FORECASTING OF RICE YIELD USING CLIMATOLOGICAL VARIABLES

By

AJITHA T. K.

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DECLARATION

I hereby declare that this thesis entitled "Forecasting of rice yield using climatological variables" 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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Ajitha
AJITHA T.K.

CERTIFICATE

Certified that this thesis entitled "Forecasting of rice yield using climatological variables" is a record of research work done independently by AJITHA T.K., under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

P.V.PRABHAKARAN
Professor of Statistics
(Chairman, Advisory Committee)

Mannuthy,
5 - 4 - 1986.

APPROVED BY

CHAIRMAN

SHRI. P.V.PRABHAKARAN

MEMBERS

1. DR.C. SREEDHARAN

2. DR.R. VIKRAMAN NAIR

3. SHRI K.L. SUNNY

EXTERNAL EXAMINER:

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INTRODUCTION

1. INTRODUCTION

Forecasting the yield of agricultural crops is of prime importance to a nation from a number of view points. First, it helps in formulating an estimate of the expected production of the crop well ahead of harvest of the crop in the particular season. Such estimates are very useful for advanced planning for food and other relief measures in areas with impending crop failure; for determining the quantity of food to be purchased in case of expected shortage and aiding with decisions regarding withdrawals and additions to the national food resources. Another use of weather crop relationship is that it makes possible to know how much of the increase in production of different crops in a given year is due to the fluctuations in weather alone and how much due to the changes in technological and other factors. A knowledge of the weather factors that have direct effect on yield will help the farmer in taking appropriate decisions in relation to weather for the choice of crop, sowing, transplanting, scheduling of irrigation, fertilizer application and other management practices. Thus in short any strategy formulated for the development of agriculture in a country cannot be a complete success unless it takes into account the vagaries of weather on the crops.

Weather has a major control over crop production. In fact it influences every phase of agricultural activities from tillage to harvest and storage. In India crop production is marginal and solely dependent on the rains especially the south-west monsoon and other weather factors. In a detailed study by Sen (1967) the drop in total output of food in India was found to be 19 per cent during the year 1965-66 when there had been 50 per cent deficit in normal rainfall. Not only the amount of rainfall, but its time of arrival and distribution over the life span of the crop are also important. In India only 20 per cent of the net area sown has irrigation facilities and even this is not wholly assured (Sharma, 1970). Crop production is thus solely dependent on the vagaries of weather. In addition to rainfall other factors such as temperature, sunshine hours, humidity etc. also have to play their decisive roles in crop growth and yield. Incidence of pest and disease also depends to a large extent on the prevailing climatic conditions. Thus the risk associated with farming of a particular crop can be ascertained only after evaluating the effect of environmental factors.

In Kerala State, though the occurrence of drought was not very common in the past, the future chances of its occurrence are not remote. However, the drought conditions of the crop do not depend on rainfall deficiencies alone. The water loss taking place in the form of evapotranspiration, run off and deep percolation are to be considered vis-a-vis the water gain due to the occurrence of rain. Not only scanty rainfall but heavy rainfall also is detrimental to the plants. Frequent cloudy days in the life cycle of the plant adversely affect the duration of the solar radiation which is very essential for photosynthesis of the crop species. As per the available statistics, the percentage of total irrigated area to the total cropped areain Kerala State during 1980-81 was about 13 per cent and that for paddy the estimate turned out to be about 34 per cent (Anon., 1983). Summer crop of paddy which accounted to about 12 per cent of total acreage under paddy in Kerala is cultivated mostly under irrigated condition. A small portion of the area (Say about 20 per cent to 40 per cent) under paddy in the winter season is also irrigated. The autumn crop is grown practically unirrigated throughout the State. Therefore it follows that crop planning in the autumn season and preferably in the winter season should be based on basic information of weather parameters which could have direct effect on growth and production of the crop. All agricultural activities such as land preparation, sowing time, choice of varieties etc. are to be fixed and adjusted giving due regard to the prevailing and expected climatic conditions.

weather and yield forecasting are inseparably linked. While irrigation, mechanization and up-to-date cultural practices have given some measure of weather-proofing to crop yields, weather is still an important factor in determining the yield rates of crops.

Basically three types of models are used to analyse the influence of weather on crops. They are (1) simulation models (2) crop weather analysis models (based on the physiology of the crop system) (3) empirical or statistical models employed for prediction. Among the different statistical models some are univariate models which examine the effect of one meteorological factor on crop yield and others are the multivariate models which examine the joint effects of several variables on the crop yield. In simple correlation and regression studies, the final yield of a crop is charted against a single variable, usually monthly or total rainfall received during a crop growing season or the temperature during supposedly critical periods. Fisher's regression integral or response curve technique is another statistical approach which deals with the effect of a single meteorological variable on crop yield. It brings out the slow continuous changes in the response of a crop to the weather pattern by fitting a response curve which gives the average change in the yield of a crop associated with an additional unit of the meteorological factor, say rainfall at a specific point of time. It is very seldom that a single weather factor accounts for all of the variations from year to year in the yield of a crop. In such cases multiple linear regression analysis was attempted by several workers and crop forecasts made on the basis of the regression function. But such methods make use of the explicit assumption that the various meteorological factors are linearly related to crop yield and the validity of the assumption is not always unwarranted. It may happen that each additional unit of variation in the values of a meteorological factor above a supposedly optimum level may decline crop yield. There are also situations when the rate of change of crop yield per unit change in the value of a meteorological variable declines as it proceeds beyond certain limiting values. Curvilinear regression analysis has been often found to result in better forecasts in such situations and have been adopted by several workers. Several non-linear transformations are also available to 'linearize' the specific non-linear relationships between variables. Another closely related approach is to make use of the multiple linear regression and curvilinear regression analyses of crop yield on the values of selected meteorological variables during certain ' selected sensitive periods' of crop growth.

In the case of multiple linear regression, the predictability of the models increases with an increase in the number of independent variables which are retained in the functional form. At the same time simplicity and practical utility of the equations greatly diminish. Thus it is necessary to identify the major explanatory variables which are to be tried in the regression equation for forecasting. Two procedures are used to meet with this objectives. They are (i) Backward elimination process (2) Stepwise regression method. In the former method at first the full model with all the independent variables is fitted. The significance of each of the partial regression coefficients is tested using the student's 't' test and the variable with smallest t value is eliminated. The process is continued until a suitable prediction equation is evolved. The latter method is essentially a forward selection procedure, but with the added provision that at each stage the possibility of deleting a variable, as in backward elimination, is considered. In this procedure a variable that entered in the earlier stages of selection may be eliminated at later stages. The calculations made for inclusion and deletion of variables are the same as forward selection and backward elimination procedures. Often different levels of significance are assumed for inclusion and exclusion of variables from the equation. However, the independent variables will be highly interrelated leading to the problem of multicollinearity among the variables. Principal component analysis is attempted in such situations which consists in transforming the original set of P correlated variables into a set of P orthogonal variables that are linear functions of the original variables. The derived variables are then used as explanatory variables in multiple linear regression analysis for forecasting.

Weather based yield prediction can be made throughout the life cycle of the crop. But some disadvantages are also there for the weather based estimates. They are (1) possibility of imperfect and incomplete mathematical relationships leading to large errors in seasons with anomalous weather, (2) inability to account for the influence of insects and epidemics of diseases (3) the inadequacy of weather stations and (4) the possibility of interactions between environmental and genotypic factors.

Rice (Oryza sativa L.) is the basic food for more than half of the population of the World. The crop grows mainly in the plains of tropical and subtropical regions under continuously flooded conditions. Rice is grown in India in an area of about 40 million hectares with an annual production of about 54 million tonnes. The average yield is very low being 1,340 kg/ha only (Tomar, 1985).

In general rice requires a growing period of 120 to 150 days with a short photo period, less than 14 hours, temperatures above 15°C, sufficient water for the rate of evapotranspiration and abundant sunshine. Many areas have bioclimatic limitations which may restrict the potential yield of rice. Agrometeorology can play a very important role in quantifying these conditions and interpreting them in terms of expected returns. In Kerala, the three main seasons for rice are fairly well-defined, the Virippu or the autumn crop followed by the Mundakan (winter crop) and the typical Punja - the summer crop. Being situated on the windward side of the Western ghats and coming within the direct sweep of the South-west monsoon, the State receives a heavy rainfall, the annual precipitation working out to an average of 2977 mm. Extremes of heat and cold are unknown in Kerala, the average maximum temperature is 33.62°C and the average minimum temperature is 21.03°C. The humidity however, is rather high, the average comes to around 83.22 per cent maximum relative humidity and 71.59 per cent minimum relative humidity (Anon., 1983).

In Kerala State, the total area under paddy comes to be 7.78 lakh hectares and the total production comes to be

13.1 lakh tonnes. In the State, the district of Palghat leads both in area and production of rice. In this district, the area under paddy comes to be around 1.73 lakh hectares and production 3.65 lakh tonnes (Anon., 1985). The amount of total rainfall that can be expected at Pattambi (Palghat district) with a confidence of 80 per cent was estimated to be between 1919 and 3293 mm (Thomas, 1977). Rice being an important food crop cultivated in the district, a study of the effect of weather on the crop and forecasting of its yield well advance of harvest deserve serious attention. The present study based on the data relating to the co-ordinated crop weather experiments conducted at the Rice Research Station, Pattambi for the period 1949-50 to 1973-74 was therefore undertaken with the following objectives.

1. To forecast yield of paddy through selected weather parameters well advance of harvest.
2. To compare the relative efficiencies of different yield forecasting functions.
3. To study differential response between varieties, if any, with regard to the action of meteorological factors.
4. To study the individual as well as joint effects of meteorological factors on crop yield.

5. To examine the influence of varying dates of sowing on yield rate.

6. To develop few composite variables to serve as ' weather indices' for the purpose of yield prediction and modelling.

7. To examine the effect of different climatological variables at various growth phases of the crop in increasing crop output.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Intensive work on crop weather relationship and preharvest forecasting of yield of crops based on environmental data have been done in India and abroad by meteorologists, statisticians and others. A short review of the available literature on the subject relating to annual crops especially on paddy is given below under different sub headings.

2.1. Rainfall

Fisher (1924) developed a special statistical technique known as the ' regression integral' which consisted in fitting orthogonal polynomial functions to describe the slow continuous response of crops to the various weather elements. He applied the method first to study the effect of rainfall on the yield of wheat at Rothamsted. The study revealed that it was the distribution of rainfall during a season rather than its total amount which influenced crop yield.

Kalamkar and Satakopan (1941) examined the influence of rainfall on cotton yield at the government experimental farm Akola and Jalgaon by the use of harmonic analysis.

The effect of weather on the yield of maize crop in Kenyan highlands was studied by Glovar (1957). He found that total rainfall in the growing season of the crop had a curvilinear relationship with yield and so he suggested a prediction equation of the form $Y = A X^{b} e^{-ax}$ where Y was the yield, X was rainfall and A, b and a were constants.

An attempt was made by Shrikande and Chaudry (1965) to investigate the influence of certain climatological factors on the yield of paddy using time series data from 1949 to 1962 collected from central Rice Research Institute, Cuttack. The multiple linear regression equations were successful to explain 83-98 per cent variation in yield under different treatments. The amount of rainfall and the number of rainy days or the associated factors like sunshine hours in August and September appeared to influence the yield considerably.

Williams and Robertson (1965) tried regression technique to analyse wheat production in relation to precipitation and Williams (1969) extended the study by including potential evapotranspiration also as an additional variable in the multiple linear regression analysis.

Tanaka <u>et al</u>. (1966) were of the opinion that in the rainy season growth rate of rice plant was higher at early stages but it became slower and sometimes even negative at later stages. On the other hand in dry season the growth rate was slow at early stages but it was kept almost constant till the end. Generally a high early growth rate whether caused by a varietal character, heavy nitrogen or seasonal effect was frequently associated with a lower rate at later stages resulting in lower grain yield.

Sreenivasan (1968) conducted a systematic study of rainfed paddy at Karjat in Maharashtra, Chinsurah in West Bengal and Pattambi in Kerala. He used the Fisherian regression integral technique for data analysis and found that 72 per cent of total variation in yield at Pattambi could be accounted by variations in rainfall during the cropping season.

Based on a study to examine the effect of total rainfall and its monthly distribution on cotton yields at Indore and Khandwa, Singh and Kapse (1969) found that relatively high amount of rainfall received during the months of July, August and September had adversely affected the crop yield.

Das (1970) used regression analysis for the issue of monthly forecasts of the yield of paddy on the basis of weather parameters during kharif season for certain homo-climatic regions. In the case of Kerala number of rainy days during the period from 16th April to 15th May and the number of occasions of drought and flood during the period from 16th June to 31st August contributed significantly towards yield.

Ghosh (1970) reported that neither rainfall nor number of rainy days had any appreciable effect on the yield of rice grown under irrigated condition. However he observed a strong detrimental effect for number of rainy days at the ripening phase on crop yield.

The method of regression analysis was employed by Das <u>et al</u>. (1971) for the forecast of the yield of autumn paddy in Mysore State. In coastal Mysore, frequency of occurrence of drought and floods during August and September was a weather factor which had significant effect on yield. In the interior Mysore south, June and September rainfall had significant effect on yield.

Joshi and Kabaria (1972) studied the effect of rainfall distribution on the yield of bunch groundnut in Saurashtra and they found that neither the total rainfall nor the distribution of rainfall had any effect on the yield. However, they observed significant correlation between the quantity of rainfall received during the period from full pegging to pod development in favourable seasons which occured once in three years.

A comparison of two statistical methods (i) Fisher's regression integral which exhibited slow continuous changes in the response of crop to weather pattern and (ii) Regression function which gave a few well defined weather periods of significance to the soil and crop was done by Sreenivasan (1972). In the case of wheat crop at Jalagaon and Niphad the regression function resulted in higher amount of precision than the regression integral. This might be due to the differential response of some of the adjacent phytophases of the crop and the changing soil characteristic to the weather factors.

Fisher's method was used by Lomas and Shashova (1973) to find out the relation between rainfall and wheat yields. Assuming a constant average rainfall, additional rainfall prior to sowing or during the period of germination and initial growth stages of the crop was found to be beneficial to the crop. Where as additional rainfall over and above the average received during mid-winter (end of January and February) and towards the end of the crop growing season (March and April) affected the crop adversely.

Sreenivasan (1973) examined the influence of rainfall on the yield of cotton for Khandwa and Indore in Madhya Pradesh using the Fisherian technique of regression integral and also by multiple regression analysis. Five out of six and three out of six rainfall distribution constants showed significant correlations with yield for Khandwa and Indore respectively. For both the stations additional rain during growth and boll formation periods exerted detrimental effects on the crop.

The influence of rainfall on the yield of rainfed rice at Karjat, Colaba district was studied by Sreenivasan and Banerjee (1973) using the Fisher's response curve technique and the method of screening of the data for sensitive periods of response. The multiple correlation coefficients calculated with and without the removal of trend were not significant indicating there by that the integrated influence of rainfall on rice at Karjat was not of serious consequence. The crop appeared to respond favourably to rain during the critical phase of panicle primordial initiation. Rainfall in the period immediately preceding harvest was found to cause depression in yield.

Sreenivasan (1974) used Fisher's regression integral technique to evaluate the influence of rainfall on the yield of wheat varieties grown at Jalgaon and Niphad in Madhya Pradesh. The results showed that any amount of rain received during the three weeks immediately before sowing and that during the germination phase would be beneficial to the crop in both the Stations.

In a study on the effect of rainfall on sorghum, Ali (1975) observed a significant and positive association between yield and rainfall during May. Further he found that the total rainfall received in the month of August and September explained about 90 per cent variation in sorghum yield.

Devanathan (1975) used the rate of dry matter production in different periods of plant growth as the dependent variable in place of yield in the correlation analysis and observed significant results in his studies on maize.

Pochop *et al.* (1975) found that the influence of added rainfall on winter wheat production in eastern wyoming was dependent upon the time at which it was received. Added rainfall was greatly responsible for increased wheat production if it was received in the middle portion of the growing season while it had negative effects if it was received late in the season.

Shaha and Banerjee (1975) made use of the Fisher's response curve technique to examine the influence of meteorological parameters on yield of cotton crop at Coimbatore. They found that rainfall and hours of sunshine should be more than their normal values for a good crop.

