INTERACTION EFFECT UNDER AMMI MODEL

By

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THESIS

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DECLARATION

I here by declare that this thesis entitled " **Interaction effect under AMMI model"** is a bonafide record of research work done by me during the course of research and that 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.

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Certified that this thesis entitled **" Interaction effect under AMMI model"** is a record of work done independently by **Sri. Eldho Varghese** , 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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Affectionately Dedicated to My Loving Parents

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Introduction

1. INTRODUCTION

In agricultural experiments quite often the treatments are factorial combinations with the prime objective of studying interaction. The analysis of data especially from field experiments is carried out in an RCBD set up. The interaction based on the combinations of factors at various levels are studied using Critical Difference. Though this type of study resulted in valid inferences in most of the situations, a rigorous methodology was not in the offing till recently to study two factor interaction. The study of G x E interaction is also a major problem.

The division of phenotypic value into genotypic value and environmental deviation and the corresponding partition of variance into genotypic and environmental components is facilitated by two major statistical assumptions regarding the effects of genotypes and the environment. First, it has to be assumed that the effects are additive in the sense that we can associate a certain environmental deviation with a specific difference of environment without regard to the genotype. Second, it has to be assumed that the effects are statistically independent or in other words there is no correlation between genotypic value and environmental deviation which would arise if the better genotypes were deliberately provided with better environments. The correlation between genotype and environment is seldom an important complication and can be avoided by the principle of randomization in designed experiments, seeking the distribution of experimental material over a common range of environments. However, it is difficult to take the additivity of genetic and environmental effects for granted. Our experience from plant improvement research is that the relative performances of crop varieties are generally different in different environments, known as genotype-environment (GE) interaction, which cannot be explained by the additive model.

The main drawback of the variance component method is that it does not have the provision for partitioning of GE interaction into components, useful in the analysis of response pattern of genotypes under different environmental conditions. The regression models considered so far can adequately describe the behaviour of genotypes over different environments only when the genotypic response is fairly linear. This

situation can be easily identified by the overwhelming contribution of linear regression component to the total GE interaction. In the event of the remainder mean square accounting for a large part of the interaction variation, indicating the possibility of nonlinear relationship, the characterization of genotypes on the basis of linear regression coefficient might be misleading. Presence of significant nonlinear interactions can be largely attributed to the presence of yield thresholds, after attaining which some of the genotypes cease to respond to further environmental changes. A different approach, altogether, is needed to deal with such nonlinear interactions.

Nonlinear GE interaction is a complex phenomenon resulting from various genetical, physiological and such other reasons characteristic of different genotypes in relation to different environmental conditions. The exact nature and role of these causal factors can rarely be identified. Moreover they are conditional in nature. The factors operating in a particular situation may or may not be present in a different situation. The best we can do in a complex case like this is to formulate various hypotheses about nonlinearity and try to test them for their adequacy by fitting relevant statistical models. When one of these hypotheses is accepted the corresponding model itself will serve in the prediction of interaction across environments. More often these models do not help to reduce the complex interactions to a series of orderly linear responses.

As an alternative to additive ANOVA model, which identifies the interaction as a source but does not analyze it, multiplicative formulations may be chosen to quantify the variety's contribution to genotype x environment interaction, which include well known Joint Regression and at the moment the most popular Additive Main effects and Multiplicative Interaction (AMMI) model. These multiplicative formulations permit the interpretation of interaction as differential genotypic sensitivity to environmental variable(s).This AMMI model has been shown to be a useful technique to capture the non linear interactions, when joint regression technique fails to perceive important effects in studies of G x E interaction.

Under this background, the present project is under taken with the objective to study two-factor interaction as in AMMI model and to quantify interaction using biplots with first two PCA axes.

Review of Literature

2. REVIEW OF LITERATURE

Performance of a crop variety is the resultant effect of its genotype and the environment in which it grows. If the genotypic and environmental effects are independent in their action the performance of this variety relative to another variety should remain the same in all the environments. But in practice the variety may perform differently in different environments. Equivalently a specified difference in environment may produce differential effects on genotypes. The inter play of genetic and non-genetic effects causing differential relative performance of different genotypes in different environment is called Genotype X Environment (G x E) interaction. The existence of interaction between genotypes and environmental factors had been recognized long ago. Different approaches are available for the statistical analysis of G x E interaction. One of the popular method for analyzing interaction is based on AMMI model. Many works have been conducted to evaluate G x E interaction using AMMI model. Some of the major works are outlined here.

Crossa (1990a) reviewed with reference to conventional analysis of variance, joint linear regression, crossover interactions, multivariate analyses of multilocation trials, the Additive Main effect and Multiplicative Interaction (AMMI) and other methods for analysing multilocational trials.

Crossa *et al.* (1990b) used the AMMI method, with additive effects for genotypes and environments and multiplicative terms for genotype X environment interaction to analyse data from two international maize cultivar trials. Results revealed that predictive assessment selected AMMI with one principal component axis and AMMI increased the precision of yield estimates. The results also showed that AMMI provided much insight into genotype X environment interactions.

Gauch and Zobel (1990) used the Expectation-Maximization (EM) algorithm to implement AMMI model for an incomplete two way table of genotypes and environment where the observation of certain genotype in one or two environment were missing.

Crossa *et al.* (1991) investigated procedures for improving predictive success of a yield trial, grouping environments and genotypes into homogeneous subsets, and determining the yield stability of 18 CIMMYT bread wheats evaluated at 25 locations. AMMI analysis gave more precise estimates of genotypic yields within locations than means across replicates.

Gauch and Furnas (1991) demonstrated that the reduced AMMI model achieved better predictive accuracy for yield trials than did the full treatment means model. Treatment means are not accurate estimates, but the AMMI model is often more accurate than its data. AMMI selectively recovers pattern related to the treatment design in its model, while selectively relegating noise related to the experimental design in its discarded residual. For estimating the yield of a particular genotype in a particular environment, the AMMI model uses the entire yield trial, rather than only the several replications of this particular trial, as in the treatment means model. This use of more information is the source of AMMI's gain in accuracy.

Shafii *et al.* (1992) conducted a study to know the Genotype X Environment (GE) interaction patterns for seed yield and oil content using the AMMI statistical model. The results indicated a significant GxE interaction which influenced the relative ranking of genotypes (cultivars) across environments.

Nachit *et al.* (1992) compared the use of AMMI and linear regression models to analyze genotype-environment interaction in durum wheat. They revealed that AMMI model was more effective in partitioning the interaction sum of squares than the linear regression technique.

Crop yield trials provide information for agronomic recommendations and breeding selections, but their value is often limited by inaccuracy and other problems. The relatively new AMMI model has helped to obtain accurate yield estimates, reliable selections and efficient designs, and helped in the understanding or modelling of complex data sets (Gauch, 1992).

Smith (1992) used AMMI model, which incorporates both additive and multiplicative components into an integrated, powerful, least squares analysis for the analysis of *Medicago sativa* cultivar trial data originating from the National Lucerne Evaluation Program, South Africa. Expected trends in results from the yield trials were not obvious using the additive main effects model (ANOVA), while the application of the AMMI model resulted in rankings of cultivars in different environments which could readily be explained by the breeding history and dormancy of the cultivars.

Romagosa *et al.* (1993) examined Genotype X Environment interaction (GE) for grain yield with the AMMI model. The results of this statistical analysis of multilocational yield data were compared with a morpho-physiological characterization of the lines at two sites. The first two principal component axes from the AMMI analysis were strongly associated with the morpho-physiological characters. The independent but parallel discrimination among genotypes reflected genetic difference and highlighted the power of the AMMI analysis as a tool to investigate GE.

Paul *et al.* (1993) evaluated ten sugarbeet (*Beta vulgaris*) cultivars for resistance to beet necrotic yellow vein furovirus at various locations in the Netherlands in two consecutive years using ANOVA and AMMI models and AMMI model was found to be better.

Mariotti *et al.* (1994) studied the nature of G x E interactions in sugarcane hybrid progenies and data were submitted to analysis of variance, joint regression analysis and multivariate AMMI analysis. Results indicated the occurrence of qualitative type G x E interactions, which modified the merit order of genotypes and affected the efficiency of selection. PCA1 scores in AMMI analysis appeared to be strongly related to linear responses to site environments. However, PCA2 appeared to be related with differences between years within sites in traits such as sucrose percentage and stalk length. PCA2 and PCA3 detected some non-systematic interactions in several yield components.

Eeuwijk *et al.* (1995) studied linear and bilinear models for the analysis of Genotype X Environment interactions in plants which are described on a theoretical basis with respect to analysis of variance models with fixed model terms, analysis of variance models with fixed and random terms, AMMI models, factorial regression, reduced rank factorial regression, and biplot representations. They reported that the structural differences between the models stem from the inclusion of random model terms in addition to fixed model terms and the representation of the interaction by additive or multiplicative parameters and also the incorporation of concomitant variables on the levels of the environmental factor.

Yau (1995) compared joint regression analysis (JRA) and AMMI analysis for analysing Genotype X Environment (G x E) interactions. Grain yield data from three seasons of a regional bread wheat (*Triticum aestivum*) yield trial, grown at 30-40 sites in West Asia, North Africa and Mediterranean Europe, were analysed. Percentages of interaction sum of squares (SS) accounted for by heterogeneity of regression in JRA were generally low (mean 11%) and unaffected by diversity of the samples, but inversely related to number of sites in the similar-diversity samples. In contrast, percentages of interaction SS accounted for by first principal components in AMMI analyses were generally high (mean 37%) and unaffected by diversity or number of sites in the samples. These percentages were always higher for AMMI than for JRA. Hence they recommended AMMI model for detailed studies of G x E effects, especially for large regional or international trials.

Falkenhagen (1996) used three methods (ANOVA, linear regression and graphical representation) for studying genotype by site interactions and that were compared with (AMMI) model. It was observed that the AMMI model did not bring new insight over those offered by the other three methods used and did not replace these methods but complements them. They reported that the main use of the AMMI approach seemed to lie in determining the model and the estimator with the best predictive accuracy, thus ensuring greater genetic gain if that estimation was used for selecting the best provenances.

Annicchiarico *et al.* (1997) compared the ability of joint regression and (AMMI) analysis to describe treatment-location interaction in eight sets of crop (lucerne, durum wheat, bread wheat, maize and oats) trials performed in Italy. AMMI analysis proved superior in five data sets while the two methods did not markedly differ in the remaining sets.

Wang *et al.* (1997) used additive main effects and multiplicative interaction model to analyse international hybrid rice nursery data.

An experiment was conducted in oat to evaluate Genotype environment interaction in oat for biomass forage yield using joint linear regression analysis (JRA), AMMI analysis and Kang's non-parametric method. Heterogeneity of regression (HR) in JRA was non-significant and interaction sum of squares (G x E SS) accounted for 12.50% (three-year mean). In contrast, the first principal component analysis axis in AMMI was highly significant. It explained 76.76% of G x E SS (three year mean). The second axis accounted for another 17.33% G x E SS. Kang's non-parametric method gave similar results to AMMI. It acted as a complementary methodology to biplot graphics, selecting cultivars with dry matter yield above average, and positive or intermediate principal component axis score. The AMMI model was more effective than JRA analysis in accounting for G x E interaction under low environmental diversity (Acciaresi *et al.*, 1997).

Genotype X location (GL) interaction effects are of special interest for breeding programmes to identify adaptation targets, adaptive traits and test sites. These effects, generally having relatively low repeatability between years, should be studied on a multi-year basis in annual crops. Their assessment by AMMI analysis is currently defined for this situation (Annicchiarico and Gollob, 1997).

It is frequently necessary to subdivide a growing region into several relatively homogeneous mega-environments and to breed and target adapted genotypes for each mega-environment for maximizing yield through out a crop's heterogeneous growing region. Gauch and Zobel (1997) applied AMMI model to identify relevant criteria for the evaluation of mega-environment analyses.

Brancourt *et al.* (1997) compared AMMI model, factorial regression and joint regression and reported that the AMMI model and factorial regression are equally efficient and superior to joint regression.

Chatwachirawong and Srinives (1997) used AMMI model for multi-environmental yield trials. They applied it for model diagnosis in which the initial model is a part of AMMI to clarify complicated genotype X environment interactions and to improve the accuracy of yield estimates.

An experiment was conducted in *Solanum tuberosum* to compare estimates of genotype-environment (GE) interaction produced using the AMMI model and the analysis of linear regression (LR), and to compare the yield stability of potato genotypes. The sum of squares (SS) for the regressions accounted for only 19.5% of the interaction SS, whereas the first principal component (PC1) of the analysis of the principal components accounted for 44.6% of the interaction SS. The SS of PC1 was more than twice the combined SS of all the three regressions (jointed, genotypic and environmental). The AMMI analysis was found to be more efficient in describing GE interactions than the LR (Silva-Pereira and Costa, 1998).

Bajpai (1998) modified the EM – AMMI model and made some contribution to improved estimation of genotype – environment interaction and analysis of genotypic stability with reference to sugar cane crop.

Shaarawy and Dugger (2000) suggested some modifications to AMMI method to increase its accuracy for measuring stability of genotypes. Using the suggested modifications, four stability levels could be defined: high, above average, average and below average. The genotype with a high level of stability should have both the first interaction principal component axis (IPCA 1) and the second interaction principal component axis (IPCA 2) equal to zero. The level of stability for a genotype with IPCA 1 equal to zero is considered to be above average. A genotype is considered as having an average level of stability if its IPCA 2 is equal to zero. Any genotype with IPCA 1 and IPCA 2 not equal to zero is considered as having below average stability.

An experiment in maize hybrids conducted in four different Mexican environments was subjected to AMMI analysis and cluster analysis to determine if the two methods can be used to classify hybrids for stability of grain yield. The results revealed that Cluster analysis did not show a clear tendency to group the evaluated hybrids. AMMI was effective to determine the stability of experimental hybrids (CastAnon *et al.*, 2000).

Vijayakumar *et al.* (2001) conducted an experiment to analyse the pattern of genotype x interaction for grain yield by AMMI model using the data generated from a National Hybrid Rice Trial (NHRT) conducted over eleven locations in India involving 16 hybrids and two inbred check varieties. The results indicated a significant genotype x environment interaction that influenced the relative ranking of the hybrids across the locations. It was evident from AMMI analysis that genotype, environment and the first principal component of interaction effect accounted for 86.96% of treatment sum of squares and that the first five principal components of the interaction effect were found to be significant.

Baiyeri and Nwokocha (2001) evaluated the sweet potato genotypes for yield stability in Southeastern Nigeria using AMMI model. Genetic variation accounted for about 65% of the total variation captured in the model, while genotype x year interaction accounted for about 7%. Low variance due to genotype x year interaction suggested similarity in the resource availability to the crops during the years of evaluation. Ranking of genotype revealed that older selections had lower crop yield and were unstable, suggesting that sweet potato genotypes probably degenerate with time and that old selections were not be suitable for recommendation.

Egesi and Asiedu (2002) reported that the AMMI model combines regular analysis of variance for additive main effects with principal component analysis for multiplicative structure within the interaction. It improved the accuracy of crop yield estimates and selected genotypes with highest yields. They used AMMI model to assess yam (*Dioscorea alata*) genotype yield, selecting stable genotypes and investigating Genotype x Environment effects from trials conducted for two years (1998 and 1999) at five locations in Nigeria. The effects of environments, genotypes,

and Genotype x Environment interaction (G x E) were highly significant ($P < 0.001$). Within environments, AMMI1 estimates ranked genotypes differently from the unadjusted means, and in six out of nine cases AMMI1 estimates changed the top yielding entry.

