *kharif* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of Rainy Days
T1	0.01	0.30	-0.33	-0.03	**0.51***	-0.31	-0.35
T2	0.02	0.40	-0.32	-0.13	**0.48***	-0.33	-0.36
T3	0.06	0.37	-0.37	-0.09	0.44	-0.23	-0.35
T4	0.07	0.39	-0.38	-0.13	0.34	-0.25	-0.20
T5	0.04	0.40	-0.30	-0.15	0.43	-0.29	-0.32
T6	0.00	0.38	-0.24	-0.17	**0.51***	-0.32	-0.34
T7	-0.02	0.20	-0.21	0.00	**0.56***	**-0.45***	-0.43
T8	0.13	**0.47***	-0.36	-0.14	0.42	-0.28	-0.29
T9	0.06	**0.50***	-0.33	-0.17	0.40	-0.23	-0.28
T10	0.16	**0.50***	-0.31	-0.14	0.39	-0.28	-0.28
T11	0.08	**0.49***	-0.36	-0.16	0.36	-0.20	-0.21
T12	0.04	0.38	-0.31	-0.02	**0.49***	-0.31	-0.35

*denotes significance at 5% level of significance **denotes significance at 1% level of significance

Table 4.17 Influence of weather variables of panicle initiation to flowering stage on crop yield during *kharif* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of Rainy Days
T1	0.24	-0.21	-0.04	-0.10	0.01	-0.20	-0.25
T2	0.26	-0.26	-0.16	-0.24	-0.03	-0.14	-0.20
T3	0.27	-0.30	-0.04	-0.21	-0.02	-0.14	-0.18
T4	0.35	-0.26	-0.06	-0.20	0.02	-0.21	-0.16
T5	0.34	-0.30	-0.11	-0.25	0.02	-0.16	-0.20
T6	0.29	-0.23	-0.03	-0.26	0.04	-0.10	-0.21
T7	0.16	-0.13	-0.12	-0.01	0.05	-0.09	-0.30
T8	0.30	-0.26	-0.08	-0.33	-0.07	-0.14	-0.13
T9	0.29	-0.22	-0.11	-0.31	-0.08	-0.19	-0.16
T10	0.33	-0.24	-0.10	-0.35	-0.05	-0.13	-0.13
T11	0.31	-0.26	-0.09	-0.28	-0.01	-0.20	-0.13
T12	0.20	-0.10	0.02	-0.12	-0.04	-0.09	-0.21

*denotes significance at 5% level of significance   **denotes significance at 1% level of significance

A brief discussion on the effect of significant weather parameters on crop yield in *kharif* season is brought forth. Negative correlation of yield with wind velocity during pre-sowing and emergence stages may be indicative of excessive loss of moisture by way of evapotranspiration. During sowing to transplanting stages, heavy rain accompanied by wind might have physical and physiological damaging effect on rice crop. During transplanting to active tillering stage, temperature ranged from 29-31^{0}C and had a positive relationship to the yield which contrasted with the findings of Samui and Chowdhury (1994). Additionally, according to IRRI (1974) high temperature is required for active growth at vegetative stages. The active tillering to panicle initiation stage depicted an average minimum temperature of 24.08^{0}C and had a positive impact on the rice yield and these were in accordance with the findings of Choudhury and Gore (1991) for rice crop in Bhandara district of Maharashtra Also, effect of temperature on tillering is affected by the amount of sunlight (Mahbubul *et al.,* 1985). Accumulated sunshine hours during tillering stage had a significant positive correlation with the grain yield and is in accordance with findings reported by Kamalam *et al.* (1988).

Tables 4.18, 4.19, 4.20, 4.21 and 4.22 depicts the correlation coefficients between weather variables and treatment responses during pre-sowing stage, sowing to transplanting stage, transplanting to active tillering stage, active tillering to panicle initiation and panicle initiation to flowering stage respectively in *rabi* season. During pre-sowing stage, maximum temperature had significant negative association with the responses of T_7 and positive correlation with T_8, and T_9 at 5 per cent level of significance. Relative humidity had negative association with yield under T_1 and T_{12} at 5 per cent level of significance and for T_2, T_3, T_4, T_5, T_9, T_{10} and T_{11} at 1 per cent level of significance. Wind speed had significant positive correlation with T_3, T_4, T_6 and T_8 at 5 per cent level as well as with T_5 at 1 per cent level of significance. During sowing and transplanting period, maximum temperature had significant positive correlation with yield under T_8 at 5 per cent level of significance. Minimum temperature had negative correlation with the responses of T_1, T_3, T_5, T_{10} and T_{11} at 5 per cent level of significance; with T_2, T_8 and T_9 at 1 per cent level of significance. Wind speed had positive correlation with

T_1, T_2, T_3, T_4, T_6, T_9, T_{10}, and T_{11} at 1 per cent level of significance and with T_5 and T_{10} at 5 per cent level of significance. Association between rainfall and treatment responses under T_2, T_8 and T_9 was negative at 5 per cent level of significance. Sunshine hours had significant positive association at 5 per cent level of significance with T_1, T_2, T_3, T_4, T_6, T_8 and T_9. Number of rainy days had significant positive correlation with T_2, T_3, T_8, T_9, T_{10}, T_{11} at 1 per cent level. During transplanting to active tillering stage, minimum temperature had negative correlation with T_2 and T_6 at 5 per cent level of significance. Relative humidity was negatively correlated to T_9 at 5 per cent level of significance. None of the other variables had significant correlation with the treatment responses during transplanting to active tillering stage.

During active tillering to panicle initiation stage, maximum temperature had significant positive correlation with T_2, T_3, T_4, T_5, T_6, T_{10} and T_{11} at 5 per cent level of significance. Maximum temperature was positively correlated to T_8 and T_9 at 1 per cent level of significance. Wind speed had positive correlation with T_4 at 5 per cent level of significance. During panicle initiation to flowering stage, minimum temperature had positive significant association with T_1, T_2, T_4 and T_{10} at 5 per cent level and with T_5, T_8 and T_9 at 1 per cent level of significance. Relative humidity had significant positive correlation with T_1, T_2, T_3, T_4, T_5, T_6, T_8, T_9, T_{10} and T_{11} at 5 per cent level of significance. Wind speed had significant negative correlation at 1 per cent level of significance with T_2 and at 5 per cent level with T_6, T_8, T_9 and T_{12}. Sunshine hours had significant negative correlation with T_1, T_2, T_5, T_6 and T_9 at 5 per cent level of significance.

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Table 4.18 Influence of weather variables in pre-sowing period on crop yield during *rabi* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall
T1	0.04	0.00	**-0.46***	0.40	0.28	-0.29
T2	0.30	-0.02	**-0.61****	0.33	0.24	-0.51
T3	0.41	0.00	**-0.73****	**0.46***	0.30	-0.55
T4	0.40	-0.07	**-0.74****	**0.50***	0.30	-0.36
T5	0.32	0.16	**-0.63****	**0.64****	0.02	-0.51
T6	0.15	-0.02	**-0.64****	**0.46***	0.22	-0.42
T7	**-0.46***	-0.03	-0.02	0.24	-0.07	0.16
T8	**0.49***	0.11	**-0.63****	**0.45***	0.17	-0.57
T9	**0.48***	-0.13	**-0.65****	0.35	0.25	-0.57
T10	0.40	-0.13	**-0.64****	0.32	0.25	-0.49
T11	0.37	-0.16	**-0.69****	0.30	0.31	-0.52
T12	0.14	0.08	**-0.55***	0.39	0.23	-0.31

*denotes significance at 5% level of significance **denotes significance at 1% level of significance

Table 4.19 Influence of weather variables of sowing to transplanting stage on crop yield during *rabi* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of rainy Days
T1	0.22	**-0.49***	-0.42	**0.72****	**0.52***	-0.30	-0.33
T2	0.40	**-0.61****	-0.40	**0.60****	**0.48***	**-0.47***	**-0.54***
T3	0.37	**-0.48***	-0.24	**0.60****	**0.46***	-0.36	**-0.49***
T4	0.21	-0.42	-0.26	**0.66****	**0.49***	-0.23	-0.32
T5	0.35	**-0.51***	-0.20	**0.56***	0.39	-0.25	-0.27
T6	0.24	-0.39	-0.32	**0.67****	**0.48***	-0.22	-0.35
T7	-0.29	0.00	0.09	0.23	0.14	0.21	0.19
T8	**0.49***	**-0.64****	-0.25	**0.51***	**0.46***	**-0.49***	**-0.51***
T9	0.43	**-0.63****	-0.39	**0.60****	**0.49***	**-0.48***	**-0.56***
T10	0.28	**-0.49***	-0.15	**0.47***	0.31	-0.39	**-0.45***
T11	0.32	**-0.53***	-0.33	**0.57****	0.36	-0.41	**-0.55***
T12	0.36	-0.34	**-0.45***	0.24	0.23	-0.39	-0.19

*denotes significance at 5% level of significance **denotes significance at 1% level of significance

Table 4.20 Influence of weather variables of transplanting to active tillering stage on crop yield during *rabi* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of rainy Days
T1	-0.01	-0.42	-0.20	0.34	-0.04	-0.08	-0.01
T2	0.11	**-0.46***	-0.20	0.24	-0.15	-0.16	-0.08
T3	0.04	-0.38	-0.32	0.41	-0.10	-0.12	-0.13
T4	0.08	-0.33	-0.37	0.42	-0.07	-0.17	-0.17
T5	0.14	-0.23	-0.21	0.37	-0.15	0.04	-0.06
T6	0.01	**-0.46***	-0.23	0.40	-0.06	-0.11	-0.11
T7	-0.21	-0.28	0.30	0.00	-0.08	0.24	0.21
T8	0.19	-0.25	-0.39	0.30	-0.12	0.02	-0.13
T9	0.19	-0.39	**-0.49***	0.28	-0.05	-0.17	-0.13
T10	0.12	-0.40	-0.29	0.17	-0.05	0.04	-0.10
T11	0.08	-0.44	-0.35	0.21	-0.10	-0.15	-0.09
T12	0.24	-0.10	-0.01	-0.09	-0.05	-0.07	-0.05

*denotes significance at 5% level of significance

**denotes significance at 1% level of significance

Table 4.21 Influence of weather variables of active tillering to panicle initiation stage on crop yield during *rabi* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of rainy Days
T1	0.43	0.04	0.19	0.26	0.24	-0.05	-0.15
T2	**0.46***	0.16	0.10	0.23	0.06	0.14	0.05
T3	**0.49***	0.20	0.03	0.37	0.04	0.02	-0.16
T4	**0.50***	0.11	-0.02	**0.46***	0.11	-0.08	-0.23
T5	**0.45***	0.27	0.06	0.39	0.07	0.01	-0.04
T6	**0.46***	0.12	0.08	0.40	0.19	0.07	-0.08
T7	-0.04	-0.07	0.25	0.09	0.25	0.26	0.11
T8	**0.60****	0.32	-0.01	0.27	0.00	-0.08	-0.20
T9	**0.60****	0.20	0.00	0.19	0.03	-0.14	-0.21
T10	**0.51***	0.15	0.08	0.22	0.08	-0.10	-0.27
T11	**0.52***	0.10	0.07	0.26	0.03	-0.13	-0.23
T12	0.18	0.12	-0.10	0.13	0.23	0.16	0.28

*denotes significance at 5% level of significance **denotes significance at 1% level of significance

Table 4.22 Influence of weather variables of panicle initiation to flowering stage on crop yield during *rabi* season

Treatments	Max. Temp.	Min. Temp.	RH I	Wind Speed	Sunshine hours	Rainfall	No. of rainy days
T1	-0.30	**0.48***	**0.56***	-0.41	**-0.49***	0.27	0.27
T2	-0.35	**0.47***	**0.55***	**-0.61****	**-0.49***	0.13	0.15
T3	-0.19	0.42	**0.47***	-0.43	-0.40	0.05	0.07
T4	-0.19	**0.52***	**0.45***	-0.38	-0.41	0.08	0.05
T5	-0.37	**0.61****	**0.45***	-0.43	**-0.49***	0.06	0.04
T6	-0.16	**0.45***	**0.50***	**-0.50***	**-0.47***	0.18	0.21
T7	-0.25	0.09	0.28	-0.12	0.00	0.27	0.34
T8	-0.34	**0.59****	**0.49***	**-0.50***	-0.31	-0.08	-0.07
T9	-0.26	**0.57****	**0.48***	**-0.46***	**-0.50***	-0.04	-0.06
T10	-0.26	**0.46***	**0.51***	-0.39	-0.19	-0.05	-0.06
T11	-0.24	0.44	**0.45***	-0.39	-0.44	-0.01	-0.04
T12	-0.08	0.32	0.30	**-0.48***	-0.22	0.27	0.27

*denotes significance at 5% level of significance **denotes significance at 1% level of significance

A brief discussion on the significant effect of weather parameters on crop yield in *rabi* season is discussed as follows:

Mean wind speed during pre-sowing, transplanting to active tillering stage were less than 6 km/hr enhancing the crop performance during development stage. Light wind helps to stir the air within the crop and to transport CO_2 to the leaf canopy and these were in accordance with the findings reported by Sreenivasan (1985). During active tillering stage, rainfall had a negative impact as high rainfall would lead to lodging and decaying in standing water. Relative humidity or vapour pressure of the atmosphere influences the rate of transpiration, which in turn influence the physiological processes affecting yield. Moreover, relative humidity is inversely proportional to sunshine hours is substantiated by results obtained in transplanting to active tillering stage and panicle initiation to flowering stage. Narayanan (2004) also found that relative humidity had positive correlation with grain yield during panicle initiation to flowering stage. Yoshida and Parao (1976) reported that solar radiation and temperature during reproductive stage (before flowering) had the greatest influence on rice yield because they determine the number of spikelets.

The comparison of phase wise weather variables in two seasons is given in Fig 4.10, 4.11, 4.12 and 4.13.