The distribution pattern of area under rice and the production potentiality of the crop in different parts of India were apparently governed by the onset and withdrawal of monsoon, the distribution of rainfall and the extent of irrigation facilities, available in the different regions (Chatterjee and Maiti, 1979).

Bhatia (1983) showed that rainfall in June had significant positive impact on the yield of paddy in the States of Andhra Pradesh, Karnataka, Madhya Pradesh and Orissa. This was because rains in June helped for timely raising of the nursery and transplantation of paddy which in turn had positive effect on yield of the crop. The study also revealed the profound influence of October rains on crop yield in the States of Assam, Bihar, Kerala, Orissa and West Bengal.

Jahagirdar and Thote (1983) revealed that instability in the occurrence of rainfall during the period from 4th June to 12th August would adversely affect productivity of rice. They also found that total rainfall received during the Kharif season had adverse effects on rice yield but frequent occurrence of dry spells during the period from 1st October to 4th November was found to favour crop production.

Sarwade (1983) concluded that occurrence of dry spells of longer duration than 8 days during the months of July and August drastically diminished the yield of kharif rice.

2.2. Number of hours of sunshine

According to Matsushima (1957) the total quantum of light energy received by the plant for a continuous period of 18 days before flowering was decisive in grain formation and any reduction in its intensity would result in the size of husk and limit grain size of paddy.

Yamagupta (1958) found that number of tillers and number of ears of paddy increased with an increase in the intensity and quantity of light energy.

Osada and Murata (1965)have shown that panicle production in paddy could be considerably influenced by light energy.

Ota and Yamada (1965) reported that grain filling in paddy would be very poor in the absence of light.

Stansel (1966) opined that light energy during the vegetative phase of crops was not found to limit the growth and yield of crops. On the basis of extensive investigations he concluded that solar radiation received during the three weeks immediately before and three weeks immediately after flowering was very crucial in determining grain yield of paddy

According to Hayashi (1967) solar radiation had a profound influence on rice yield. A high positive correlation was recorded between the amount of solar radiation received one month before harvest and grain yield.

An experiment was conducted by Moomaw et al.(1967) at Los Banos to study the response of paddy to different dates of planting and they concluded that yield of rice was greater when harvesting period coincided with the period of maximum solar radiation.

The effect of environment on crop yield was examined by Katayama (1970) in 24 species of rice. Seven species were unaffected by climatic conditions while seven others varied inconsistently with climate. In nine species, time of flowering was dependent upon day length but in one species its reliance was on maximum temperature.

Murata and Togari (1972) found that solar radiation during the three weeks before and the four weeks after heading had shown strong association with spikelet production in paddy.

Yoshida (1972) observed that quantity of solar radiation absorbed by the plant at initial growth stages would not limit grain yield in rice but as the plant grew and produced more number of leaves it became less efficient and mutual shading of lower leaves by upper leaves limited the utilization of available sunlight.

In sorghum, a marginal decrease in light intensity to 75 per cent of the normal sunlight increased plant height, node number, internodal length and leaf length but caused a substantial decrease in the width of leaves, dry weight and grain yield (Bhatt and Seshadrinathan, 1975).

Murata (1975) studied the effect of climatic factors on the yield of rice in Japan by using simulation models. He found that the most important climatic factor which controled rice yield was solar radiation or sunshine hours during the period from booting to active grain filling in middle and southern regions, but it was mean air temperature during the same period in Northern regions.

Based on the results of a field trial on paddy conducted at Cuttack, Orissa, Sreedharan and Vamadevan (1976) claimed that solar radiation and air temperature were the most important factors governing evapotranspiration in rice.

Murty and Murty (1981) computed simple correlation coefficients between climatic factors and spikelet sterility in rice and found that solar radiation at different periods of reproductive and ripening stages especially on the day of anthesis was significantly and negatively associated with sterility.

2.3. Temperature

Sato (1956) studied the effect of temperature on rice yield and concluded that highest yields were associated with mean temperature of 27°C and 400 hours of sunshine in two months of the ripening period.

When rice plants in their early stages of grain development were subjected to high temperature, Nagato and Ebata (1960) observed a high percentage of chalky grains at about 10 days after flowering and an acceleration in their development and in maturation.

Gangopadhyaya and Sarker (1964) applied the technique of curvilinear regression in studying the effect of meteorological factors on the growth of sugarcane. They found that at Poona the maximum and the minimum temperature influenced elongation most and their optimum values were equal to 87.5°F and less than or equal to 68°F respectively.

Ramamurti and Banerjee (1966) attempted a curvilinear regression study of weather factors on wheat yield at Dharwar by using the successive approximation technique and found that a minimum temperature of about 16°C, a maximum temperature of about 29.3°C and a mean temperature in the range 22° to 23°C were most favourable for wheat production.

As per the findings of Nel and Small (1969), temperature upsets the balance between photosynthesis and respiration. According to these authors low night temperature was expected to increase ear number, grain number per ear, grain yield of rice, 1000-grain weight and straw yield, but need not necessarily affect number of ears per plant.

Vergara and Visperas (1970) found that improved rice varieties such as IR 8 were relatively insensitive to photoperiod but their growth would be delayed by low temperature.

According to Hoshino et al. (1972) there was a strong influence of temperature on dry weight, tiller number and carbohydrate content of rice.

Shaha and Banerjee (1975) revealed that a lower minimum temperature during sowing period and high maximum and minimum temperatures during flowering were beneficial for better cotton crop.

According to Sarwade (1983), temperature and other weather factors did not exert any significant influence on the yield of kharif rice.

2.4. Humidity

Balasubramaniam (1965) noted that the range of humidity varied between 78 to 86 per cent during years with comparatively very high rice yields.

According to Ghildyal and Jana (1967) relative humidity of the atmosphere would influence the rate of transpiration and the increased or decreased transpiration might influence the physiological processes affecting crop yield. They also found that cooler weather, low relative humidity, medium evaporation, bright sunshine hours and shallow flooding were the most favourable agrometeorological environment for maximum rice production.

Murata and Togari (1972) observed a negative correlation between rice yield and relative humidity and this infact could be attributed to the positive influence of solar radiation.

Shaha and Banerjee (1975) pointed out that higher humidity during the time of elongation and branching of the crop was useful for increased cotton output.

A study on rice by Sreedharan (1975) revealed that relative humidity had not extended any influence on the various growth and yield attributes of the rice crop. The effect of relative humidity was in fact masked by either solar energy or by temperature.

2.5. Effect of weather at different phases of crop on yield

Mayr (1967) observed positive correlation between solar radiation at the vegetative phase and grain yield of paddy.

Sreenivasan (1968) noticed that at Pattambi and Chinsurah, rainfall received in the week of transplanting and that in the elongation phase were detrimental to paddy where as that during the tillering, flowering and postflowering phase was beneficial. According to him higher mean temperature at the time of transplantation and elongation of the crop was detrimental where as the same received during the tillering and ripening phases exerted beneficial effects. Bright sunshine at very early stages of tillering, panicle emergence and the ripening phases seemed to be conducive for crop growth and yield.

DeDatta and Zarate (1969) observed a significant and positive correlation between temperature during the ripening period of the crop and rice yield.

A negative correlation between rice yield and rainfall at the ripening period of crop growth was obtained by Murata and Togari (1972).

Huda et al. (1975) employed a second degree multiple regression equation in quantifying the relationship between rice yield and weather variables. According to them above average weekly total rainfall and above average minimum daily temperature received during the nursery period of the crop had significant positive effects on yield.

A study on paddy by Sreedharan (1975) revealed that minimum and maximum air temperature at the vegetative phase were significantly and negatively correlated with grain number. Minimum air temperature at the reproductive phase and summation of minimum air temperature throughout the crop growth period were negatively correlated with number of grains/m^2.

Tomar (1975) studied the effect of weather factors at different stages of crop growth. According to him if the total amount of rainfall in each week during the nursery period was 1 mm above the average value, beneficial effect on rice yield was realised whereas higher amount of rainfall received during the vegetative phase resulted in adverse effects. Similar was the result during the reproductive phase also. Further, there should be clear sunny days and increased sunshine hours in the ripening phase for better production.

The behaviour of the Co-25 variety of irrigated rice was examined by Sreenivasan and Banerjee (1978) under two environments in Aduthurai. Number of hours of sunshine received at the time of panicle emergence and maximum temperature during the period from the later half of tillering to the middle of the elongation phase was found to be positively correlated with yield. Relative humidity at maximum epoch during tillering phase and minimum temperature during the week of harvest showed negative linear relationships with the yield.

A study of the individual effects of weather variables on rice yield, by Agrawal et al.(1983) indicated that the crop reacted differently to different climatic variables during different stages of its growth. Above average maximum daily temperature had a small beneficial effect during the active vegetative phase while its effect during the other phases of the crop were negative. Above average relative humidity had small beneficial effects during initial growth, lag vegetative and reproductive phases while small adverse effects during active vegetative and ripening phases. Increase in relative humidity and number of rainy days had beneficial effects in general through out the cropping season. Effects were pronounced in later part of the reproductive phase. Increase in rainfall was beneficial through out the cropping season suggesting that crop production could be increased by supplying additional water.

2.6. Joint effects of weather variables.

2.6.1. Weather indices and composite regression models

Tullis (1934) has reported that high temperature accompanied by increased wind velocity on clear bright days would cause scald of paddy.

A weather index $W = R + T(80-T)$ where R was rainfall in centimeter and T was mean temperature in degree centigrade was developed by Bean (1964).

Murata (1967) found a positive correlation between rice yield and solar radiation in the northern regions of Japan where the temperature was low while there was no positive correlation between them in the southern regions where the temperature was high. This was attributed to the maskening effect of high temperature on favourable effect of solar radiation.

A second degree orthogonal polynomial model was used by Runge (1968) to examine the joint effects of maximum daily temperature and rainfall on corn yield. It was found that the effects were more pronounced one week before anthesis and remained at constant level thereafter.

According to Yoshida and Ahn (1968) the starch content in rice during wet season was remarkedly low as compared to that during the dry season due to the combination of relatively high temperature with low solar radiation resulting in less net photosynthesis in wet season.

Lange as quoted by Dubey (1970) assumed that the effectiveness of rainfall was directly proportional to total precipitation and inversily proportional to the mean temperature and suggested a simple weather index I = P/T.

Lee (1971) stressed that rice yield was significantly affected by temperature and radiation during the period from 20 days before to 20 days after flowering.

According to Sato (1971) high temperature along with low relative humidity was more conducive to ripening in rice.

A high solar radiation accompanied by a low temperature during 25 days period before flowering was found to give maximum rice yield at Los Banos (Anon; 1974).

Agrawal *et al.* (1980) developed two models for forecasting the yield of rice in Raipur district. In the first, weighted averages of weekly weather variables and their interactions using powers of week number as weights were used. The respective correlation coefficients with yield in place of week number were taken in the second model. The stepwise regression technique was followed for obtaining the forecasting equations. The first model was

$$Y = Ao + \sum_{i=1}^{P} \sum_{j=0}^{2} a_{ij} Z_{ij} + \sum_{i \neq i'=1}^{P} \sum_{j=0}^{2} b_{ii'j} Q_{ii'j} + CT$$

Where Y = crop yield , Ao, a_{ij}, $b_{ii'j}$

($i \neq i' = 1,2,..P$, $j = 0,1,2,$) and C were constants.

P = no. of weather variables, T = year no. included to correct for the long term upward or downward trend in yield.

Z_{ij} and $Q_{ii'j}$ were generated first and second order variables defined as

$$Z_{ij} = \sum_{w=1}^{n} w^j X_{iw} \Big/ \sum_{w=1}^{n} w^j$$

$$Q_{ii'j} = \sum_{w=1}^{n} w^j X_{iw} X_{i'w} \Big/ \sum_{w=1}^{n} w^j$$

n = no. of weeks upto the time of forecast

w = week identification; X_{iw} was the value of the i^{th} weather variable in the w^{th} week. Second model was

$$Y = Ao + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} Z'_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=0}^{2} b_{ii'j} Q'_{ii'j} + CT$$

$$Z'_{ij} = \sum_{w=1}^{n} r^{j}_{iw} X_{iw} \Big/ \sum_{w=1}^{n} r^{j}_{iw}$$

$$Q'_{ii'j} = \sum_{w=1}^{n} r^{j}_{ii'w} X_{iw} X_{i'w} \Big/ \sum_{w=1}^{n} r^{j}_{ii'w}$$

r_{iw} = the correlation coefficient of Y with the i^{th} weather variable in the w^{th} week

$r_{ii'w}$ = the correlation coefficient of Y with the product of the i^{th} and i'^{th} weather variables in the w^{th} week. Two weighted weather indices taking all significant generated variables into consideration were constructed. In the first one, correlation coefficients were taken as weights where as in the second one standardized partial regression coefficients were taken as weights.

Rao (1980) attempted to examine the effects of rainfall and temperature and their interactions on the yield of tossa jute. He used a second degree orthogonal polynominal of the form,

$$
\begin{aligned}
Z = Ao &+ a_o \left(\sum_{i=1}^{n} t_i^{o} x_i\right) + b_o \left(\sum_{i=1}^{n} t_i^{o} Y_i\right) + C_o \left(\sum_{i=1}^{n} t_i^{o} X_i Y_i\right) \\
&+ a_1 \left(\sum_{i=1}^{n} t_i^{1} X_i\right) + b_1 \left(\sum_{i=1}^{n} t_i^{1} Y_i\right) + C_1 \left(\sum_{i=1}^{n} t_i^{1} X_i Y_i\right) \\
&+ a_2 \left(\sum_{i=1}^{n} t_i^{2} X_i\right) + b_2 \left(\sum_{i=1}^{n} t_i^{2} Y_i\right) + C_2 \left(\sum_{i=1}^{n} t_i^{2} X_i Y_i\right) \\
&+ DT
\end{aligned}
$$

Where Z was the fibre yield, X was the average weekly maximum temperature (°C), Y was the total weekly rainfall (cm), t was the number of the weekly period commencing from germination, T was the serial number of the year which was included to correct the trend in yields. The study revealed that about 87 per cent of the total variation in jute yield could be explained by the polynominal model.

Agrawal et al. (1983) revealed that beneficial effects of above average maximum temperature on rice yield increased with rise in humidity while detrimental effects decreased. Joint effects of maximum temperature and rainfall showed that beneficial effects of above average maximum temperature on yield increased with increase in rainfall while adverse effect decreased in general.

2.6.2. Principal component analysis

Kutzbach (1961) Clarke and Peterson (1973) used Principal component analysis to determine the relationships between various meteorological variables.

Principal component regression technique was applied by Fritts et al. (1971) to relate tree-ring growth to climatic change.

Pochop et al. (1975) performed principal component analysis using the climatological data, which consisted of 42 variables for eight countries and 45 years. Thirty one out of 42 components explained 90 per cent of the variance in the original datacomplex and were retained for regression analysis. The principal components regressed against country wheat yield data resulted in the regional production model of the form

$$Y_q = \beta_0 + \beta_1 m_{1q} + \ldots\ldots \beta_p m_{pq}$$

where $\beta_0, \ldots\ldots\ldots\ldots \beta_p$ were the regression coefficients, Y_q was the estimated yield in year q, and m_{1q} ... . m_{pq} were the P principal components for the year q. The regression model accounted for 54 per cent of the variation in yield.

Principal components of the generated variables were obtained and used in regression instead of the original weather variables by Agrawal et al. (1980). The regression equation could explain 80 per cent of variation in yield. It was also revealed that forecasting of rice yield was possible by weekly climatic variables, 2½ months after sowing for a crop of five months duration.

2.7. Effect of date of sowing on crop yield

Palaniswamy *et al.* (1968) studied the effect of time of sowing on duration, yield and other components of paddy yield with reference to day length and temperature. They did not find any significant effect due to time of sowing on yield components except in the number of grains per panicle. Low yields and delayed flowering were recorded for the crop when sown after September while relatively high yields were resulted when the sowing was in the later half of August.

Singh *et al.* (1975) have reported that sorghum yield was higher when it was planted as early as in June than that planted in July.