Raju (2002) made drastic improvement of the existing AMMI model in the study of G x E interaction. He observed that AMMI model was a useful technique to capture non linear interaction when joint regression technique fails to perceive important effects in the study of G x E interaction. He proposed the stability measure $W_{i\,(AMMI)}$ which accommodate all PCA axes and was shown equivalent to Wricks (1965) ecovalence. He interpreted G x E interaction using AMMI model as the differential genotypic stability to environmental variables and biplots formulation of interaction enabled in deriving a more comprehensive stability measure from AMMI model.

Rajbir *et al.* (2002) studied seven barley genotypes using AMMI method to test its suitability and reliability for the precise prediction of the yield. According to AMMI analysis, the first and second PCA axes accounts for 45 and 34% interaction, leaving only 20% of interaction to the residual with approximately 50% degree of freedom.

A study carried out to determine the yield performance of 20 bread wheat genotypes across six environments in Central Anatolia, Turkey using AMMI analysis indicated that the yield performance of genotypes were under the major environmental effects of Genotype X Environment interactions. The first two principal component axes (PCA 1 and 2) were significant ($p < 0.01$), which cumulatively contributed to 78.64% of the total genotype-environment interaction. They generated a biplot using genotypic and environmental scores of the first two AMMI components and reported that genotypes with larger PCA 1 and lower PCA 2 scores gave high yields (stable genotypes) while genotypes with lower PCA 1 and larger PCA 2 scores had low yields (unstable genotypes) (Kaya *et al.*, 2002).

Redshaw and Govender (2002) conducted an experiment to compare relative yields amongst sugarcane varieties for making variety recommendations for different agroclimatic zones. He used the residual maximum likelihood and the AMMI methods to analyse data with G x E interaction. He reported that the two methods provided useful and thought-provoking information that warrant their future use as statistical tools for the analysis of data from sugarcane variety trials across a range of environments.

Lavoranti *et al.* (2002) evaluated the adaptability and phenotypic stability of 200 progenies of *Eucalyptus grandis* originated from 100 Australian locations using AMMI methodology.

An experiment was conducted on eight improved cassava (*Manihot esculenta*) genotypes and one local cultivar in three agro-ecological zones of Nigeria to study their response to natural infestations of African cassava mosaic disease (ACMD; *African cassava mosaic virus*), cassava bacterial blight (CBB; *Xanthomomas axonopodis pv. manihotis*), cassava anthracnose disease (CAD; *Glomerella cingulata*) and cassava green mite (CGM; *Mononychellus tanajoa*). They identified genotypes with stable resistance using the AMMI statistical model (Dixon *et al.*, 2002).

Duarte and Pinto (2002) studied the foundations of biplot graphic display associated with AMMI and their application to genetic studies.

Oliveira *et al.* (2003) conducted a study to assess the grain yield stability in 36 maize genotypes in ten environments located in central Brazil using AMMI model.

Moreno-Gonzalez *et al.* (2003) developed shrinkage factors for AMMI multiplicative terms based on the eigenvalue partition (EVP) method and compared AMMI fitted by EVP and other shrinkage methods.

Morais *et al.* (2003) reported the stability and adaptability of soybean cultivar across different sowing periods using AMMI methodology. Based on the analysis of variance, significant interaction was observed among sowing periods and cultivars. The estimates of stability and adaptability were obtained using the AMMI method.

The results also showed the possibility of grouping genotypes and sowing periods to obtain high grain yield.

The genotype x environment interaction analysis was done using AMMI in selected potato genotypes and the stable genotypes were identified using biplots by (Abalo *et al.*, 2003)

Wang *et al.* (2003) used the AMMI model and its biplots to analyse the data of eight elite rapeseed (*Brassica napus*) varieties in the regional trials at nine sites carried out in Sichuan province of China. They reported that AMMI model was superior to the conventionally adopted linear regression analysis in interpreting G x E interaction. Variation of yield of different varieties and at different sites could be clearly shown on the biplots of AMMI and varieties with good adaptability could be identified. In addition, the varieties which showed greatest interaction with a given site could be found by the biplots of the AMMI model.

Love *et al.* (2004) diagnosed the interaction pattern and measured clone stability using AMMI model in Potatoes.

Materials and Methods

3. MATERIALS AND METHODS

A brief account of the materials and methods used in the present study is given below

Methodology

The genesis of the methodology is based on the Additive Main effects and Multiplicative Interaction (AMMI) model.

AMMI model to study two factor interaction is given by

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_{m=1}^{m'} \lambda_m \gamma_{mi} \delta_{mj} + \theta_{ij} \quad \text{---------- (1)}$$

$i = 1,2, \ldots\ldots\ldots\ldots K$

$j = 1,2, \ldots\ldots\ldots\ldots N$

where

Y_{ij} is the observation of the i^{th} level of first factor and j^{th} level of second factor

μ is the grand mean

α_i is the effect of the i^{th} level of the first factor

β_j is the effect of the j^{th} level of the second factor

m' is the number of PCA axes retained in the model

λ_m is the singular value for the PCA axis m

γ_{mi} is the PCA vector score for axis m of the i^{th} level of the first factor

δ_{mj} is the PCA vector score for axis m of the j^{th} level of the second factor

θ_{ij} is the residual

The identification constraints for the model (1) are as under

$$\theta_{ij} \sim N(0, \sigma^2)$$

$$\sum_i \gamma^2_{mi} = 1 = \sum_j \delta^2_{mj}, \forall m \quad \text{---------- (2)}$$

$$\sum_i \gamma_{mi}\gamma_{m^*i} = 0 \quad \text{and} \quad \sum_j \delta_{mj}\delta_{m^*j} = 0 \text{ where } m \neq m^* \text{ -------(3)}$$

Ordinarily the number m' of interaction principal component axes retained in the model is chosen with empirical considerations of F test of significance, predictive accuracy, agricultural interpretability of the associated interaction PCA vector scores, and so on. The residual combines the M-m' discarded axes, where M = min [(K-1), (N-1)]. Equation (2) states that the vectors γ_{mi} and δ_{mj} are normalized: According to equation (3), the vectors γ_{mi} and γ_{m^*i} are orthogonal with a similar statement for δ_{mj} and δ_{m^*j}.

The basic model is essentially a two way ANOVA model, which requires that the matrix of interaction parameters be decomposed by using factor analytic techniques.

The equation (1) is reparameterised so as to obtain the matrix of interaction parameters as

$$Y_{ij} = \mu + \alpha_i + \beta_j + V_{ij} \text{ ---------- (4)}$$

$$\text{where} \quad V_{ij} = \sum_{m=1}^{m'} \lambda_m \gamma_{mi} \delta_{mj} + \theta_{ij}$$

Now the estimates of V_{ij} may be obtained as

$$\hat{V}_{ij} = Y_{ij} - \hat{\mu} - \hat{\alpha}_i - \hat{\beta}_j$$

Form the matrix X of interaction estimates from V_{ij}'s such that each row of X denotes the interactions of a particular level of first factor over N levels of the second factor. Using factor analytic decomposition, the matrix X may be written as

$$X = ADB' \text{ ---------- (5)}$$

Where

X is K x N matrix with V_{ij}'s as elements

A is K x M orthonormal matrix

D is M x M diagonal matrix with elements $d_1 \geq d_2 \geq ...\geq d_m \geq ...d_M$

B is N x M orthonormal matrix

M is the rank of X

The matrices A, D and B of equation (5) are obtained from the characteristic vectors and characteristic roots of the K x K matrix XX'. The K x M matrix A then consists of the characteristic vectors and the M x M diagonal matrix D consists of the square roots of the characteristic roots of XX'. The N x M matrix B can then be obtained by solving

$$B = X'AD^{-1} \text{ ---------- (6)}$$

The above solution specifies that the matrices D and A be found by solving the eigen values and eigen vectors of the matrix XX' and then the matrix B be obtained from (6). It is also possible to solve for the matrices D and B by finding the eigen values and eigen vectors of the matrix X'X and then obtaining A from $A = X BD^{-1}$. For ease of calculation it is convenient to solve for the eigen values and eigen vectors of either of X'X or XX' which ever has the smaller dimension.

The second factor eigen vector corresponding to λ_1 (first column of B) represents the hypothetical second factor variable that describes the largest amount of interaction and thus best discriminates between different levels of first factor, the second axis the second largest amount, and so on. If all the M possible axes are retained in the model, it completely factors out the interaction without leaving any residual. Multiplicative modelling of interaction is successful when the additive ANOVA interaction with (K - 1) (N - 1) independent parameters can be replaced by only a few multiplicative terms ($m' << M$), thus adequately describing the interactions with considerably fewer parameters.

Graphical display of interaction with AMMI interaction parameters is known as Biplot.

Biplot with First PCA Axis

First PCA vector scores of different levels of the first factor and second factor are plotted against their respective means. This biplot formulates the interactions as $E(X_{ij}) = \lambda_1 \gamma_{1i} \delta_{1j} = \gamma^*_{1i} \delta^*_{1j}$, where X_{ij} is the interaction of i^{th} level of the first factor and the j^{th} level of second factor. Now the pattern of interaction may be visualized from this plot. If any level of the first and second factor has a PCA vector score of nearly zero, it will have smaller interaction effects. If any level of the first and second factor are having the same sign on the PCA axis, their interaction is positive, if different, their interaction is negative.

Biplot with First Two PCA Axes

For a better description of the interaction, both first and second PCA vector scores of different levels of first factor and second factor may be considered for plotting. Here second PCA vector scores of the different levels of first factor and second factor are plotted against their respective first PCA vector scores. The interaction from this biplot may formulated as $E(X_{ij}) = \gamma^*_{1i} \delta^*_{1j} + \gamma^*_{2i} \delta^*_{2j}$. Simple geometry reveals that the interaction between the i^{th} level of the first factor and the j^{th} level of the second factor can be obtained from a projection of either vector on to the other. In any quadrant the interaction between a level of first factor and a level of second factor will be positive.

However the scope of biplots is very much limited. Biplot formulation of interaction will be successful only when significant proportion of interaction is concentrated in the first or first two PCA axes

Keeping in mind, the limitations of biplots concerning interaction conclusions, Raju (2002) derived a more comprehensive measure of interaction, retaining all possible 'M' PCA axes, which is equivalent to Wricke's ecovalence (W_i).

The proposed measure of interaction may be viewed in terms of AMMI parameters and denoted as $W_{i(AMMI)}$

ie., $$\sum_{j=1}^{N} V^2_{ij} = W_{i(AMMI)} = \sum_{m=1}^{M} \lambda^2_m \gamma^2_{mi} \quad \text{---------- (7)}$$

Therefore it may be concluded that the stability rank order obtained from the proposed measure($W_{i(AMMI)}$) will be equivalent to that of Wricke's ecovalence.

When the first PCA axis only is retained in the AMMI model, then, we may measure the interaction from FP_i as

$$FP_i = \lambda^2_1 \gamma^2_{1i} \quad \text{---------- (8)}$$

More the absolute value of γ_{mi}, more will be the interaction. The comparison of genotypes for stability based on this measure will be equivalent to the comparison based on Biplot with first PCA axis.

If the first two PCA axes are retained in the model, we may use the measure of interaction B_i as

$$B_i = \sum_{m=1}^{2} \lambda^2_m \gamma^2_{mi} \quad \text{---------- (9)}$$

We may also consider the measure based on fitted AMMI model by retaining m' axes, where m' is determined by the postdiction (F tests).

$$FA_i = \sum_{m=1}^{m'} \lambda^2_m \gamma^2_{mi} \quad \text{---------- (10)}$$

In comparison to $W_{i(AMMI)}$, the above three measures will be less precise, as is evident from the fact that, they could not exploit the complete information. The reliability of a measure improves with the increase in the number of axes retained.

The above formulation of studying interaction using AMMI model can very well be extended. The spectral decomposition of the appropriate interaction matrix will enable one to study interaction with the same precision as that of studying the main effects. To put in other words we can order the interaction effects, according to their relative importance.

The usual ANOVA for any character is first worked out and the significance of the two factor interaction is assessed. The estimate of interaction effects is obtained as

$$V_{ij} = Y_{ij} - \bar{Y}_{i.} - \bar{Y}_{.j} + \bar{Y}_{..} \quad \text{---------- (11)}$$

$i = 1,2, \ldots\ldots\ldots\ldots K$

$j = 1,2, \ldots\ldots\ldots\ldots N$

where

Y_{ij} is the observation corresponding to the i^{th} level of first factor and j^{th} level of second factor

$\bar{Y}_{..}$ is the grand mean

$\bar{Y}_{i.}$ is the mean of the i^{th} level of the first factor over the levels of the second factor

$\bar{Y}_{.j}$ is the mean of the j^{th} level of second factor over the levels of the first factor

Form the matrix X of interaction effects as $X = \left[V_{ij} \right]_{K \times N}$

The K eigen values and eigen vectors of the matrix XX' and N eigen values and eigen vectors of X'X are to be obtained. This is equivalent to finding the principle components of XX' and X'X. The biplots of the mean of a factor versus its PCA1 vector score as also PCA1 vector score versus PCA2 vector score may be plotted accordingly taking into consideration the variance explained by the PCA's for both the factors. From the biplots the relative importance of the different levels of the factor under consideration can be more explicitly visualized.

The above methodology has been illustrated using the data detailed below

Source of data

Secondary data from the projects viz., "Development of a bimodal phasic management system to improve both quantity and quality in Kacholam (*Kaempferia galanga*)" and "Development of a bimodal phasic management system to improve both quantity and quality in Njavara (*Oriza Sativa*)" were used for the study. Data from the first and second projects consisted of observations on biometric, chemical and qualitative characters listed as under.

First Project

Biometric Characters : Spread of plant, number of leaves and shoots at monthly intervals, final tuber yield

Chemical Characters : Contents of macro and micronutrients in harvested tubers

Qualitative Characters : Total essential oil content in harvested produce.

Experimental details

Design : RCBD

No. of Replications : 4

Treatments

Ca at three levels, i.e., Ca_0 = 0 Kg / ha

Ca_1 = 200 Kg / ha

Ca_2 = 400 Kg / ha

Three sources S_1 = 1-% $FeSO_4$

S_2 = 1 % $MnSO_4$

S_3 = 1 % Ammonium Sulphate

Second Project

Biometric characters : Height of the plant, number of tillers per hill at major growth stages, panicle characters and yield of grain and straw

Chemical characters : Contents of macro and micro nutrients at maximum tillering and harvest

Qualitative characters : Total free amino acid content in grain

Experimental details

Design : RCBD

No. of Replications : 2

Treatments

a) Two types of Njavara ; One black glumed (Badagara) and other golden glumed (Payyannur)

b) T_1 : 5 tones FYM / ha

T_2 : 5 tones FYM / ha + $MnSO_4$ @ 5 kg / ha

T_3 : 5 tones FYM / ha + $MnSO_4$ @ 10 kg / ha

T_4 : 5 tones FYM / ha + $MnSO_4$ @ 15 kg / ha

T_5 : 10 kg N / ha + $MnSO_4$ @ 5 kg / ha

T_6 : 10 kg N / ha + $MnSO_4$ @ 10 kg / ha

T_7 : 10 kg N / ha + $MnSO_4$ @ 15 kg / ha

T_8 : 20 kg N / ha + $MnSO_4$ @ 5 kg / ha

T_9 : 20 kg N / ha + $MnSO_4$ @ 10 kg / ha

T_{10}: 20 kg N / ha + $MnSO_4$ @ 15 kg / ha

T_{11}: 10 kg P / ha + $MnSO_4$ @ 5 kg / ha

T_{12}: 10 kg P / ha + $MnSO_4$ @ 10 kg / ha

T_{13}: 10 kg P / ha + $MnSO_4$ @ 15 kg / ha

T_{14}: 20 kg P / ha + $MnSO_4$ @ 5 kg / ha

T_{15}: 20 kg P / ha + $MnSO_4$ @ 10 kg / ha

T_{16}: 20 kg P / ha + $MnSO_4$ @ 15 kg / ha

Results and Discussion

4. RESULTS AND DISCUSSION

The data on various parameters of both of the experiments were subjected to the usual analysis of variance and the multiple range test carried out wherever the significant interaction was noticed. All the significant interactions were analysed based on the factor analytical procedure explained in the previous chapter. In most of the cases first PCA explained more than 90 per cent variation. The PCA 1 vector scores were plotted against the respective means for each character and the results are presented experiment wise and character wise.