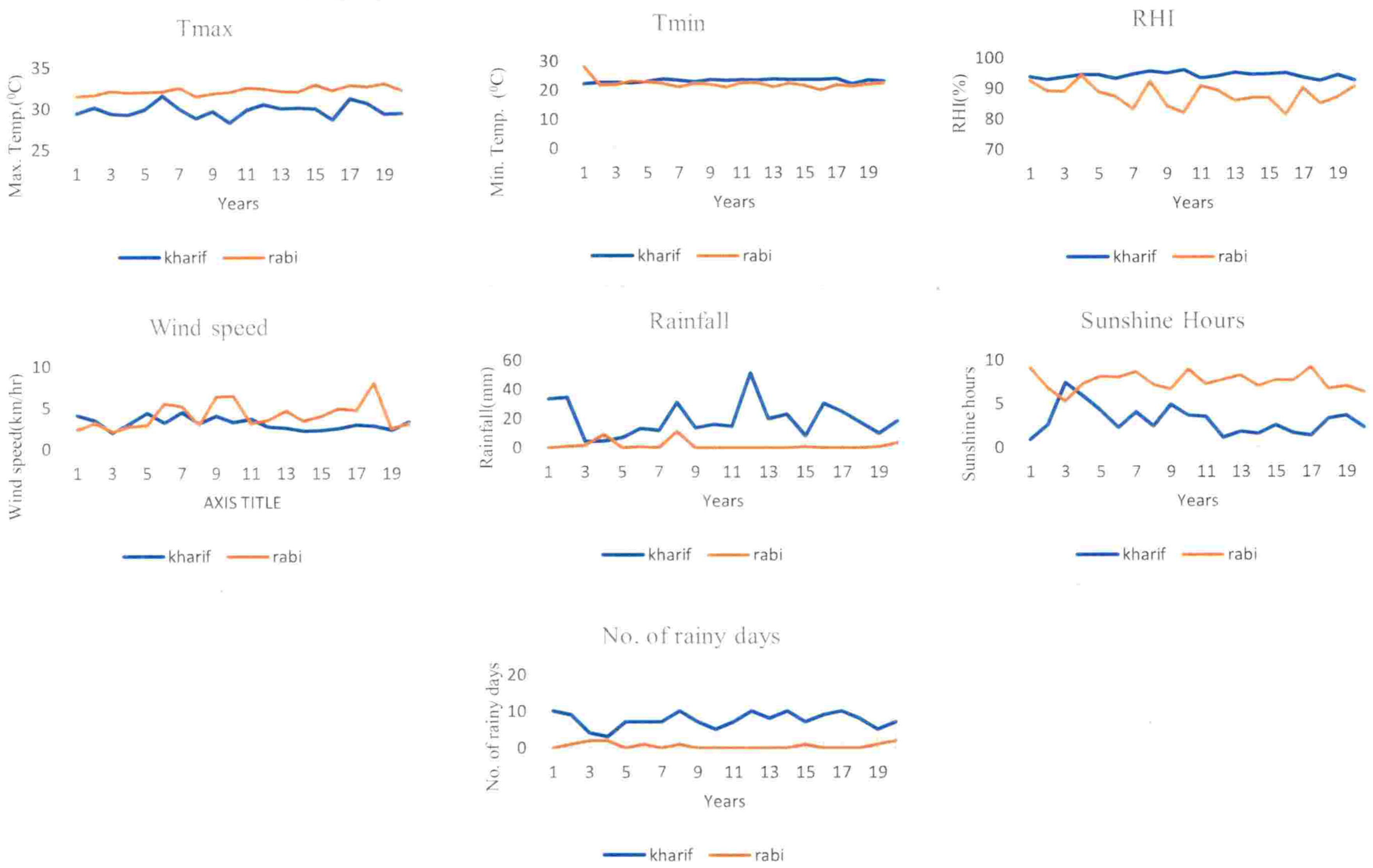

Fig 4.10 Comparison of weather variables in *kharif* and *rabi* seasons during sowing to transplanting stage

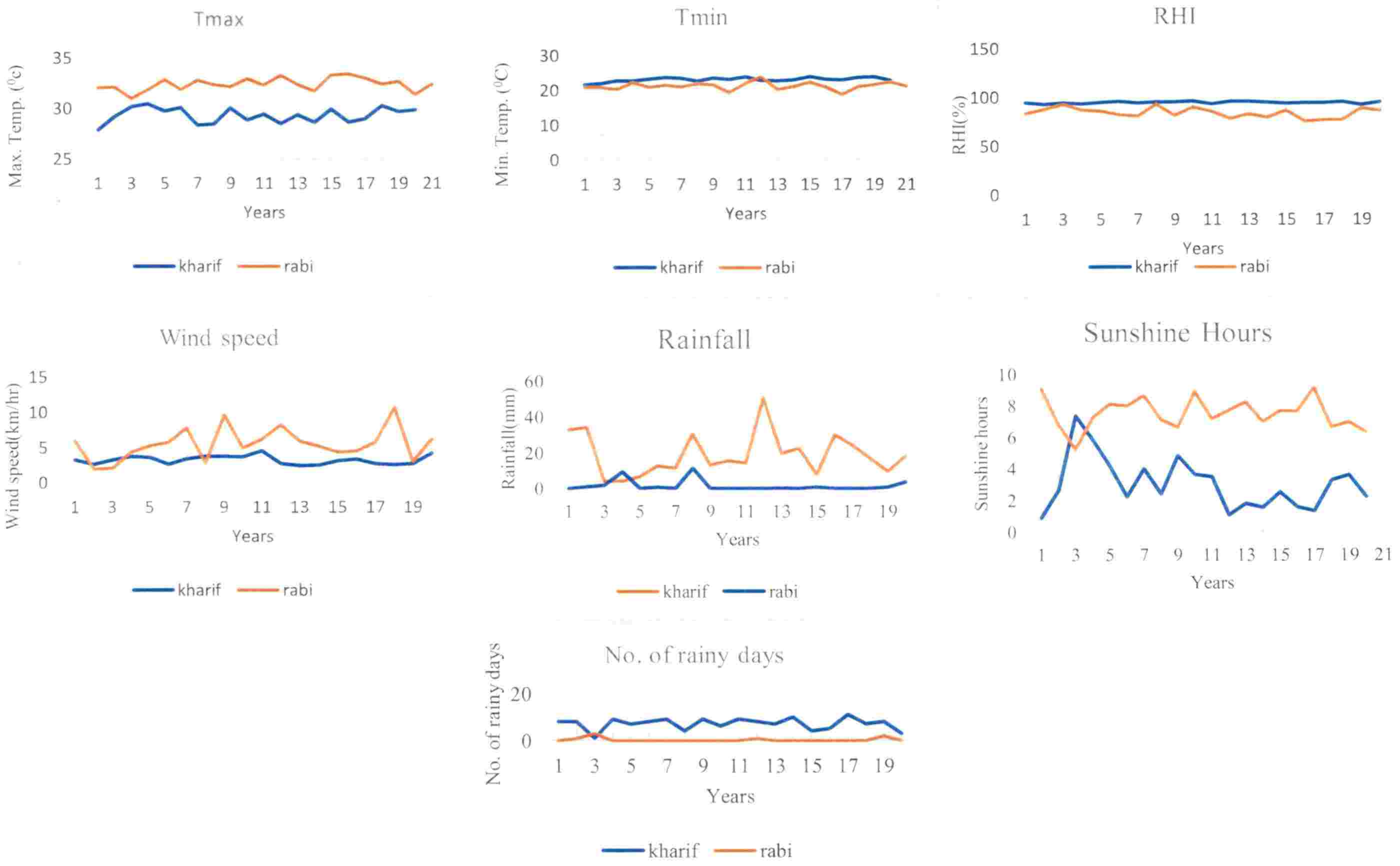

Fig 4.11 Comparison of weather variables in *kharif* and *rabi* seasons during transplanting to active tillering stage

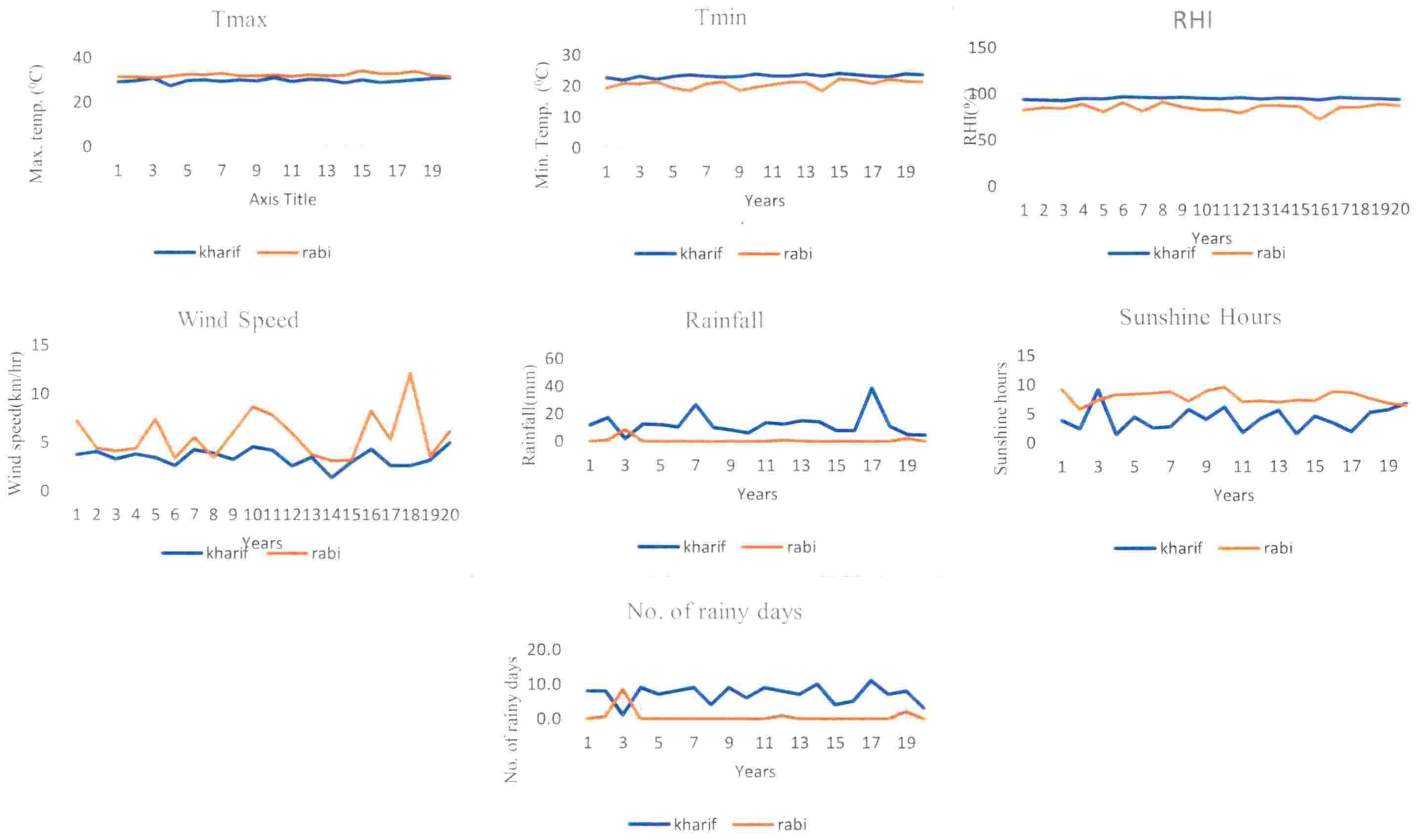

Fig 4.12 Comparison of weather variables in *kharif* and *rabi* seasons during active tillering to panicle initiation stage

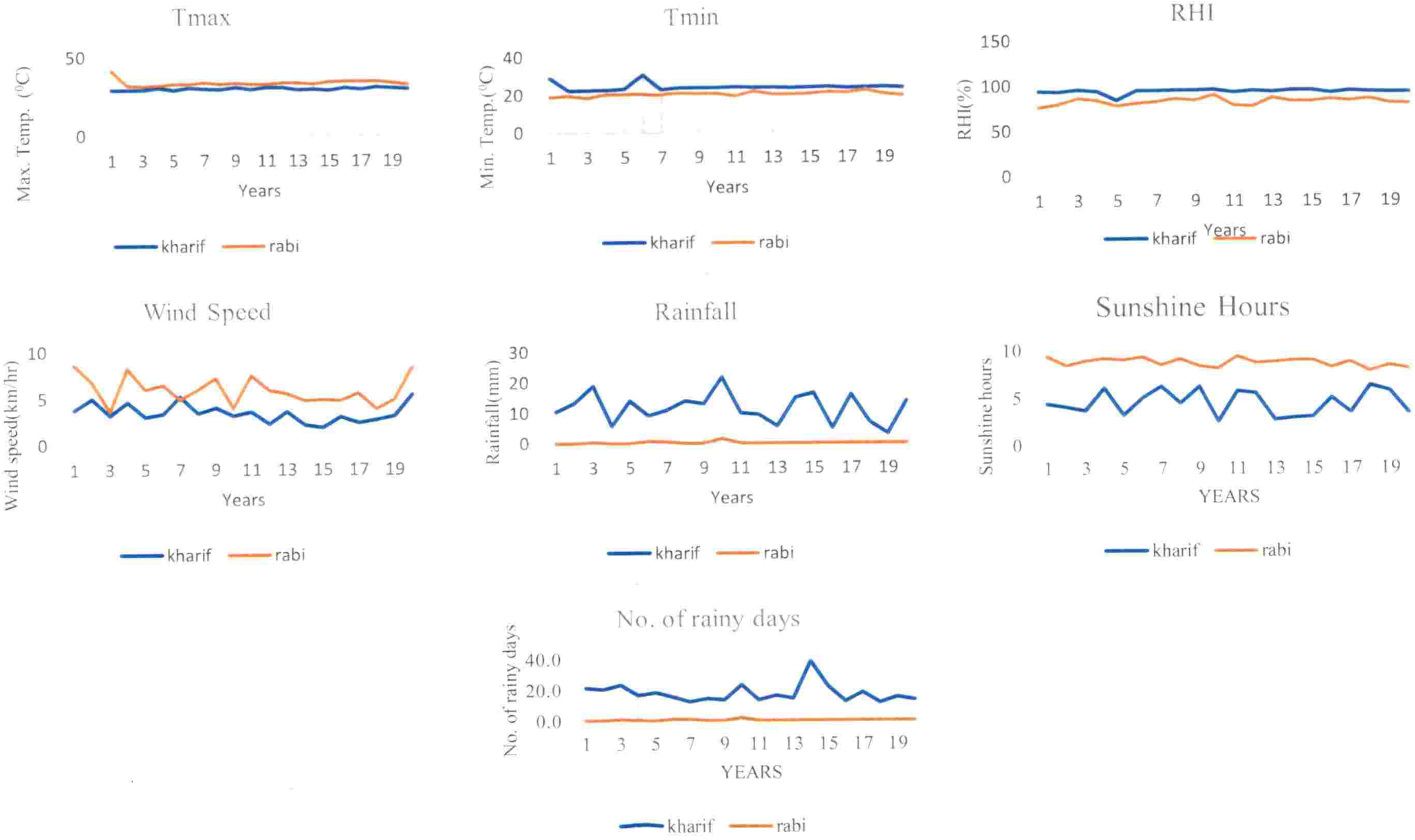

Fig 4.13 Comparison of weather variables in *kharif* and *rabi* seasons during panicle initiation to flowering stage

4.6.2 Effect of plant nutrients on treatment responses

Establishment of a quantitative relationship between grain yield and amount of applied nutrients taken up by the crop is crucial for fertiliser recommendations. Nutrient management should ideally provide input-output balance in long term (Heckman *et al.* 2003). An increasing nutrient supply produces an increase in the yield up to a maximum value, but, if the supply continues increasing, the production may be affected in a negative way. This shows that the influence of plant nutrients on crop yield need not always be linear.