De *et al.* (1983) observed that the productivity of dryland unirrigated wheat could be increased considerably by adjusting the date of sowing to conducive atmospheric temperatures.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The data utilised for the present investigation were collected from the available records of the meteorological observatory of the Rice Research Station, Pattambi (latitude 10° 48'N, longitude 76° 12'E, altitude 200 m) located in Palghat district of Kerala State. Systematic observations on daily weather and grain yield of four varieties of paddy grown in two distinct seasons of the year relating to the period from 1949-50 to 1973-74 were used for statistical analysis. The year 1949 for the winter season and the year 1972 for the autumn season were excluded from the analysis due to certain abnormalities. The tract enjoyed a warm humid tropical climate and received a good amount of rainfall through south west monsoon and some amount through north east monsoon. Total rainfall at Pattambi during the year 1981 was about 3270. 1 mm which was well above the State total rainfall of the year (Anon., 1983). The soil of the research station was of sandy loam type with good water-holding capacity. The experimental fields of the research station are situated at a place quite close to the meteorological observatory.

Crops were grown as rainfed in both the seasons. The PTB varieties PTB 1 and PTB 5 were under observation in the autumn season whereas PTB 12 and PTB 20 had their turn in the winter season. These photo sensitive and medium duration varieties were very popular in the Palghat tract during the period under report. The duration of the varieties PTB 1 and PTB 5 was in the range of 130 days to 145 days while that for PTB 12 and PTB 20 was from 110 days to 135 days. In both the seasons rice seedlings were transplanted at the rate of two seedlings per hole with a mean distance of 15 cm either way.

Daily meteorological observations on various climatic variables such as total rainfall (mm), number* of rainy days, total hours of sunshine (h), maximum temperature (°C), minimum temperature (°C), maximum relative humidity (%), minimum relative humidity (%) and wind velocity (km/h) were available for the period under report. Data on the date of sowing of the crop, date of transplanting, and the date of harvesting were also recorded at the agrometeorological observatory.

3.1. Test for the presence of Trend

The first thing to ponder after getting a time series data is to decide whether there is any upward or downward trend presented in the data. With this purpose in mind the bivariate data (t_i, y_i) are plotted graphically and the number of peaks or troughs in the series counted. A ' peak' is a value which is greater than the two neighbouring values.

* A day with a total precipitation of 2mm or above is considered here as a rainy day.

Likewise a 'trough' is a value which is lower than its two neighbours. Both peaks and troughs are considered as turning points of the series. The number of turning points is clearly one less than the number of runs up and down in the series. The statistical significance of secular trend is then tested by using the Z - statistic (Kendall 1958) given by

$$Z = \frac{n - E(n)}{S.E(n)} \qquad (3.1)$$

where n = observed number of turning points in the data

$$E(n) = \frac{2\,(N-2)}{3}, \quad S.E.\ (n) = \sqrt{\frac{16\,N - 29}{90}}$$

N being total number of observations.

Z is expected to follow the Student's t distribution

If the value of Z is not significant at a pre selected level of probability then the conclusion is that there is no long term trend in the series.

3.2. Fortnightly and monthly forecasting of paddy yield

The weekly weather parameters of the successive weeks starting from one week prior to sowing to the twelfth week after sowing were determined from the daily meteorological data and were correlated with crop yield in the particular season. For the varieties PTB 1 and PTB 5, 24 years data were available for the weather variables, total rainfall, temperature and relative humidity, 21 years data for number of hours of sunshine and 16 years data for wind velocity. For the variety PTB 12, 21 year's data were available for wind velocity and 24 years data for all other variables. In the case of PTB 20 the yield data were available only for 23 years and hence meteorological data for the same period above could be used for the studies. As the time series was not long enough to include a large number of explanatory variables a preliminary selection of variables had to be attempted. This was done in accordance with relative magnitudes of the simple correlation coefficients of the weekly weather factors with yield. Only those variables which showed significant linear relationship with yield at a particular level of significance were selected for inclusion in the regression equations. A term representing secular trend also has to be included in the model in case the effect of trend is found to be significant. A class of multiple linear regression equations were fitted for making fortnightly and monthly yield forecasts of PTB varieties based on weekly weather data and the adequacy of the fitted models determined on the basis of the relative values of the adjusted coefficient of determination ($\bar{R}^2$) . Since the data for wind velocity were available only for few years the same could not be included for regression analysis. According to the availability of data a 21 year series of crop and weather data was used for regression analysis in the autumn season and a 23 year series of crop weather data was used for the same purpose in the winter season. Yield forecasts were attempted upto the end of the third month after sowing. As a further step, an attempt was also made to establish general yield forecasting formulae for PTB varieties from weekly weather parameters by regressing the relevant climatological variables on the observed mean yield of paddy (disregarding varieties) in the particular season.

3.2.1. Multiple linear regression analysis

The technique of multiple linear regression deals with the problem of predicting a 'dependent variable' Y from a set of p'independent variables', X_1, X_2.......X_p, P>1. The functional form of the multiple linear regression is given by

$$Y_i = \beta o + \beta 1 \, X_{1i} + \dots\dots\dots\dots + \beta p \, X_{pi} + CT + e_i \quad - \quad (3.2)$$

Where βo is a constant, βi's are partial regression coefficients of Y on X_i. The error term e_i is assumed to follow a normal distribution with mean 'o' and constant variance σ^2. The term CT is the correction for trend if it is presented in yield data. C is a constant and T is the year number included for the correction. The term 'linear' refers to linearity in the parameters and not in the independent variables. The independent variables X_i need not always be statistically independent but are expected to be measured without error. The parameters βo, $\beta 1$ ....β_p are estimated by the principle of ordinary least squares. If b_1, b_2, ... b_p are the least square estimates of $\beta 1$, $\beta 2$ ....βp the normal equations for obtaining them are given by

$$\underline{S}\, iy_{px1} = \underset{\sim}{S}\, ij_{pxp} \; \underline{B}_{px1} \qquad - \qquad (3.3)$$

Where $\underline{S}$ iy is the vector of sum of products of the i^{th} independent variable with the dependent variable. $\underset{\sim}{S}\, ij_{pxp}$ is the sum of squares and sum of product matrix of the P explanatory variables, $\underline{B}_{px1}$ is the vector of constants.

$$\therefore \; \underline{B}_{px1} = \underset{\sim}{C}\, ij_{pxp} \; \underline{S}\, iy_{px1} \qquad - \qquad (3.4)$$

where $\underset{\sim}{C}\, ij_{pxp}$ is the inverse of the matrix of sum of squares and sum of products. Further

$$b_o = \bar{Y} - \sum_{i=1}^{p} b_i \bar{X}_i \qquad - \qquad (3.5)$$

Thus the estimated value of the dependent variable could be obtained as

$$\hat{Y} = b_o + \sum_{i=1}^{P} b_i X_i \qquad - \qquad (3.6)$$

As a consequence of the Gauss - Markov theorem the predicted value Y has a minimum variance among all linear predictors of Y for given values of $X_1, X_2 \ldots\ldots\ldots X_p$. The proportion of variation of Y explained by the regression of Y on $X_1, \ldots\ldots\ldots X_p$ is calculated by the ratio,

$$R^2 = \sum_{i=1}^{p} \frac{bi \quad S_{iy}}{S_{yy}} \qquad - \qquad (3.7)$$

Where S_{yy} is the total sum of squares of the values of dependent variable y.

The coefficient of determination, R^2, thus provides with a measure of 'goodness of fit'. That is, larger the R^2, better the model approximates y.

The statistical significance of R^2 is tested by employing the variance ratio test given by

$$F = \frac{R^2}{1-R^2} \times \frac{n - p-1}{p} \qquad - \qquad (3.8)$$

The hypothesis Ho : $\beta k = 0$ for $k = 1, 2, \ldots\ldots\ldots p$ may be viewed as a hypothesis that 'the variable X_k does not significantly improve the prediction of y over that obtained by regressing y on the other (p-1) variables'. One test statistic for the test of this hypothesis against the alternative hypothesis, $H_1 : \beta_k \neq 0$ is

$$t = \frac{b_k}{SE(b_k)} \qquad - \qquad (3.9)$$

Where $SE(b_k) = \sqrt{C_{kk}}$ M.S.E., C_{kk} is the diagonal element of the inverse of the sum of squares and sum of product matrix and M.S.E. is the error mean square.

Under the null hypothesis the above ratio has a student's 't' distribution with n-p-1 degrees of freedom.

The intermediate hypothesis that a subset of m regression coefficients is zero is tested by F statistic given by:

$$F = \frac{(SSR' - SSR)}{M.S.R.} \Big/ m \qquad - \qquad (3.10)$$

Where SSR' and SSR denote the residual sum of squares of the full model and reduced model respectively and M.S.R. the error mean square of the full model.

One defect of coefficient of determination as a measure of predictability is that it does not take into account the number of degrees of freedom associated with the relevant variables and hence is of limited use in comparing the relative efficiencies of different models based on varying number of observations. As a solution to this problem the calculation of adjusted coefficient of determination ($\bar{R}^2$) has been suggested by many workers.

Pindyck and Rubinsfield (1981) have indicated many properties of adjusted R^2 which make it a more desirable goodness of fit measure than R^2. When new variables are added to a regression model, R^2 always increases while $\bar{R}^2$ may rise or fall. The difficulty with R^2 as a measure of goodness of fit is that it pertains to the explained and unexplained variation in Y and therefore does not account for the number of degrees of freedom in the problem. A natural solution is to concern oneself with variance, not variations. Thus eliminating the dependence of R^2 on the number of independent variables in the model. Hence the adjusted coefficient of determination $\bar{R}^2$ is defined as

$$\bar{R}^2 = 1 - \frac{\mathrm{Var}(\hat{E})}{\mathrm{Var}(Y)} \qquad - \qquad (3.11)$$

$$\mathrm{Var}(\hat{E}) = S^2 = \frac{\sum (\hat{Y}_i - \bar{Y})^2}{n-p-1}$$

$$\mathrm{Var}(Y) = \frac{\sum (Y_i - \bar{Y})^2}{n-1}$$

It is easy to derive the relationship between R^2 and $\bar{R}^2$

$$\bar{R}^2 = 1 - \left\{(1-R^2)\ \frac{n-1}{n-p-1}\right\} \quad - \qquad (3.12)$$

3.2.2. Backward elimination process and Stepwise regression process for model fitting.

In many regression situations the experimenter does not have sufficient information about the order of importance of the independent variables X_1, X_2 ....X_p in predicting the dependent variable Y. If some of the X variables contribute little or nothing to the accuracy of prediction, attempts may be made to get a simpler prediction model providing with sufficient degree of precision. One solution to the above problem is to regress Y on all possible subsets of independent variables and then to select the best subset of variables for prediction. For each possible subset of size k, K = 1, ... P, one may select the subset S_k yielding the largest multiple correlation coefficient. If S_m is the best subset of variables in predicting Y then S_m gives the largest multiple correlation coefficient in m variables and the remaining (p-m) variables do not significantly improve the predictability of Y. But when the number of independent variables is large it becomes impractical even with the availability of high speed computers to determine the best subset using this procedure. In fact, when there are P variables there are 2^P-1 regression equations to be fitted and the time and expense involved necessitates finding other methods for solving the problem. Backward elimination process and stepwise regression process are two elegant approaches which are commonly applied for model fitting in linear regression.

3.2.2.1. Backward elimination process

In this method, first the experimenter fits the regression equation containing all potential x variables. The statistical significance of the regression equation is then tested by F test. If the regression is not statistically significant then there exists no appropriate linear model with these variables for yield forecasting. Otherwise examine the relative importance of the different X variables by using the student's 't' test. The null hypothesis tested is that the proportionate contribution of the i^{th} variable towards variation in Y is zero (that is $H_0: \beta_i = 0$, $H_1: \beta_i \neq 0$). Select the least important variable as the one having the smallest non-significant 't' value at a pre selected level of significance. Drop this variable from the model and compute the regression equation again. The reduction in the value of coefficient of determination will be noted. The process is terminated at a stage when no variable is qualified for omission.

3.2.2.2. Stepwise regression

In stepwise regression one adds variables to a model to maximise the R^2 or equivalently to minimise the error sum of squares. The first step in stepwise regression identifies the single variable which best predicts Y. The second step finds the variable which best predicts Y given the first variable is entered. In the steps that follow either (a) a variable is entered which best improved the prediction of Y given all the variables entered from the previous steps or (b) a variable is deleted from the set of predictors if its predictive ability falls below a given level. The process is terminated when no further variables improve the prediction of Y. The variables are usually entered in the order of their importance.

The computation procedure of stepwise regression can be explained in different steps.

Step o The simple correlation coefficient r_{yx_i} and the F to enter

$$F_{yx_i} = \frac{r^2_{yx_i}\,(n-2)}{1 - r^2_{yx_i}} \qquad - \quad (3.13)$$

are calculated for $i = 1,2,\ldots\ldots\ldots P$. Tests of significance are conducted with the null hypothesis, $H_o: \rho_{yx_i}=0$, $i = 1,2,\ldots\ldots P$. If all the F to enter are less than a prescribed inclusion level called the 'F to include' the process is terminated and we conclude that Y is estimated by $\bar{Y}$ for any value of $X_1, X_2 \ldots\ldots\ldots X_p$.

Step 1 The variable X_{i_1} having the largest F to enter or equivalently the largest squared correlation with Y is selected as the best predictor of Y. The ordinary least square equation $Y = f(X_1) + e$ is fitted, the constants estimated and the analysis of variance table formed. Also the F to remove for X_1 which is equal to the F to enter for X_1 is calculated. Then the partial correlation coefficient $r_{yx_i \cdot X_{i_1}}$ and F to enter

$$F_{Yx_i \cdot X_{i_1}} = \frac{r^2_{YX_i \cdot X_{i_1}} (n-3)}{1- r^2_{YX_i \cdot X_{i_1}}} \qquad - \quad (3.14)$$

are calculated for $i = 1, \ldots\ldots\ldots P$, $i \neq i_1$, that is, for each variable not included in the regression equation. The significance of the partial correlation coefficient is tested. If all the F to enter are less than F to include the process terminates and a table is formed with the relevant equation, R^2 and F values. Otherwise Step 2 is executed.

Step 2 The variable X_{i_2} having the largest F to enter (or equivalently the largest squared partial correlation with Y given X_{i_1}) is selected as the best predictor of Y, given X_{i_1} has already been selected. The least square equation $Y = f(X_{i_1}, X_{i_2})$ will be fitted. The analysis of variance table, the multiple correlation coefficient, the adjusted coefficient of determination are calculated. Also the F to remove $F_{YX_{i_1}\cdot X_{i_2}}$ and $F_{YX_{i_2}\cdot X_{i_1}}$ are calculated as follows:

$$F_{YX_{i_1}\cdot X_{i_2}} = \frac{r^2_{YX_{i_1}\cdot X_{i_2}}(n-3)}{1-r^2_{YX_{i_1}\cdot X_{i_2}}} \qquad -(3.15)$$

$$F_{YX_{i_2}\cdot X_{i_1}} = \frac{r^2_{YX_{i_2}\cdot X_{i_1}}(n-3)}{1-r^2_{YX_{i_2}\cdot X_{i_1}}} \qquad -(3.16)$$

Then test the hypothesis that $H_0: \rho_{YX_{i_1}\cdot X_{i_2}}=0$ and $H_0: \rho_{YX_{i_2}\cdot X_{i_1}}=0$ respectively. Finally the partial correlation coefficient $r_{YX_i\cdot X_{i_1}X_{i_2}}$ between Y and the independent variables keeping the two variables already selected as constant are calculated and their significance tested by using an F test with 1 and (n-4) degrees of freedom. If all F to enter are less than 'F to include' then the process terminates. Otherwise step 3 is executed.

<u>Step 3(a)</u> Let 'L' denotes the set of 'ℓ' independent variables which have been entered into the regression equation. If any of the F to remove for the variables in L are less than a prescribed deletion level, called the 'F to exclude' then the variable with the smallest F to remove is deleted from L and step 3(b) is executed with 'ℓ' replaced by '$\ell-1$'. If all of the F to enter for the variables not in L are less than F to include then the process is stopped. Otherwise the variable with the largest F to enter is chosen and is added to L so that 'ℓ' is replaced by '$\ell+1$'. The least square equation, analysis of variance, multiple correlation coefficient, adjusted R^2 are calculated for the variables selected. Also the F to remove $F_{YX_{i_j}\cdot(\ell-1)}$, where

$$F_{YX_{i_j}\cdot(\ell-1)} = F_{YX_{i_j}\cdot X_{i_1}, X_{i_2}\cdots\cdots X_{i_{(j-1)}}, X_{i_{(j+1)}}\cdots\cdots X_{i\ell}}$$

is calculated between Y and X_{i_j} in L given the ($\ell-1$) remaining variables in L are entered. The partial correlation coefficient $r_{YX_i\cdot\ell}$ where

$$r_{YX_i\cdot\ell} = r_{YX_i\cdot X_1 X_2\cdots\cdots\cdots X_{(i-1)}, X_{(i+1)}\cdots\cdots X_\ell}$$ and

the F to enter are calculated for Y and X_i not in L given the variables in L are entered.