Experiment I

4.1.1 Percentage Content of Phosphorus in Rhizome

The multiple range test was carried out separately for each levels of the factors viz. calcium and sources. Under source I no significant difference could be noticed in the phosphorus content over the three levels of calcium applied where as under source II phosphorus content was more at the first and third levels of calcium and were found to be on par. Under source III phosphorus content was more at the first two levels and were found to be on par (Table 4.1.1a).

The percentage content of phosphorus was also ranked for the various sources under the different levels of calcium. At the first level of calcium all the sources contributed the same quantum of phosphorus. When the level of calcium was increased to the second level source I and source III contributed more to phosphorus content and were on par where as at the still higher level of calcium, source I and source II contributed more to phosphorus content and were statistically on par (Table 4.1.1c). This method of multiple range comparison leads to conflict of inference and a summary conclusion cannot be drawn.

The very same interaction when viewed based on the factor analytical procedure orders the interaction effect. From (Table 4.1.1b) as also from (Fig. 4.1a), it can be inferred that the source II and second level of calcium had the highest positive

Table 4.1.1a : Multiple range comparison of the percentage content of phosphorus in rhizome for the different levels of calcium in each source

Means	Source 1	Source 2	Source 3
Ca0	0.400 [a]	0.435 [ab]	0.413 [ab]
Ca1	0.445 [a]	0.392 [b]	0.445 [a]
Ca2	0.407 [a]	0.450 [a]	0.370 [b]

Table 4.1.1c : Multiple range comparison of the percentage content of phosphorus in rhizome for the different sources under each calcium level

Means	Ca0	Ca1	Ca2
Source 1	0.400 [a]	0.445 [a]	0.407 [ab]
Source 2	0.435 [a]	0.392 [b]	0.450 [a]
Source 3	0.413 [a]	0.445 [a]	0.370 [b]

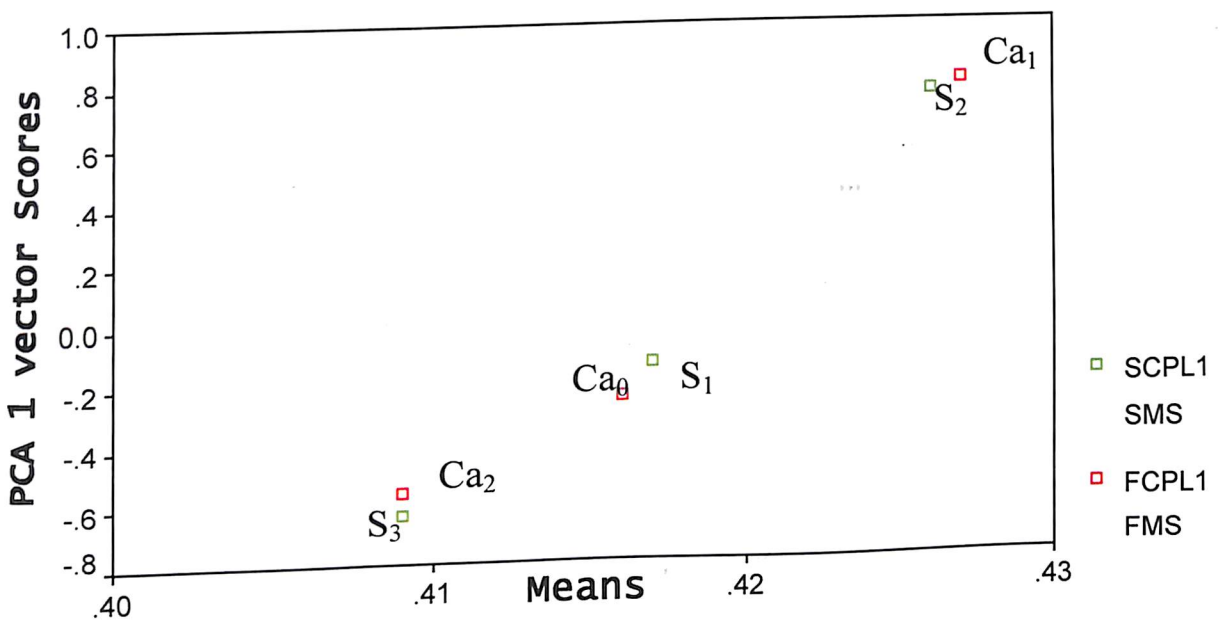
Table 4.1.1b : Overall mean for different levels of calcium with PCA 1 vector scores for the percentage content of phosphorus in rhizome

	Overall Means for different levels of Ca	PCA 1 Vector Scores
Ca0	0.416	-0.24455
Ca1	0.427	0.79692
Ca2	0.409	-0.55237

Table 4.1.1d : Overall mean for different sources with PCA 1 vector scores for the percentage content of phosphorus in rhizome

	Overall Means for different Sources	PCA 1 Vector Scores
Source 1	0.417	-0.13875
Source 2	0.426	0.76620
Source 3	0.409	-0.62745

Fig. 4. 1a Biplot for the percentage content of phosphorus in rhizome



"FCPL 1","SCPL1" = First component loadings for the levels of first and second factor; "FMS", "SMS" = First and Second Factor Means

interaction. The interaction of the other levels of calcium with source II was negative. source I and first level of calcium were least interacting. source III had positive interaction with third level of calcium.

4.1.2 Percentage Content of Potassium in Rhizome

In the case of potassium content the multiple range tests were carried out for each levels of the factors. Under source I potassium content was more at the first and second levels of calcium and no significant difference could be noticed in the potassium content over the three levels of calcium under source II. Under source III potassium content was more at third level of calcium and found to be on par with first level of calcium (Table 4.1.2a).

The percentage content of potassium was also ranked for the various sources under the same level of calcium. At the first level of calcium, all the sources contributed same quantum of potassium. But when the level of calcium was increased to the second level source I and source II were contributing more to potassium content and were found to be on par whereas at the still higher level of calcium source III contributed more to potassium content and was statistically significant from others (Table 4.1.2c).

To find out which source contributed more to percentage content of potassium in association with calcium, the interaction was subjected to factor analytical procedure. From (Fig. 4.1b) and (Table 4.1.2d), it is evident that the source III and third level of calcium had the highest positive interaction. The interaction of other two levels of calcium with source III was negative. source II and first level of calcium were least interacting. source I had positive interaction with second level of calcium.

4.1.3 North /South Foliage Spread

The DMRT was carried out separately for each levels of the factors. Under source I no significant difference could be noticed in the area of foliage spread over the three levels of Ca applied where as under source II area of foliage spread was

Table 4.1.2a : Multiple range comparison of the percentage content of potassium in rhizome for the different levels of calcium in each source

Means	Source 1	Source 2	Source 3
Ca0	1.540 [a]	1.658 [a]	1.638 [a]
Ca1	1.513 [a]	1.487 [a]	1.285 [b]
Ca2	1.255 [b]	1.462 [a]	1.820 [a]

Table 4.1.2c : Multiple range comparison of the percentage content of potassium in rhizome for the different sources under each calcium level

Means	Ca0	Ca1	Ca2
Source 1	1.54 [a]	1.513 [a]	1.255 [b]
Source 2	1.658 [a]	1.487 [ab]	1.462 [b]
Source 3	1.638 [a]	1.285 [b]	1.820 [a]

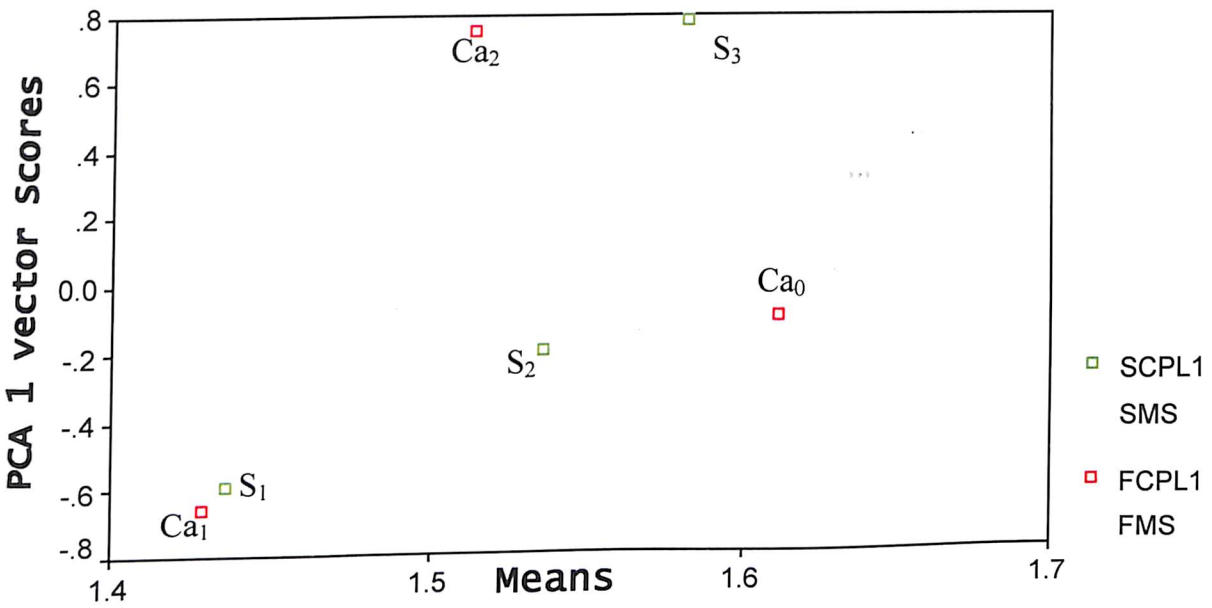
Table 4.1.2b : Overall mean for different levels of calcium with PCA 1 vector scores for the percentage content of potassium in rhizome

	Overall Means for different levels of Ca	PCA 1 Vector Scores
Ca0	1.612	-0.09792
Ca1	1.429	-0.65304
Ca2	1.513	0.75097

Table 4.1.2d : Overall mean for different sources with PCA 1 vector scores for the percentage content of Potassium in rhizome

	Overall Means for different Sources	PCA 1 Vector Scores
Source 1	1.436	-0.58840
Source 2	1.536	-0.19605
Source 3	1.581	0.78445

Fig. 4. 1b Biplot for the percentage content of potassium in rhizome



"FCPL 1","SCPL1" = First component loadings for the levels of first and second factor; "FMS", "SMS" = First and Second Factor Means

Table 4.1.3a : Multiple range comparison of the area of North-South foliage spread in rhizome for the different levels of calcium in each source

Means	Source 1	Source 2	Source 3
Ca0	21.150 [a]	22.350 [ab]	17.450 [a]
Ca1	20.850 [a]	25.000 [a]	21.500 [a]
Ca2	23.100 [a]	17.550 [b]	20.450 [a]

Table 4.1.3c : Multiple range comparison of the area of North-South foliage spread in rhizome for the different sources under each calcium level

Means	Ca0	Ca1	Ca2
Source 1	21.150 [a]	20.850 [a]	23.100 [a]
Source 2	22.350 [a]	25.000 [a]	17.550 [b]
Source 3	17.450 [a]	21.500 [a]	20.450 [ab]

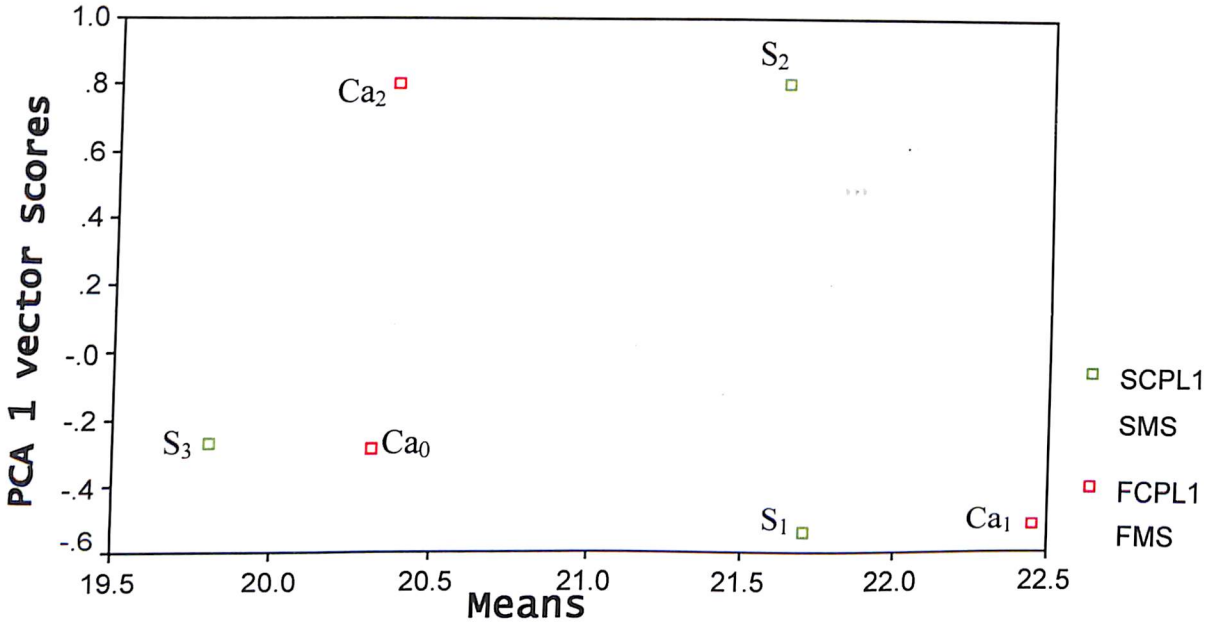
Table 4.1.3b : Overall mean for different levels of calcium with PCA 1 vector scores for the area of North-South foliage spread

	Overall Means for different levels of Ca	PCA 1 Vector Scores
Ca0	20.316	-0.28651
Ca1	22.450	-0.51889
Ca2	20.367	0.80540

Table 4.1.3d : Overall mean for different sources with PCA 1 vector scores for the area of North-South foliage spread

	Overall Means for different Sources	PCA 1 Vector Scores
Source 1	21.700	-0.53617
Source 2	21.633	0.80137
Source 3	19.800	-0.26520

Fig. 4. 1c Biplot for the area of North-South foliage spread



"FCPL 1","SCPL1" = First component loadings for the levels of first and second factor; "FMS", "SMS" = First and Second Factor Means

more at first and second levels of Ca and were found to be on par and under source III area of foliage spread was more or less same at all the levels of Ca and no significant difference was observed. (Table 4.1.3a).