Polynomial regression was used to quantify the relative contribution of the uptake of plant nutrients N, P and K on the treatment responses for both seasons and the results are depicted in Table 4.23 and Table 4.24. During *kharif* season, when the quadratic model was fitted for grain yields with respect to different treatments, the R^2 value ranged from 0.67 to 0.89 showing the relative contribution of plant nutrients to the total variability in grain yield (Fig 4.14). During *rabi* season, the R^2 values were comparatively higher than that of *kharif* season and ranged from 0.75 to 0.96 (Fig 4.15).

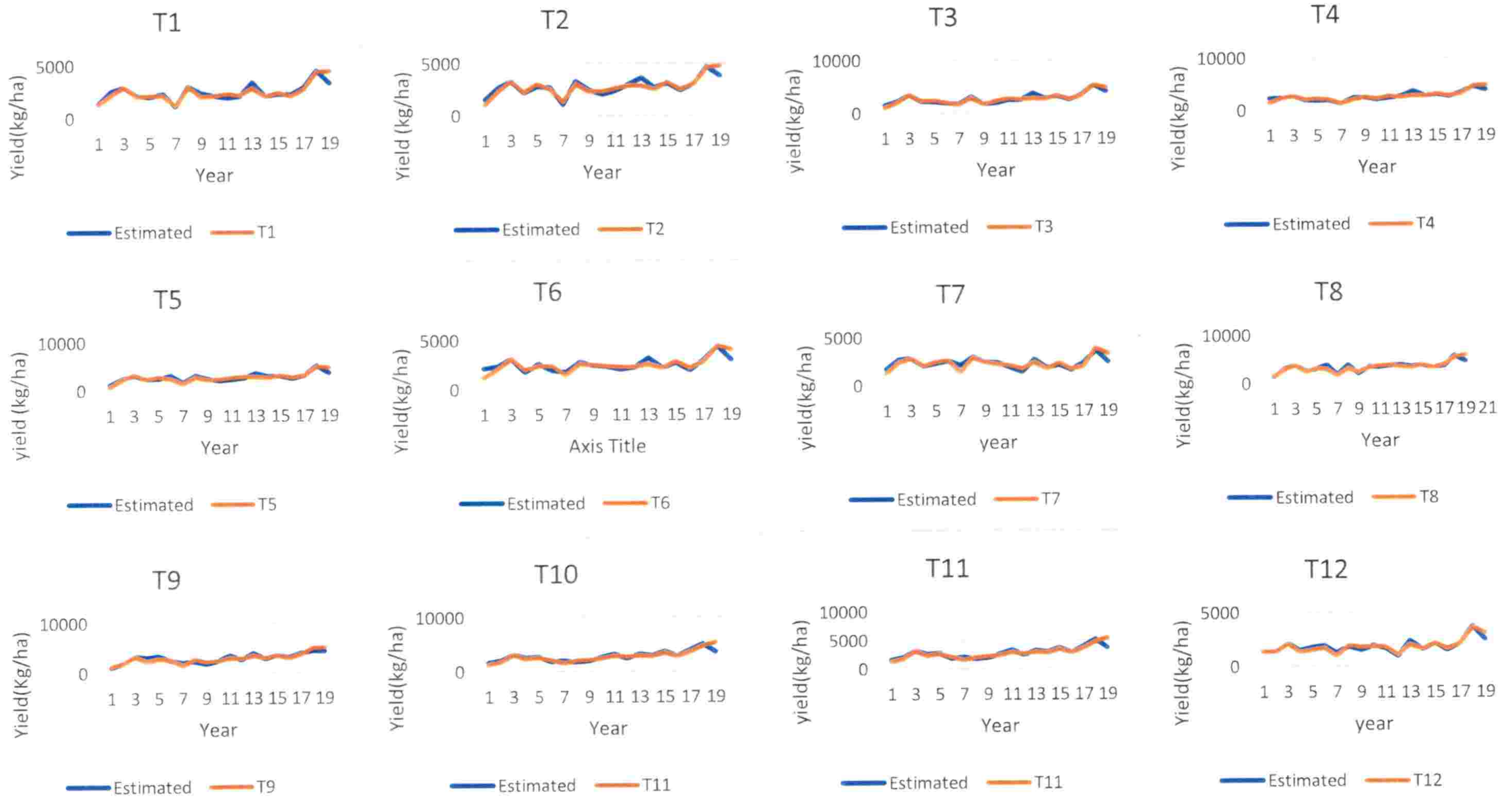

Fig 4.14 Comparison of actual and estimated rice yield using quadratic model in *kharif* season

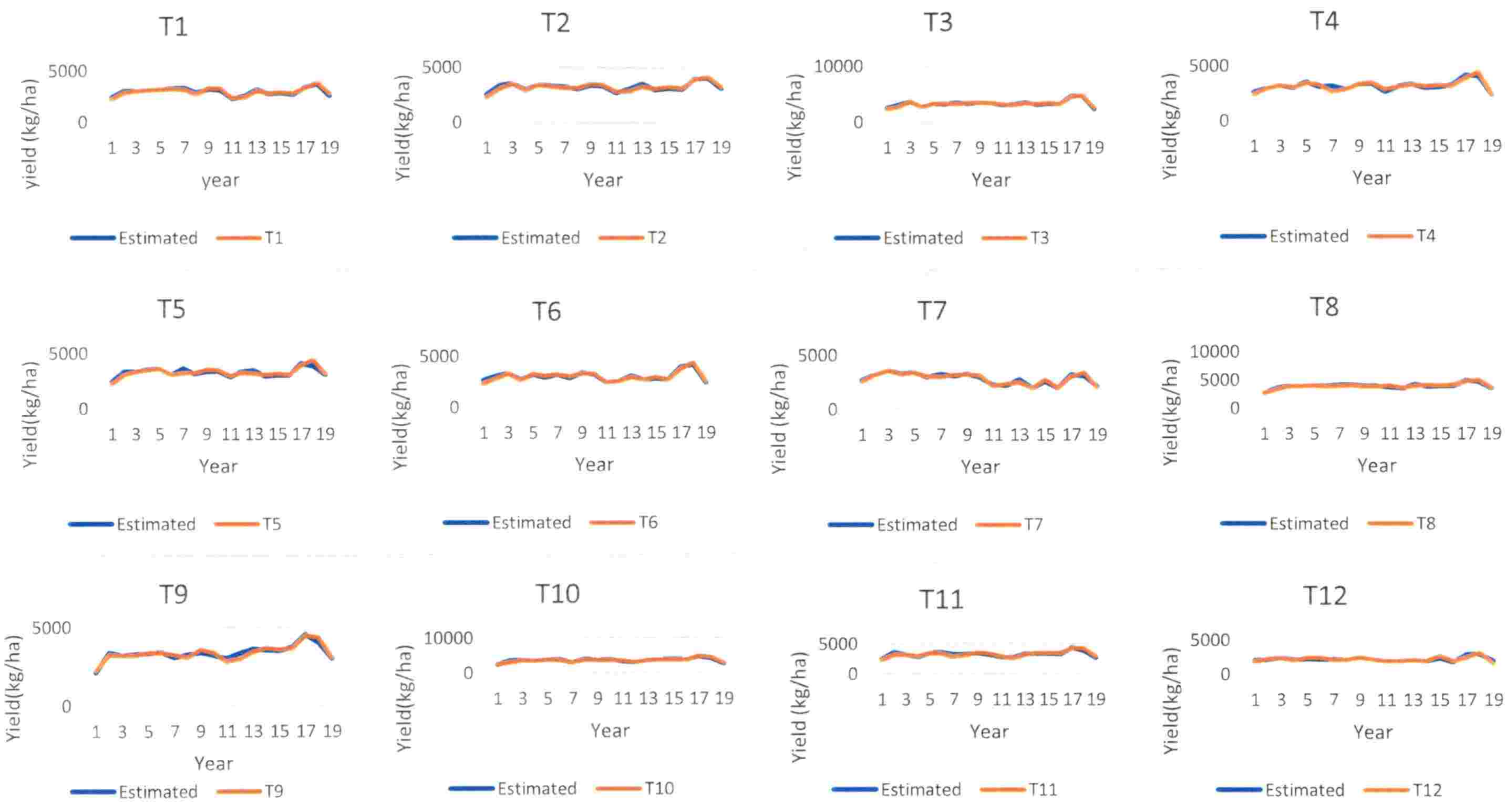

Fig 4.15 Comparison of actual and estimated rice yield using quadratic model in *rabi* season

Table 4.23 Model summary of nonlinear regression analysis for treatment responses in *kharif* season

Treatments		b_0	b_1 (N)	b_2 (P)	b_3(K)	b_4 (N^2)	b_5 (P^2)	b_6(K^2)	b_7(NP)	b_8(NK)	b_9(PK)	R^2
T_1	Estimates	-601.99	138.68	-144.96	12.78	-3.94	-45.95	-1.42	8.69	2.16	12.14	0.83
	Std Error	2616.87	68.67	579.55	94.01	1.19	19.61	1.08	6.05	1.53	9.62	
T_2	Estimates	-3816.96	229.49	3.53	40.91	-3.28	-66.41	-1.21	8.92	0.27	14.16	0.84
	Std Error	3649.33	72.52	541.54	97.00	0.84	33.58	1.24	4.41	1.19	14.84	
T_3	Estimates	-971.95	118.73	471.58	-46.04	-3.13	-39.90	-0.35	7.95	1.63	3.33	0.89
	Std Error	2788.21	72.92	328.58	60.44	0.83	20.33	0.52	5.58	0.96	6.54	
T_4	Estimates	-2894.20	166.81	592.71	-37.63	-3.25	-42.99	0.20	12.66	0.60	-1.17	0.81
	Std Error	4311.43	124.20	643.31	107.09	1.68	22.30	1.40	13.04	1.88	8.45	
T_5	Estimates	262.89	124.37	227.38	-63.98	-5.04	-31.03	-1.39	-1.35	5.29	8.59	0.80
	Std Error	4208.33	99.22	1013.64	134.42	1.20	28.96	1.46	8.19	2.07	17.04	
T_6	Estimates	-1930.47	143.05	458.51	-38.99	-2.45	-48.53	-0.25	8.17	0.76	4.86	0.69
	Std Error	4009.35	72.78	894.44	66.45	1.41	18.16	0.41	6.50	2.08	11.62	
T_7	Estimates	831.62	356.34	-1193.98	-60.93	-6.58	-52.32	-2.40	13.50	1.59	35.32	0.70
	Std Error	2012.11	117.56	693.39	79.98	2.02	22.71	1.36	7.71	1.85	12.88	
T_8	Estimates	-4361.47	416.26	-510.11	-51.25	-5.40	-0.20	-1.62	-5.78	3.86	10.61	0.82
	Std Error	3795.35	179.44	541.09	98.00	2.56	35.06	0.74	10.54	2.64	9.91	
T_9	Estimates	-6771.31	73.50	376.60	216.44	-2.92	-75.58	-3.61	13.02	1.87	13.20	0.83
	Std Error	3146.28	77.67	766.49	148.45	1.14	27.53	2.16	5.84	2.20	16.86	
T_{10}	Estimates	-3448.12	162.26	1129.35	-66.42	-3.04	-10.03	0.27	0.92	2.15	-10.61	0.67
	Std Error	3870.68	96.34	884.01	97.28	1.42	24.30	1.62	6.44	2.42	16.21	
T_{11}	Estimates	-2224.33	136.69	-138.80	48.62	-3.43	-72.44	-1.31	25.07	0.01	13.15	0.76
	Std Error	4485.66	138.41	1067.17	108.14	1.66	34.88	0.97	15.32	3.46	17.20	
T_{12}	Estimates	-4557.69	116.41	488.27	144.23	-3.91	-125.56	-2.38	29.67	-0.89	14.12	0.88
	Std Error	2377.05	68.39	417.78	83.34	0.98	29.60	1.16	11.65	1.88	6.01	

Table 4.24 Model summary of nonlinear regression analysis for treatment responses in *rabi* season

Treatments		b_0	b_1 (N)	b_2 (P)	b_3(K)	b_4 (N^2)	b_5 (P^2)	b_6(K^2)	b_7(NP)	b_8(NK)	b_9(PK)	R^2
T_1	Estimates	1295.69	36.12	211.27	-39.55	-1.62	-36.11	-0.48	4.17	1.63	6.59	0.91
	Std Error	2503.54	55.01	344.50	71.55	0.79	11.48	0.52	5.62	0.93	7.33	
T_2	Estimates	-490.34	113.67	159.03	-8.79	-1.76	-28.28	-0.35	4.12	0.66	4.53	0.86
	Std Error	1474.74	66.71	238.53	51.81	0.91	14.25	0.41	5.36	1.12	5.80	
T_3	Estimates	2521.93	-83.12	768.00	-83.57	-0.82	-85.71	-0.14	14.40	1.21	6.93	0.96
	Std Error	1322.14	91.64	166.28	50.13	0.67	15.12	0.40	4.42	0.54	3.62	
T_4	Estimates	2779.93	10.66	271.69	-90.81	0.23	-62.26	-0.03	6.91	-0.35	12.31	0.83
	Std Error	3046.19	111.91	274.82	62.30	1.14	35.65	0.73	9.70	1.28	9.16	
T_5	Estimates	-3444.54	232.11	56.88	67.47	-0.66	-3.81	-0.21	-2.38	-1.94	2.12	0 .75
	Std Error	2195.94	148.25	649.20	71.69	0.75	27.37	1.04	11.25	1.28	12.33	
T_6	Estimates	4075.69	-24.07	-660.93	3.57	-0.26	-76.70	-0.57	25.48	-1.35	16.33	0.92
	Std Error	3180.27	102.46	596.39	46.32	0.73	23.79	0.28	10.22	1.76	8.96	
T_7	Estimates	-579.68	20.63	914.04	-46.75	-5.35	11.16	0.74	11.30	6.12	-28.60	0. 94
	Std Error	563.95	71.45	457.62	35.08	1.56	17.57	0.80	6.05	2.58	16.04	
T_8	Estimates	-3234.09	172.11	17.03	39.36	-1.14	-12.93	-0.34	2.71	-0.33	2.14	0.89
	Std Error	1957.74	105.38	142.64	53.92	0.77	10.31	0.52	3.83	0.59	3.67	
T_9	Estimates	-2983.88	263.02	122.10	-16.78	-2.06	-6.71	0.37	2.54	-0.72	-1.14	0.89
	Std Error	1567.66	95.59	511.55	53.13	1.00	7.52	0.76	5.80	0.95	8.35	
T_{10}	Estimates	-4474.84	139.50	510.05	71.73	-1.77	-11.71	-1.27	-2.22	1.48	-0.72	0.94
	Std Error	1318.92	71.18	317.66	58.02	0.72	24.49	1.06	9.34	1.41	6.36	
T_{11}	Estimates	-2958.63	296.48	-882.27	117.62	-0.91	-16.55	-1.10	6.90	-3.42	15.45	0.85
	Std Error	2469.24	146.49	599.84	65.35	1.32	19.28	0.76	8.09	1.52	6.24	
T_{12}	Estimates	4891.11	-44.71	-3044.50	229.38	3.02	-45.96	-5.81	35.24	-5.89	71.80	0. 76
	Std Error	3196.00	89.36	1517.29	104.78	2.14	14.49	2.97	13.89	2.23	34.88	

4.7 Dynamics of soil characteristics in relation to crop yield

Consistent use of inorganic fertilisers and manures in soil alters the physico-chemical and biological properties of the soil. Long-term field experiments (LTEs) serves as an aid to understand the changes of soil properties due to different soil management practices and to evaluate their positive and negative influences on soil. To study the dynamics of soil characteristics, the variables considered were soil organic carbon, soil pH, available K and available P.