Step 4 Repeat step 3 recursively. When the 'F to enter' for all variables not in L is less than F to include the process stops. Otherwise it continues to next stage. When all the variables have been entered and the F to remove for the entered variables is greater than F to exclude, the process terminates.

3.2.3. Composite regression models to forecast paddy yield

In composite regression models composite functions of the original variables are used as independent variables. Weather indices and principal components also serve as explanatory variables in such models.

A suitable methodology applied by Agrawal *et al.* (1980) to forecast rice yield in Raipur district using weekly weather variables is adopted in the present study for the same purpose. Two composite regression models have been proposed. In the first regression model, weighted averages of weekly weather variables and their interactions using powers of week number as weights were used. The respective simple correlation coefficients of weather factors with yield in place of week number were taken as weights in the second model. Stepwise regression method was used for obtaining the forecast equations. The first model is given by,

$$Y = Ao + \sum_{i=1}^{p} \sum_{j=0}^{2} \sum_{k=1}^{m} a_{ijk} Z_{ijk} +$$

$$\sum_{i \neq i'=1}^{p} \sum_{j=0}^{2} \sum_{k=1}^{m} b_{ii^1jk} \; Q_{ii^1jk} + CT \qquad - (3.17)$$

Where Y = crop yield,

Ao, a_{ijk}, b_{ii^1jk} $(i \neq i^1 = 1, 2, \ldots p,\ j = 0, 1, 2,\ k = 1, 2, \ldots m)$

and C are constants. P = number of weather variables, T = year number included to correct for the long-term upward or downward trend in yield. Z_{ijk} and Q_{ii^1jk} are generated first and second order variables in the k^{th} fortnight ($k = 1, 2 \ldots 6$) defined as

$$Z_{ijk} = \sum_{w=1}^{n} w^j x_{iw} \Big/ \sum_{w=1}^{n} w^j \qquad - (3.18)$$

$$Q_{ii^1jk} = \sum_{w=1}^{n} w^j \, x_{iw} \, X_{i^1w} \Big/ \sum_{w=1}^{n} w^j \qquad - (3.19)$$

n = number of weeks upto the time of forecast, w the week's identification number, X_{iw} is the value of the i^{th} weather variable in the w^{th} week.

The second model is given by

$$Y = Ao + \sum_{i=1}^{p} \sum_{j=0}^{2} \sum_{k=1}^{m} a_{ijk} Z'_{ijk} +$$

$$\sum_{i \neq i'=1}^{p} \sum_{j=0}^{2} \sum_{k=1}^{m} b_{ii'jk} \, Q'_{ii'jk} + CT \qquad - (3.20)$$

where

$$Z'_{ijk} = \sum_{w=1}^{n} r^{j}_{iw} X_{iw} \Big/ \sum_{w=1}^{n} r^{j}_{iw} \qquad - \quad (3.21)$$

$$Q'_{ii'jk} = \sum_{w=1}^{n} r^{j}_{ii'w} X_{iw} X_{i'w} \Big/ \sum_{w=1}^{n} r^{j}_{ii'w} \qquad - \quad (3.22)$$

r_{iw} is the correlation coefficient of Y with the i^{th} weather variable in the w^{th} week, r_{ii^1w} is the correlation coefficient of Y with the product of the i^{th} and $i^1{}_{th}$ weather variable in the w^{th} week. The rest of notations bear the same meaning as in the case of model-1

The stepwise regression procedure was used to select significant generated variables Z_{ijk}'s and Q_{ii^1jk}'s in the case of model 1 and Z^1_{ijk}'s and $Q'_{ii'jk}$'s in the case of model 2.

Prediction equations were developed for fortnightly forecasting of paddy yield and their efficiencies compared in terms of adjusted coefficient of determination. According to the availability, twenty one years crop weather data were used for the autumn varieties while data for 24 years and 23 years were used for PTB 12 and PTB 20 respectively in the winter season.

3.2.3.1. Principal Component analysis

In many multivariate situations there may be substantial intercorrelations among the original explanatory variables which make the problem difficult to comprehend. Principal component analysis is a powerful method used in such situations which aims at explaining the relationship among numerous correlated variables in terms of a relatively few uncorrelated generated variables commonly called as components or factors. Hence it is possible to find a parsimonious description of the dependence structure which conveys approximately the same amount of information expressed by the original variables. In effect, principal component analysis consists in transforming a set of observed characters $X_1, X_2 \ldots\ldots\ldots X_p$ into a new set of composite characters $Y_1, Y_2 \ldots\ldots\ldots Y_p$ which have certain unique properties. Principal component analysis was initially described by Karl pearson (1901) and further developed by Hotelling (1933). Weights are assigned to each variable so that the resulting composite variable as a set may have maximum variance. The generated composite variables can be further used as independent variables in multiple linear regression analysis. Prediction equations can be developed by regressing crop yield on the independent generated variables. The generated variables also serve as weather indices for the purpose of yield forecasting.

Suppose that the original random variables $X_1, X_2 \ldots$ $\ldots X_p$ have a multivariate distribution (not necessarily normal) with mean vector 'μ' and covariance matrix $\underset{\sim}{\Sigma} = (\sigma_{ij})$. The rank of $\underset{\sim}{\Sigma}$ is $r \leq p$ and the q largest characteristic roots $\lambda_1 > \ldots\ldots > \lambda_q$ of $\underset{\sim}{\Sigma}$ are all distinct.

The method of principal components then select for P linear combinations

$$Y_1 = \sum_{j=1}^{p} \alpha_{1j} X_j$$

$$Y_2 = \sum_{j=1}^{p} \alpha_{2j} X_j$$

$$\vdots$$

$$Y_p = \sum_{j=1}^{p} \alpha_{pj} X_j$$

So that

$$\mathrm{Cov}\,(Y_i, Y_j) = 0 \text{ for } i, j = 1, \ldots\ldots p, \; i \neq j$$

$$V(Y_1) \geqslant V(Y_2) \geqslant \ldots\ldots\ldots \geqslant V(Y_p)$$

$$\text{and} \sum_{i=1}^{p} V(Y_i) = \sum_{i=1}^{p} \sigma_{ii}$$

Assuming $\underset{\sim}{\Sigma}$ known we let

$$Y_1 = \alpha_{11} x_1 + \ldots\ldots\ldots\ldots \alpha_{1p} X_p \qquad - \quad (3.23)$$

We wish to find $\alpha_{11}, \alpha_{12} \ldots\ldots\ldots\ldots\ldots \ldots \alpha_{1p}$ so that

$V(Y_1) = \sum_{i=1}^{p} \sum_{j=1}^{p} \alpha_{1i} \alpha_{1j} \sigma_{ij}$ is maximum subject to the condition that

$$\sum_{j=1}^{p} \alpha_{1j}^2 = 1$$

$\alpha_1 = (\alpha_{11} \ldots\ldots \alpha_{1p})$ is called the first eigen vector and is associated with the largest eigen value of

$$Y_1 = \sum_{j=1}^{p} \alpha_{1j} X_j \qquad - \qquad (3.24)$$

is called the first principal component of $X_1, X_2, \ldots. X_p$. Thus the first principal component must correspond to the largest eigen value. In the same manner the second principal component will be the eigen vector which corresponds to the second largest eigen value and so on.

If $\underset{\sim}{\Sigma}$ is unknown the best estimator of $\underset{\sim}{\Sigma}$ is the sample variance - covariance matrix $\underset{\sim}{S}$. To obtain estimated principal components we apply the above procedure to $\underset{\sim}{S}$. Obtaining estimates a_{ij} of α_{ij}, $i, j = 1,2,\ldots\ldots\ldots p$, the q^{th} estimated principal component is

$$Y_q = \sum_{j=1}^{p} a_{qj} \; X_j \qquad - \qquad (3.25)$$

which corresponds to the q^{th} largest eigen value of $\underset{\sim}{S}$ and the q^{th} eigen vector.

$$a_q = (a_{q1}, q_{q2}, \ldots\ldots\ldots a_{qp})', \; q = 1,2,\ldots\ldots\ldots p$$

Thus the first estimated principal component of the observation is

$$Y_1 = a_{11}X_1 + \ldots\ldots\ldots\ldots + a_{p1}X_p \qquad - \qquad (3.26)$$

That is $Y_1 = a_1' X$

Variance of Y_1 is given by

$$sY_1^2 = \sum_{i=1}^{p} \sum_{j=1}^{p} a_{1i} \, a_{1j} \, s_{ij} \qquad - \quad (3.27)$$

The coefficient vectors are to be normalised so that

$a_1' a_1 = 1$

Further the coefficients are so determined that the components should have maximum variance. Introducing Legrange multiplier λ_1 the factor to be maximised is

$$L = (sY_1^2 + \lambda_1 (1 - a_1' a_1) \qquad - \quad (3.28)$$

Differentiating and equating to zero

$$2 \; (S - \lambda_1 I) \; a_1 = 0 \qquad - \quad (3.29)$$

Thus it follows that the coefficients must satisfy the p simultaneous linear equations given by

$$(S - \lambda_1 I) \; a_1 = 0 \qquad - \quad (3.30)$$

If the solutions to these equations to be other than the null vector, the value of λ_1 must be chosen in such a way that

$$|S - \lambda_1 I| = 0 \qquad - \quad (3.31)$$

Thus λ_1 should be the characteristic root of the covariance matrix and a_1 its associated characteristic vector

$$V(Y_1) = \underset{\sim}{a_1'}\underset{\sim}{S}\,\underset{\sim}{a_1} \qquad - \quad (3.32)$$

$$= \underset{\sim}{a_1'}\,\lambda_1\,\underset{\sim}{a_1}$$

$$= \lambda_1 \text{ since } a_1'\,a_1 = 1$$

If λ_i is the i^{th} eigen value then the variance of the i^{th} principal component is λ_i. The first principal component must be eigen vector of $\underset{\sim}{S}$, corresponding to the largest eigen value λ_1. In the same manner the second principal component will be the eigen vector corresponding to the second eigen value and so on.

The sums of variances of the original variables and their principal components will be the same. The total variance in the system will be trace $\underset{\sim}{S}$ which is the same as sum of the eigen values. Instead of the covariance matrix the correlation matrix $\underset{\sim}{R}$ which is unit free, can also be used for the study. In that case the total variance of the system will be equal to Trace $\underset{\sim}{R} = p$. The percentage contribution of the variation explained by the i^{th} component is given by $\frac{\lambda_i}{p} \times 100$.

$$e\,(Y_i) = \frac{\lambda_i}{p} \times 100 \qquad - \quad (3.33)$$

Where $e\,(Y_i)$ is the relative contribution of the i^{th} component. The first m components account for $\sum_{j=1}^{m} \frac{\lambda_j}{p} \times 100$ per cent of the total variation. Correlation between j^{th}

component and i^th^ variable is given by

$$r(X_i\ Y_j) = \lambda_j^{1/2}\ a_{ij} \qquad - (3.34)$$

This is known as factor loading or component loading for the j^th^ component on the i^th^ variable.

In this study principal component analysis was done on the basis of the correlation matrix of generated variables and the eigen values and eigen vectors extracted. As a further step the principal components were used as independent variables in a multiple linear regression analysis and suitable prediction models developed.

3.2.3.2. Weather Index

It is often felt necessary to decompose the numerous meteorological variables in one or at most a few composite variables in the form of index numbers, which would be conveniently handled in the forecasting problems. The characteristic vectors obtained from the principal component analysis would serve as useful weather indices for the purpose of yield forecasting. The joint effects of rainfall and temperature can also be expressed as a simple index of the form $W_1 = P/T$ where W_1 is the index of precipitation per unit temperature. Similar composite variables such as $W_2 = P.T$ and $W_3 = H.S$ are also useful indicators of joint effects of the relevant variables on crop yield where H is the relative humidity and S is number of hours of sunshine. Weather indices were also developed by using various systems of weighting as described in the previous section and used as explanatory variables in multiple linear regression analysis. A weather index suggested by Bean (1964) and is given by $W = R + T(80-T)$ where R is the total rainfall (cm), T is the mean temperature (^{o}C) was also formed in different weeks of plant growth in the two seasons. The simple correlation coefficients of these weather indices with yield were obtained and multiple linear regression equations fitted using the backward elimination procedure described earlier.

3.3. Effect of meteorological variables at different phases of crop growth on yield

The entire crop growing period of the rice plant was divided into five growth phases, viz., (1) nursery period, vegetative phase which includes (2) active vegetative phase and (3) lag vegetative phase, (4) reproductive phase and (5) ripening phase. The nursery period extends from the date of sowing to date of transplanting. The vegetative phase extends from the date of transplanting to the date of panicle initiation. The active vegetative phase involves roughly about 3 weeks. The next 5 weeks of the vegetative phase is considered as constituting the lag vegetative phase in the case of the autumn varieties PTB 1 and PTB 5. For the winter varieties PTB 12 and PTB 20, lag vegetative phase is shorter and is roughly about 3 weeks. Reproductive phase starts with the initiation of panicle primordia and terminates with initiation of the grain development. This phase involves roughly 3 weeks. The following days from the initiation of the grain development upto harvest is taken as the ripening phase. Ripening phase usually covers four or more number of weeks. The meteorological variables at different phases were correlated with paddy yield for all varieties.

3.4. Effect of date of sowing on paddy yield

In order to find out the effect of date of sowing on paddy yield the sowing dates for the four varieties of paddy in autumn and winter season in different years were arranged in the ascending order on the time scale. Corresponding crop yield of the varieties were also arranged and ranks were given according to the ascending order of their magnitude. The rank correlation coefficient between the ranks of the two series was then calculated and tested for statistical significance.

As a further step the median date of sowing was located for the series and the whole set of data were classified into two classes, those above the median and those below the median and the statistical significance of the difference between the groups was tested by using the student's 't' test given by

$$t = \frac{|\bar{X}_1 - \bar{X}_2|}{\sqrt{\frac{(n_1-1)\, s_1^2 + (n_2-1) s_2^2}{n_1 + n_2 - 2} \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad - (3.35)$$

In cases where the sample variances s_1^2 and s_2^2 were found to be heterogenous the Cochran-Cox 't' test was used instead of the ordinary 't' test to test the equality of means of the two classes. The test criterion for the test is given by

$$t' = \frac{|\bar{X}_1 - \bar{X}_2|}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad - (3.36)$$

The critical value t_c for the test is calculated as $t_c = \frac{W_1\, t_1 + W_2\, t_2}{W_1 + W_2}$ - (3.37)

Where $W_1 = \frac{s_1^2}{n_1}$, $W_2 = \frac{s_2^2}{n_2}$, t_1 and t_2 are the critical values of student's 't' at the desired level of significance and relevant degrees of freedom.

RESULTS

4. RESULTS

4.1. Test for trend

The details of the Z statistic computed for the PTB varieties in the two crop growing seasons to test for the presence of trend in the yield data are given in Table 1.

Table 1. The calculated Z values to test the presence of trend

Season	Variety	Number of years used	Number of turning points	Z value
autumn	PTB 1	24	15	0.1658
	PTB 5	24	15	0.1658
winter	PTB 12	24	17	1.1709
	PTB 20	23	17	1.5464

None of the Z values were found to be significant. Hence it could be concluded that there was no long term trend in the series of yield data for the varieties in the two seasons and therefore there was no need to include an additional term in the regression model as correction for trend.

4.2. Simple correlation analysis of weekly weather variables with yield of PTB varieties.

The correlation coefficients between yield and different weekly meteorological variables viz., total rainfall, number of rainy days, rainfall range, average maximum temperature, average minimum temperature, average mean temperature, average maximum humidity, average minimum humidity, average mean humidity, average number of hours of sunshine and average wind velocity were calculated for the two varieties in each season and for their aggregate data. The values of the correlation coefficients obtained in different weeks starting from the week before sowing upto the twelfth week after sowing are given in Table 2(a) and Table 2(b) respectively for the varieties tried in the autumn and winter seasons. In Table 2(a) the three entries in each cell represent the correlation coefficients of meteorological factors with yield of PTB 1, PTB 5 and with their mean yield respectively. In Table 2(b) the three entries in each cell represent the correlation coefficients for PTB 12, PTB 20 and for their aggregate yield.