The area of foliage spread was also ranked for the various sources under the different levels of Ca. At the first level of Ca there was no significant difference observed among the different sources. When the level of Ca was increased to the second level, no significant difference could be observed among the different sources. At the higher level of Ca , source I and III contributed more to the area of foliage spread and were statistically on par (Table 4.1.3c).

When the interaction was subjected to factor analytical procedure, it became evident that the source II and third level of calcium had the highest positive interaction. The interaction of other two levels of calcium with source II was negative. source I had positive interaction with first and second levels of calcium. Similarly source III had positive interaction with first and second levels of calcium (Fig. 4.1c) and (Table 4.1.3d).

Experiment II

4.2.1 Grain Yield

The grain yield data ensuing from the experiment laid out with two biotypes viz. Payyanur and Badagara and sixteen treatments as an RCBD was analysed and DMRT was performed separately for the biotypes. For biotype I (Payyanur) T_{15} recorded the highest yield and was found to be significantly different from the rest. T_2 recorded the second highest yield and was found to be on par with T_1, T_8, T_{13}. The lowest yield was observed with T_{10} (Table 4.2.1a) .

For biotype II (Badagara) highest yield was recorded under T_1 and was found to be on par with T_7 . The lowest yield was recorded with T_{10} . When the differential response of the biotypes to the treatments were considered, significant difference was noticed for treatments T_1, T_2, T_4, T_5, T_8, T_{11}, T_{12}, T_{13}, T_{14}, and T_{15} (Table 4.2.1a).

Table 4.2.1a : Multiple range comparison of grain yield for different treatments in two biotypes

Means	Payyanur	Badagara
T_1	534.38 ^{bc}	401.55 ^{a}
T_2	571.00 ^{b}	168.15 ^{efgh}
T_3	185.10 ^{h}	226.28 ^{cdef}
T_4	376.25 ^{ef}	217.10 ^{cdef}
T_5	391.68 ^{ef}	273.48 ^{bcd}
T_6	312.00 ^{fg}	295.55 ^{bc}
T_7	401.50 ^{de}	326.25 ^{ab}
T_8	561.40 ^{bc}	186.10 ^{defg}
T_9	255.25 ^{gh}	241.80 ^{bcde}
T_{10}	62.65 ^{I}	99.90 ^{h}
T_{11}	389.65 ^{ef}	225.13 ^{cdef}
T_{12}	439.80 ^{de}	147.13 ^{fgh}
T_{13}	565.55 ^{bc}	337.23 ^{defg}
T_{14}	484.83 ^{cd}	102.95 ^{gh}
T_{15}	704.98 ^{a}	278.90 ^{bc}
T_{16}	416.75 ^{de}	229.78 ^{cdef}
***C.D. value** = 76.92		

* Indicates the Critical Difference for comparing each treatment in two biotypes

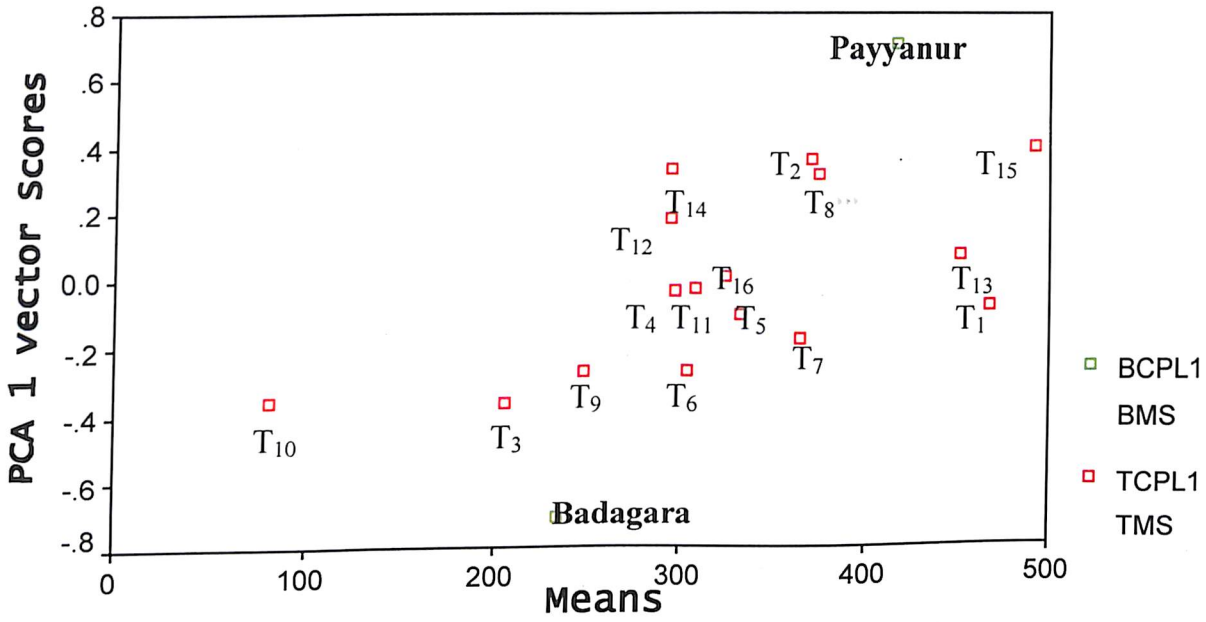
Table 4.2.1b : Overall mean for treatments with PCA 1 vector scores for grain yield

	Overall Treatment Means	PCA 1 Vector Scores
T_1	467.965	-0.07887524
T_2	369.575	0.36355769
T_3	205.690	-0.36399395
T_4	296.675	-0.03574941
T_5	332.580	-0.10284677
T_6	303.775	-0.26956609
T_7	363.875	-0.17322117
T_8	373.750	0.31841649
T_9	248.525	-0.27448165
T_{10}	81.275	-0.35755457
T_{11}	307.390	-0.02695057
T_{12}	293.465	0.18302566
T_{13}	451.390	0.07758695
T_{14}	293.890	0.32919795
T_{15}	491.940	0.40162049
T_{16}	323.265	0.00983419

Table 4.2.1c : Overall mean for biotypes with PCA 1 vector scores for grain yield

	Overall Biotype Means	PCA 1 Vector Scores
Payyanur	415.80	0.707106781
Badagara	234.83	-0.707106781

Fig. 4. 2a Biplot for grain yield



"TPCL 1", "BPCL 1" = First component loadings for treatments and biotypes; "TMS", "BMS" = treatment and biotype means

To arrive at a conclusion based on the above mode of discussion is very difficult. So the interaction was recast using factor analytical technique. From (Fig. 4.2a), (Table 4.2.1b) and (Table 4.2.1c) , it can be inferred that Payyanur and Badagara were equally interacting. When the effect of the fertilizers alone were considered T_2, T_3, T_8, T_{10}, and T_{15} recorded the maximum interactive response. In addition, the treatments T_2, T_8, T_{12}, T_{13}, T_{14}, and T_{15} had positive response with Payyanur where as the treatments T_1, T_3, T_6, T_7, T_9, and T_{10} had positive response with Badagara.

4.2.2 Percentage Content of Nitrogen in Grain

As in the case of the previous character, analysis of variance was performed and thereafter multiple range test carried out. From the DMRT result it can be seen that T_5 is having the highest mean for biotype I and the treatments T_1, T_2, T_3, T_4, T_8, T_9, T_{11}, T_{12}, T_{13}, T_{14}, and T_{16} are not significantly different from T_5 . Among the rest of the treatments in biotype I , T_7 has the lowest mean and all other treatments except T_5 are on par with T_7 (Table 4.2.2a) .

For biotype II highest percent content of nitrogen was recorded under T_{14} and was found to be on par with T_1, T_2, T_3, T_4, T_5, T_{11}, T_{12}, T_{13}, and T_{15} .The lowest mean was recorded with T_4 and was found to be on par with T_6, T_7, T_8, T_9, T_{10} and T_{16}. As regards the differential response of the biotypes to the treatments, significant difference was noticed for treatments T_1, T_2, T_3, T_5, T_6, T_7, T_{10}, T_{11}, T_{13}, T_{14} and T_{15} (Table 4.2.2a) .

The interaction was subjected to factor analytical Technique. From (Fig. 4.2b), (Table 4.2.2b) and (Table 4.2.2c) , it can be inferred that Badagara and Payyanur showed similar interactive response as regards the effect of the fertilizers alone. The treatments T_2, T_4, T_8, T_9 and T_{14} recorded the maximum interactive response. The treatments T_4, T_5, T_8, T_9, T_{12}, and T_{16} had positive response with Payyanur where as the treatments T_2, T_3, T_7, T_{10}, T_{14} and T_{15} had positive response with Badagara. The interactive response of the treatments T_1, T_6, T_{11}, and T_{13} was relatively very low.

Table 4.2.2a : Multiple range comparison of the percentage content of nitrogen in grain

Means	Payyanur	Badagara
T_1	2.19 ^{ab}	3.07 ^{abcd}
T_2	2.19 ^{ab}	3.83 ^{a}
T_3	2.17 ^{ab}	3.60 ^{ab}
T_4	2.16 ^{ab}	2.13 ^{e}
T_5	3.01 ^{a}	3.13 ^{abc}
T_6	1.98 ^{b}	2.74 ^{bcde}
T_7	1.73 ^{b}	2.91 ^{bcde}
T_8	2.36 ^{ab}	2.24 ^{de}
T_9	2.18 ^{ab}	2.22 ^{e}
T_{10}	1.96 ^{b}	3.34 ^{bcde}
T_{11}	2.54 ^{ab}	3.33 ^{abc}
T_{12}	2.47 ^{ab}	3.12 ^{abc}
T_{13}	2.38 ^{ab}	3.25 ^{abc}
T_{14}	2.21 ^{ab}	3.85 ^{a}
T_{15}	1.97 ^{b}	3.41 ^{ab}
T_{16}	2.15 ^{ab}	2.49 ^{cde}
***C.D. value** = .7521		

* Indicates the Critical Difference for comparing each treatment in two biotypes

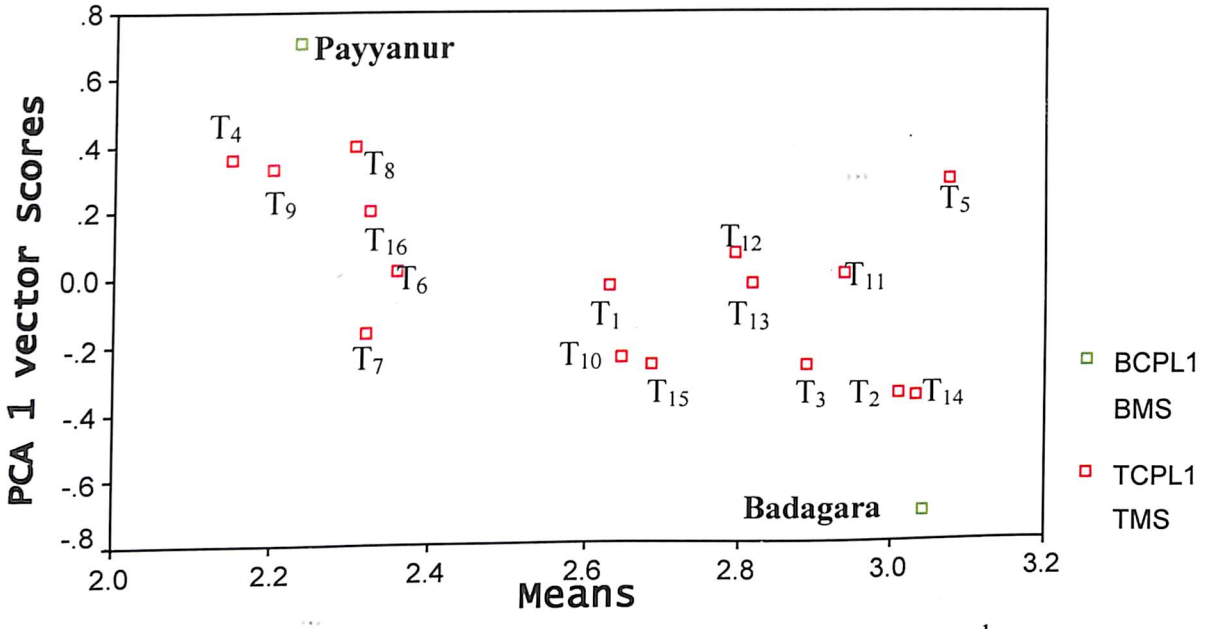
Table 4.2.2b : Overall mean for treatments with PCA 1 vector scores for the percentage content of nitrogen in grain

	Overall Treatment Means	PCA 1 Vector Scores
T_1	2.633	-0.032011
T_2	3.008	-0.350798
T_3	2.887	-0.261538
T_4	2.145	0.3611582
T_5	3.072	0.2952758
T_6	2.357	0.0232448
T_7	2.317	-0.155275
T_8	2.302	0.3972874
T_9	2.197	0.3292796
T_{10}	2.647	-0.240285
T_{11}	2.935	0.0083681
T_{12}	2.795	0.0678749
T_{13}	2.815	-0.025636
T_{14}	3.03	-0.352923
T_{15}	2.687	-0.265788
T_{16}	2.322	0.2017651

Table 4.2.2c : Overall mean for biotypes with PCA 1 vector scores for the percentage content of nitrogen in grain

	Overall Biotype Mean	PCA 1 Vector Scores
Payyanur	2.229688	0.70711
Badagara	3.039375	-0.70711

Fig. 4. 2b Biplot for the percentage content of nitrogen in grain



"TPCL 1", "BPCL 1" = First component loadings for treatments and biotypes; "TMS", "BMS" = treatment and biotype means

4.2.3 Percentage Content of Phosphorus in Grain

In the case of the percentage content of phosphorus in grain, DMRT result showed T_3 as having the highest mean for biotype I with its significance on par with T_7 and with all other treatments significantly different. Among the rest of the treatments in biotype I , T_2 had the lowest mean and all other treatments except T_3, T_7, T_{14} were on par with T_2 (Table 4.2.3a).

For biotype II highest percent content of phosphorus in grain was recorded under T_{14} and was found to be on par with T_1, T_2, T_3, T_4, T_5, T_7, T_8, T_9, T_{10}, T_{11}, T_{12} and T_{16} . The lowest phosphorus content was recorded with T_{13} and was found to be on par with T_1, T_2, T_5, T_6, T_8, T_9, T_{11}, T_{12}, T_{15} and T_{16}. There was significant difference between the treatments T_1, T_2, T_3, T_4, T_5, T_{10}, and T_{16} (Table 4.2.3a) as regards the differential response of biotypes to treatments.

As it is difficult to draw a conclusion based on the above mode of discussion, the data were analysed based on the factor analytical technique . From (Fig. 4.2c), (Table 4.2.3b) and (Table 4.2.3c), it can be inferred that both Payyanur and Badagara had a very low interactive effect. Considering the effect of the fertilizers alone T_2, T_3, T_4, T_7 and T_{13} recorded the maximum interactive response. In addition, the treatments T_3, T_6, T_7, T_{12} and T_{13} contributed positively to the phosphorus content in grain in Payyanur where as the treatments T_1, T_2, T_4, T_5, T_6, T_8, T_9, T_{10} and T_{16} contributed in the same manner to Badagara. The treatments T_{11}, T_{14} and T_{15} did not have any interactive response at all.