4.7.1 Soil Organic Carbon (OC)

For *kharif* season, the overall change in average soil OC for different years is given in Fig. 4.16. The soil OC with respect to treatment T_8 was highest, followed by that with T_{10} and T_9. It is evident that, initially there was sharp decline in OC in the beginning years. Eventually after 2014, it was maintained at constant level. Kruskal-Wallis H test showed that there was a statistically significant difference in the OC per cent between different treatments over the years at 5 per cent level of significance. Pairwise comparison revealed that OC per cent under treatments T_1, T_2, T_6 and T_7 were statistically inferior to OC per cent under treatment T_8 at 5 per cent level of significance.

During *rabi* season, the soil OC was highest with respect to treatment T_8 (100 per cent NPK+ FYM @5t ha^{-1}), followed by that with T_{10} and T_9. The decline in soil OC was less when compared to that of *kharif* season in the initial period of the experiment. After 2012, the OC per cent was stabilized and the values ranged from 1-2 per cent (Fig 4.17). Kruskal-Wallis H test showed that there was a statistically significant difference in the OC per cent between different treatments over the years at 5 per cent level of significance.

Organic carbon per cent of soil was higher when adequate rate of FYM was incorporated into the soil as treatment combination. Suresh *et al.*(1999) found that the FYM had profound effect on the organic carbon content of soil.

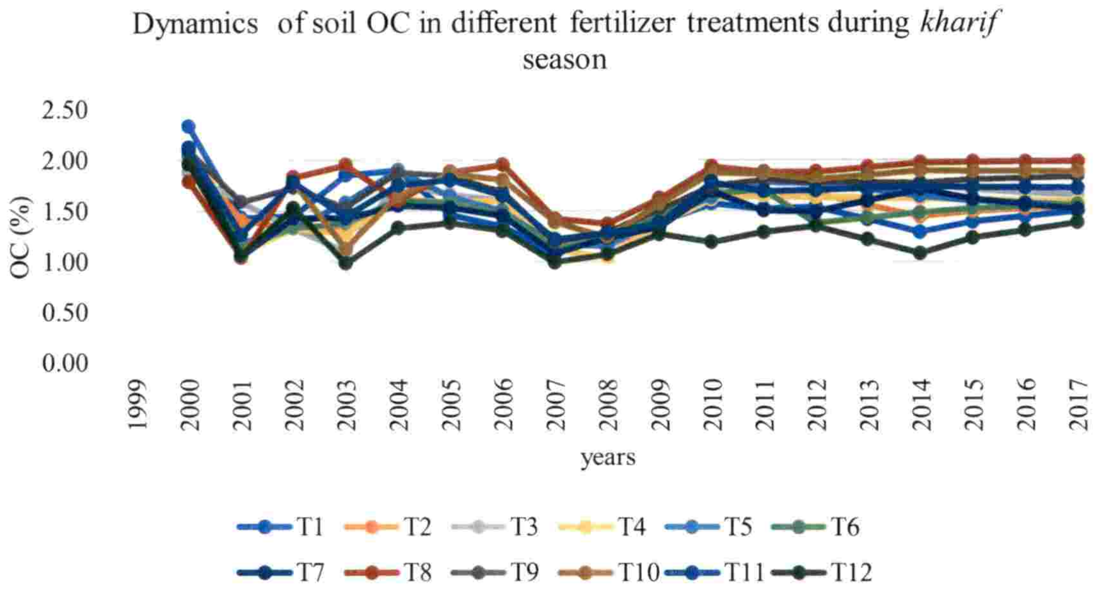

Fig 4.16 Dynamics of soil OC in different fertiliser treatments during *kharif* season

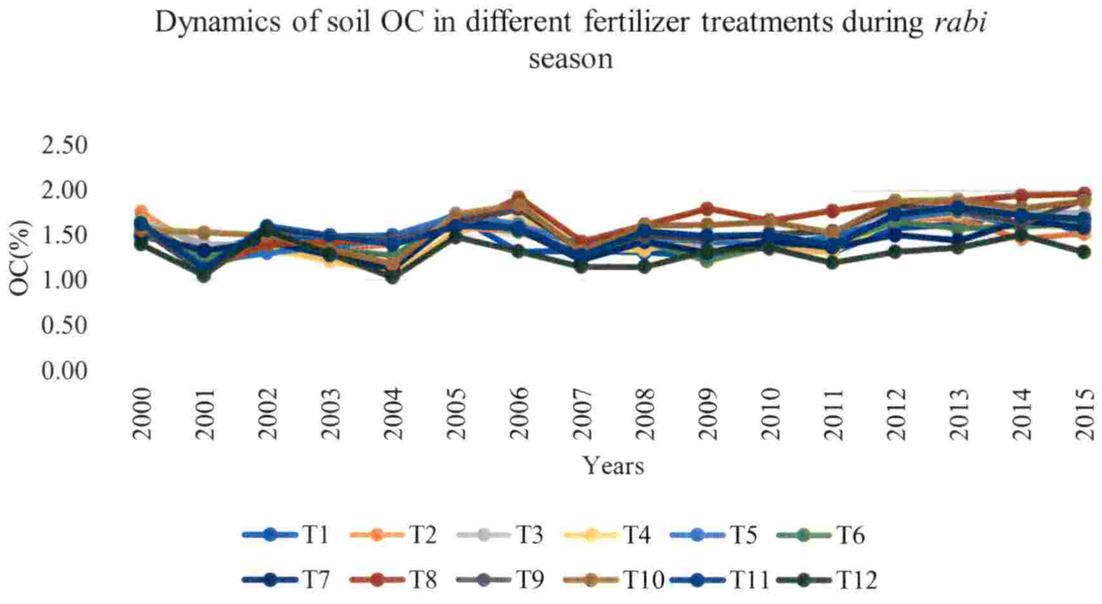

Fig 4.17 Dynamics of soil OC in different fertiliser treatments during *rabi* season

Rudrappa et al. (2006) also found that farmyard manure and NPK fertilisers treatment combinations enabled alluviation of more recalcitrant organic C in soil. This may be related to the fact that the organic matter might have stabilized over time.

4.7.2 Soil pH

During *kharif* season, the soil pH value ranged in between 4 and 6, *i.e.* the soil is acidic in nature and had a decline towards the end of experimental period (Fig. 4.18). Kruskal-Wallis H test showed that there was no statistically significant difference in the soil pH with respect to different treatments over the years.

During *rabi* season, the soil pH stabilized towards the end of the experimental period (Fig.4.19). Kruskal-Wallis H test showed that there was no statistically significant difference in the soil pH with respect to different treatments over the years as in the case of *kharif* season.

These results are in agreement with the findings reported by Sheeba and Chellamuthu (2000). The continued application of varying quantities of inorganic fertilisers and their combinations with FYM over 20 years did not alter the pH appreciably. This might be due to residual effect of organics that tried to shift towards alkaline reaction after the rice harvest. This might also be attributed to the buffering action of soil and also conversion of some organic acids into bicarbonate and carbonates with time.

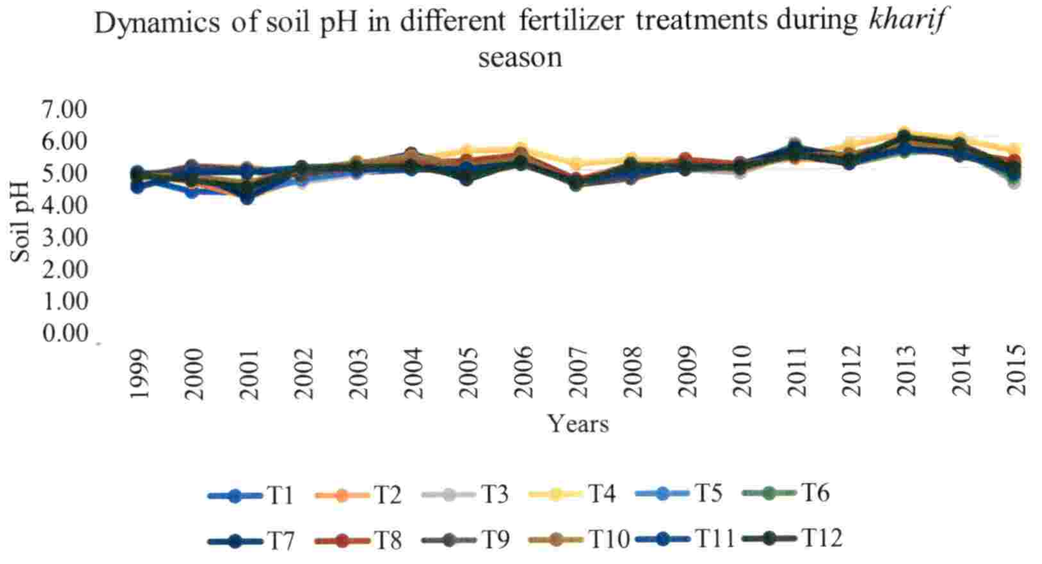

Fig 4.18 Dynamics of soil pH in different fertiliser treatments during *kharif* season

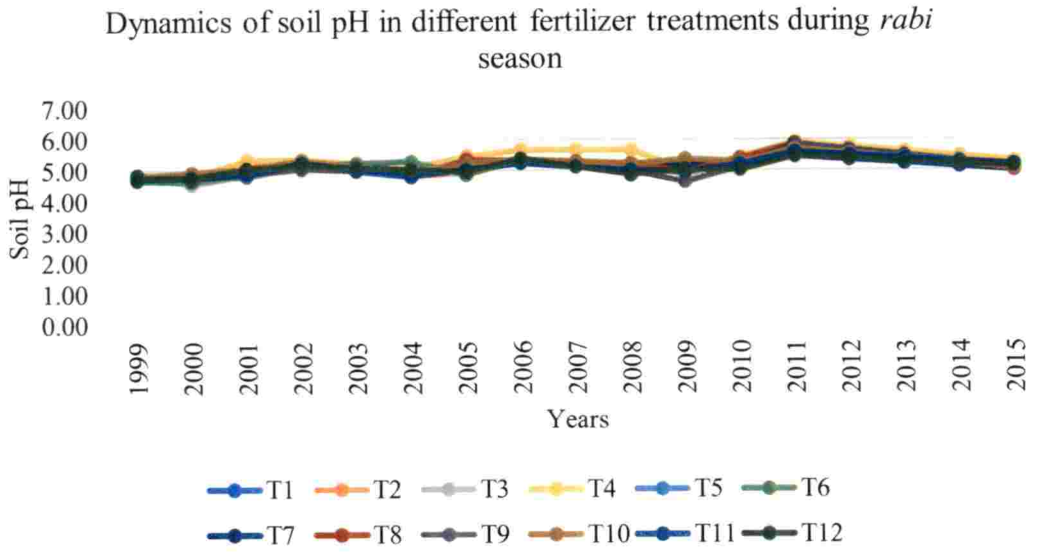

Fig 4.19 Dynamics of soil pH in different fertiliser treatments during *rabi* season

4.7.3 Available Phosphorus (P)

During *kharif* season, the available P in the soil with respect to different treatments is depicted in Fig 4.20. The available P in the soil increased and reached a peak value during 2003, after which the values are constant till 2006. This pattern was also seen again after 2009. This can be credited to the fact that organic anions might compete with phosphatic ions for binding to soil colloids which reduces the phosphorus fixation.

Repeated measures ANOVA was used to measure the effect of available P over years. Since the values of available P in kgha^{-1} is measured every year, we can test whether there is a difference in available P over time due the treatment effects. The repeated measures ANOVA is given in Table 4.25. Since the variances were heterogenous, Greenhouse-Geisser correction was used.

Table 4.25 Repeated measures ANOVA for *kharif* season

Source of variation	d.f.	MSS	F cal	Partial Eta Squared
Years	3.25	405.99	21.64**	0.66
Error	35.78	18.76		

** 1 per cent level of significance

The results show that there was significant difference between the available P over the years at 1 per cent level of significance. Time variable could explain 66 per cent of the variability in available P, provided the effects of other variables were partialed out.

During *rabi* season, the available P values were fluctuating in between 7.90 to 28.18 kgha^{-1} over the years (Fig 4.21). The repeated measures ANOVA with Greenhouse-Geisser correction is given in Table 4.26.

Table 4.26 Repeated measures ANOVA for *rabi* season

Source of variation	df	MSS	F cal	Partial Eta Squared
Years	3.36	789.62	48.72**	0.82
Error	36.97	16.21		

** 1 per cent level of significance

There was a significant effect of time on the available P in soil at 1 per cent level of significance and 82 per cent of the variability in available P was explained by time, keeping all the other variables fixed.

4.7.4 Available Potassium (K)

During *kharif* season, the values of available K fluctuated between 22.43 to 123.20 kgha^{-1} over the years (Fig 4.22). The repeated measures ANOVA with Greenhouse-Geisser correction is given in Table 4.27.

Table 4.27 Repeated measures ANOVA for *kharif* season

Source of variation	df	MSS	F cal	Partial Eta Squared
Years	2.78	29251.94	157.55**	0.94
Error	22.96	181.101		

** 1 per cent level of significance

There was a significant effect of time on the available K in soil at 1 per cent level and 94 per cent of the variability in available K was explained by time, keeping all the other variables fixed.

During *rabi* season, the values were more or less constant till 2007, after which there was fluctuation in the values of available K (Fig 4.23). The repeated measures ANOVA for *rabi* season is given in Table 4.28.