It could be seen that in the case of PTB varieties grown in the autumn season none of the weather parameters of the presowing period exerted any significant effect on paddy yield. Total rainfall during the first week after sowing showed significant and positive relationship with yield ($r_1 = 0.4371$, $r_2 = 0.4342$, $r_3 = 0.4356$). The correlation coefficient of number of hours of sunshine during the above period was significantly negative ($r_1 = -0.4749$; $r_2 = -0.4788$, $r_3 = -04836$). Range of rainfall distribution in general showed negative relationship with yield of PTB varieties. Range of rainfall in the fourth ($r_1 = -0.4268$, $r_2 = -0.4907$, $r_3 = -0.4668$), eighth ($r_1 = -0.4341$, $r_2 = -0.4337$, $r_3 = -0.4365$) and eleventh weeks ($r_2 = 0.4114$, $r_3 = -0.4066$) after sowing exerted statistically significant effects on yield. Total amount of rainfall received during the eighth ($r_1 = -0.5691$, $r_2 = -0.5230$ $r_3 = -0.5561$) and eleventh weeks ($r_1 = -0.4397$, $r_2 = -0.4807$, $r_3 = -0.4629$) after sowing showed significant and negative association with yield. This indicated that amount of precipitation higher than the average was detrimental to crop growth and yield when it was received during the eighth and eleventh weeks after sowing. Maximum temperature of the tenth week after sowing ($r_2 = -0.5228$, $r_3 = -0.4660$) showed significant negative correlation with crop yield. None of the weekly parameters relating to minimum temperature, mean temperature, maximum humidity, minimum humidity, mean humidity and wind velocity were significantly correlated with yield of PTB varieties in the autumn season.

Table 2 (a) Zero order correlation coefficients between weekly climatic variables and yield of PTB varieties in the autumn season and their aggregate yield.

No.of weeks after sowing	Total rainfall	Rainfall range	No.of rainy days	Maximum tempera-ture	Minimum temperat-ure	Mean tempera-ture	Maximum humidity	Minimum humidity	Mean humidity	No.of hours of sun-shine	Wind velocity
-1	-0.1459	-0.2052	-0.2567	0.0733	0.0589	0.0849	-0.1157	-0.1203	-0.1471	-0.2081	0.1402
	-0.0574	-0.0988	-0.2389	0.0551	0.0694	0.0767	-0.1147	-0.1479	-0.1757	-0.1281	0.0882
	-0.0568	-0.1263	-0.2469	0.0727	0.0611	0.0822	-0.2128	-0.1362	-0.1640	-0.1716	0.1156
1	0.4371*	0.0673	0.2120	-0.2119	-0.0868	-0.1719	-0.0355	-0.0056	0.0708	-0.4749*	0.1132
	0.4342*	0.0368	0.2814	-0.2690	-0.0728	-0.2007	0.0279	0.0755	0.0717	-0.4788*	0.1271
	0.4356*	0.0532	0.2488	-0.2445	-0.0815	-0.1893	0.1269	0.0839	0.0724	-0.4836*	0.1506
2	-0.0127	-0.1193	-0.0019	-0.0426	-0.0808	-0.0626	0.0097	-0.0799	-0.0676	-0.1475	0.1134
	0.0564	-0.0106	-0.0447	0.0119	-0.0522	-0.0187	-0.0053	-0.1398	-0.1247	-0.0354	-0.0421
	0.0218	-0.0669	-0.0193	-0.0113	-0.0672	-0.0428	-0.0022	-0.1114	-0.0976	-0.0936	0.0376
3	0.0066	-0.1937	0.3379	-0.2418	-0.1556	-0.2130	0.0952	0.2039	0.1949	-0.2401	0.2440
	0.0052	-0.1594	0.2459	-0.2015	-0.1454	-0.1855	0.0538	0.1928	0.1768	-0.1695	0.3088
	0.0059	-0.1799	0.2978	-0.2255	-0.1535	-0.2027	0.0759	0.2023	0.1894	-0.2201	0.2807
4	-0.1328	-0.4268*	0.0693	0.1832	-0.0728	0.0905	0.2411	-0.1115	0.1883	0.1022	0.4671
	-0.2628	-0.4907*	-0.0313	0.2814	0.0070	0.1839	0.2313	-0.2335	-0.1673	0.1754	0.3509
	-0.2003	-0.4668*	0.0201	0.2357	-0.0419	0.1375	0.2031	-0.1731	-0.1135	0.1401	0.4187
5	-0.2885	-0.2219	0.3582	0.1117	-0.2615	-0.0856	0.2344	-0.1370	-0.0838	-0.0295	-0.0927
	-0.3268	-0.2015	0.2963	0.1275	-0.2289	-0.0632	0.2769	-0.1407	-0.0799	0.0199	-0.3389
	-0.3128	-0.2156	0.3336	0.1104	-0.2502	-0.0766	0.2603	-0.1413	-0.0834	-0.0059	-0.2171
6	-0.3630	0.0978	0.0603	0.0856	0.0369	0.0669	0.0919	-0.2606	-0.2156	0.1801	0.3683
	-0.3535	0.1558	0.1838	-0.0283	-0.0409	-0.0256	0.1953	-0.1449	-0.0948	0.0866	0.2793
	-0.3161	0.1286	0.1233	0.0304	-0.0036	0.0261	0.1448	-0.2074	-0.1591	0.1356	0.3306
7	-0.1989	-0.0601	-0.3202	0.2591	0.1274	0.3638	0.0158	-0.2948	-0.2528	0.2769	-0.0213
	-0.1309	-0.0195	-0.3402	0.1434	0.0582	0.2141	0.0218	-0.2422	-0.2049	0.2931	0.0554
	-0.1683	-0.0409	-0.3359	0.2055	0.0935	0.2961	0.0191	-0.2736	-0.2340	0.2896	0.0179
8	-0.5691**	-0.4341*	-0.2927	0.1813	0.0645	0.1556	-0.0586	-0.2799	-0.2446	0.1978	-0.3716
	-0.5230**	-0.4337*	-0.2279	0.1834	0.0437	0.1643	-0.0446	-0.2009	-0.1767	0.2387	-0.2466
	-0.5561**	-0.4365*	-0.2655	0.1851	0.0421	0.1632	-0.0525	-0.2452	-0.2152	0.2214	-0.3154
9	0.1956	0.2291	0.1739	-0.3347	-0.2166	-0.3239	0.3138	0.2003	0.2424	-0.2844	-0.3662
	0.2129	0.2278	0.2542	-0.4276*	-0.2471	-0.3995	0.3695	0.2272	0.2785	-0.2629	-0.3091
	0.2083	0.2325	0.1789	-0.3867	-0.2362	-0.3673	0.2898	0.2173	0.2649	-0.2776	-0.3446
10	0.0734	0.1766	0.0841	-0.3968	-0.1388	-0.3163	0.2289	0.0029	0.0456	-0.1201	0.0245
	0.2112	0.3159	-0.1674	-0.5228**	-0.2350	-0.4442*	0.2998	0.0667	0.1171	-0.2751	-0.0600
	0.1238	0.2497	0.1529	-0.4660*	-0.1914	-0.3869	0.2685	0.0348	0.0822	-0.1991	-0.0168
11	-0.4397*	-0.3763	-0.1449	0.1278	0.0009	0.0725	0.0584	-0.2904	-0.2493	0.2168	-0.2316
	-0.4807*	-0.4114*	-0.2799	-0.1378	-0.0405	0.0444	-0.0232	-0.2934	-0.2704	0.2809	-0.1354
	-0.4629*	-0.4066*	-0.1489	0.1376	-0.0109	0.0602	0.0183	-0.2974	-0.2640	0.2527	-0.1869
12	-0.0863	-0.0815	0.0027	-0.0884	0.2076	0.0444	-0.0954	-0.3338	-0.3137	0.1425	-0.0866
	-0.1030	-0.0375	-0.2439	-0.0875	0.1834	0.0322	-0.0345	-0.4024	-0.3613	0.1821	-0.2036
	-0.0962	-0.0609	0.0205	-0.0879	0.1978	0.0395	-0.0667	-0.3743	-0.3431	0.1649	-0.1471

* Significant at 5% level

** Significant at 1% level

Table 2 (b) Zero order correlation coefficients between weekly climatic variables and yields of PTB varieties in the winter season and their aggregate yield.

No. of weeks after sowing	Total rainfall	Rainfall range	No. of rainy days	Maximum tempera- ture	Minimum tempera- ture	Mean tempera- ture	Maximum humidity	Minimum humidity	Mean humidity	No. of hours of sun- shine	Wind velocity
-1	0.1627	0.0160	0.2703	-0.4510*	-0.3732	-0.5362**	0.4456*	0.2566	0.3368	-0.2112	0.2399
	0.2909	0.1301	0.3621	-0.5145*	-0.2323	-0.5038*	0.4162*	0.3068	0.3571	-0.2837	0.1226
	0.2522	0.1063	0.3351	-0.4931*	-0.2886	-0.5269**	0.4414*	0.3005	0.3574	-0.2739	0.1666
1	-0.1130	-0.1855	0.0318	-0.3348	-0.2767	-0.3751	0.2915	0.0587	0.1543	-0.0101	0.0973
	0.1265	0.0684	0.2072	-0.2457	-0.1015	-0.2129	0.2259	0.2478	0.2208	-0.0759	0.0941
	0.0539	0.0137	0.1470	-0.2738	-0.1565	-0.2646	0.2755	0.2087	0.2152	-0.0798	0.0857
2	0.2226	0.3024	0.1498	-0.1324	-0.1945	-0.1843	0.3388	0.1059	0.1805	0.1313	0.2673
	0.1363	0.2659	0.0195	-0.2115	-0.0475	-0.1979	0.2396	0.2489	0.2872	0.0632	0.2692
	0.2080	0.3226	0.1033	-0.1791	-0.1251	-0.2019	0.3043	0.2078	0.2653	0.0879	0.2475
3	0.3531	0.2091	0.4499*	-0.1159	-0.1288	-0.1453	0.2266	0.2325	0.2521	-0.1538	-0.2716
	0.5697**	0.3931	0.4643*	-0.1049	-0.0371	-0.0858	0.2572	0.2874	0.2993	-0.1050	-0.1535
	0.5269**	0.3883	0.4701*	-0.1349	-0.0644	-0.1205	0.2534	0.3216	0.3226	-0.1818	-0.1841
4	0.0880	0.0740	0.1231	-0.4064*	-0.1601	-0.4275*	0.2661	0.3439	0.3368	-0.2622	-0.0247
	0.1126	0.1029	0.0154	-0.3591	-0.1079	-0.3554	0.1573	0.2493	0.2312	-0.1184	0.0612
	0.1155	0.1096	0.0749	-0.4038	-0.0931	-0.3851	0.2247	0.3284	0.3109	-0.2258	0.0089
5	0.3067	0.3052	0.2975	-0.3446	-0.0453	-0.2828	0.2959	0.2851	0.3076	-0.2044	-0.1737
	0.2830	0.2245	0.2589	-0.2773	-0.0998	-0.2564	0.1778	0.2259	0.2201	-0.0046	0.1019
	0.2949	0.2606	0.2757	-0.2955	-0.1007	-0.2693	0.2472	0.2513	0.2654	-0.0798	0.0149
6	-0.2559	-0.2272	-0.3759	-0.2963	-0.1391	-0.2722	0.2582	0.0310	0.1304	0.0908	-0.1779
	-0.2692	-0.2281	-0.4169*	-0.2562	-0.0653	-0.1633	0.0903	-0.0332	0.0030	0.1171	0.0645
	-0.2806	-0.2438	-0.4162*	-0.2639	-0.0596	-0.1697	0.1535	0.0161	0.0663	0.1067	-0.0373
7	0.2282	0.4870*	0.0087	-0.3261	-0.1824	-0.3719	0.4566*	0.2243	0.3636	-0.1378	-0.2445
	0.1917	0.4243*	0.0327	-0.3616	-0.1818	-0.3532	0.3949	0.1346	0.2799	-0.0799	-0.1577
	0.2051	0.4622*	0.0123	-0.3452	-0.1832	-0.3502	0.4376*	0.1779	0.3259	-0.0987	-0.2242
8	-0.0459	-0.0656	-0.0235	-0.2777	-0.4575*	-0.5203**	0.2663	-0.2610	0.0042	0.3682	-0.2822
	-0.1273	-0.1402	-0.0562	-0.3696	-0.2963	-0.4489*	0.1909	-0.1797	0.0011	0.2853	-0.1671
	-0.1248	-0.1159	-0.0509	-0.3139	-0.3602	-0.4703*	0.2177	-0.2170	-0.0055	0.3268	-0.2211
9	-0.3258	-0.2799	-0.3183	0.0342	-0.2553	-0.1949	-0.0302	-0.1512	-0.1918	0.3209	0.0032
	-0.3230	-0.2692	-0.4168*	0.1018	-0.3929	-0.2268	-0.0805	-0.4196*	-0.2711	0.4307*	-0.0453
	-0.3449	-0.2920	-0.4192*	0.1136	-0.4242*	-0.2426	-0.0911	-0.4141*	-0.2788	0.4246*	-0.0480
10	0.0971	0.0700	0.0194	-0.4536*	-0.2864	-0.4131*	0.3371	-0.0984	0.0909	-0.1507	-0.4174
	0.1782	0.1683	0.0122	-0.5289**	-0.2493	-0.3942	0.2724	-0.1087	0.0484	-0.3015	-0.4373*
	0.1421	0.1236	0.0117	-0.4912*	-0.2804	-0.4157*	0.2974	-0.1039	0.0621	-0.3085	-0.4389*
11	0.1059	0.0069	0.2237	-0.6269**	-0.1264	-0.4563*	0.3063	0.1687	0.2525	-0.6316**	-0.0864
	0.1149	-0.0137	0.2749	-0.5365**	-0.0045	-0.2819	0.2125	0.0931	0.1574	-0.6406**	-0.3136
	0.1104	-0.0093	0.2554	-0.5828**	-0.0592	-0.3236	0.2540	0.1352	0.2029	-0.7051**	-0.3949
12	0.2791	0.2869	0.2884	-0.6463**	-0.4139*	-0.5143*	0.2601	0.0301	0.1887	-0.0864	-0.0729
	0.1644	0.1716	0.1806	-0.6245**	-0.3126	-0.5265**	0.1319	-0.0437	0.0622	-0.0977	-0.0422
	0.2201	0.2278	0.2333	-0.6564**	-0.3572	-0.5724**	0.1739	0.0097	0.1173	-0.1098	-0.0442

* Significant at 5% level

** Significant at 1% level

In the case of PTB varieties grown in the winter season effects of climatic factors on crop growth and yield were more pronounced. Above average maximum humidity of the presowing period ($r_1 = 0.4456$, $r_2 = 0.4162$, $r_3 = 0.4414$) showed significant positive relationship with final grain yield whereas the effects of above average maximum temperature ($r_1 = -0.4510$, $r_2 = -0.5145$, $r_3 = -0.4931$) and above average mean temperature ($r_1 = -0.5362$, $r_2 = -0.5038$, $r_3 = -0.5269$) of the period were significant but negative. Above average total rainfall in the third week after sowing was found to be beneficial for crop growth and yield especially in the case of PTB 20 and for the aggregate data ($r_2 = 0.5697$, $r_3 = 0.5269$). Range of daily total rainfall during the seventh week after sowing showed significant positive relationship with yield ($r_1 = 0.4870$, $r_2 = 0.4243$, $r_3 = 0.4622$). Number of rainy days during the third week after sowing had a positive and significant association with yield ($r_1 = 0.4499$, $r_2 = 0.4643$, $r_3 = 0.4701$) while that during the sixth ($r_1 = -0.3759$, $r_2 = -0.4169$, $r_3 = -0.4162$) and ninth weeks ($r_1 = -0.3183$, $r_2 = -0.4168$, $r_3 = -0.4192$) after sowing exhibited negative relationship with yield. Above average maximum temperature during the tenth ($r_1 = -0.4536$, $r_2 = -0.5189$, $r_3 = -0.4912$) eleventh ($r_1 = -0.6269$, $r_2 = -0.5365$, $r_3 = -0.5828$) and twelfth weeks ($r_1 = -0.6463$, $r_2 = -0.6245$, $r_3 = -0.6564$) after sowing was significantly and negatively related with grain yield. Mean temperature above average during the eighth ($r_1 = -0.5203$, $r_2 = -0.4489$, $r_3 = -0.4703$) and twelfth weeks ($r_1 = -0.5143$, $r_2 = -0.5265$, $r_3 = -0.5724$) also exhibited a significant and negative correlation with yield. Above average maximum humidity in the seventh week seemed to be beneficial for the crop growth and yield ($r_1 = 0.4566$, $r_3 = 0.4376$). Number of hours of sunshine received in the ninth week ($r_2 = 0.4307$, $r_3 = 0.4246$) showed positive relationship with yield especially for PTB 20. However the same variable exerted adverse effects in the eleventh week ($r_1 = -0.6316$, $r_2 = -0.6406$, $r_3 = -0.7051$) after sowing of the crop. Wind velocity in the tenth week after sowing had negative relationship with grain yield ($r_2 = -0.4373$, $r_3 = -0.4389$). Dry winds during the later periods of crop growth might adversely affect crop growth and grain production.