4.2.4 Percentage Content of Phosphorus in Straw

In the case of the percentage content of phosphorus in straw, the data obtained from the experiment were subjected to the analysis of variance and the DMRT was performed separately for the biotypes. From the DMRT result it can be seen that T_5 was having the highest mean for biotype I and was on par with T_7, T_8 and T_{15}. Among the rest of the treatments in biotype I , T_1 had the lowest mean and all other treatments significantly different from T_1 (Table 4.2.4a).

Table 4.2.3a :Multiple range comparison of the percentage content of phosphorus in grain

Means	Payyanur	Badagara
T_1	0.47 ^{cd}	0.61 ^{abc}
T_2	0.46 ^{d}	0.61 ^{abc}
T_3	0.71 ^{a}	0.59 ^{abc}
T_4	0.48 ^{cd}	0.64 ^{ab}
T_5	0.47 ^{cd}	0.61 ^{abc}
T_6	0.51 ^{cd}	0.51 ^{bc}
T_7	0.67 ^{ab}	0.64 ^{ab}
T_8	0.49 ^{cd}	0.59 ^{abc}
T_9	0.51 ^{cd}	0.61 ^{abc}
T_{10}	0.52 ^{cd}	0.65 ^{a}
T_{11}	0.51 ^{cd}	0.56 ^{abc}
T_{12}	0.56 ^{bcd}	0.59 ^{abc}
T_{13}	0.58 ^{bcd}	0.49 ^{c}
T_{14}	0.59 ^{bc}	0.67 ^{a}
T_{15}	0.54 ^{cd}	0.61 ^{abc}
T_{16}	0.49 ^{cd}	0.61 ^{abc}
***C.D. value** = .1117		

* Indicates the Critical Difference for comparing each treatment in two biotypes

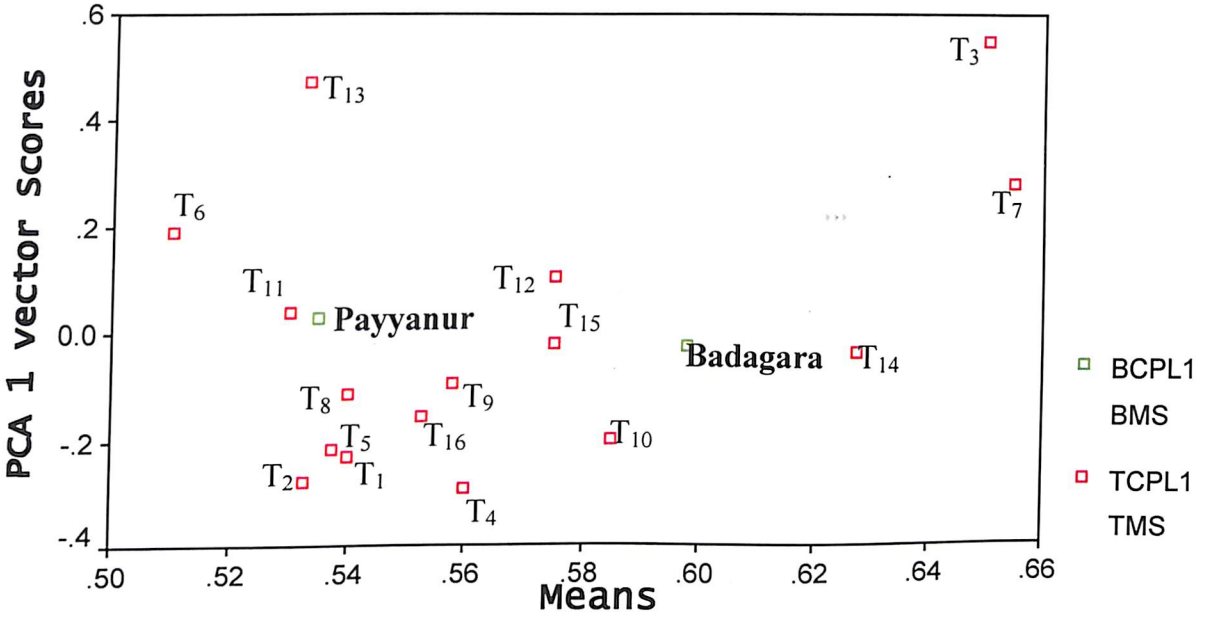
Table 4.2.3b : Overall mean for treatments with PCA 1 vector scores for the percentage content of phosphorus in grain

	Overall Treatment Means	PCA 1 Vector Scores
T_1	0.54	-0.230643
T_2	0.53	-0.2756465
T_3	0.65	0.54941793
T_4	0.56	-0.2906477
T_5	0.53	-0.2156419
T_6	0.51	0.1893898
T_7	0.65	0.27939683
T_8	0.54	-0.1106336
T_9	0.55	-0.0956325
T_{10}	0.58	-0.2006407
T_{11}	0.53	0.03937808
T_{12}	0.57	0.09938277
T_{13}	0.53	0.47441206
T_{14}	0.63	-0.0356278
T_{15}	0.58	-0.0206266
T_{16}	0.55	-0.1556372

Table 4.2.3c : Overall mean for biotypes with PCA 1 vector scores for the percentage content of phosphorus in grain

	Overall Biotype Mean	PCA 1 Vector Scores
Payyanur	0.534688	0.02777
Badagara	0.597813	-0.02777

Fig. 4. 2c Biplot for the percentage content of phosphorus in grain



"TPCL 1", "BPCL 1" = First component loadings for treatments and biotypes; "TMS", "BMS" = treatment and biotype means

Table 4.2.4a : Multiple range comparison of percentage content of phosphorus in straw

Means	Payyanur	Badagara
T_1	0.26 ^{f}	0.52 ^{a}
T_2	0.40 ^{de}	0.49 ^{abc}
T_3	0.38 ^{de}	0.50 ^{ab}
T_4	0.37 ^{de}	0.49 ^{abc}
T_5	0.59 ^{a}	0.48 ^{abc}
T_6	0.40 ^{de}	0.50 ^{ab}
T_7	0.51 ^{abc}	0.49 ^{abc}
T_8	0.52 ^{ab}	0.45 ^{abc}
T_9	0.47 ^{bcd}	0.40 ^{bc}
T_{10}	0.36 ^{e}	0.42 ^{abc}
T_{11}	0.37 ^{de}	0.47 ^{abc}
T_{12}	0.38 ^{de}	0.39 ^{c}
T_{13}	0.40 ^{de}	0.46 ^{abc}
T_{14}	0.45 ^{bcde}	0.47 ^{abc}
T_{15}	0.52 ^{ab}	0.48 ^{abc}
T_{16}	0.41 ^{cde}	0.40 ^{bc}
*C.D. value = .09121		

* Indicates the Critical Difference for comparing each treatment in two biotypes

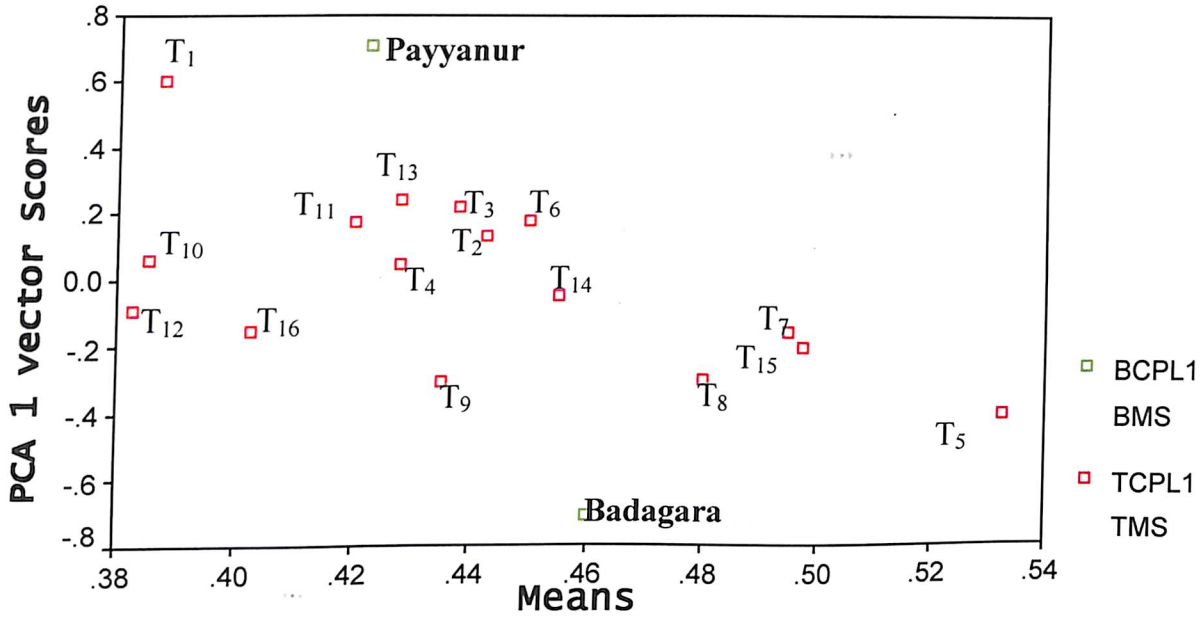
Table 4.2.4b : Overall mean for treatments with PCA 1 vector scores for the percentage content of phosphorus in straw

	Overall Treatment Means	PCA 1 Vector Scores
T_1	0.38	0.60717982
T_2	0.44	0.13191965
T_3	0.44	0.21578909
T_4	0.43	0.24374557
T_5	0.53	-0.3992535
T_6	0.45	0.17385437
T_7	0.49	-0.1616234
T_8	0.48	-0.3014058
T_9	0.43	-0.3014058
T_{10}	0.38	0.06202845
T_{11}	0.42	0.17385437
T_{12}	0.38	-0.0917322
T_{13}	0.43	0.0480502
T_{14}	0.45	-0.0497975
T_{15}	0.49	-0.2035581
T_{16}	0.40	-0.1476452

Table 4.2.4c : Overall mean for biotypes with PCA 1 vector scores for the percentage content of phosphorus in straw

	Overall Biotype Mean	PCA 1 Vector Scores
Payyanur	0.42	0.707107
Badagara	0.46	-0.707107

Fig. 4. 2d Biplot for the percentage content of phosphorus in straw



"TPCL 1", "BPCL 1" = First component loadings for treatments and biotypes; "TMS", "BMS" = treatment and biotype means

For biotype II highest mean was associated with T_1 and was found to be on par with T_2, T_3, T_4, T_5, T_6, T_7, T_{11}, T_{13}, T_{14} and T_{15} . The lowest percent content of phosphorus was recorded with T_{12} and was found to be on par with T_2, T_4, T_5, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{16}. When the differential response of the biotypes to the treatments were considered, significant difference could be noticed for treatments T_1, T_3, T_4, T_5, T_6 and T_{11} (Table 4.2.4a).

The data when subjected to factor analytical technique revealed that Payyanur and Badagara were equally interacting (Fig. 4 2d), (Table 4.2.4b) and (Table4.2.4c). When the effect of the fertilizers alone were considered T_1, T_5 T_8, and T_9 recorded the maximum interactive response. In addition, the treatments T_1, T_2, T_3, T_4, T_6 and T_{11} had positive response with Payyanur where as the treatments T_5, T_8, T_9, T_{12}, T_{14}, and T_{15} had positive response with Badagara. Eventhough the treatments T_{10} and T_{13} had some response in two biotypes, their interactive effect was very near to zero.

4.2.5 Percentage Content of Potassium in Straw

In the case of the percentage content of potassium in straw, DMRT result showed that T_8 was having the highest mean for biotype I and was on par with T_5, T_6, T_7, T_9, T_{10}, T_{11}, T_{12}, T_{14} and T_{15}. Among the rest of the treatments in biotype I , T_{13} had the lowest mean and all other treatments except T_8 and T_{16} were on par with T_{13} (Table 4.2.5a).

For biotype II highest potassium content was obtained in association with T_6 and was found to be on par with T_3, T_4, T_5 and T_{16} . The lowest potassium content was recorded with T_{11} and was found to be on par with T_1, T_2, T_3, T_5, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{16}. When the differential response of the biotypes to the treatments were considered, significant difference was noticed for treatments T_2, T_3, T_4, T_5 and T_6 (Table 4.2.5a).

Table 4.2.5a : Multiple range comparison of the percentage content of potassium in straw

Means	Payyanur	Badagara
T_1	0.69 ^{bc}	0.86 ^{c}
T_2	0.69 ^{bc}	0.92 ^{bc}
T_3	0.70 ^{bc}	1.02 ^{abc}
T_4	0.69 ^{bc}	1.1 ^{ab}
T_5	0.76 ^{abc}	1.01 ^{abc}
T_6	0.87 ^{abc}	1.15 ^{a}
T_7	0.89 ^{abc}	0.86 ^{c}
T_8	0.99 ^{a}	0.81 ^{c}
T_9	0.84 ^{abc}	0.92 ^{bc}
T_{10}	0.80 ^{abc}	0.90 ^{bc}
T_{11}	0.78 ^{abc}	0.80 ^{c}
T_{12}	0.84 ^{abc}	0.87 ^{bc}
T_{13}	0.67 ^{c}	0.86 ^{c}
T_{14}	0.87 ^{abc}	0.80 ^{c}
T_{15}	0.91 ^{abc}	0.83 ^{c}
T_{16}	0.92 ^{ab}	1.00 ^{abc}
***C.D. value** = .2040		

* Indicates the Critical Difference for comparing each treatment in two biotypes

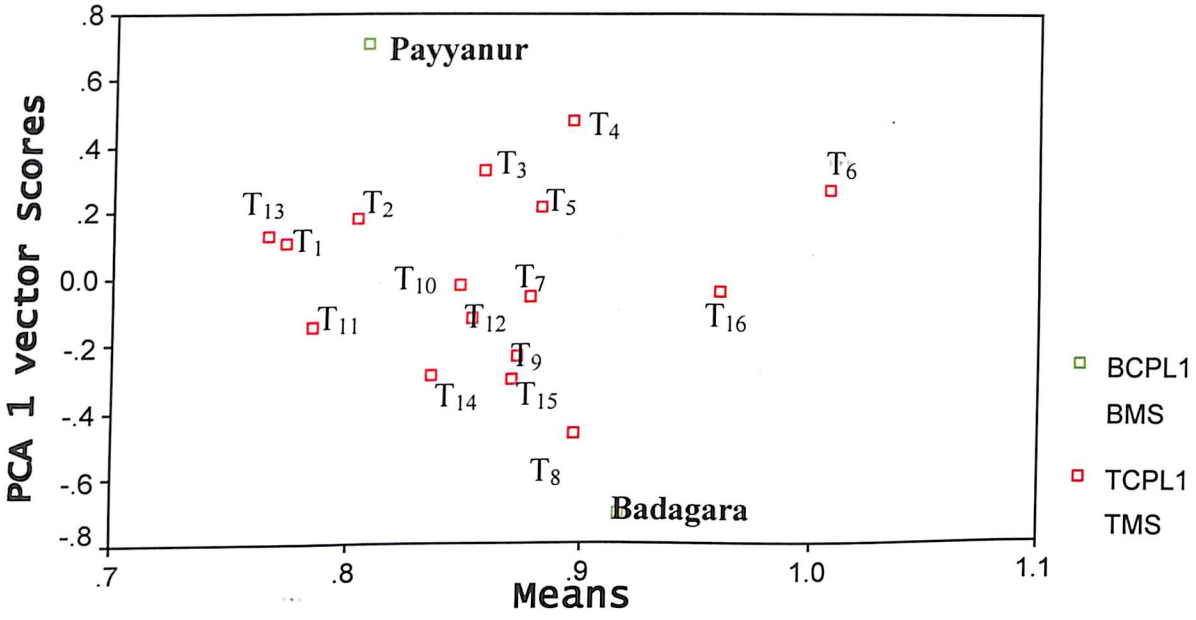
Table 4.2.5b : Overall mean for treatments with PCA 1 vector scores for the percentage content of potassium in straw

	Overall Treatment Means	PCA 1 Vector Scores
T_1	0.7725	0.102565
T_2	0.802	0.182228
T_3	0.857	0.32562
T_4	0.895	0.476978
T_5	0.882	0.214092
T_6	1.007	0.26189
T_7	0.872	-0.23202
T_8	0.897	-0.471
T_9	0.877	-0.05676
T_{10}	0.847	-0.02489
T_{11}	0.785	-0.14439
T_{12}	0.852	-0.12049
T_{13}	0.765	0.126464
T_{14}	0.835	-0.28778
T_{15}	0.870	-0.30371
T_{16}	0.960	-0.04879

Table 4.2.5c : Overall mean for biotypes with PCA 1 vector scores for the percentage content of potassium in straw

	Overall Biotype Mean	PCA 1 Vector Scores
Payyanur	0.806	0.707107
Badagara	0.917	-0.707107

Fig. 4. 2e Biplot for the percentage content of potassium in straw



"TPCL 1", "BPCL 1" = First component loadings for treatments and biotypes; "TMS", "BMS" = treatment and biotype means

The results based on factor analytical technique revealed that Payyanur and Badagara were equally interacting as in the case of the predecessor characters (Fig. 4.2e), (Table 4.2.5b) and (Table 4.2.5c). When the effect of the fertilizers alone were considered T_3, T_4, T_8, T_{14}, and T_{15} recorded the maximum interactive response. In addition, the treatments T_1, T_2, T_3, T_4, T_5, T_6 and T_{13} had positive response with Payyanur where as the treatments T_7, T_8, T_{11}, T_{12}, T_{14} and T_{15} had positive response with Badagara. Even though the treatments T_9, T_{10} and T_{16} have some response in two biotypes, their contribution to the interaction is negligibly small.