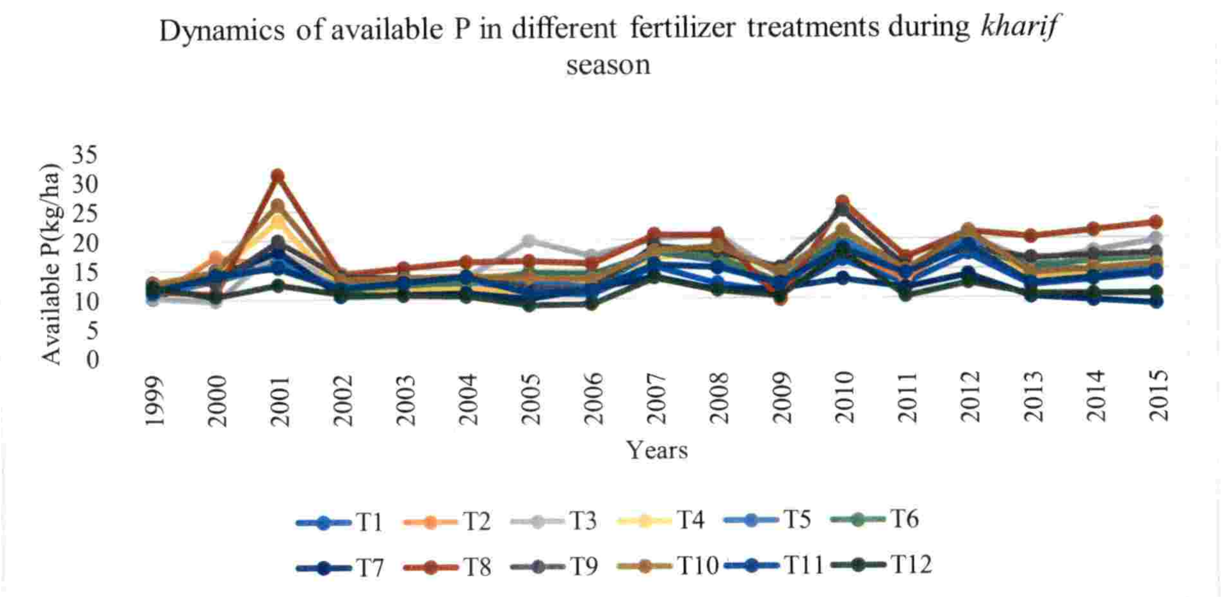

Fig 4.20 Dynamics of available P in different fertiliser treatments during *kharif* season

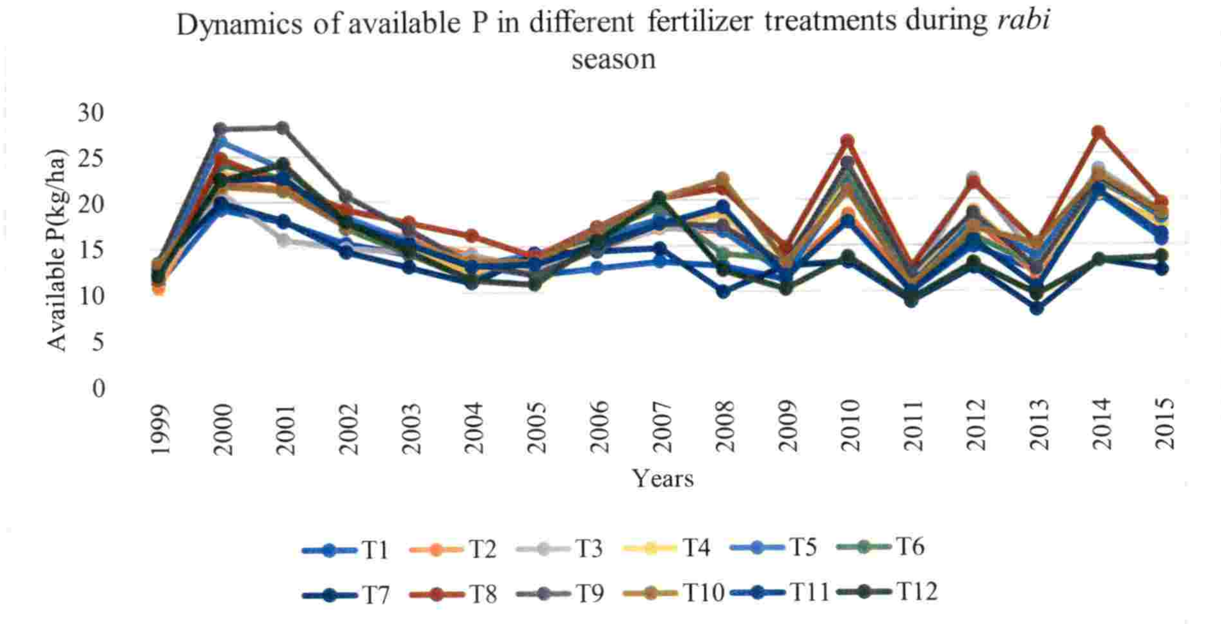

Fig 4.21 Dynamics of available P in different fertiliser treatments during *rabi* season

Table 4.28 Repeated measures ANOVA for *rabi* season

Source of variation	df	MSS	F cal	Partial Eta Squared
Years	2.09	33724.60	186.22**	0.94
Error	22.96	181.10		

** 1 per cent level of significance

The results obtained revealed that there was statistically significant difference between the available potassium due to years at 1 per cent level of significance. Also, 94 per cent of the variation in available k in soil could be explained by the time variable, if all the other variables were fixed.

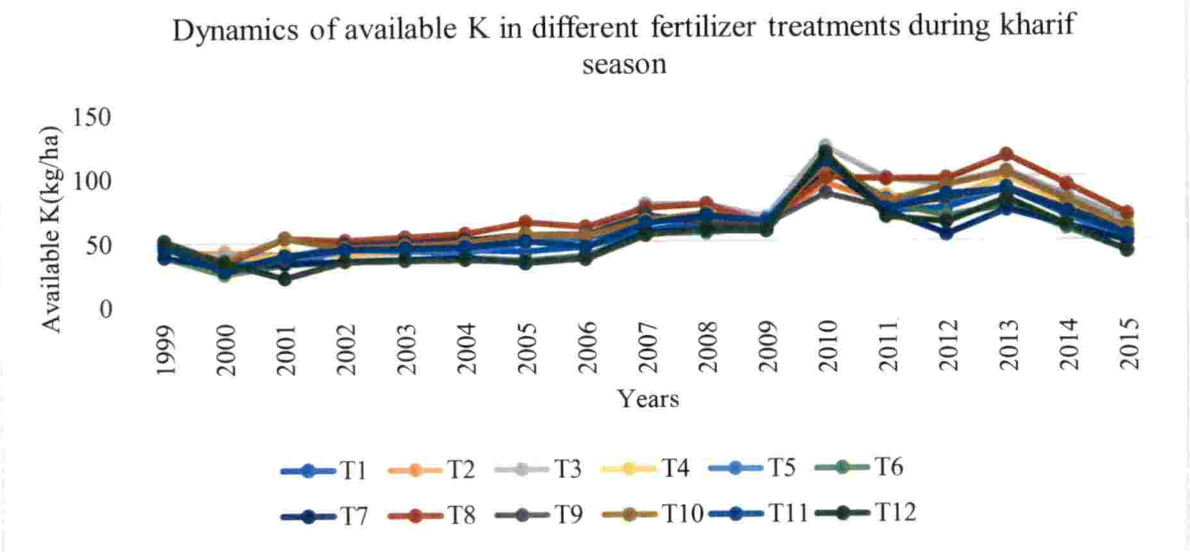

Fig 4.22 Dynamics of available K in different fertiliser treatments during *kharif* season

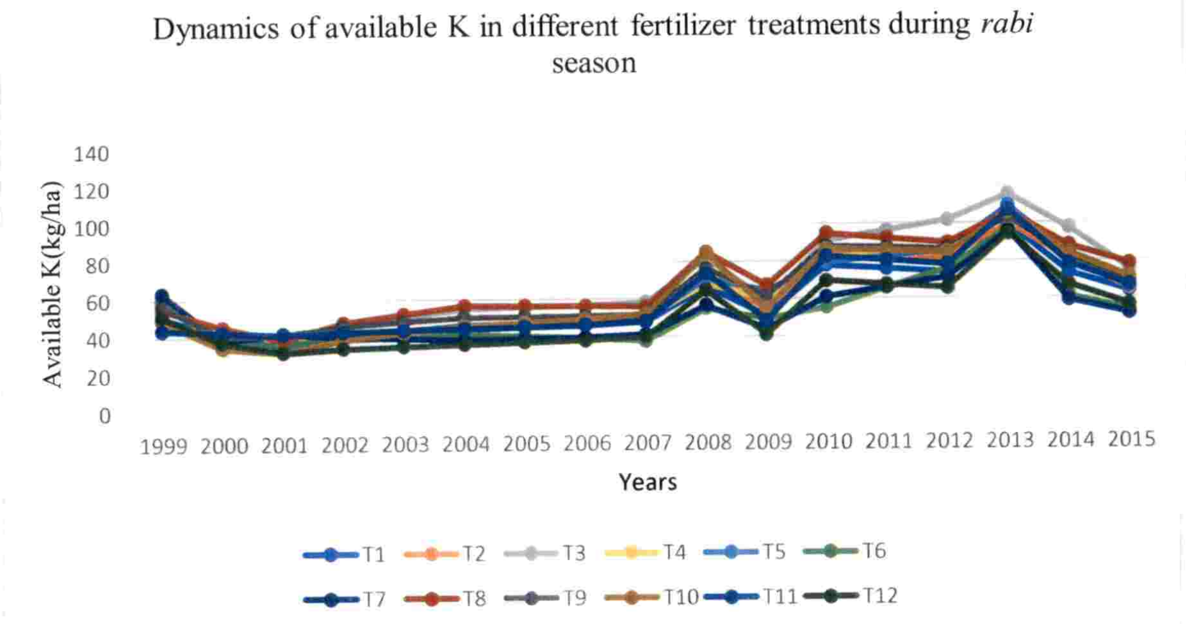

Fig 4.23 Dynamics of available K in different fertiliser treatments during *rabi* season

4.8 Pre-harvest forecasting of crop yield

Yield prediction is the most crucial issue faced in agricultural sector. Regression analysis is a structured approach which deals with analysis of data for research purpose on prediction or forecast. In the present study, multiple regression analysis was used to examine the capability of statistical models to predict crop yield with respect to changes in weather variables during both the seasons.

For each growth stage, step wise regression was performed to regress grain yield on weather variables which were significantly correlated to grain yield under each treatment. Table 4.29 represents the regression models for *kharif* season.

Table 4.29 Linear Regression models for crop responses under different treatments for *kharif* season

Treatments	Regression equation	R^2	Adj. R^2
T_1	$Y_1= -9132.25-355.23W_1X_3+W_2X_1+160.68W_3X_6$	0.49	0.38
T_2	$Y_2= -11281.92-422.18W_1X_3+145.83W_3X_6$	0.52	0.43
T_3	$Y_3= -10506.41-706.04W_1X_3^{*}+533.91W_2X_1$	0.41	0.33
T_4	$Y_4= -9400.32+494.81W_2X_1^{*}-641.75W_0X_3$	0.42	0.36
T_5	$Y_5=-12210.15-418.21W_1X_3-600.96W_2X_1-341.54\ W_0X_3$	0.51	0.42
T_6	$Y_6=-11007.27-3.79W_1X_3+479.71W_2X_1+128.61\ W_3X_6$	0.59	0.51
T_7	$Y_7= -12662.32+492.72W_2X_1^{**}+146.06W_3X_6^{**}$	0.62	0.58
T_8	$Y_8=-6504.25-595.45W_1X_3+539.60W_3X_2-210.42\ W_0X_3$	0.41	0.30
T_9	$Y_9=-24663.71-13.473W_1X_3+509.56W_2X_1^{*}+612.89\ W_3X_2$	0.54	0.46
T_{10}	$Y_{10}= -11276.22-754.39W_1X_3+734.01W_2X_3$	0.46	0.40
T_{11}	$Y_{11}=-24614.43+526.80W_2X_1+603.47W_2X_2-73.90\ W_0X_6$	0.51	0.42
T_{12}	$Y_{12}= -9485.56+369.96W_2X_1+143.03W_3X_6^{*}$	0.39	0.32

* 5 per cent level of significance ** 1 per cent level of significance

From the regression models in Table 4.29, it could be inferred that among the different weather variables, wind velocity, sunshine hours, maximum and minimum temperature were the most influencing predictors. The adjusted R^2 values ranged from 0.32 to 0.58 *i.e.* the weather variables could account for 32-58 per cent of variability in crop yield.

During *rabi* season, weather variables that were significantly correlated with each treatment responses exhibited the problem of multicollinearity, when multiple regression equations were fitted. This leads to the violation of the assumptions of multiple regression analysis. Hence to remove multicollinearity, PCA was conducted and the principal components so obtained were used to fit regression.

For treatment T_1, only one principal component was extracted which had eigen value greater than one, and it explained 52.4 per cent variability in data (Table 4.30). The first principal component was a linear combination of minimum temperature, relative humidity, sunshine hours and wind speed and the component matrix is given in Table 4.31.

Table 4.30 Total variance explained by principal components for T_1

	Initial Eigenvalues			Extracted Sums of Squared Loadings		
Components	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1	3.71	52.94	52.94	3.71	52.94	52.94
2	0.94	13.47	66.41			
3	0.82	11.65	78.06			
4	0.54	7.71	85.77			
5	0.53	7.63	93.40			
6	0.34	4.86	98.27			
7	0.12	1.73	100.00			

Table 4.31 Component loadings of principal components extracted for T_1

Variables	Component
	1
W_1X_2	-0.76
W_1X_3	0.87
W_1X_6	0.74
W_4X_2	0.70
W_4X_4	0.63
W_4X_6	-0.75
W_0X_4	-0.62

Table 4.32 Total variance explained by principal components for T_2

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1	6.09	46.88	46.88	6.09	46.88	46.88
2	1.77	13.63	60.50	1.77	13.63	60.50
3	1.38	10.64	71.14	1.38	10.64	71.14
4	1.03	7.91	79.05	1.03	7.91	79.05
5	0.79	6.10	85.15			
6	0.70	5.39	90.53			
7	0.42	3.23	93.76			
8	0.26	1.97	95.73			
9	0.24	1.87	97.60			
10	0.16	1.19	98.79			
11	0.10	0.74	99.53			
12	0.04	0.31	99.83			
13	0.02	0.17	100.00			

Four principal components having eigen value greater than one, were extracted for treatment T_2. The four principal components could explain 79.05 per cent of variability in data (Table 4.32). The components matrix for extracted principal components is given in Table 4.33.

For T_3 responses, two principal components were extracted with eigen value greater 1. These extracted variables could explain 63.32 per cent of the variability in the data (Table 4.34). The components matrix for extracted principal components is given in Table 4.35.