4.3. Fortnightly forecasting of paddy yield

4.3.1. Linear regression of yield on weekly weather variables of the crop growing season.

Yield prediction equations were developed in different fortnights of crop growth through multiple linear regression analysis using weekly weather factors as explanatory variables and their relative efficiencies compared.

As the present study was based on a series not sufficiently long enough to include as many terms as there were independent variables it was felt necessary to have a preliminary selection of important variables and this was done with reference to the relative magnitudes of the simple correlation coefficients of the independent variables with crop yield. The critical value of the correlation coefficient which would make a variable competent for inclusion in the linear model was fixed as the tabulated entry for the statistical significance (at $p = 0.2$) of the sample correlation coefficient. The confidence coefficient could not be enhanced from this value any further because such a procedure would adversely affect the predictability of the resulting regression equations. All the variables in the first fortnight which exerted significant influences on grain yield were first selected to build up the prediction model for that fortnight. After that the major contributors and the resulting simpler forecasting models were identified through backward elimination process discussed in the earlier chapter. The significant variables of the second fortnight were also incorporated along with the selected important variables of the first fortnight for making prediction equations of the second fortnight. The process was continued till the end of the sixth fortnight. Those variables which showed significant partial regression coefficients with yield during a fortnight alone were considered as 'important' and retained in the subsequent models. The following are the important weather variables used in general in the various fortnightly prediction equations of the investigation for the PTB varieties grown in the two seasons

Table 3. List of weather factors involved in the various fortnightly prediction equations.

Symbol	Name of the variable	No. of weeks after sowing
X_1	Maximum temperature	-1*
X_2	Minimum temperature	-1
X_3	total rainfall	1
X_4	Maximum temperature	1
X_5	Number of hours of sunshine	1
X_6	Maximum humidity	2
X_7	total rainfall	3
X_8	rainfall range	3
X_9	number of rainy days	3
X_{10}	rainfall range	4
X_{11}	maximum temperature	4
X_{12}	total rainfall	5
X_{13}	number of rainy days	5
X_{14}	number of rainy days	6
X_{15}	number of rainy days	7

(contd..)

Table 3 (contd.)

Symbol	Name of the variable	No. of weeks after sowing
X_{16}	maximum humidity	7
X_{17}	total rainfall	8
X_{18}	rainfall range	8
X_{19}	minimum temperature	8
X_{20}	minimum temperature	9
X_{21}	number of hours of sunshine	9
X_{22}	minimum humidity	9
X_{23}	maximum humidity	10
X_{24}	total rainfall	11
X_{25}	number of rainy days	11
X_{26}	number of hours of sunshine	11
X_{27}	maximum temperature	12
X_{28}	minimum humidity	12

* The week number (-1) denotes one week prior to sowing.

Both variety based (specific) equations and a general equation on the basis of the aggregate yield data have been developed for predicting the yield of the crop in the particular season. The specific and general prediction equations, the standard errors of the partial regression coefficients and adjusted coefficients of determination of the different equations have been presented in Tables 4 (a) to 4 (f) for the

Table 4(a) Specific and general yield prediction equations for PTB varieties in autumn season in the first fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 2386.52 - \underset{(52.19)}{122.68}\, X_5^{*}$	0.225
2	$Y_2 = 2142.96 - \underset{(50.65)}{120.39}\, X_5^{*}$	0.229
3	$Y_3 = 2239.61 - \underset{(51.14)}{123.52}\, X_5^{*}$	0.234

Table 4(b) Specific and the general yield prediction equations for the PTB varieties in the autumn season in the second fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = -3299.35 + \underset{(1.01)}{1.49}\, X_3 + \underset{(55.59)}{141.87}\, X_9^{*} - \underset{(2.14)}{5.57}\, X_{10}^{*} + \underset{(85.61)}{158.09}\, X_{11}$	0.422
2	$Y_2 = -4204.13 + \underset{(0.93)}{1.66}\, X_3 + \underset{(51.34)}{118.44}\, X_9^{*} - \underset{(1.98)}{5.83}\, X_{10}^{**} + \underset{(79.06)}{184.88}\, X_{11}^{*}$	0.479
3	$Y_3 = -3751.89 + \underset{(0.94)}{1.58}\, X_3 + \underset{(51.96)}{130.16}\, X_9^{*} - \underset{(2.00)}{5.69}\, X_{10}^{*} + \underset{(80.01)}{171.49}\, X_{11}^{*}$	0.466

Figures in brackets indicate the standard error of partial regression coefficients.

* Significant at 5% level

** Significant at 1% level

Table 4 (c) Specific and the general yield prediction equations for PTB varieties in the autumn season in the third fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = -114.73 + \underset{(35.73)}{151.94}\,\overset{**}{X_9} - \underset{(1.46)}{5.24}\,\overset{**}{X_{10}} - \underset{(0.57)}{1.59}\,\overset{**}{X_{12}} + \underset{(54.86)}{312.07}\,\overset{**}{X_{13}}$	0.756
2	$Y_1 = 186.51 - \underset{(27.78)}{71.85}\,X_5 + \underset{(30.72)}{148.02}\,\overset{**}{X_9} - \underset{(1.39)}{3.67}\,\overset{*}{X_{10}} - \underset{(0.49)}{1.59}\,\overset{**}{X_{12}} + \underset{(47.29)}{301.67}\,\overset{**}{X_{13}}$	0.820
3	$Y_2 = 108.92 + \underset{(43.23)}{119.60}\,\overset{*}{X_9} - \underset{(1.77)}{5.69}\,\overset{**}{X_{10}} - \underset{(0.69)}{1.48}\,\overset{*}{X_{12}} + \underset{(66.37)}{261.93}\,\overset{**}{X_{13}}$	0.622
4	$Y_2 = 380.76 - \underset{(36.79)}{64.84}\,X_5 + \underset{(40.69)}{116.07}\,\overset{*}{X_9} - \underset{(1.85)}{4.26}\,\overset{*}{X_{10}} - \underset{(0.65)}{1.49}\,\overset{*}{X_{12}} + \underset{(62.62)}{252.55}\,\overset{**}{X_{13}}$	0.666
5	$Y_3 = -2.87 + \underset{(37.77)}{135.77}\,\overset{**}{X_9} - \underset{(1.55)}{5.46}\,\overset{**}{X_{10}} - \underset{(0.60)}{1.53}\,\overset{*}{X_{12}} + \underset{(57.99)}{286.99}\,\overset{**}{X_{13}}$	0.711
6	$Y_3 = 283.64 - \underset{(30.59)}{68.35}\,\overset{*}{X_5} + \underset{(33.83)}{132.05}\,\overset{**}{X_9} - \underset{(1.54)}{3.96}\,\overset{*}{X_{10}} - \underset{(0.54)}{1.54}\,\overset{*}{X_{12}} + \underset{(52.07)}{277.11}\,\overset{**}{X_{13}}$	0.769

Figures in brackets indicate the standard error of partial regression coefficients.

* Significant at 5% level

** Significant at 1% level

Table 4 (d) Specific and the general yield prediction equations for PTB varieties in the autumn season in the fourth fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 204.86 + \underset{(30.22)}{165.00}\ \overset{**}{X}_9 - \underset{(1.44)}{3.65}\ \overset{*}{X}_{10} + \underset{(41.39)}{245.48}\ \overset{**}{X}_{13} - \underset{(0.71)}{2.72}\ \overset{**}{X}_{17}$	0.811
2	$Y_1 = 999.19 - \underset{(24.65)}{67.21}\ \overset{*}{X}_5 + \underset{(22.14)}{136.68}\ \overset{**}{X}_9 - \underset{(1.06)}{3.52}\ \overset{**}{X}_{10} - \underset{(0.44)}{1.56}\ \overset{**}{X}_{12} + \underset{(37.36)}{238.27}\ \overset{**}{X}_{13} - \underset{(24.86)}{76.22}\ \overset{**}{X}_{15} - \underset{(0.88)}{3.08}\ \overset{**}{X}_{17} + \underset{(3.56)}{10.43}\ \overset{*}{X}_{18}$	0.909
3	$Y_2 = 391.63 + \underset{(39.95)}{133.01}\ \overset{**}{X}_9 - \underset{(1.91)}{4.41}\ \overset{*}{X}_{10} + \underset{(54.70)}{199.11}\ \overset{**}{X}_{13} - \underset{(0.94)}{2.35}\ \overset{*}{X}_{17}$	0.651
4	$Y_2 = 1515.09 - \underset{(37.68)}{78.96}\ X_5 + \underset{(33.85)}{101.00}\ \overset{*}{X}_9 - \underset{(1.62)}{4.20}\ \overset{*}{X}_{10} - \underset{(0.68)}{1.55}\ \overset{*}{X}_{12} + \underset{(57.13)}{173.50}\ \overset{*}{X}_{13} - \underset{(38.02)}{109.61}\ \overset{*}{X}_{15} - \underset{(1.35)}{2.69}\ X_{17} + \underset{(5.44)}{11.09}\ X_{18}$	0.754
5	$Y_3 = 298.24 + \underset{(33.51)}{149.00}\ \overset{**}{X}_9 - \underset{(1.60)}{4.03}\ \overset{*}{X}_{10} + \underset{(45.89)}{222.29}\ \overset{**}{X}_{13} - \underset{(0.79)}{2.54}\ \overset{**}{X}_{17}$	0.754
6	$Y_3 = 1257.16 - \underset{(28.24)}{73.08}\ \overset{*}{X}_5 + \underset{(25.37)}{118.84}\ \overset{**}{X}_9 - \underset{(1.21)}{3.86}\ \overset{**}{X}_{10} - \underset{(0.51)}{1.55}\ \overset{**}{X}_{12} + \underset{(42.81)}{205.88}\ \overset{**}{X}_{13} - \underset{(28.49)}{92.92}\ \overset{**}{X}_{15} - \underset{(1.01)}{2.88}\ \overset{*}{X}_{17} + \underset{(4.08)}{10.76}\ \overset{*}{X}_{18}$	0.873

Figures in brackets indicate the standard error of partial regression coefficients.

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

Table 4 (e) Specific and general yield prediction equations for PTB varieties in the autumn season in the fifth fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 1255.50 - \underset{(20.83)}{76.58X_5^{**}} + \underset{(18.54)}{131.00X_9^{**}} - \underset{(0.89)}{3.14X_{10}^{**}} - \underset{(0.37)}{1.56X_{12}^{**}} +$ $\underset{(31.91)}{219.85X_{13}^{**}} - \underset{(20.80)}{70.42X_{15}^{**}} - \underset{(0.74)}{3.20X_{17}^{**}} + \underset{(2.97)}{10.89X_{18}^{**}} - \underset{(15.67)}{39.53X_{21}^{*}}$	0.937
2	$Y_2 = 1732.99 - \underset{(37.62)}{87.01X_5^{*}} + \underset{(33.50)}{96.13X_9^{*}} - \underset{(1.61)}{3.87X_{10}^{*}} - \underset{(0.67)}{1.56X_{12}^{*}} +$ $\underset{(57.66)}{157.69X_{13}^{*}} - \underset{(37.58)}{104.63X_{15}^{*}} - \underset{(1.33)}{2.79X_{17}} + \underset{(5.36)}{11.49X_{18}} - \underset{(28.32)}{33.92X_{21}}$	0.783
3	$Y_3 = 1254.76 - \underset{(26.12)}{81.79X_5^{**}} + \underset{(23.26)}{113.57X_9^{**}} - \underset{(1.12)}{3.51X_{10}^{**}} - \underset{(0.46)}{1.56X_{12}^{**}} +$ $\underset{(40.02)}{188.78X_{13}^{**}} - \underset{(26.08)}{87.53X_{15}^{**}} - \underset{(0.92)}{2.99X_{17}^{**}} + \underset{(3.72)}{11.19X_{18}^{*}} - \underset{(19.66)}{36.72X_{21}}$	0.895

Figures in brackets indicate the standard error of partial regression coefficients

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

Table 4(f) Specific and the general yield prediction equations for PTB varieties in the autumn season in the sixth fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 4249.22 + \underset{(32.07)}{91.84X_{9}^{*}} - \underset{(1.22)}{3.36X_{10}^{*}} + \underset{(41.03)}{183.09X_{13}^{**}} - \underset{(30.22)}{103.09X_{15}^{**}} - \underset{(1.19)}{5.82X_{17}^{**}} + \underset{(5.58)}{17.43X_{18}^{**}} - \underset{(1.62)}{3.53X_{24}} - \underset{(38.64)}{120.67X_{26}^{**}} - \underset{(10.35)}{30.02X_{28}^{*}}$	0.888
2	$Y_2 = 6218.79 - \underset{(1.47)}{2.62X_{10}} + \underset{(47.19)}{95.89X_{13}} - \underset{(34.88)}{153.84X_{15}^{**}} - \underset{(1.31)}{7.19X_{17}^{**}} + \underset{(5.96)}{27.28X_{18}^{**}} - \underset{(2.52)}{7.79X_{24}^{*}} + \underset{(38.44)}{69.54X_{25}} - \underset{(45.20)}{155.60X_{26}^{*}} - \underset{(10.08)}{44.05X_{28}^{*}}$	0.820
3	$Y_3 = 4667.58 + \underset{(30.14)}{60.90X_{9}} - \underset{(1.19)}{2.91X_{10}^{*}} + \underset{(38.57)}{148.94X_{13}^{**}} - \underset{(28.48)}{125.17X_{15}^{**}} - \underset{(1.13)}{6.29X_{17}^{**}} + \underset{(5.29)}{21.58X_{18}^{**}} - \underset{(2.06)}{6.52X_{24}^{**}} + \underset{(29.34)}{60.49X_{25}} - \underset{(36.74)}{133.82X_{26}^{**}} - \underset{(9.83)}{32.36X_{28}^{**}}$	0.895

Figures in brackets indicate the standard error of partial regression coefficients.