Summary

5. SUMMARY

AMMI model has been shown to be a useful technique to capture the non linear interaction when joint regression technique fails to perceive important effects in the studies of G x E interaction. The application of biplots to draw reliable stability conclusions is a subject of great interest when significant proportion of interaction is explained by the first or first two PCA axes. Conceptually it must be possible to study any two factor interaction using AMMI model. The study was undertaken to know how much effective is the AMMI model in explaining two factor interaction.

The data on various parameters of both of the experiments were subjected to the usual analysis of variance and significant interactions were taken out. These characters were subjected to DMRT. All the significant interactions were further analysed based on the factor analytic procedure and the results were compared to know the efficacy of the factor analytic procedure in explaining two factor interaction.

From the first experiment only three characters showed significant interaction viz., percentage content of phosphorus in rhizome, percentage content of potassium in rhizome and North - South foliage spread.

As per DMRT no significant difference could be noticed over the three levels of calcium under source I in the phosphorus content where as under source II phosphorus content was more at the first and third levels of calcium and were found to be on par. Under source III phosphorus content was more at the first two levels and were found to be on par. At the first level of calcium all the sources contributed the same quantum of phosphorus. When the level of calcium was increased to the second level source I and source III contributed more to phosphorus content and were on par where as at the still higher level of calcium, source I and source II contributed more to phosphorus content and were statistically on par.

In the case of potassium content the multiple range tests were carried out for each levels of the factors. Under source I potassium content was more at the first and second levels of calcium and no significant difference could be noticed in the

potassium content over the three levels of calcium under source II. Under source III potassium content was more at third level of calcium and found to be on par with first level of calcium. The percentage content of potassium was also ranked for the various sources under the same level of calcium. At the first level of calcium, all the sources contributed same quantum of potassium. But when the level of calcium was increased to the second level source I and source II were contributing more to potassium content and were found to be on par whereas at the still higher level of calcium source III contributed more to potassium content and was statistically significant from others.

Under source I no significant difference could be noticed in the area of foliage spread over the three levels of Ca applied where as under source II area of foliage spread was more at first and second levels of Ca and were found to be on par and under source III area of foliage spread was more or less same at all the levels of Ca and no significant difference was observed. At the first level of Ca there was no significant difference observed among the different sources. When the level of Ca was increased to the second level, no significant difference could be observed among the different sources. At the higher level of Ca, source I and III contributed more to the area of foliage spread and were statistically on par.

The very same interaction when viewed based on the factor analytical procedure orders the interaction effect. From (Table 4.1.1b) as also from (Fig. 4.1a), it can be inferred that the source II and second level of calcium had the highest positive interaction. The interaction of the other levels of calcium with source II was negative. source I and first level of calcium were least interacting. source III had positive interaction with third level of calcium.

In the case of percentage content of phosphorus it became evident that the source III and third level of calcium had the highest positive interaction. The interaction of other two levels of calcium with source III was negative. source II and first level of calcium were least interacting. source I had positive interaction with second level of calcium

Factor analytical procedure revealed that the source II and third level of calcium had the highest positive interaction in the case of potassium content. The

interaction of other two levels of calcium with source II was negative. source I had positive interaction with first and second levels of calcium. Similarly source III had positive interaction with first and second levels of calcium.

In the second experiment only five characters showed significant interaction viz., grain yield, percentage content of nitrogen in grain, percentage content of phosphorus in grain, percentage content of phosphorus in straw, percentage content of potassium in straw.

From the DMRT it can be seen that T_{15} recorded the highest yield with Payyanur and was found to be significantly different from the rest. T_2 recorded the second highest yield and was found to be on par with T_1, T_8, T_{13}. The lowest yield was observed with T_{10}. For Badagara, highest yield was recorded under T_1 and was found to be on par with T_7. The lowest yield was recorded with T_{10}. When the differential response of the biotypes to the treatments were considered, significant difference was noticed for treatments T_1, T_2, T_4, T_5, T_8, T_{11}, T_{12}, T_{13}, T_{14}, and T_{15}.

In the case of percentage content of nitrogen in grain T_5 was having the highest mean for biotype I and the treatments T_1, T_2, T_3, T_4, T_8, T_9, T_{11}, T_{12}, T_{13}, T_{14}, and T_{16} were not significantly different from T_5. Among the rest of the treatments in biotype I, T_7 has the lowest mean and all other treatments except T_5 were on par with T_7. For biotype II highest percent content of nitrogen was recorded under T_{14} and was found to be on par with T_1, T_2, T_3, T_4, T_5, T_{11}, T_{12}, T_{13}, and T_{15}. The lowest mean was recorded with T_4 and was found to be on par with T_6, T_7, T_8, T_9, T_{10} and T_{16}. As regards the differential response of the biotypes to the treatments, significant difference was noticed for treatments T_1, T_2, T_3, T_5, T_6, T_7, T_{10}, T_{11}, T_{13}, T_{14} and T_{15}.

As regards the percentage content of phosphorus in grain, DMRT result showed T_3 as having the highest mean for biotype I with its significance on par with T_7 and with all other treatments significantly different. Among the rest of the treatments in biotype I, T_2 had the lowest mean and all other treatments except T_3, T_7, T_{14} were on par with T_2. For biotype II highest percent content of phosphorus in grain was recorded under T_{14} and was found to be on par with T_1, T_2, T_3, T_4, T_5, T_7,

T_8, T_9, T_{10}, T_{11}, T_{12} and T_{16} . The lowest phosphorus content was recorded with T_{13} and was found to be on par with T_1, T_2, T_5, T_6, T_8, T_9, T_{11}, T_{12}, T_{15} and T_{16}. There was significant difference between the treatments T_1, T_2, T_3, T_4, T_5, T_{10}, and T_{16} as regards the differential response of biotypes to treatments.

The data on the percentage content of phosphorus in straw was subjected to the analysis of variance and the DMRT was performed separately for the biotypes. From the DMRT result it can be seen that T_5 was having the highest mean for biotype I and was on par with T_7, T_8 and T_{15}. Among the rest of the treatments in biotype I , T_1 had the lowest mean and all other treatments significantly different from T_1. For biotype II highest mean was associated with T_1 and was found to be on par with T_2, T_3, T_4, T_5, T_6, T_7, T_{11}, T_{13}, T_{14} and T_{15} . The lowest percent content of phosphorus was recorded with T_{12} and was found to be on par with T_2, T_4, T_5, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{16}. When the differential response of the biotypes to the treatments were considered, significant difference could be noticed for treatments T_1, T_3, T_4, T_5, T_6 and T_{11} .

The DMRT result in the case of the percentage content of potassium in straw, showed that T_8 was having the highest mean for biotype I and was on par with T_5, T_6, T_7, T_9, T_{10}, T_{11}, T_{12}, T_{14} and T_{15}. Among the rest of the treatments in biotype I , T_{13} had the lowest mean and all other treatments except T_8 and T_{16} were on par with T_{13}. For biotype II highest potassium content was obtained in association with T_6 and was found to be on par with T_3, T_4, T_5 and T_{16} . The lowest potassium content was recorded with T_{11} and was found to be on par with T_1, T_2, T_3, T_5, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{16}. When the differential response of the biotypes to the treatments were considered, significant difference was noticed for treatments T_2, T_3, T_4, T_5, and T_6.

To arrive at a conclusion based on the above mode of discussion is very difficult. The data when subjected to factor analytical technique showed that both Payyanur and Badagara had equal interactive response. When the effect of the fertilizers alone were considered T_2, T_3, T_8, T_{10}, and T_{15} recorded the maximum interactive response. In addition, the treatments T_2, T_8, T_{12}, T_3, T_{14}, and T_{15} had

positive response with Payyanur where as the treatments T_1, T_3, T_6, T_7, T_9, and T_{10} had positive response with Badagara.

In the case of percentage content of nitrogen, both Badagara and Payyanur had very low interactive effect. When the effect of the fertilizers alone were considered T_2, T_8, T_9 and T_{14} recorded the maximum interactive response. In addition, the treatments T_4, T_5, T_8, T_9, T_{12}, and T_{16} had positive response with Payyanur where as the treatments T_2, T_3, T_7, T_{10}, T_{12} and T_{15} had positive response with Badagara. The response of the treatments T_1, T_6, T_{11}, and T_{13} was relatively very low.

As far as the percentage content of phosphorus in grain was concerned the treatments T_2, T_3, T_4, T_7 and T_{13} recorded the maximum interactive response. In addition, the treatments T_3, T_6, T_7, T_{12} and T_{13} contributed positively to the phosphorus content in grain in Payyanur where as the treatments T_1, T_2, T_4, T_5,T_6, T_8, T_9, T_{10} and T_{16} contributed in the same manner to Badagara. The treatments T_{11}, T_{14} and T_{15} did not have any response at all.

In the case of percentage content of phosphorus in straw, the treatments T_1, T_5, T_8, and T_9 recorded the maximum interactive response. In addition, the treatments T_1, T_2, T_3, T_4, T_6 and T_{11} had positive response with Payyanur where as the treatments T_5, T_8, T_9, T_{12}, T_{14}, and T_{15} had positive response with Badagara. Eventhough the treatments T_{10} and T_{13} had some response in two biotypes, their interactive effect was very near to zero.

When the effect of the fertilizers alone were considered T_3, T_4, T_8, T_{14}, and T_{15} recorded the maximum interactive response for potassium content in straw. In addition, the treatments T_1, T_2, T_3, T_4, T_5, T_6 and T_{13} had positive response with Payyanur where as the treatments T_7, T_8, T_{11}, T_{12}, T_{14} and T_{15} had positive response with Badagara. Even though the treatments T_9, T_{10} and T_{16} had some response in two biotypes, their contribution to the interaction was negligibly small.

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* Original not seen

Appendices

APPENDIX I

Observations on various characters of the two experiments

Experiment I

	Percentage content of phosphorus in rhizome			
Treatment	R1	R2	R3	R4
Ca0S1	0.44	0.39	0.37	0.4
Ca1S1	0.49	0.46	0.39	0.44
Ca2S1	0.41	0.41	0.42	0.39
Ca0S2	0.42	0.47	0.49	0.36
Ca1S2	0.42	0.4	0.39	0.36
Ca2S2	0.44	0.42	0.44	0.5
Ca0S3	0.43	0.46	0.39	0.37
Ca1S3	0.45	0.38	0.47	0.48
Ca2S3	0.37	0.42	0.36	0.33

	Percentage content of potassium in rhizome			
Treatment	R1	R2	R3	R4
Ca0S1	1.55	1.62	1.49	1.5
Ca1S1	1.68	1.66	1.7	1.59
Ca2S1	1.6	1.63	1.62	1.7
Ca0S2	1.65	1.1	1.83	1.47
Ca1S2	1.55	1.32	1.6	1.48
Ca2S2	1.1	1.2	1.5	1.34
Ca0S3	1.28	1.18	1.26	1.3
Ca1S3	1.58	1.62	1.43	1.22
Ca2S3	1.9	1.82	1.69	1.87

	North-South foliage spread (in cm)			
Treatment	R1	R2	R3	R4
Ca0S1	26.8	22.6	21.4	13.8
Ca1S1	24.4	19.4	23	16.6
Ca2S1	21	23.2	23.6	24.6
Ca0S2	25.6	23.8	21.8	18.2
Ca1S2	24.8	29.4	24.8	21
Ca2S2	14.6	21	17.2	17.4
Ca0S3	14.8	17.8	26.4	10.8
Ca1S3	26	20.4	22	17.6
Ca2S3	23.4	18.2	25.2	15

Experiment II

Grain yield			
Payyannur		Badagara	
R1	R2	R1	R2
531.25	537.51	398.5	404.6
567.25	574.75	171	165.3
182.75	187.45	243.75	208.81
397.75	354.75	224	210.2
383.25	400.11	274.15	272.81
299.45	324.55	311.15	279.95
411.5	391.5	330.8	321.7
558.25	564.55	209.25	162.95
243.4	267.1	211.6	272
89.4	35.9	109.5	90.3
391.5	387.8	241.6	208.66
425	454.6	158.8	135.46
560.5	570.6	321.5	52.96
492	477.66	118.6	87.3
697.25	712.71	306.6	251.2
415.74	417.76	256.6	202.96

Percentage content of nitrogen in grain			
Payyanur		Badagara	
R1	R2	R1	R2
2.21	2.17	3.19	2.96
1.96	2.42	4.31	3.34
2.04	2.31	3.58	3.62
2.02	2.31	1.61	2.64
3.22	2.81	3.22	3.04
1.9	2.06	2.63	2.84
1.48	1.98	2.87	2.94
2.77	1.96	1.64	2.84
2.32	2.04	2.23	2.2
1.76	2.16	3.25	2.42
2.74	2.34	3.7	2.96
2.44	2.5	3.02	3.22
2.28	2.48	3.02	3.48
2.44	1.98	4.06	3.64
1.82	2.12	3.33	3.48
1.99	2.32	2.02	2.96