Table 4.33 Component loadings of principal components extracted for T_2

Variables	Component			
	1	2	3	4
W_1X_2	0.82	0.20	-0.20	0.27
W_1X_3	-0.75	0.26	-0.11	0.47
W_1X_6	-0.73	-0.04	0.28	0.45
W_1X_5	0.72	0.53	-0.34	0.03
W_1X_7	0.75	0.45	-0.25	0.04
W_2X_2	0.34	0.49	0.66	-0.29
W_3X_1	-0.71	0.35	0.29	0.16
W_4X_2	-0.61	0.62	0.19	0.11
W_4X_4	-0.63	-0.24	-0.39	-0.11
W_4X_3	0.78	0.26	0.03	0.15
W_4X_6	0.66	-0.29	0.29	0.24
W_0X_4	0.57	-0.32	0.51	-0.07
W_0X_5	0.69	-0.34	0.09	0.56

Table 4.34 Total variance explained by principal components for T_3

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1	4.28	47.52	47.52	4.28	47.52	47.52
2	1.42	15.80	63.32	1.42	15.80	63.32
3	0.98	10.88	74.20			
4	0.86	9.54	83.74			
5	0.56	6.26	90.00			
6	0.42	4.72	94.71			
7	0.23	2.57	97.28			
8	0.14	1.60	98.88			
9	0.10	1.12	100.00			

Table 4.35 Component loadings of principal components extracted for T_3

Variables	Components	
	1	2
W_1X_2	-0.78	0.41
W_1X_3	0.81	0.20
W_1X_6	0.74	-0.15
W_1X_7	-0.68	0.53
W_3X_1	0.74	0.00
W_4X_4	0.61	-0.20
W_0X_4	-0.64	-0.55
W_0X_3	0.47	0.76
W_0X_5	-0.69	-0.06

The total variation explained by the principal components for T_4 responses was 67.78 per cent and was explained by two components (Table 4.36). These components extracted were used as predictors for further regression analysis.

Table 4.36 Total variance explained by principal components for T_4

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1	4.05	50.63	50.63	4.05	50.63	50.63
2	1.37	17.15	67.78	1.37	17.15	67.78
3	0.90	11.25	79.03			
4	0.59	7.36	86.39			
5	0.53	6.63	93.03			
6	0.23	2.91	95.94			
7	0.19	2.35	98.29			
8	0.14	1.71	100.00			

Table 4.37 Component loadings of principal components extracted for T_4

Variables	Components	
	1.00	2.00
W_1X_3	0.88	0.21
W_1X_6	0.69	0.41
W_3X_1	0.71	0.38
W_3X_3	0.71	-0.59
W_4X_2	0.76	0.20
W_4X_4	0.43	0.44
W_0X_2	-0.73	0.39
W_0X_4	0.71	-0.53

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Table 4.38 Total variance explained by principal components for T_5

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1	4.54	50.43	50.43	4.54	50.43	50.43
2	1.21	13.47	63.90	1.21	13.47	63.90
3	0.99	11.03	74.93			
4	0.76	8.46	83.39			
5	0.54	5.97	89.36			
6	0.39	4.30	93.65			
7	0.31	3.48	97.13			
8	0.18	2.03	99.16			
9	0.08	0.84	100.00			

In the case of T_5, two principal components had eigen value greater than one and it could explain 63.90 per cent of variability in the data (Table 4.38). Hence these were utilized for further analysis. The components matrix is given in Table 4.39.

For T_6, three principal components were extracted which could explain 75.56 per cent of variability in the data (Table 4.40). For T_8, four principal components accounted for 81.02 per cent variability in the data (Table 4.42). For T_9, four principal components could explain 81.79 per cent variability in the data (Table 4.44). In the case of T_{10}, 65.13 per cent variation in the data was accounted by two principal components (Table 4.46). In the case of T_{11}, two principal components accounted for 66.40 per cent variability in the data (Table 4.48). These principal components were used as regressors to perform linear regression. For T_7 and T_{12} the weather variables which were significantly correlated with grain yield were used for regression.

Table 4.39 Component loadings of principal components extracted for T_5

Variables	Components	
	1	2
W_1X_2	-0.69	0.53
W_1X_3	0.80	0.11
W_3X_1	0.70	0.03
W_4X_2	0.77	0.16
W_4X_4	0.57	-0.59
W_4X_6	-0.76	0.01
W_0X_4	-0.70	-0.38
W_0X_3	0.60	0.60
W_0X_5	-0.77	0.21

Table 4.40 Total variance explained by principal components for T_6

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1.00	4.07	45.16	45.16	4.07	45.16	45.16
2.00	1.64	18.20	63.36	1.64	18.20	63.36
3.00	1.10	12.20	75.56	1.10	12.20	75.56
4.00	0.62	6.84	82.40			
5.00	0.55	6.05	88.45			
6.00	0.43	4.75	93.20			
7.00	0.31	3.45	96.66			
8.00	0.21	2.29	98.94			
9.00	0.10	1.06	100.00			

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Table 4.41 Component loadings of principal components extracted for T_6

Variables	Components		
	1	2	3
W_1X_3	0.88	0.10	-0.14
W_1X_6	0.77	0.01	0.25
W_2X_2	-0.30	0.75	0.30
W_3X_1	0.73	0.22	0.49
W_4X_2	0.73	0.47	0.15
W_4X_2	0.61	-0.56	-0.18
W_4X_3	-0.68	0.49	-0.35
W_4X_5	-0.68	-0.07	0.39
W_0X_3	0.50	0.49	-0.60

Table 4. 42 Total variance explained by principal components for T_8

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1.00	6.25	48.07	48.07	6.25	48.07	48.07
2.00	1.92	14.74	62.81	1.92	14.74	62.81
3.00	1.38	10.59	73.40	1.38	10.59	73.40
4.00	1.01	7.80	81.20	1.01	7.80	81.20
5.00	0.72	5.51	86.71			
6.00	0.56	4.29	91.00			
7.00	0.33	2.51	93.51			
8.00	0.26	2.02	95.53			
9.00	0.22	1.68	97.21			
10.00	0.16	1.23	98.44			
11.00	0.14	1.04	99.47			
12.00	0.05	0.41	99.88			
13.00	0.02	0.12	100.00			

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Table 4.43 Component loadings of principal components extracted for T_8

Variables	Components			
	1.00	2.00	3.00	4.00
W_1X_1	0.65	-0.11	-0.59	0.00
W_1X_2	-0.82	0.23	-0.17	0.08
W_1X_3	0.70	0.38	0.38	0.31
W_1X_6	0.74	0.01	0.17	0.51
W_1X_5	-0.77	0.53	0.07	-0.20
W_1X_7	-0.76	0.49	0.11	-0.19
W_3X_1	0.77	0.24	-0.25	0.02
W_4X_2	0.66	0.61	0.01	-0.08
W_4X_4	0.53	-0.14	0.71	-0.32
W_4X_3	-0.74	0.35	-0.21	0.23
W_0X_1	0.71	0.25	-0.40	-0.07
W_0X_3	0.32	0.73	0.11	0.13
W_0X_5	-0.70	-0.15	0.14	0.63

Table 4.44 Total variance explained by principal components for T_9

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1.00	6.34	48.80	48.80	6.34	48.80	48.80
2.00	1.91	14.68	63.48	1.91	14.68	63.48
3.00	1.35	10.41	73.89	1.35	10.41	73.89
4.00	1.03	7.90	81.79	1.03	7.90	81.79
5.00	0.72	5.50	87.29			
6.00	0.49	3.75	91.04			
7.00	0.33	2.51	93.56			
8.00	0.31	2.41	95.97			
9.00	0.20	1.52	97.49			
10.00	0.18	1.38	98.86			
11.00	0.09	0.70	99.56			
12.00	0.04	0.30	99.86			
13.00	0.02	0.14	100.00			

Table 4.45 Component loadings of principal components extracted for T_9

Variables	Components			
	1	2	3	4
W_1X_2	0.82	0.35	0.01	0.07
W_1X_3	-0.75	0.26	0.08	0.49
W_1X_6	-0.75	0.11	-0.33	0.41
W_1X_5	0.73	0.40	0.48	0.13
W_1X_7	0.74	0.34	0.44	0.19
W_2X_4	0.48	-0.71	0.33	-0.09
W_3X_1	-0.76	0.33	-0.02	-0.12
W_4X_2	-0.68	0.51	0.29	0.00
W_4X_4	-0.54	-0.50	0.36	0.39
W_4X_3	0.73	0.42	-0.04	-0.02
W_4X_6	0.63	0.00	-0.44	-0.08
W_0X_1	-0.71	0.36	-0.03	-0.47
W_0X_5	0.69	0.08	-0.54	0.40

Table 4.46 Total variance explained by principal components for T_{10}

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	Per cent of Variance	Cumulative per cent	Total	Per cent of Variance	Cumulative per cent
1	4.09	51.16	51.16	4.09	51.16	51.16
2	1.17	14.57	65.73	1.17	14.57	65.73
3	0.82	10.18	75.92			
4	0.73	9.17	85.08			
5	0.65	8.18	93.26			
6	0.34	4.20	97.46			
7	0.14	1.78	99.24			
8	0.06	0.77	100.00			

Table 4.47 Component loadings of principal components extracted for T_{10}

Variables	Components	
	1	2
W_1X_2	-0.77	0.50
W_1X_3	0.77	0.17
W_1X_7	-0.64	0.51
W_3X_1	0.77	0.32
W_4X_2	0.73	0.47
W_4X_4	0.60	-0.43
W_0X_4	-0.62	-0.32
W_0X_5	-0.76	-0.06

Table 4.48 Total variance explained by principal components for T_{11}

Components	Initial Eigenvalues			Extracted Sums of Squared Loadings		
	Total	per cent of Variance	Cumulative per cent	Total	per cent of Variance	Cumulative per cent
1	3.63	51.87	51.87	3.63	51.87	51.87
2	1.02	14.52	66.40	1.02	14.52	66.40
3	0.81	11.62	78.02			
4	0.68	9.70	87.72			
5	0.51	7.30	95.02			
6	0.21	3.03	98.05			
7	0.14	1.95	100.00			

Table 4.49 Component loadings of principal components extracted for T_{11}

Variables	Components	
	1	2
W_1X_2	0.80	0.49
W_1X_3	-0.75	0.18
W_1X_7	0.72	0.36
W_3X_1	-0.74	0.33
W_4X_4	-0.65	-0.36
W_0X_4	0.63	-0.59
W_0X_5	0.76	-0.18

It is evident from Table 4.50 that adjusted R^2 values were improved when principal components were used as regressors for predicting the grain yield with respect to all treatments in *rabi* season.

Table 4.50 Regression models for crop responses under different treatments for *rabi* season

Treatments	Regression equations	R^2	Adj. R^2
T1	$2973.97 + 278.50Z_1^{**}$	0.54	0.51
T2	$3225.71 - 296.83Z_1^{**} - 7.43Z_2 - 89.60Z_3 + 32.05Z_4$	0.64	0.55
T3	$3368.43 + 427.57Z_1^{**} + 115.12Z_2$	0.58	0.53
T4	$3161.66 + 350.58Z_1^{**} + 0.29Z_2$	0.57	0.52
T5	$3262.08 + 313.72Z_1^{**} + 58.94Z_2$	0.58	0.53
T6	$2994.48 + 345.38Z_1^{**} - 62.32Z_2 - 91.99Z_3$	0.58	0.50
T7	$14858.11 - 384.241W_0X_1$	0.21	0.17
T8	$3844.72 + 336.32Z_1^{**} + 64.11Z_2 + 28.47Z_3 - 29.71Z_4$	0.58	0.46
T9	$3355.67 - 365.90Z_1^{**} + 35.91Z_2 + 15.48Z_3 + 39.82Z_4$	0.57	0.46
T10	$3587.50 + 356.78Z_1^{**} - 3.79Z_2$	0.46	0.40
T11	$3243.38 - 348.12Z_1^{**} + 61.55Z_2$	0.55	0.50
T12	$3676.41 - 24.32W_1X_4 - 82.96W_4X_3 + 12.13W_0X_4$	0.27	0.13

** significant at 1 per cent level of significance

4.10 Response curve using polynomial regression

Linear regression requires the relation between the dependent variable and the independent variable to be linear and a straight line may not always be able to capture the pattern in the data. This leads to underfitting of the data which can be overcome by employing a complex model. Polynomial models such as quadratic and cubic models can resolve the issue of under fitting.

Various response curves were fitted for grain yield of rice crop. The parameters of the polynomial models are depicted in Table 4.51 and Table 4.52 for *kharif* and *rabi* seasons. For all the treatment responses in *kharif* season, the actual yields are clustered around the cubic trendline, hence cubic response curve could be considered as the best fit with respect to time. Fluctuating yields were observed over the years. The yield seems to increase with time up to a point and later it decreases, and so on. But in *rabi* season, the original data points lie far apart from the trendlines. Moreover, R^2 values are very low. Hence none of the model could be considered as best fit. Similar results were reported by Chandana (2015).