* Significant at 5% level

** Significant at 1% level

Table 5(a) Specific and the general yield prediction equations for PTB varieties in the winter season in the first fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 858.70 - \underset{(75.59)}{196.03}X_1^{*} + \underset{(34.01)}{73.73}X_6^{*}$	0.238
2	$Y_2 = -3060.25 - \underset{(122.59)}{409.33}X_1^{**} + \underset{(162.70)}{232.55}X_4 + \underset{(47.03)}{108.19}X_6^{*}$	0.308
3	$Y_3 = 1981.85 - \underset{(80.47)}{250.31}X_1^{**} + \underset{(36.21)}{78.88}X_6^{*}$	0.297

Table 5(b) Specific and the general yield prediction equations for PTB varieties in the winter season in the Second fortnight after sowing

1	$Y_1 = 4991.37 - \underset{(74.38)}{149.78}X_1 - \underset{(82.93)}{177.41}X_2^{*} + \underset{(32.19)}{56.42}X_6 + \underset{(4.27)}{10.53}X_7^{*} - \underset{(7.11)}{13.38}X_8$	0.407
2	$Y_2 = 8204.96 - \underset{(74.42)}{239.65}X_1^{**} - \underset{(82.97)}{182.}X_2^{*} + \underset{(32.21)}{52.10}X_6 + \underset{(4.27)}{19.43}X_7^{**} - \underset{(7.12)}{25.97}X_8^{**}$	0.632
3	$Y_3 = 6226.62 - \underset{(71.63)}{204.91}X_1^{*} + \underset{(79.86)}{175.81}X_2^{*} + \underset{(31.01)}{60.23}X_6 + \underset{(4.11)}{14.47}X_7^{**} - \underset{(6.85)}{19.24}X_8^{*}$	0.555

Figures in brackets indicate the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 5(c) Specific and the general yield prediction equations for PTB varieties in the winter season in the third fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 4277.72 - \underset{(73.92)}{144.03X_1} - \underset{(86.02)}{148.62X_2} + \underset{(31.92)}{56.31X_6} + \underset{(4.29)}{9.70X_7^{*}} - \underset{(7.08)}{12.69X_8} - \underset{(42.62)}{48.49X_{14}}$	0.418
2	$Y_2 = 7393.58 - \underset{(73.08)}{233.11X_1^{**}} - \underset{(85.04)}{149.59X_2} + \underset{(31.57)}{51.98X_6} + \underset{(4.25)}{18.49X_7^{**}} - \underset{(6.99)}{25.08X_8^{**}} - \underset{(42.14)}{55.15X_{14}}$	0.647
3	$Y_3 = 5516.32 - \underset{(70.99)}{119.18X_1^{*}} - \underset{(82.62)}{148.16X_2} + \underset{(30.66)}{60.12X_6} + \underset{(4.13)}{13.64X_7^{**}} - \underset{(6.79)}{18.54X_8^{*}} - \underset{(40.93)}{48.26X_{14}}$	0.565

Table 5(d) Specific and the general yield prediction equations for PTB varieties in the winter season in the fourth fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 5589.29 - \underset{(57.65)}{114.42X_1} + \underset{(3.38)}{7.52X_7^{*}} - \underset{(5.97)}{9.67X_8} - \underset{(34.19)}{100.65X_{14}^{**}} + \underset{(7.37)}{23.03X_{16}^{**}} - \underset{(41.69)}{101.05X_{19}^{*}}$	0.632
2	$Y_2 = 7371.84 - \underset{(52.01)}{197.54X_1^{**}} + \underset{(3.05)}{15.73X_7^{**}} - \underset{(5.38)}{20.73X_8^{**}} - \underset{(30.85)}{113.63X_{14}^{**}} + \underset{(6.65)}{26.92X_{16}^{**}} - \underset{(37.61)}{83.29X_{19}^{*}}$	0.814
3	$Y_3 = 6233.75 - \underset{(50.64)}{159.04X_1^{**}} + \underset{(2.97)}{10.99X_7^{**}} - \underset{(5.24)}{14.19X_8^{*}} - \underset{(30.03)}{106.85X_{14}^{**}} + \underset{(6.47)}{27.04X_{16}^{**}} - \underset{(36.62)}{87.59X_{19}^{*}}$	0.770

Figures in brackets indicate the standard error of partial regression coefficients.

* Significant at 5% level

** Significant at 1% level

Table 5(e) Specific and the general yield prediction equations for PTB varieties in the winter season in the fifth fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = -1117.24 - \underset{(30.59)}{107.39} X_{14}^{**} + \underset{(6.41)}{26.93} X_{16}^{**} - \underset{(6.06)}{27.31} X_{22}^{**} + \underset{(7.67)}{27.84} X_{23}^{**}$	0.719
2	$Y_1 = 1200.60 - \underset{(47.91)}{76.56} X_1 - \underset{(29.53)}{102.18} X_{14}^{**} + \underset{(6.24)}{25.27} X_{16}^{**} - \underset{(6.08)}{24.48} X_{22}^{**} + \underset{(7.36)}{27.79} X_{23}^{**}$	0.742
3	$Y_2 = 3959.48 - \underset{(50.32)}{167.39} X_1^{**} + \underset{(3.22)}{10.71} X_7^{**} - \underset{(4.83)}{14.68} X_8^{**} - \underset{(29.79)}{113.19} X_{14}^{**} + \underset{(6.36)}{28.82} X_{16}^{**} - \underset{(7.13)}{19.94} X_{22}^{*} + \underset{(9.62)}{20.49} X_{23}^{*}$	0.840
4	$Y_2 = 5515.81 - \underset{(49.15)}{163.28} X_1^{**} + \underset{(3.37)}{12.34} X_7^{**} - \underset{(5.37)}{18.11} X_8^{**} - \underset{(29.29)}{108.12} X_{14}^{**} + \underset{(6.82)}{25.04} X_{16}^{**} - \underset{(51.60)}{68.98} X_{20} - \underset{(7.36)}{16.73} X_{22}^{*} + \underset{(9.37)}{20.31} X_{23}^{*}$	0.848
5	$Y_3 = 2028.52 - \underset{(43.98)}{125.23} X_1^{*} - \underset{(27.11)}{113.01} X_{14}^{**} + \underset{(5.73)}{29.08} X_{16}^{**} - \underset{(5.58)}{24.96} X_{22}^{**} + \underset{(6.75)}{31.71} X_{23}^{**}$	0.824
6	$Y_3 = 7494.88 - \underset{(41.17)}{96.09} X_1^{*} + \underset{(2.71)}{7.38} X_7^{*} - \underset{(4.24)}{10.35} X_8^{*} - \underset{(23.42)}{95.32} X_{14}^{**} + \underset{(6.49)}{34.05} X_{16}^{**} - \underset{(41.89)}{72.16} X_{20} - \underset{(46.96)}{109.64} X_{21}^{*} - \underset{(10.01)}{39.18} X_{22}^{**} + \underset{(7.51)}{22.89} X_{23}^{**}$	0.876

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 5(f) Specific and the general yield prediction equations for PTB varieties in the winter season in the sixth fortnight after sowing

Sl. No.	Regression equations	Adjusted R^2
1	$Y_1 = 3278.70 - \underset{(43.43)}{91.31X_1} - \underset{(26.69)}{95.13X_{14}^{**}} + \underset{(5.89)}{21.14X_{16}^{**}} - \underset{(6.03)}{18.66X_{22}^{**}} + \underset{(8.32)}{16.34X_{23}} - \underset{(33.44)}{75.57X_{26}^{*}}$	0.792
2	$Y_2 = 9454.64 - \underset{(50.32)}{145.73X_1} + \underset{(2.86)}{13.49X_7} - \underset{(4.89)}{18.99X_8} - \underset{(31.49)}{89.57X_{14}^{*}} + \underset{(7.32)}{23.82X_{16}^{**}} - \underset{(5.88)}{13.13X_{22}^{*}} - \underset{(65.71)}{137.01X_{27}^{*}}$	0.838
3	$Y_3 = 3629.93 - \underset{(41.76)}{136.59X_1^{**}} - \underset{(25.62)}{107.58X_{14}^{**}} + \underset{(5.66)}{25.91X_{16}^{**}} - \underset{(5.79)}{20.48X_{22}^{**}} + \underset{(7.99)}{22.89X_{23}^{*}} - \underset{(32.11)}{58.23X_{26}}$	0.845

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

autumn season and those for the winter season in Tables 5(a) to 5(f). In the case of tables related to autumn season the symbols Y_1, Y_2 and Y_3 respectively denote the expected yields of PTB 1, PTB 5 and their general mean yield. Y_1, Y_2 and Y_3 in the other season represent the expected yields of PTB 12, PTB 20 and their general mean yield.

It could be seen that the values of the adjusted coefficient of determination ($\bar{R}^2$) of the fitted models in both the seasons were rather low in the earlier periods of crop growth but found rapid progress in the subsequent fortnights and attained their maximum value towards the fifth fortnight. The added precision for the later forecasts than that at the fifth fortnight was not substantial.

In the autumn season the maximum values of $\bar{R}^2$ of the fitted models in the first and fifth fortnights ranged from 23% to 94%. The maximum value of $\bar{R}^2$ of the fitted models in the second fortnight came to be 48% but it was increased to 82% in the third fortnight and the corresponding forecasting equation for PTB 1 is given by

$$Y = 186.51 - 71.85X_5 + 148.02X_9^{**} - 3.67X_{10}^{*} - 1.59X_{12}^{**} + 301.67X_{13}^{**} \qquad - (4.1)$$

Where X_5 = number of hours of sunshine during the first week after sowing

X_9 = Number of rainy days during the third week after sowing

X_{10} = rainfall range during the fourth week after sowing

X_{12} = total rainfall during the fifth week after sowing

X_{13} = number of rainy days during the fifth week after sowing

The same five variables explained as much as 67% of the variation in the yield of PTB 5 and 77% of the variation in the aggregate yield data. Among the variables X_9 and X_{13} exerted beneficial effects on crop yield whereas the effects of the other variables were unfavourable. It was also found that the effect of X_5 on yield was relatively small when compared to that of the other variables and the prediction equation involving these four variables could explain as much as 76% variation in crop yield. In the fourth fortnight the maximum value of $\bar{R}^2$ of the fitted models came to be 91% and that in the fifth fortnight rose to 94%. The additional important variables included to the model during the fourth fortnight were number of rainy days during the seventh week after sowing (X_{15}), total rainfall during the eighth week after sowing (X_{17}) and rainfall range during the eighth week after sowing (X_{18}). Among these three variables X_{18} alone had shown beneficial effects on crop growth and yield. An important variable selected from the fifth fortnight was number of hours of sunshine during the ninth week after sowing(X_{21}) which had negative relationship with yield.

The prediction equation for PTB 1 in the fifth fortnight with an accuracy of 94% is given by

$$Y = 1255.50 - 76.58X_5^{**} + 131.00X_9^{**} - 3.14X_{10}^{**} - 1.56X_{12}^{**} + 219.85X_{13}^{**} - 70.42X_{15}^{**} - 3.20X_{17}^{**} + 10.89X_{18}^{**} - 39.53X_{21}^{*} \qquad - (4.2)$$

Using the same independent variables of (4.2), the prediction equation for PTB 5 could explain about 78% of the variation in yield and is given by,

$$Y = 1732.99 - 87.01X_5^{*} + 96.13X_9^{*} - 3.87X_{10}^{*} - 1.56X_{12}^{*} + 157.69X_{13}^{*} - 104.63X_{15}^{*} - 2.79X_{17} + 11.49X_{18} - 33.92X_{21} \qquad - (4.3)$$

In the case of aggregate yield data also the maximum precision for the prediction equation ($\bar{R}^2 = 90\%$) was achieved in the fifth fortnight after sowing as in the case of PTB 1. The relevant equation is given by

$$Y = 1254.76 - 81.79X_5^{**} + 113.57X_9^{**} - 3.51X_{10}^{**} - 1.56X_{12}^{**} + 188.78X_{13}^{**} - 87.53X_{15}^{**} - 2.99X_{17}^{**} + 11.19X_{18}^{*} - 36.72X_{21} \qquad - (4.4)$$

The values of $\bar{R}^2$ of the fitted models in the sixth fortnight had shown no substantial improvement from that in the previous fortnight in the case of PTB 1 and for the aggregate data. Prediction equations for the other variety in the sixth fortnight had shown slight increment in goodness of fit(about 4%) when compared to that of the previous fortnight.

The results of analysis indicated that preharvest forecasting of yield of paddy in the autumn season could be done as early as in the third fortnight after sowing of the crop in general providing with sufficiently high degree of precision for the estimates. The accuracy of the prediction equations could be substantially improved by incorporating more climatological variables in the subsequent fortnights. Further among the different climatological variables, number of rainy days during the third week after sowing (X_9), range of rainfall during the fourth week after sowing (X_{10}), number of rainy days during the fifth week after sowing (X_{13}), total rainfall during the eighth week after sowing (X_{17}) were found to be decisive in making yield forecast of the crop in the autumn season. The forecasting equation using these four variables explained about 81% of the total variation in yield of PTB 1. The relevant equation is given by

$$Y = 204.86 + 165.00\overset{**}{X}_9 - 3.65\overset{*}{X}_{10} + 245.48\overset{**}{X}_{13} - 2.72\overset{**}{X}_{17} \qquad -(4.5)$$

Further, in the case of PTB 5 a regression equation with these four independent variables explained about 65% of the total variation in yield. The equation is given by

$$Y = 391.63 - 133.01\overset{**}{X}_9 - 4.41\overset{*}{X}_{10} + 199.11\overset{**}{X}_{13} - 2.35\overset{*}{X}_{17} \qquad -(4.$$

It was also evident from the results that the prediction of PTB 1 was less risky and expected to be more reliable than that of PTB 5.

In the case of winter crops, prediction equations with sufficient degree of precision could be attempted only after the fourth fortnight because all of the earlier forecasts had resulted in relatively low predictability ($\bar{R}^2$ being less than 65%). The maximum value of $\bar{R}^2$ of the different forecasting equations in various fortnights varied from 31% in the first fortnight to 88% in the fifth fortnight. Maximum value of $\bar{R}^2$ for the yield prediction equations of PTB 12 in the first six fortnights after sowing were respectively 24%, 41%, 42%, 63%, 74% and 79%. In the case of PTB 20 these values were 31%, 63%, 65%, 81%, 85% and 84% respectively. For the variety PTB 20 and also for the general prediction equation the forecasting equations of the fourth fortnight resulted in sufficiently high degree of precision. The relevant equation for PTB 20 with 81% precision is given by

$$Y = 7371.84 - 197.54X_1^{**} + 15.73X_7^{**} - 20.73X_8^{*} \backslash 113.63X_{14}^{**} + 26.92X_{16}^{**} - 83.29X_{19}^{*} \qquad -(4.7)$$

Where X_1 = maximum temperature during one week before sowing

X_7 = total rainfall during the third week sowing

X_8 = rainfall range during the third week after sowing

It was also evident from the results that the prediction of PTB 1 was less risky and expected to be more reliable than that of PTB 5.

In the case of winter crops, prediction equations with sufficient degree of precision could be attempted only after the fourth fortnight because all of the earlier forecasts had resulted in relatively low predictability ($\bar{\bar{R}}^2$ being less than 65%). The maximum value of $\bar{\bar{R}}^2$ of the different forecasting equations in various fortnights varied from 31% in the first fortnight to 88% in the fifth fortnight. Maximum value of $\bar{\bar{R}}^2$ for the yield prediction equations of PTB 12 in the first six fortnights after sowing were respectively 24%, 41%, 42%, 63%, 74% and 79%. In the case of PTB 20 these values were 31%, 63%, 65%, 81%, 85% and 84% respectively. For the variety PTB 20 and also for the general prediction equation the forecasting equations of the fourth fortnight resulted in sufficiently high degree of precision. The relevant equation for PTB 20 with 81% precision is given by

$$Y = 7371.84 - 197.54X_1^{**} + 15.73X_7^{**} - 20.73X_8^{**} - 113.63X_{14}^{**} + 26.92X_{16}^{**} - 83.29X_{19}^{*} \quad -(4.7)$$

Where X_1 = maximum temperature during one week before sowing

X_7 = total rainfall during the third week after sowing

X_8 = rainfall range during the third week after sowing

X_{14} = number of rainy days during the sixth week after sowing

X_{16} = maximum humidity during the seventh week after sowing

X_{19} = minimum temperature during the eighth week after sowing

The same independent variables of the prediction equation (4.7) explained about 63% of the variation in the yield of PTB 12 and 77% variation in the aggregate yield data. Among the variables X_{14} and X_{16} appeared to have greater influence on crop yield in general. X_{16} had beneficial effects on yield where as X_{14} adversely affected the crop yield. The five decisive variables explaining about 77% of variation in the yield of PTB 20 in the winter season formed a prediction equation.

$$Y = 4591.35 - 176.09X_1^{**} + 14.28X_7^{**} - 16.23X_8^{**} - 122.36X_{14}^{**} + 30.23X_{16}^{**} \qquad -(4.8)$$

The same five independent variables of (4.8) could explain only 53% and 71% of the variation in the yield of PTB 12 and aggregate data respectively. Among the different variables X_{14} and X_{16} alone were found to produce significant influence on yield of PTB 12. However the reliability of the forecasts of PTB 12 was found to increase drastically with an increase in the age of the crop but realised gain in precision was relatively small in the later forecasts than that at the fifth fortnight. By identifying the important variables for PTB 12 the prediction equation with maximum precision ($\bar{R}^2 = 79\%$) was achieved in the sixth fortnight and is given by

$$Y = 3278.70 - 91.31X_1 - 95.13X_{14}^{**} + 21.14X_{16}^{**} - 18.66X_{22}^{**} + 16.34X_{23} - 75.57X_{26}^{*} \qquad - (4.9)$$

Where X_{22} = minimum humidity during ninth week after sowing

X_{23} = maximum humidity during the tenth week after sowing

X_{26} = number of hours of sunshine during the eleventh week after sowing

An efficient forecasting equationfor PTB 12 ($\bar{R}^2 = 72\%$), with less number of independent variables is given by

$$Y = {}^{-}1117.24 - 107.39X_{14}^{**} + 26.93X_{16}^{**} - 27.31X_{22}^{**} + 27.84X_{23}^{**} \qquad - (4.10)$$

Among the forecasting equations for aggregate data, the one with maximum precision ($\bar{R}^2 = 88\%$) was obtained in the fifth fortnight after sowing and is given by

$$Y = 7494.88 - 96.09X_1^{*} + 7.38X_7^{*} - 10.35X_8^{*} - 95.32X_{14}^{**} + 34.05X_{16}^{**} - 72.16X_{20} - 39.18X_{22}^{**} - 109.64X_{21}^{*} + 22.89X_{23}^{**} \qquad - (4.11)$$

Where X_{20} = minimum temperature during the ninth week after sowing

X_{21} = number of hours of sunshine during the ninth week after sowing.