Percentage content of phosphorus in grain			
Payyanur		Badagara	
R1	R2	R1	R2
0.43	0.51	0.54	0.68
0.45	0.46	0.66	0.56
0.74	0.68	0.6	0.58
0.44	0.52	0.66	0.62
0.46	0.48	0.58	0.63
0.5	0.52	0.48	0.54
0.62	0.72	0.69	0.59
0.5	0.48	0.56	0.62
0.48	0.54	0.57	0.64
0.51	0.53	0.63	0.67
0.53	0.48	0.62	0.49
0.58	0.54	0.51	0.67
0.56	0.6	0.49	0.48
0.54	0.64	0.67	0.66
0.51	0.57	0.64	0.58
0.5	0.49	0.68	0.54

Percentage content of phosphorus in straw			
Payyanur		Badagara	
R1	R2	R1	R2
0.28	0.24	0.55	0.48
0.42	0.38	0.53	0.44
0.41	0.35	0.47	0.52
0.34	0.39	0.48	0.5
0.5	0.67	0.46	0.5
0.38	0.42	0.52	0.48
0.55	0.46	0.51	0.46
0.55	0.48	0.46	0.43
0.54	0.4	0.4	0.4
0.33	0.38	0.39	0.44
0.34	0.4	0.44	0.5
0.34	0.42	0.35	0.42
0.42	0.38	0.47	0.44
0.45	0.44	0.45	0.48
0.53	0.5	0.46	0.5
0.4	0.42	0.37	0.42

Percentage content of potassium in straw			
Payyanur		Badagara	
R1	R2	R1	R2
0.65	0.72	0.8	0.92
0.7	0.68	0.78	1.05
0.63	0.77	1.03	1
0.63	0.75	1.08	1.12
0.7	0.82	1.03	0.98
1	0.74	1.15	1:14
0.88	0.9	0.73	0.98
0.83	1.15	0.73	0.88
0.9	0.78	0.78	1.05
0.78	0.82	0.8	0.99
0.75	0.8	0.75	0.84
0.73	0.94	0.7	1.04
0.68	0.66	0.85	0.87
0.9	0.84	0.7	0.9
0.8	1.02	0.78	0.88
0.85	0.99	1.08	0.92

APPENDIX II

Analysis of variance tables

Experiment I

Percentage content of phosphorous in rhizome

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	3	0.004	0.001	0.8293	
Factor A	2	0.002	0.001	0.6996	
Factor B	2	0.002	0.001	0.5642	
AB	4	0.021	0.005	3.5571	0.0205*
Error	24	0.035	0.001		
Total	35	0.064			

Percentage content of potassium in rhizome

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	3	0.062	0.021	0.9575	
Factor A	2	0.132	0.066	3.048	0.0661
Factor B	2	0.202	0.101	4.6599	0.0195*
AB	4	0.677	0.169	7.8088	0.0004**
Error	24	0.52	0.022		
Total	35	1.594			

North - South foliage spread

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	3	180.48	60.16	5.2938	0.0061**
Factor A	2	35.576	17.788	1.5653	0.2296
Factor B	2	27.902	13.951	1.2276	0.3107
AB	4	125.791	31.448	2.7673	0.0305*
Error	24	272.74	11.364		
Total	35	642.489			

Experiment II

Grain yield

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	1	4678.218	4678.218	3.2886	0.0795
Factor A	1	579688.1	579688.1	407.5012	0.0000**
Factor B	15	558353.9	37223.59	26.1669	0.0000**
AB	15	407774.2	27184.95	19.1101	0.0000**
Error	31	44098.84	1422.543		
Total	63	1594593			

Percentage content of nitrogen in grain

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	1	0.034	0.034	0.2491	
Factor A	1	9.695	9.695	71.5261	0.0000**
Factor B	15	6.282	0.419	3.0896	0.0039**
AB	15	5.204	0.347	2.5595	0.0132*
Error	31	4.202	0.136		
Total	63	25.417			

Percentage content of phosphorous in grain

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	1	0.002	0.002	0.8215	
Factor A	1	0.064	0.064	23.213	0.0000**
Factor B	15	0.114	0.008	2.7586	0.0083**
AB	15	0.111	0.007	2.6965	0.0095**
Error	31	0.085	0.003		
Total	63	0.376			

Percentage content of phosphorous in straw

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	1	0.0001	0.0001	0.019	
Factor A	1	0.023	0.023	11.1486	0.0022**
Factor B	15	0.112	0.007	3.6436	0.0011**
AB	15	0:128	0.009	4.1569	0.0004**
Error	31	0.064	0.002		
Total	63	0.327			

Percentage content of potassium in straw

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Block	1	0.119	0.119	12.1624	0.0015
Factor A	1	0.196	0.196	20.0082	0.0001**
Factor B	15	0.248	0.017	1.6864	0.1069
AB	15	0.394	0.026	2.6836	0.0098**
Error	31	0.303	0.01		
Total	63	1.26			

* Significant at 5% level
** Significant at 1% level

APPENDIX III

Eigen values and eigen vectors for each character

Percentage content of phosphorus in rhizome			
X ' X = S			
E V	EVECT		
0.004839	-0.13875	-0.80462	0.577351
0.000466	0.766197	0.28215	0.57735
3.33E-10	-0.62745	0.522472	0.57735

Percentage content of phosphorus in rhizome			
X X ' =Ca			
E V	EVECT		
0.004839	-0.24455	-0.77901	0.57735
0.000466	0.796921	0.177719	0.57735
3.33E-10	-0.55237	0.601295	0.57735

Percentage content of potassium in rhizome			
X ' X = S			
E V	EVECT		
0.168535	-0.5884	-0.56609	0.57735
0.000885	-0.19605	0.79261	0.57735
-4E-18	0.784446	-0.22652	0.57735

Percentage content of potassium in rhizome			
X X ' = Ca			
E V	EVECT		
0.168535	-0.09792	-0.81059	0.577372
0.000885	-0.65304	0.490124	0.577342
-8E-12	0.75097	0.32051	0.577337

Area of North-South foliage spread			
X ' X = S			
E V	EVECT		
27.13302	-0.53617	-0.61578	0.57735
4.314757	0.801368	-0.15645	0.57735
2.67E-09	-0.2652	0.772229	0.57735

Area of North-south foliage spread			
X X ' = Ca			
E V	EVECT		
27.13302	-0.28651	0.764577	0.57735
4.314757	-0.51889	-0.63041	0.57735
-1.7E-09	0.805399	-0.13416	0.57735

Grain Yield									
X X ' = Treatments									
E V	EVECT								
		COL1	COL2	COL3	COL4	COL5	COL6	COL7	COL8
186237.4	ROW1	-0.07888	0.053176	0.033759	0.050635	0.014927	0.198963	0.20131	0.399052
1.55E-05	ROW2	0.363558	0.344064	-0.37455	-0.31521	-0.52318	0.163987	-0.05666	0.058288
1.13E-05	ROW3	-0.36399	0.456097	0.359567	0.148955	-0.02288	0.082071	-0.26335	-0.03991
4.75E-06	ROW4	-0.03575	0.03769	0.031362	0.015436	-0.007	-0.12755	0.5381	0.605611
1.34E-06	ROW5	-0.10285	-0.00726	0.031762	0.119196	0.111755	0.743973	0.133016	0.115741
6.37E-07	ROW6	-0.26957	0.485304	-0.43436	0.028796	0.490906	-0.14601	0.088733	-0.09089
1.81E-07	ROW7	-0.17322	-0.20161	-0.19187	0.198206	-0.07739	-0.3623	0.378747	-0.20433
7.2E-08	ROW8	0.318416	0.191962	0.326976	-0.31157	0.050427	-0.14892	0.311586	-0.10297
-2.9E-09	ROW9	-0.27448	-0.01216	0.441482	-0.37158	0.031039	-0.01623	0.071209	-0.01248
-8E-08	ROW10	-0.35755	-0.33867	-0.15954	0.197147	-0.39331	0.079108	0.014173	0.007445
-1E-07	ROW11	-0.02695	-0.03279	0.028117	0.098864	-0.08527	-0.0224	-0.21285	-0.05063
-8E-07	ROW12	0.183026	-0.40197	-0.21013	-0.26394	0.533174	0.130145	-0.21148	0.131235
-1.9E-06	ROW13	0.077587	-0.00132	-0.01185	0.035946	0.047487	0.39105	0.456441	-0.56029
-6.4E-06	ROW14	0.329198	0.248014	-0.05682	0.550301	0.073299	0.005049	-0.02039	0.103374
-8.9E-06	ROW15	0.40162	-0.13137	0.355251	0.404622	0.093005	-0.07317	-0.02211	-0.03067
-1.5E-05	ROW16	0.009834	-0.00305	-0.00382	-0.0054	0.000711	-0.00068	0.163449	-0.22236

EVECT								
	COL9	COL10	COL11	COL12	COL13	COL14	COL15	COL16
ROW1	4032.004	5252.306	395.8909	-2688.56	-1139.72	-4835.76	-5899.61	-144.46
ROW2	-18584.6	-24209.3	-1824.77	12392.31	5253.261	22289.35	27192.94	665.8536
ROW3	18606.92	24238.37	1826.96	-12407.2	-5259.57	-22316.1	-27225.6	-666.653
ROW4	1827.466	2380.555	179.4336	-1218.56	-516.565	-2191.76	-2673.94	-65.4748
ROW5	5257.399	6848.571	516.209	-3505.66	-1486.09	-6305.43	-7692.61	-188.363
ROW6	13779.88	17950.42	1353.007	-9188.49	-3895.12	-16526.8	-20162.7	-493.709
ROW7	8854.851	11534.81	869.4325	-5904.46	-2502.98	-10620	-12956.4	-317.253
ROW8	-16277.1	-21203.4	-1598.2	10853.62	4600.989	19521.79	23816.53	583.1778
ROW9	14031.16	18277.75	1377.68	-9356.04	-3966.15	-16828.2	-20530.3	-502.711
ROW10	18277.75	23809.58	1794.639	-12187.7	-5166.52	-21921.3	-26743.9	-654.859
ROW11	1377.68	1794.639	135.2704	-918.643	-389.425	-1652.31	-2015.82	-49.3598
ROW12	-9356.04	-12187.7	-918.643	6238.654	2644.647	11221.12	13689.73	335.2103
ROW13	-3966.15	-5166.52	-389.425	2644.647	1121.1	4756.777	5803.253	142.1
ROW14	-16828.2	-21921.3	-1652.31	11221.12	4756.777	20182.79	24622.94	602.924
ROW15	-20530.3	-26743.9	-2015.82	13689.73	5803.253	24622.94	30039.92	735.5654
ROW16	-502.711	-654.859	-49.3598	335.2103	142.1	602.924	735.5654	18.01125

Percentage content of nitrogen in grain

X X' = Treatments									
E V	EVECT								
		COL1	COL2	COL3	COL4	COL5	COL6	COL7	COL8
2.767537	ROW1	-0.03201	-0.16153	0.410643	0.041794	0.071143	0.115603	0.579395	-0.13829
1.88E-09	ROW2	-0.3508	0.110504	0.083866	0.449944	0.295673	-0.0338	0.039346	-0.05986
5.42E-10	ROW3	-0.26154	-0.14904	0.39292	-0.04179	-0.07114	-0.1156	-0.5794	0.13829
5.15E-17	ROW4	0.361158	0.45844	0.412377	0.128514	0.080596	-0.34011	0.161428	0.083297
4.7E-17	ROW5	0.295276	0.075328	0.133753	0.423802	-0.65006	0.291972	-0.03929	0.094888
1.39E-17	ROW6	0.023245	0.090139	0.112748	-0.01911	0.250368	0.133992	-0.05858	-0.21669
3.82E-18	ROW7	-0.15528	0.099858	0.098963	-0.4244	0.14743	0.313351	0.264922	0.521647
1.88E-18	ROW8	0.397287	0.069774	0.14163	-0.4113	0.06342	0.063044	-0.30408	-0.22799
7.55E-21	ROW9	0.32928	0.073476	0.136379	-0.20757	-0.05906	-0.00203	0.101104	0.022673
-1.7E-18	ROW10	-0.24029	0.104487	0.092399	-0.25461	-0.2811	-0.68398	0.113489	-0.15443
-4.6E-18	ROW11	0.008368	-0.37341	0.294003	-0.03552	-0.00485	0.14785	-0.12194	-0.21122
-1.7E-17	ROW12	0.067875	-0.37665	0.298598	0.065964	0.022326	-0.1954	-0.04054	0.591515
-2.4E-17	ROW13	-0.02564	-0.37156	0.291377	-0.03044	-0.01747	0.047548	0.162484	-0.38029
-5.1E-16	ROW14	-0.35292	0.497319	0.357238	-0.12851	-0.0806	0.340112	-0.16143	-0.0833
-1.2E-09	ROW15	-0.26579	0.105875	0.09043	0.123912	-0.24931	-0.01065	0.072815	-0.00676
-3.9E-09	ROW16	0.201765	0.080419	0.126532	0.319327	0.482646	-0.07191	-0.18971	0.026525

EVECT								
	COL9	COL10	COL11	COL12	COL13	COL14	COL15	COL16
ROW1	0.1788	0.028123	0.273068	-0.0557	-0.01723	0.020358	-0.54006	-0.16264
ROW2	0.054763	0.079321	-0.03682	0.40502	-0.37325	-0.35946	0.032695	0.342439
ROW3	-0.1788	-0.02812	-0.27307	0.055697	0.017232	-0.02036	-0.50056	-0.1353
ROW4	-0.06081	-0.16152	-0.32445	-0.03231	-0.23265	0.062354	0.168112	-0.30868
ROW5	-0.02442	0.039714	-0.01929	-0.21119	-0.01081	-0.25952	-0.0785	0.26549
ROW6	-0.29541	-0.75886	0.146037	-0.19498	0.158159	-0.10002	-0.03168	0.29789
ROW7	-0.03187	0.085789	-0.35942	-0.23422	-0.10576	-0.09123	-0.00096	0.319152
ROW8	0.054529	0.187752	0.297464	0.022483	-0.54149	0.042355	-0.09606	0.253341
ROW9	-0.00473	0.018824	-0.11333	0.700872	0.479552	-0.01968	-0.08436	0.26144
ROW10	0.147606	0.055886	0.075538	-0.24193	0.142205	-0.23754	0.013674	0.329277
ROW11	0.660797	-0.21326	-0.31723	-0.03163	0.012424	0.006415	0.32586	0.035804
ROW12	-0.06371	-0.10032	0.497642	0.083611	-0.02432	-0.00329	0.315618	0.028717
ROW13	-0.59709	0.313577	-0.18041	-0.05198	0.011894	-0.00312	0.331712	0.039854
ROW14	0.060814	0.161519	0.32445	0.032315	0.232653	-0.06235	0.291017	-0.22363
ROW15	-0.02031	-0.09921	-0.00458	0.099424	-0.13852	0.822734	0.018064	0.332314
ROW16	0.119845	0.390777	0.014399	-0.34547	0.38992	0.202356	-0.06241	0.276628