Table 4.51 Parameters of response curve for grain yield during *kharif* season

Treatments		b_o(constant)	b_1	b_2	b_3	R^2	Adj R^2	RMSE
T_1	Linear	1523.36	97.72^{**}			0.42	0.38	703.84
	Quadratic	2455.14	-156.40	12.10^{*}		0.58	0.54	610.99
	Cubic	1504.35	328.75	-44.27	1.79^{*}	0.68	0.62	555.26
T_2	Linear	1713.01	110.33^{**}			0.48	0.45	699.20
	Quadratic	2441.18	-88.26	9.46		0.57	0.52	652.14
	Cubic	1381.94	452.23	-53.34	1.99^{*}	0.68	0.62	585.02
T_3	Linear	1486.29	140.26^{**}			0.55	0.53	763.56
	Quadratic	2504.41	-137.41	13.22^{*}		0.69	0.65	660.89
	Cubic	1638.46	304.45	-38.12	1.63	0.73	0.69	625.14
T4	Linear	1492.55	124.65^{**}			0.64	0.62	572.02
	Quadratic	2420.75	-128.50	12.05^{**}		0.79	0.77	443.16
	Cubic	2006.95	82.65	-12.48	0.78	0.81	0.78	438.10
T5	Linear	1599.72	122.52			0.53	0.51	694.76
	Quadratic	2270.06	-60.30	8.71		0.61	0.56	657.89
	Cubic	1212.25	479.46	-54.01	1.99^{*}	0.70	0.64	592.06
T_6	Linear	1683.14	84.99^{**}			0.42	0.39	605.73
	Quadratic	2252.34	-70.25	7.39		0.51	0.45	576.24
	Cubic	1486.86	320.34	-37.99	1.44	0.59	0.51	543.65
T_7	Linear	1953.33	40.27			0.13	0.08	625.36
	Quadratic	2447.14	-94.41	6.41		0.22	0.13	609.60
	Cubic	1379.53	450.35	-56.88^{*}	2.01^{*}	0.44	0.34	532.42
T_8	Linear	2001.70	142.58^{**}			0.59	0.57	722.71
	Quadratic	2760.63	-64.40	9.86		0.66	0.62	672.84
	Cubic	2142.59	250.96	-26.79	1.16	0.69	0.63	666.10
T_9	Linear	1520.51	141.01^{**}			0.65	0.63	623.44
	Quadratic	2292.55	-69.55	10.03^{**}		0.74	0.71	554.73
	Cubic	1631.81	267.60	-29.15	1.24	0.78	0.73	533.20
T_{10}	Linear	1821.71	142.28^{**}			0.61	0.59	690.65
	Quadratic	2434.39	-24.82	7.96		0.66	0.62	663.08
	Cubic	1656.53	372.09	-38.16	1.46	0.70	0.65	638.78
T_{11}	Linear	1349.41	144.17^{**}			0.65	0.63	641.30
	Quadratic	2293.60	-113.34	12.26^{**}		0.78	0.75	529.32
	Cubic	1725.34	176.62	-21.43	1.07	0.80	0.76	515.89
T_{12}	Linear	1098.02	80.34^{**}			0.46	0.43	524.47
	Quadratic	1833.33	-120.20	9.55^{**}		0.64	0.59	443.92
	Cubic	1312.40	145.61	-21.34	0.98	0.68	0.62	427.64

** 1 % level of significance

*5 % level of significance

Table 4.52 Parameters of response curve for grain yield during *rabi* season

Treatments		b_o(constant)	b_1	b_2	b_3	R^2	Adj R^2	RMSE
T_1	Linear	2842.30	12.54			.038	≈0.00	383.42
	Quadratic	2797.78	24.68	-0.58		0.04	≈0.00	394.10
	Cubic	2357.12	249.53	-26.70	0.83	0.15	≈0.00	382.16
T_2	Linear	2953.39	25.94			0.16	0.11	367.23
	Quadratic	2849.08	54.38	-1.35		0.17	0.07	375.36
	Cubic	2563.72	199.99	-18.27	0.54	0.21	0.06	376.49
T_3	Linear	2885.08	46.03			0.22	0.18	526.91
	Quadratic	2714.27	92.62	-2.22		0.23	0.14	537.47
	Cubic	2450.32	227.30	-17.87	0.50	0.25	0.11	547.84
T4	Linear	2877.10	27.10			0.12	0.07	446.10
	Quadratic	2732.58	66.52	-1.88		0.14	0.03	455.05
	Cubic	2738.00	63.75	-1.56	-0.01	0.14	≈0.00	469.06
T5	Linear	3000.50	24.91			0.12	0.07	404.21
	Quadratic	2876.82	58.64	-1.61		0.14	0.03	412.72
	Cubic	2440.46	281.30	-27.48	0.82	0.23	0.08	402.96
T_6	Linear	2800.16	18.51			0.05	0.00	477.73
	Quadratic	2787.12	22.06	-0.17		0.05	≈0.00	491.55
	Cubic	2431.93	203.30	-21.23	0.67	0.10	≈0.00	494.37
T_7	Linear	3295.34	-49.41			0.30	0.26	459.42
	Quadratic	3307.97	-52.85	0.16		0.30	0.22	472.71
	Cubic	2764.91	224.25	-32.03	1.02	0.38	0.27	456.74
T_8	Linear	3407.41	41.65			0.29	0.26	391.75
	Quadratic	3095.75	126.65	-4.05		0.37	0.29	381.55
	Cubic	2900.97	226.04	-15.60	0.37	0.38	0.27	388.55
T_9	Linear	2858.85	47.32			0.33	0.29	411.54
	Quadratic	2750.61	76.84	-1.41		0.34	0.26	421.06
	Cubic	2701.58	101.85	-4.31	0.09	0.34	0.21	433.74
T_{10}	Linear	3178.01	39.00			0.19	0.15	486.68
	Quadratic	2894.31	116.37	-3.68		0.24	0.15	486.59
	Cubic	2881.30	123.01	-4.46	0.02	0.24	0.09	501.55
T_{11}	Linear	2813.89	40.90			0.26	0.22	420.15
	Quadratic	2797.33	45.42	-0.22		0.26	0.17	432.28
	Cubic	2678.73	105.94	-7.25	0.22	0.26	0.13	444.04
T_{12}	Linear	2083.31	11.90			0.04	≈0.00	361.06
	Quadratic	2169.37	-11.57	1.12		0.05	≈0.00	369.79
	Cubic	1995.47	77.17	-9.19	0.33	0.07	≈0.00	377.28

** 1 % level of significance

*5 % level of significance

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

The present investigation titled "optimization techniques in long term trials: rice-rice system" was undertaken to study the cumulative effect of weather factors and plant nutrients on the crop productivity, dynamics of soil characters in relation to the fertiliser treatment responses and to suggest appropriate statistical optimisation techniques with respect to yield and its forecast. The results of the study based on the secondary data on grain yield, weather and soil parameters for a period from 1997 to 2017 collected from RARS, Pattambi are summarized as given below:

Linear upward trend was observed in annual average yield of Aiswarya variety of rice in *kharif* season while in *rabi* season no trend was seen. From the descriptive statistics, highest grain yield was found to be obtained under T_8 (100 percent NPK + FYM @5t/ha to the *kharif* rice) followed by T_{10} (100 percent NPK + *in situ* growing of *Sesbania aculeata,* as green manure crop for *kharif* rice only) and T_9 (50 percent NPK + FYM @5t/ha to the *kharif* rice only) in both the seasons. Treatment T_8 gave a mean yield response of 3498.78 kg ha^{-1} in *kharif* season and 3844.72kg ha^{-1} in *rabi* season which clearly established the advantage of integrated use of FYM and green manuring with chemical fertilisers, which provided greater stability in crop production as compared to 100% NPK. In general, crops in *rabi* season had better and consistent performance than crops in *kharif* season. The CV values revealed that the most consistent treatment in *kharif* season was T_7 (27.51 per cent) whereas in *rabi* season it was T_8 (11.81 per cent). Exploratory data analysis using box plot also confirmed that *rabi* season was more consistent with respect to grain yield when compared to *kharif* season. Comparative performance of different treatments in both seasons was evaluated using independent t test. The grain yield response under T_7 was significantly different at 1 per cent level in the two seasons. Analysis of variance showed that treatments are significantly different at 1per cent level of significance in all the years except 1998 and 2006 in *kharif* season and 1998 in *rabi* season.

Split plot analysis was used to study the significance of treatment and time interaction. The time period used for the study, *i.e.* 20 years were split into three periods having 7,7 and 6 years respectively. It was found that in *kharif* season the treatments, years and their interaction had significant effect on grain yield in all the three periods at 1 per cent level of significance. During *rabi* season, the treatments and year was significant only for second and third period.

Repeated measures ANOVA with Greenhouse-Geisser correction revealed that the grain yield had a significant influence of time variable in both the seasons. In *kharif* season, 86 per cent of the variability in grain yield was explained by the time variable whereas in *rabi* season, only 59 per cent of the variability in grain yield was explained by time variable, validating the absence of linear trend in yield in *rabi* season.

Influence of weather variables on crop yield was studied through correlation analysis. During *kharif* season, wind velocity of pre-sowing period, had a negative association with treatment responses of T_3, T_4, T_5, T_8, T_9,T_{10} a and T_{11} at 5 per cent level of significance. Wind speed in sowing to transplanting stage also, had a significant negative association with grain yield under T_1, T_2, T_3, T_4, T_5, T_6, T_9, T_{10} and T_{11} at 5 per level and with T_8 at 1 per cent level of significance. Maximum temperature in transplanting to active tillering stage, had significant positive correlation with responses of T_1, T_2, T_3, T_4, T_5, T_9, T_{11}, and T_{12} at 5 per cent level and for the responses of T_6 and T_7 at 1 per cent level significance. Minimum temperature had significant positive association with the yield due to T_{10} at 5 per cent level of significance. Minimum temperature in active tillering to panicle initiation stage had significant positive association with yield under T_8, T_9, T_{10} and T_{11} at 5 per cent level of significance. There was a significant negative correlation at 5 per cent level of significance for rainfall with response T_7.

In *rabi* season, maximum temperature in pre-sowing stage, had significant negative association with the responses of T_7 and positive correlation with T_8, and T_9 at 5 per cent level of significance. Relative humidity had negative association with yield under T_1 and T_{12} at 5 per cent level of significance and for T_2, T_3, T_4, T_5, T_9, T_{10} and T_{11} at 1 per cent level of significance. Wind speed had significant

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positive correlation with T_3, T_4, T_6 and T_8 at 5 per cent level as well as with T_5 at 1 per cent level of significance. Rainfall had significant negative correlation with treatment responses under T_2, T_3, T_5, T_{10} and T_{11} at 5 per cent level; with T_8 and T_{10} at 1 per cent level of significance. Maximum temperature in sowing to transplanting period, had significant positive correlation with yield under T_8 at 5 per cent level of significance. Minimum temperature had negative correlation with the responses of T_1, T_3, T_5, T_{10} and T_{11} at 5 per cent level of significance; with T_2, T_8 and T_9 at 1 per cent level of significance. Wind speed had positive correlation with T_1, T_2, T_3, T_4, T_6, T_9, T_{10}, and T_{11} at 1 per cent level of significance and with T_5 and T_{10} at 5 per cent level of significance. Association between rainfall and treatment responses namely T_2, T_8 and T_9 was negative at 5 per cent level of significance. Sunshine hours had significant positive association at 5 per cent level of significance with T_1, T_2, T_3, T_4, T_6, T_8 and T_9. Number rainy days had significant positive correlation with T_2, T_3, T_8, T_9, T_{10}, T_{11} at 1 per cent level. Minimum temperature in transplanting to active tillering stage, had negative correlation with T_2 and T_6 at 5 per cent level of significance. Relative humidity was negatively correlated to responses of T_9 at 5 per cent level of significance. Maximum temperature in active tillering to panicle initiation stage, had significant positive correlation with T_2, T_3, T_4, T_5, T_6, T_{10} and T_{11} at 5 per cent level of significance and with T_8 and T_9 at 1 per cent level of significance. Wind speed had positive correlation with yield under T_4 at 5 per cent level of significance. Minimum temperature in panicle initiation to flowering stage, had positive significant association with T_1, T_2, T_4 and T_{10} at 5 per cent level and with T_5, T_8 and T_9 at 1 per cent level of significance. Relative humidity had significant positive correlation with T_1, T_2, T_3, T_4, T_5, T_6, T_8, T_9, T_{10} and T_{11} at 5 per cent level of significance. Wind speed had significant negative correlation at 1 per cent level with T_2 and at 5 per cent level of significance with T_6, T_8, T_9 and T_{12}. Sunshine hours had significant negative correlation with T_1, T_2, T_5, T_6 and T_9 at 5 per cent level of significance.

Relative contribution of plant nutrients on grain yield was quantified through nonlinear regression. More than 80 per cent of variability in grain yield were explained by the plant nutrients under every treatment in both *kharif* and *rabi*

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seasons. Studies on dynamics of soil OC during *kharif* season showed a sharp decline during the initial years. The highest OC per cent was for T_8 which was statistically superior to that with respect to T_1, T_2, T_6 and T_7. Similarly, in *rabi* season there was decline but was less steep when compared to *kharif* season. The soil pH showed a decline towards the end of experimental period during *kharif* season whereas in *rabi* season it was stabilized. The available P in the soil increased and reached a peak value during 2003, after which the values were constant till 2006. This pattern was also seen again after 2009. In *kharif* season, 66 per cent of the variability in available P was explained by time variable. In *rabi* season, 82 per cent of the variability in available P was explained by the time variable. The values of available K in *kharif* season was found to be fluctuating whereas in *rabi* season it remained constant till 2007 after which there was an instability. In both the seasons, 94 per cent of the variation in available K in soil could be explained by the time variable.

Regression analysis was performed to identify the most significant weather variables contributing to crop yield. Treatment wise linear regression models were found to be a reasonable fit for treatment responses during *kharif* season. To account for the multicollinearity that may arise due weather variables, in *rabi* season, PCA was done. Regression models with the principal components as regressors improved the predictability of grain yield. Response curves were fitted using linear, quadratic and cubic models to forecast crop yield taking time as the predictor. For *kharif* season, cubic function was found to be a best fit to the treatment responses as they could capture fluctuating growth patterns over time.