Percentage content of phosphorus in grain

X X ' = Treatments

E V	EVECT								
		COL1	COL2	COL3	COL4	COL5	COL6	COL7	COL8
0.055546875	ROW1	-0.230643	0.28639	-0.09103	-0.148943	-0.351223	-0.024655	0.221854	0.66857
3.73828E-09	ROW2	-0.275647	-0.233426	-0.128908	0.069153	0.536487	-0.367434	-0.241527	0.20410
1.14072E-10	ROW3	0.549418	0.163387	-0.083385	0.193266	0.352887	0.20425	0.35273	0.07313
2.99346E-18	ROW4	-0.290648	0.295852	-0.091618	0.192081	-0.249847	0.257747	-0.149926	-0.1544
1.03645E-18	ROW5	-0.215642	-0.242888	-0.12832	0.116167	0.106374	0.36027	-0.328308	0.17447
4.30612E-19	ROW6	0.18939	0.220158	-0.086914	-0.068478	0.035038	0.170562	-0.290586	0.21282
3.59482E-19	ROW7	0.279397	0.205965	-0.086031	-0.103937	0.189824	0.221919	-0.114746	-0.00823
2.90378E-19	ROW8	-0.110634	0.267466	-0.089854	-0.11725	0.177669	-0.276728	-0.00646	-0.33915
-2.98026E-20	ROW9	-0.095632	-0.261811	-0.127144	-0.172824	0.068675	-0.015224	0.592542	-0.03287
-1.29391E-19	ROW10	-0.200641	0.281659	-0.090736	0.197976	-0.034443	-0.352127	0.255718	-0.12535
-2.88113E-19	ROW11	0.039378	0.20342	0.405157	0.618688	-0.069623	-0.06452	0.019478	0.02503
-4.68785E-19	ROW12	0.099383	0.23435	-0.087796	-0.144715	-0.119905	-0.200968	-0.268584	-0.32730
-5.70216E-19	ROW13	0.474412	-0.351698	-0.121557	-0.020716	-0.494714	-0.375025	-0.170199	0.057781
-1.369E-18	ROW14	-0.035628	-0.225785	0.727481	1.71E-08	-1.94E-09	3.04E-10	2.28E-11	4.26E-10
-6.14221E-10	ROW15	-0.020627	0.212882	0.404569	-0.618688	0.069623	0.06452	-0.019478	-0.02503
-9.2968E-10	ROW16	-0.155637	-0.252349	-0.127732	0.008219	-0.216823	0.397414	0.147492	-0.40348

EVECT								
	COL9	COL10	COL11	COL12	COL13	COL14	COL15	COL16
ROW1	0.152951	-0.3344	0.035964	-0.01129	-0.05048	-0.14374	0.130224	0.193212
ROW2	0.007615	-0.1263	0.24897	0.061782	-0.33924	0.157783	-0.06609	0.314886
ROW3	0.146483	-0.23729	0.010854	-0.20386	0.06468	0.383393	0.111304	0.219373
ROW4	0.023473	0.187263	-0.23907	0.168573	-0.36015	0.550195	0.13168	0.1912
ROW5	-0.05364	-0.06853	-0.34475	-0.0845	0.588627	-0.01312	-0.06754	0.316898
ROW6	-0.04375	0.600958	0.27055	-0.4289	-0.12109	-0.22606	0.120037	0.207299
ROW7	-0.17932	-0.03685	-0.00207	0.740489	-0.06551	-0.3443	0.117853	0.210317
ROW8	0.66799	0.06907	-0.29182	-0.05043	0.100986	-0.25923	0.127313	0.197237
ROW9	-0.30839	0.284997	-0.39518	-0.08273	-0.22199	-0.1502	-0.07045	0.320923
ROW10	-0.28945	0.224078	0.352652	0.141935	0.525293	0.133321	0.129496	0.194219
ROW11	-0.00904	-0.03024	-0.08659	-0.03046	-0.1239	-0.2855	-0.49271	0.226006
ROW12	-0.47839	-0.47282	-0.13706	-0.35653	-0.09373	-0.09358	0.12222	0.20428
ROW13	0.158905	0.109811	-0.04384	0.159036	0.048613	0.169494	-0.08428	0.34004
ROW14	2.62E-10	-4.4E-10	-1.6E-10	-5.6E-10	-3.2E-10	-7.9E-10	0.606011	0.226437
ROW15	0.009038	0.030237	0.086591	0.030463	0.123902	0.285501	-0.49125	0.223994
ROW16	0.19552	-0.19997	0.534795	-0.05358	-0.07601	-0.16395	-0.069	0.318911

Percentage content of phosphorus in straw

X X ' = Treatments

E V	EVECT								
		COL1	COL2	COL3	COL4	COL5	COL6	COL7	COL8
0.063974	ROW1	0.60718	-0.11397	0.137103	0.290709	0.458395	-0.39099	0.042564	-0.05622
2.94E-09	ROW2	0.13192	-0.23674	0.134346	0.199903	-0.08502	-0.11794	0.227122	-0.4924
1.4E-09	ROW3	0.215789	-0.05464	0.306307	0.158533	-0.06206	0.612267	-0.21082	-0.15532
5.67E-10	ROW4	0.243746	-0.25369	0.086002	0.237668	-0.2767	0.270003	0.290171	0.033776
1.35E-18	ROW5	-0.39925	0.038594	0.572198	-0.04917	-0.07401	-0.19233	-0.03678	-0.34162
6.54E-19	ROW6	0.173854	0.363298	0.036487	0.201085	-0.22737	-0.16483	-0.40231	-0.00912
2.29E-19	ROW7	-0.16162	0.414153	0.181519	0.087792	0.466221	0.206429	0.079385	-0.14759
1.85E-19	ROW8	-0.30141	-0.07057	-0.25876	0.554975	1.72E-09	-7.6E-09	1.64E-08	-1.6E-08
9.41E-20	ROW9	-0.30141	-0.07057	-0.25876	0.554975	-2.5E-09	6.22E-09	-1.6E-08	1.59E-08
1.23E-21	ROW10	0.062028	0.380249	0.084831	0.163321	-0.03917	0.195323	0.22639	0.152133
-9.5E-27	ROW11	0.173854	0.363298	0.036487	0.201085	-0.24116	-0.17603	-0.40396	0.028249
-6.5E-20	ROW12	-0.09173	-0.20283	0.231034	0.124374	0.073181	0.229852	-0.33071	-0.0969
-1.4E-19	ROW13	0.04805	-0.02921	0.378822	0.101886	-0.32232	-0.02894	0.205037	0.55317
-3.8E-19	ROW14	-0.0498	0.397201	0.133175	0.125556	0.04149	-0.06089	0.500487	-0.02367
-2.8E-18	ROW15	-0.20356	-0.18588	0.279378	0.086609	-0.18391	-0.38999	-0.0075	0.05828
-3E-09	ROW16	-0.14765	-0.19436	0.255206	0.105492	0.47245	0.008068	-0.17908	0.497246

EVECT								
	COL9	COL10	COL11	COL12	COL13	COL14	COL15	COL16
ROW1	0.152951	-0.3344	0.035964	-0.01129	-0.05048	-0.14374	0.130224	0.193212
ROW2	0.007615	-0.1263	0.24897	0.061782	-0.33924	0.157783	-0.06609	0.314886
ROW3	0.146483	-0.23729	0.010854	-0.20386	0.06468	0.383393	0.111304	0.219373
ROW4	0.023473	0.187263	-0.23907	0.168573	-0.36015	0.550195	0.13168	0.1912
ROW5	-0.05364	-0.06853	-0.34475	-0.0845	0.588627	-0.01312	-0.06754	0.316898
ROW6	-0.04375	0.600958	0.27055	-0.4289	-0.12109	-0.22606	0.120037	0.207299
ROW7	-0.17932	-0.03685	-0.00207	0.740489	-0.06551	-0.3443	0.117853	0.210317
ROW8	0.66799	0.06907	-0.29182	-0.05043	0.100986	-0.25923	0.127313	0.197237
ROW9	-0.30839	0.284997	-0.39518	-0.08273	-0.22199	-0.1502	-0.07045	0.320923
ROW10	-0.28945	0.224078	0.352652	0.141935	0.525293	0.133321	0.129496	0.194219
ROW11	-0.00904	-0.03024	-0.08659	-0.03046	-0.1239	-0.2855	-0.49271	0.226006
ROW12	-0.47839	-0.47282	-0.13706	-0.35653	-0.09373	-0.09358	0.12222	0.20428
ROW13	0.158905	0.109811	-0.04384	0.159036	0.048613	0.169494	-0.08428	0.34004
ROW14	2.62E-10	-4.4E-10	-1.6E-10	-5.6E-10	-3.2E-10	-7.9E-10	0.606011	0.226437
ROW15	0.009038	0.030237	0.086591	0.030463	0.123902	0.285501	-0.49125	0.223994
ROW16	0.19552	-0.19997	0.534795	-0.05358	-0.07601	-0.16395	-0.069	0.318911

Percentage content of potassium in straw

X X ' = Treatments

E V	EVECT								
		COL1	COL2	COL3	COL4	COL5	COL6	COL7	COL8
0.196971875	ROW1	0.102565	0.120704	0.134885	-0.240953	-0.318221	-0.205777	0.054913	0.068034
9.98077E-18	ROW2	0.182228	0.13274	0.620473	-0.135142	0.016151	-0.105621	-0.267585	-0.148751
1.96418E-18	ROW3	0.32562	-0.238628	-0.087668	0.6571	-0.384636	0.047819	0.063256	0.109484
1.51945E-18	ROW4	0.476978	0.425671	-0.372255	0.049355	0.066291	-0.085848	-0.073309	-0.049743
1.03267E-18	ROW5	0.214092	-0.062371	-0.005145	-0.285724	-0.344745	-0.035871	-0.159786	-0.128853
3.50328E-19	ROW6	0.26189	0.086423	0.04075	0.228047	0.533358	-0.040177	0.168323	-0.018343
9.91696E-20	ROW7	-0.232016	-0.131267	-0.513558	-0.169143	0.001365	-0.20829	-0.008548	0.114663
-1.41155E-20	ROW8	-0.471003	0.289324	-0.07128	0.191703	-0.240317	-0.029871	0.06828	0.117952
-2.93326E-19	ROW9	-0.056759	-0.103785	0.016779	-0.154357	0.176102	-0.084432	0.67196	-0.373742
-4.5864E-19	ROW10	-0.024894	-0.128209	-0.022664	-0.152839	0.341082	-0.007205	-0.326018	0.572251
-7.7738E-19	ROW11	-0.144388	-0.191006	0.17433	0.156487	0.244066	-0.387464	0.043747	0.148896
-1.06038E-18	ROW12	-0.120489	0.035069	-0.112572	0.061309	0.219861	0.669425	-0.264796	-0.312695
-2.30371E-18	ROW13	0.126464	-0.14511	0.090629	-0.327648	-0.137805	0.50686	0.380082	0.40151
-1.72627E-17	ROW14	-0.28778	-0.242973	0.284458	0.277908	-0.07704	0.0945	-0.072303	-0.07515
-9.1801E-10	ROW15	-0.303713	0.5566	0.036656	0.017489	-0.060363	0.007357	0.000831	-0.025281
-4.04915E-09	ROW16	-0.048793	-0.403183	-0.213817	-0.173591	-0.035151	-0.135406	-0.279049	-0.400231

EVECT								
	COL9	COL10	COL11	COL12	COL13	COL14	COL15	COL16
ROW1	0.375664	0.67314	-0.098892	0.034641	-0.200458	-0.072993	0.17618	0.256192
ROW2	-0.353097	-0.203453	0.021744	-0.362858	-0.217289	-0.03731	0.178619	0.249112
ROW3	0.033846	-0.049984	0.133028	-0.182868	-0.054327	0.290256	0.183008	0.236367
ROW4	0.046234	-0.156606	0.105381	0.064567	-0.239439	-0.364334	0.356532	-0.267492
ROW5	0.074114	-0.382382	-0.24002	0.481456	0.405816	0.087331	0.179594	0.24628
ROW6	-0.314229	0.366824	-0.197169	0.165973	0.405187	0.016262	0.181057	0.242032
ROW7	-0.423388	-0.036521	-0.350252	-0.055117	-0.382395	0.134746	0.165939	0.285929
ROW8	-0.063904	-0.083572	0.119654	-0.179642	0.356782	-0.520512	0.158624	0.307169
ROW9	0.159462	-0.223121	0.351454	0.063234	-0.16102	0.038109	0.171304	0.270352
ROW10	0.175791	-0.07278	0.492081	0.15179	-0.017008	0.077474	0.172279	0.26752
ROW11	0.440206	-0.237426	-0.445414	-0.206383	0.058332	-0.022234	0.337512	-0.212266
ROW12	0.33574	0.01185	-0.231628	-0.116608	-0.135289	-0.013363	0.169353	0.276016
ROW13	-0.174825	0.004805	-0.098677	-0.193887	0.096796	-0.055612	0.345803	-0.236339
ROW14	-0.20654	0.103702	0.041619	0.577091	-0.301171	-0.211174	0.333123	-0.199522
ROW15	-0.022827	0.028219	0.099935	0.040363	0.075177	0.650762	0.332636	-0.198106
ROW16	-0.082249	0.257307	0.297157	-0.28175	0.310306	0.002592	0.340439	-0.220763

Grain yield		
X ' X		
E V	EVECT	
186237.4	0.707106781	0.707107
0	-0.707106781	0.707107

Percentage content of nitrogen in grain		
X ' X		
E V	EVECT	
2.767536718	0.707107	0.707107
0	-0.70711	0.707107

Percentage content of phosphorus in grain		
X ' X		
E V	EVECT	
0.055547	0.707107	0.707107
0	-0.70711	0.707107

Percentage content of phosphorus in straw		
X ' X		
E V	EVECT	
0.063974	0.707107	0.707107
0	-0.70711	0.707107

Percentage content of potassium in straw		
X ' X		
E V	EVECT	
0.196972	0.707107	0.707107
0	-0.70711	0.707107

Abstract

INTERACTION EFFECT UNDER AMMI MODEL

By

ELDHO VARGHESE

ABSTRACT OF THE THESIS

submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agricultural Statistics

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ABSTRACT

The study of interaction is one of the major objectives of most of agricultural experiments. Conceptually this is done based on regression technique. Among the interactions studied, two factor interaction derives its importance as it is the simplest of the interactions. The joint regression technique is employed to study the G x E interaction. The regression techniques are having the assumption of additivity of effects. When there is departure from these assumption the joint regression technique fails. Additive Main effects and Multiplicative Interaction studies have helped a lot at this juncture. Raju (2002) derived a more comprehensive measure of interaction based on AMMI model. This was achieved using the spectral decomposition of the relevant interaction matrix which enabled the study of interaction with the same precision as that of studying the main effects. Biplots formulations of interaction effects based on the PCA vector scores are the most simplest and explicit representation of interaction.

The study of interaction based on spectral decomposition has been illustrated using the secondary data on the biometric, chemical and qualitative characters from the projects "Development of a bimodal phasic management system to improve both quantity and quality in Kacholam (*Kaempferia galanga*)" and "Development of a bimodal phasic management system to improve both quantity and quality in Njavara (*Oriza Sativa*)".

The DMRT tests for each level of the factors viz., calcium and source were carried out for the parameters viz., percentage content of phosphorus in rhizome, percentage content of potassium in rhizome and North – South foliage spread. In all these characters no specific interaction effect could be sorted out. These interactions when studied based on the factor analytical technique revealed that source II and second level of calcium had the highest positive interaction as regards the percentage content of phosphorus; source III and third level of calcium for percentage content of potassium and source II and third level of calcium for North – South foliage spread.

When the order of the interaction matrix was high as in the case of the second experiment, DMRT tests failed to highlight the appropriate interactive effect in the

characters viz., grain yield, percentage content of nitrogen in grain, percentage content of phosphorus in grain, percentage content of phosphorus in straw and percentage content of potassium in straw. The study based on the factor analytical technique revealed that the treatments T_{15}, T_8, T_3, T_1 and T_4 respectively had the highest interactive effect with Payyanur for the above said characters where as for Badagara they were T_3, T_{14}, T_4, T_5 and T_8.