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APPENDICES

CHAPTER 7

APPENDIX I

LIST OF ABBREVIATIONS USED

IID: Independently and identically distributed

W_0X_1: Maximum temperature during pre-sowing period

W_0X_2: Minimum temperature during pre-sowing period

W_0X_3: Wind speed during pre-sowing period

W_0X_4: Relative humidity during pre-sowing period

W_0X_5: Rainfall during pre-sowing period

W_0X_6: Sunshine hours during pre-sowing period

W_0X_7: Number of rainy days during pre-sowing period

W_1X_1: Maximum temperature during sowing to transplanting phase

W_1X_2: Minimum temperature during sowing to transplanting phase

W_1X_3: Wind speed during sowing to transplanting phase

W_1X_4: Relative humidity during sowing to transplanting phase

W_1X_5: Rainfall during sowing to transplanting phase

W_1X_6: Sunshine hours during sowing to transplanting phase

W_1X_7: Number of rainy days during sowing to transplanting phase

W_2X_1: Maximum temperature during transplanting to active tillering phase

W_2X_2: Minimum temperature during transplanting to active tillering phase

W_2X_3: Wind speed during transplanting to active tillering phase

W_2X_4: Relative humidity during transplanting to active tillering phase

W_2X_5: Rainfall during transplanting to active tillering phase

W_2X_6: Sunshine hours during transplanting to active tillering phase

W_2X_7: Number of rainy days during transplanting to active tillering phase

W_3X_1: Maximum temperature during active tillering to panicle initiation phase

W_3X_2: Minimum temperature during active tillering to panicle initiation phase

W_3X_3: Wind speed during active tillering to panicle initiation phase

W_3X_4: Relative humidity during active tillering to panicle initiation phase

W_3X_5: Rainfall during active tillering to panicle initiation phase

W_3X_6: Sunshine hours during active tillering to panicle initiation phase

W_3X_7: Number of rainy days during active tillering to panicle initiation phase

W_4X_1: Maximum temperature during panicle initiation to flowering phase

W_4X_2: Minimum temperature during panicle initiation to flowering phase

W_4X_3: Wind speed during panicle initiation to flowering phase

W_4X_4: Relative humidity panicle initiation to flowering phase

W_4X_5: Rainfall during panicle initiation to flowering phase

W_4X_6: Sunshine hours during panicle initiation to flowering phase

W_4X_7: Number of rainy days during panicle initiation to flowering phase

APPENDIX II

ANOVA summary for *kharif* season

Years	Treatments											
	T$_1$	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12
1999	2216.00^{bcde}	2328.00^{bcd}	2158.00^{bcde}	2465.75^{b}	2239.75^{bcd}	2068.75^{cde}	2420.00^{bc}	2934.5^{a}	1954.25^{de}	2491.50^{b}	1842.75^{e}	1406.50^{f}
2000	2956.47^{de}	3338.55^{bcd}	3607.32^{ab}	2858.97^{e}	3335.91^{bcd}	3162.00^{cde}	2858.97^{e}	3810.21^{a}	3291.11^{bcd}	3483.47^{abc}	3198.89^{bcde}	2168.61^{f}
2001	2091.82^{ab}	2245.71^{ab}	2396.06^{ab}	2089.54^{ab}	2447.53^{ab}	2059.37^{ab}	2092.07^{ab}	2493.91^{a}	2297.67^{ab}	2402.39^{ab}	2271.32^{ab}	1319.08^{c}
2002	2140.25^{d}	3058.75^{ab}	2483.50^{cd}	2331.25^{cd}	2836.00^{abc}	2405.00^{cd}	2517.75^{bcd}	3223.00^{a}	2831.25^{abc}	3184.00^{a}	2601.00^{bcd}	1511.25^{e}
2003	2187.00^{c}	2559.25^{b}	2150.25^{c}	2118.25^{c}	2525.00^{b}	2414.75^{b}	2630.25^{b}	2948.25^{a}	2588.75^{b}	2907.00^{a}	2098.75^{c}	1704.50^{d}
2004	2187.00^{c}	2559.25^{b}	2150.25^{c}	2118.25^{c}	2525.00^{b}	2414.75^{b}	2630.25^{b}	2948.25^{a}	2588.75^{b}	2907.00^{a}	2098.75^{c}	1704.50^{d}
2005	1195.25^{de}	1383.90^{cd}	1714.75^{a}	1457.55^{bc}	1460.75^{bc}	1436.50^{bc}	1425.75^{cd}	1741.75^{a}	1427.75^{cd}	1670.50^{ab}	1577.50^{abc}	987.00^{e}
2007	2973.50^{bc}	3037.75^{bc}	2998.75^{bc}	2115.25^{f}	2831.75^{d}	2623.75^{e}	2905.00^{cd}	3231.00^{a}	2666.50^{e}	3102.00^{ab}	2022.00^{f}	1982.00^{f}
2008	2305.00^{e}	2638.00^{d}	2905.00^{b}	2801.00^{c}	2722.00^{cd}	2295.00^{e}	2120.00^{f}	3706.00^{a}	2958.00^{b}	3682.00^{a}	2897.00^{b}	1842.00^{g}
2009	2177.25^{e}	2876.25^{bc}	2656.00^{cd}	2558.25^{d}	2936.50^{b}	2279.25^{e}	1804.75^{f}	3805.75^{a}	2799.25^{bcd}	3731.00^{a}	2665.00^{cd}	1094.00^{g}
2010	2853.75^{cd}	2878.50^{cd}	2941.00^{bcd}	2841.00^{cd}	2874.25^{cd}	2549.25^{de}	2453.25^{de}	3572.25^{a}	3409.75^{ab}	3122.00^{abc}	2895.50^{cd}	2062.00^{e}
2011	2062.00^{h}	2549.00^{f}	2750.00^{de}	2784.00^{d}	2685.00^{e}	2167.00^{g}	1750.00^{i}	3333.00^{a}	2967.00^{c}	3167.00^{b}	2833.00^{d}	1661.00^{i}
2012	2444.50^{g}	3209.75^{e}	3434.00^{d}	3180.00^{e}	3186.00^{e}	2890.50^{f}	2374.25^{h}	3990.25^{a}	3501.00^{c}	3890.00^{b}	3425.50^{d}	2191.75^{i}
2013	3333.00^{a}	3167.00^{b}	2967.00^{c}	2833.00^{cd}	2784.00^{d}	2750.00^{d}	2685.00^{de}	2549.00^{e}	2167.00^{f}	2062.00^{f}	1750.00^{g}	1661.00^{g}
2014	2733.25^{e}	3080.00^{d}	3506.75^{c}	3233.25^{d}	3173.25^{d}	2830.00^{e}	1943.25^{g}	3900.00^{a}	3676.75^{bc}	3743.25^{ab}	3640.00^{bc}	2160.00^{f}
2015	4390.00^{e}	4634.00^{d}	5425.00^{a}	4687.00^{d}	4921.00^{c}	4432.00^{e}	3888.00^{f}	5467.00^{a}	4888.00^{c}	5083.00^{b}	4680.00^{d}	3645.00^{g}
2016	4451.00^{f}	4759.75^{e}	4954.75^{de}	4787.50^{e}	4784.75^{e}	4078.25^{g}	3360.75^{h}	5931.25^{a}	5054.50^{d}	5671.50^{b}	5396.00^{c}	3092.25^{i}
2017	4215.00^{e}	4528.00^{cd}	4985.00^{ab}	4489.00^{de}	4538.00^{cd}	3547.00^{f}	3248.00^{g}	5148.00^{a}	4795.00^{bc}	4989.00^{ab}	4558.00^{cd}	3278.00^{fg}

Note: Subgroups of treatments to be identified row wise, treatment means with same superscript row wise do not differ significantly at $p < 0.05$

APPENDIX III

ANOVA summary for *rabi* season

Years	Treatments											
	T_1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12
1999	2877.00^{ab}	3058.75^{ab}	2783.75^{b}	2951.00^{ab}	3022.25a^{b}	2781.50^{b}	3223.75^{ab}	3307.25^{a}	3223.50^{ab}	3098.25^{ab}	3160.00^{ab}	2223.75^{c}
2000	3017.50^{e}	3511.64^{bcd}	3693.08^{ab}	3232.34^{de}	3334.99^{cde}	3320.67^{cde}	3599.84^{abc}	3847.27^{a}	3189.37^{de}	3640.56^{abc}	3156.62^{e}	2351.44^{f}
2001	3105.25^{cde}	2927.00^{def}	2754.75^{ef}	3034.00^{def}	3453.25^{bc}	2656.25^{f}	3212.00^{bcd}	3887.00^{a}	3196.75^{bcd}	3524.50^{ab}	2906.50^{def}	1994.50^{g}
2002	3177.50^{c}	3449.50^{bc}	3368.50^{bc}	3424.25^{bc}	3596.50^{abc}	3226.75^{c}	3399.75^{bc}	3916.75^{a}	3350.00^{bc}	3794.50^{ab}	3444.00^{bc}	2389.75^{d}
2003	3244.25^{b}	3254.00^{b}	3351.50^{b}	3261.25^{b}	3031.75^{c}	3029.25^{c}	3020.00^{c}	3724.25^{a}	3354.25^{b}	3638.25^{a}	3378.00^{b}	2349.25^{d}
2004	3149.50^{bc}	3151.75^{bc}	3294.00^{b}	2593.25^{e}	3168.00^{bc}	3186.75^{bc}	2968.00^{cd}	3872.25^{a}	3234.25^{bc}	2976.75^{cd}	2803.50^{de}	2047.00^{f}
2005	2703.25^{f}	3152.50^{cd}	3442.75^{b}	2866.25^{ef}	3254.25^{bc}	2998.25^{de}	3130.50^{cd}	3952.75^{a}	3062.50^{cde}	3822.00^{a}	3089.00^{cde}	2089.75^{g}
2007	3332.50^{def}	3492.50^{bcde}	3531.00^{bc}	3349.25^{cdef}	3516.50^{bcd}	3306.25^{ef}	3196.50^{f}	3755.00^{a}	3549.75^{b}	3628.50^{ab}	3485.50^{bcde}	2456.50^{g}
2008	3264.75^{e}	3417.50^{c}	3473.50^{b}	3485.00^{b}	3482.75^{b}	3229.50^{e}	3098.25^{f}	3717.50^{a}	3346.50^{d}	3666.50^{a}	3342.00^{d}	2164.50^{g}
2009	2366.00^{f}	2795.00^{e}	3250.00^{c}	2854.00^{de}	2931.00^{d}	2420.00^{f}	2117.00^{g}	3900.00^{a}	2788.00^{e}	3525.00^{b}	2875.00^{de}	1922.00^{h}
2010	2398.00^{e}	2882.00^{cd}	3024.00^{bc}	3067.00^{bc}	3250.00^{ab}	2518.00^{e}	2328.00^{e}	3606.00^{a}	2973.00^{bc}	3016.00^{bc}	2544.00^{de}	1952.50^{f}
2011	3090.50^{e}	3289.50^{cde}	3448.50^{bc}	3287.25^{cde}	3126.00^{de}	2994.25^{e}	2470.25^{f}	3853.00^{a}	3416.00^{bcd}	3618.50^{ab}	3171.75^{cde}	2072.50^{g}
2012	2800.50^{h}	3114.25^{fg}	3226.50^{e}	3150.25^{ef}	3026.25^{g}	2700.00^{h}	1955.25^{i}	4046.50^{a}	3669.00^{c}	3817.00^{b}	3474.25^{d}	1937.25^{i}
2013	2939.25^{g}	3263.75^{e}	3430.75^{d}	3237.25^{e}	3121.00^{f}	2920.75^{g}	2714.75^{h}	3922.00^{a}	3553.75^{c}	3827.50^{b}	3440.75^{d}	2676.00^{h}
2014	2801.00^{h}	3114.00^{fg}	3227.00^{e}	3150.00^{ef}	3026.00^{g}	2700.00^{i}	1955.00^{j}	4069.00^{a}	3669.00^{c}	3817.00^{b}	3474.00^{d}	1937.00^{j}
2015	3375.00^{f}	3931.00^{d}	4587.50^{b}	3870.75^{de}	3916.75^{d}	3777.00^{e}	3025.00^{g}	4714.50^{a}	4473.00^{b}	4820.75^{a}	4245.75^{c}	2489.75^{h}
2016	3864.25^{f}	4107.50^{e}	4817.75^{a}	4418.00^{bc}	4383.75^{c}	4342.25^{cd}	3359.00^{g}	4884.25^{a}	4323.75^{cd}	4561.25^{b}	4214.50^{de}	3158.00^{h}
2017	2793.15^{abc}	3210.75^{ab}	2618.96^{bc}	2400.94^{bc}	3141.71^{ab}	2547.13^{bc}	1983.02^{cd}	3538.80^{a}	3059.27^{ab}	2948.72^{ab}	2907.309^{ab}	1538.09^{d}

Note: Subgroups of treatments to be identified row wise, treatment means with same superscript row wise do not differ significantly at $p < 0.05$

OPTIMISATION TECHNIQUES IN LONG TERM FERTILISER TRIALS: RICE-RICE SYSTEM

By

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ABSTRACT OF THE THESIS

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CHAPTER 8

ABSTRACT

The present study titled "Optimization techniques in long term fertilizer trails: rice-rice system" was carried out using the experimental data from AICRP on Long Term Fertilizer Experiments(LTFE) in rice at RARS, Pattambi for a period from 1997-2017 with the objectives to study the effect of weather factors and plant nutrients on crop production, to study the dynamics of soil characters in relation to fertilizer treatment and to suggest appropriate statistical optimization tools with respect to yield and its forecast.

A significant upward linear trend was observed in annual average yield of Aiswarya variety of rice in *kharif* season (Virippu) while in *rabi* season (Mundakan)it was not so pronounced. Highest grain yield was obtained under T_8 (100 percent NPK + FYM @ 5t/ha to the *kharif* rice) followed by T_{10}(100 percent NPK + *in situ* growing of *Sesbania aculeata,* as green manure crop for *kharif* rice only) and T_9 (50 percent NPK + FYM @ 5t/ha to the *kharif* rice only) in both the seasons. The most consistent treatment in *kharif* season was T_7 (100 per cent N) whereas in *rabi* season it was T_8. Exploratory data analysis through box plot revealed that grain yield in *rabi* season was higher and more consistent when compared to that of *kharif* season. Comparative performance of different treatments in both seasons exposed that grain yield response under T_7 was significantly different at 1 per cent level in the two seasons owing to the fact that it was the most imbalanced treatment susceptible to even minute changes of weather variables and other factors.

The *post hoc* test effected for analysis of variance performed for each of the experiments during both the seasons using DMRT revealed that superior treatment in all the experiments was T_8. Analysis of groups of experiments also showed superiority of treatment T_8 followed by T_{10} in both the seasons. The minute changes due to time variable were studied by splitting the whole period of study into three subperiods. It was found that in *kharif* season the treatments, years and their interaction effects were significant in all the three periods. During *rabi* season, the treatments and year interaction was absent for the first period. Repeated measures

ANOVA revealed that86 per cent and 59 per cent of the variability in grain yield during *kharif* and *rabi* season respectively was explained by the time variable, when all the other variables were fixed.

Correlation analysis showed that in *kharif* season, significant positive effect was there for maximum temperature in the early stages of crop growth while sunshine hours and minimum temperature in early as well as later stages had significant positive influence on crop yield. Wind velocity and rainfall in early and later stages had negative impact on treatment responses. During *rabi* season, maximum temperature in the later stages had significant positive impact on treatment responses. Minimum temperature in early stages affected the crop yield negatively. Relative humidity in early and later stages had significant negative correlation with crop yield. Wind velocity had significant positive correlation with crop yield but towards flowering stage it had negative effect. Rainfall and number of rainy days during early vegetative stage had negatively affected treatment responses.

The influence of plant nutrients *viz.,* N,P and K uptake on crop yield was quantified using a quadratic model. Studies on dynamics of soil organic carbon during *kharif* season showed a sharp decline during the initial years. Similarly, in *rabi* season there was decline but was less steep when compared to *kharif* season. The soil pH showed a decline towards the end of experimental period during *kharif* season whereas in *rabi* season it was stabilized towards the end. Time variable explained 66 per cent and 82 per cent of the variability in available P in *kharif* and *rabi* seasons respectively. In both the seasons, 94 per cent of the variability in available K in soil could be explained by the time variable.

Linear regression models using weather variables were found to give a reasonable fit for treatment responses during *kharif* season. The predictability of linear regression models could be improved using principal components as regressors in *rabi* season. Response curves were fitted using linear, quadratic and cubic models to forecast crop yield taking time as the predictor. For *kharif* season, cubic function was found to be a best fit to the treatment responses as they could capture fluctuating growth patterns over time.

Compiling the results from aforesaid analyses, the optimal fertilizer treatment for rice was T_8 (100 percent NPK + FYM @5t/ha to the *kharif* rice) followed by T_{10}(100 percent NPK + *in situ* growing of *Sesbania aculeata,* as green manure crop for *kharif* rice only). Significant treatment x year interaction could be exposed through split plot analysis and the percentage variability in crop yield over the entire period of study was better quantified using repeated measures analysis. For *kharif* season, the linear regression models taking significant weather variables at different crop growth stages and response curves using time as the predictor provided reasonable fit to the yield data. For *rabi* season, linear regression models with principal components of weather variables as regressors gave better predictability.

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