A comparison of the regression equations for the two varieties in the winter season elucidates that the yield prediction equations developed for PTB 20 are more efficient than those for PTB 12 and are expected to produce estimates of greater consistency.

4.3.2. Composite regression models to forecast paddy yield in different fortnights of crop growth.

Multiple linear regression analysis on the basis of the generated variables was also attempted and prediction equations developed in each fortnight through the stepwise procedure discussed in the previous chapter. As mentioned in section 3.2.3. two composite regression models based on weighted weather indices were used for the purpose. In model 1 the weights constituted different powers of week identification number and in model 2 appropriate powers of the correlation coefficients of the relevant variables with crop yield served as weights. The generated variables (weighted weather indices) $Z_{ijk's}$ and $Q_{ii'jk's}$ for model 1 and $Z'_{ijk's}$ and $Q'_{ii'jk's}$ for model 2 constituted the predictor variables of the regression equations for the two varieties in each of the two seasons. The general prediction equation was not attempted as it has already been obtained with sufficient degree of precision using original weather variables. Complete data of crop and weather for twenty one years were available for PTB varieties in the autumn season while twenty four years data and twenty three years data were available for the same purpose in the case of PTB 12 and PTB 20 respectively in the winter season. In model 1 the weather index Z_{ijk} represents the cumulative effect of the j^{th} component of the i^{th} weather variable X_i starting from the week before sowing of the crop upto the k^{th} fortnight after sowing. $Q_{ii'jk}$ refers to the cumulative effect of the interaction of the variables X_i and $X_{i'}$ starting from one week before sowing upto the k^{th} fortnight after sowing. A variable with subscript $j = 0,1,2$ indicates the component of the effect where the exponent of the weighting coefficient is 'j'. As 'j' assumes the value zero the ordinary unweighted index is obtained.

The meteorological variables which were utilised for the construction of weather indices for the study constituted total rainfall, number of rainy days, maximum temperature, number of hours of sunshine, minimum humidity and maximum humidity. Among them the first five alone were used for the evolution of generated variables for the varieties in the autumn season and the first four and the sixth were used for the same purpose in the case of the varieties in the winter season. The values of the generated variables were determined for the different fortnights starting from the first fortnight after sowing to the sixth fortnight after sowing in both the seasons and were further used for the correlation studies.

Table 6 (a) Zero order correlation coefficients of the generated variables Z_{ijk}'s and Q_{ijk}'s under model 1 with yield of PTB 1 in the autumn season

No. of fortnights after sowing	Total rain-fall (R)	No. of rainy days (D)	Maxi-mum temper-ature (T)	No. of hours of sun-shine (S)	Minimum humidity (H_1)	RD	RT	RS	RH_1	DT	DS	DH_1	TS	TH_1	SH_1
1	0.1286	-0.0923	-0.0805	-0.3811	-0.0129	0.1947	0.1119	-0.4537*	0.1483	-0.1486	-0.5658**	-0.0403	-0.3484	-0.0956	-0.4737*
	0.1549	-0.1913	-0.1022	-0.3493	-0.0219	0.1964	0.1449	-0.4227	0.1609	-0.0522	-0.4632*	-0.0093	-0.3263	-0.1104	-0.4215
	0.1449	0.0094	-0.0952	-0.2975	-0.0415	0.1728	0.1388	-0.3949	0.1423	-0.0072	-0.3781	-0.0069	-0.2784	-0.1317	-0.3599
2	0.0291	0.1122	-0.0673	-0.3667	-0.0002	0.1153	0.0218	-0.4193	0.0338	0.0898	-0.4359*	0.1137	-0.3349	-0.0624	-0.4461*
	-0.0258	0.2302	-0.0376	-0.2492	-0.0107	0.0463	-0.0238	-0.3316	-0.0283	0.2484	-0.2198	0.1815	-0.2316	-0.3859	-0.2974
	-0.0798	0.2441	0.0029	-0.1374	-0.0297	-0.0179	-0.0739	-0.2622	-0.0854	0.2769	-0.0602	0.0224	-0.1255	-0.0402	-0.1543
3	-0.1401	0.3341	-0.0331	-0.2799	-0.0945	-0.0399	-0.1466	-0.4163	-0.1398	0.3592	-0.2667	0.2396	-0.2614	-0.2139	-0.3595
	-0.2663	0.4379*	0.0253	-0.0679	-0.1836	0.0564	-0.2681	-0.3029	-0.2776	0.4842*	0.0717	0.3043	-0.0657	-0.2299	-0.1117
	-0.3159	0.3598	0.0718	-0.3498	-0.2365	-0.2519	-0.3163	-0.1761	-0.3307	0.4007	0.2457	0.1796	0.0679	-0.2718	0.0519
4	-0.2905	0.0602	0.0444	-0.1296	-0.1589	-0.2297	-0.2959	-0.4347*	-0.2841	0.0812	-0.1962	-0.0072	-0.1206	0.3393	-0.1802
	-0.4413*	-0.0085	0.1464	0.1254	-0.2651	0.0276	-0.4466*	-0.3530	-0.4386*	0.0362	0.1324	-0.1002	0.1227	-0.2794	0.1103
	-0.5060*	-0.1060	0.1879	0.2382	-0.3179	-0.4822*	-0.5127*	-0.2834	-0.5025*	-0.0662	0.2458	-0.0294	0.2340	-0.4179	0.2373
5	-0.2393	0.1288	-0.0950	-0.2105	-0.1039	-0.1591	-0.2508	-0.4593*	-0.2363	0.1511	-0.2589	0.0917	-0.2031	-0.2089	-0.2618
	-0.3232	0.1389	-0.1652	-0.0757	-0.1336	0.0704	-0.3347	-0.3623	-0.3319	0.1288	0.0139	0.0681	-0.0819	-0.2788	-0.0895
	-0.2995	0.0911	-0.2556	-0.0604	-0.1099	-0.2394	-0.3138	-0.2639	-0.3141	0.0791	-0.0414	0.0504	-0.0698	-0.2973	-0.0631
6	-0.2691	0.0784	-0.0913	-0.0886	-0.1942	-0.1882	-0.2826	-0.4758*	0.1537	0.0606	-0.1679	0.0689	-0.0884	-0.3292	-0.1179
	-0.3573	0.0291	-0.1302	0.0717	-0.2877	0.0733	-0.3747	-0.3768	-0.3624	0.0148	0.0146	-0.0442	0.0633	-0.4625*	0.0302
	-0.3471	-0.0129	-0.1644	0.1088	-0.3141	-0.2855	-0.3645	-0.3645	-0.3566	-0.0331	0.0333	-0.0748	0.0987	0.2333	0.0691

* Significant at 5% level

** Significant at 1% level

Table 6 (b) Zero order correlation coefficients of the generated variables Z_{ijk}'s and $Q_{i'jk}$'s under model 1 with yield of PTB .5 in the autumn Season

No. of fortnights after sowing	Total rainfall (R)	No. of rainy days (D)	Maximum Temperature (T)	No. of hours of sunshine (S)	Minimum humidity (H_1)	RD	RT	RS	RH_1	DT	DS	DH_1	TS	TH_1	SH_1
1.	0.0583	-0.1399	-0.0215	-0.2893	-0.0936	0.1343	0.0401	-0.4334*	0.0726	-0.1958	-0.5119*	-0.0985	-0.2563	-0.1811	-0.7263**
	0.1014	0.1275	-0.0404	-0.2545	-0.0931	0.1476	0.0923	-0.3772	0.1003	-0.0814	-0.3854	-0.0565	-0.2321	-0.1776	-0.3339
	0.1010	-0.0156	-0.0299	-0.1991	-0.1044	0.1301	0.0973	-0.3264	0.0908	-0.0251	-0.2829	-0.0454	-0.1820	-0.1828	-0.2638
2.	-0.0593	0.0126	0.0074	-0.2345	-0.0943	0.0278	-0.0659	-0.3845	-0.0700	-0.0115	-0.3610	0.0096	-0.2051	-0.1536	-0.3230
	-0.1127	0.1276	0.0455	-0.1136	-0.1033	-0.0472	-0.1075	-0.2799	-0.1242	0.1489	-0.1215	0.0719	-0.0982	-0.1298	-0.1665
	-0.1709	0.1437	0.0909	-0.0125	-0.1211	-0.1178	-0.1607	-0.2109	-0.1849	0.1827	0.0455	0.0710	-0.0024	-0.1166	-0.0512
3.	-0.1911	0.2580	0.0213	-0.1815	-0.1511	-0.0960	-0.1976	-0.3586	-0.1981	0.2805	-0.1919	0.1598	-0.1628	-0.2556	-0.2483
	-0.2801	0.4165	0.0549	-0.0170	-0.1939	-0.0326	-0.2797	-0.2128	-0.2997	0.4671*	0.1499	0.2750	-0.0147	-0.2249	-0.0514
	-0.3030	0.3747	0.0759	-0.3371	-0.2099	-0.2668	-0.3010	-0.0651	-0.3252	0.4179	0.3086	0.2498	0.0706	-0.2311	0.0693
4.	-0.3261	0.0950	0.0878	-0.0365	-0.2020	-0.2710	-0.3315	-0.3583	-0.3252	-0.0203	-0.1208	-0.0621	-0.0278	0.3243	-0.0903
	-0.4444*	-0.0091	0.1674	0.1763	-0.2652	-0.0079	-0.4475*	-0.2640	-0.4466*	0.0373	0.2067	-0.1025	0.1730	-0.2666	0.1649
	-0.4943*	-0.0804	0.1978	0.2632	-0.2944	-0.4778*	-0.4983*	-0.1849	-0.4943*	-0.0386	0.3080	0.1003	0.2578	-0.3892	0.2678
5.	-0.2549	0.1396	-0.0695	-0.1598	-0.1366	-0.1809	-0.2661	-0.3939	-0.2601	0.1288	-0.1902	0.0633	-0.1522	-0.2426	-0.2149
	-0.2887	0.1739	-0.1836	-0.0929	-0.1210	0.0550	-0.2981	-0.2679	-0.3066	0.1658	0.1016	0.0973	-0.1009	-0.2708	-0.1045
	-0.2377	0.1579	-0.3028	-0.1166	-0.0767	-0.1877	-0.2504	-0.1888	-0.2604	0.1381	-0.0066	0.1024	-0.1287	-0.2755	-0.1179
6.	-0.2849	0.0950	-0.0693	-0.0274	-0.2288	-0.2099	-0.2976	-0.4129	0.1382	0.0817	-0.0764	0.0552	-0.0281	-0.3659	-0.0803
	-0.3329	0.0940	-0.1438	0.0907	-0.2927	0.0566	-0.3476	-0.2583	-0.3489	0.0881	0.1084	0.0063	0.0839	-0.4739*	0.0554
	-0.3079	0.0705	-0.1938	0.1215	-0.3144	-0.2517	-0.3225	-0.1871	-0.3284	0.0548	0.1252	-0.0084	0.1085	0.1510	-0.0829

* Significant at 5% level

** Significant at 1% level

Table 7(a) Zero order correlation coefficients of the generated variables Z'_{ijk}'s and Q'_{ijk}'s under model 2 with yield of PTB 1 in the autumn season

No. of fortnights after sowing	Total rainfall (R)	No. of rainy days (D)	Maximum temperature (T)	No. of hours of sunshine (S)	Minimum humidity (H_1)	RD	RT	RS	RH_1	DT	DS	DH_1	TS	TH_1	SH_1
1	0.1286	-0.0923	-0.0805	-0.3811	-0.0219	0.1947	0.1119	-0.4537*	0.1483	-0.1481	-0.5658**	-0.0403	-0.3484	-0.0956	-0.4737*
	0.3805	-0.3050	-0.2754	-0.3638	-0.0887	0.3386	0.4466*	-0.5321*	0.3577	-0.3311	-0.6370**	-0.2936	-0.4494*	-0.2274	-0.5802**
	0.2398	-0.2130	-0.2182	-0.4829*	-0.0862	0.3346	0.3522	-0.5834**	-0.0969	-0.2638	-0.6684**	-0.0202	-0.4730*	-0.2029	-0.5974**
2	0.0291	0.1122	-0.0673	-0.3667	-0.0002	0.1153	0.0218	-0.4193	0.0338	0.0898	-0.4359*	0.1137	-0.3349	-0.0624	-0.4461*
	-0.4050	0.4410*	-0.4017	-0.4208	-0.2675	0.3312	0.4046	-0.5009*	0.3933	0.4647*	-0.6303**	0.4978*	-0.4971*	-0.2146	-0.5765**
	0.1862	0.2122	-0.1573	-0.5213*	0.0677	0.3037	0.1728	-0.5626**	0.2867	0.1725	-0.6617**	0.4792*	-0.5070*	-0.1903	-0.5982**
3	-0.1401	0.3341	-0.0331	-0.2799	-0.0945	-0.0399	-0.1466	-0.4163	-0.1398	0.3592	-0.2667	0.2396	-0.2614	-0.2139	-0.3595
	-0.4869*	0.6225**	-0.4034	-0.4612*	-0.3241	-0.4338*	-0.5327*	-0.5223*	-0.5279*	0.6495**	-0.6969**	0.5339*	-0.5486**	-0.3899	-0.5998**
	-0.1391	0.4796*	-0.1430	-0.4841*	-0.1964	0.1556	-0.0642	-0.5577**	-0.0033	0.5320*	-0.6019**	0.5076*	-0.4739*	-0.3851	-0.5901**
4	-0.2905	0.0602	0.0444	-0.1296	-0.1589	-0.2297	-0.2959	-0.4347*	-0.2841	0.0812	-0.1962	-0.0072	-0.1206	0.3393	-0.1802
	-0.6536**	0.7162**	0.5313*	-0.5376*	-0.3970	-0.6401**	-0.6528**	-0.5334*	-0.6239**	0.7533**	-0.7053**	-0.6615**	-0.6326**	-0.4346*	-0.6559**
	-0.4910*	0.0939	0.0168	-0.3657	-0.2719	-0.4291	-0.4693*	-0.5627**	-0.4300	0.3247	-0.5970**	0.3069	-0.3438	-0.4178	-0.4967*
5	-0.2393	0.1288	-0.0950	-0.2105	-0.1039	-0.1591	-0.2508	-0.4593*	-0.2363	0.1511	-0.2589	0.0917	-0.2031	-0.2089	-0.2618
	-0.6295**	0.6918**	-0.5880**	-0.5862**	-0.4188	-0.6581**	-0.6595**	-0.5616**	-0.6464**	0.7229**	-0.7434**	0.3273	-0.6569**	-0.4188	-0.6562**
	-0.4920*	0.1267	-0.3885	-0.4334*	0.0348	-0.4057	-0.4641*	-0.5813**	-0.4057	0.3315	-0.5167*	0.3273	-0.3679	-0.4197	-0.5134*
6	-0.2691	0.0784	-0.0913	-0.0886	-0.1942	-0.1882	-0.2826	-0.4758*	0.1537	0.0106	-0.1679	0.0689	-0.0884	-0.3292	-0.1179
	-0.6419**	0.6961**	-0.6229**	-0.6480**	-0.4754*	-0.6933**	-0.6677**	-0.5815**	-0.6561**	0.7338**	-0.7487**	-0.6902**	-0.6666**	-0.5508**	-0.6659**
	-0.5166*	0.1047	0.0145	-0.3666	-0.3846	-0.4594*	-0.5070*	-0.5931**	-0.3613	0.3092	-0.6318**	0.3319	-0.3609	-0.5444*	-0.4788*

* Significant at 5% level

** Significant at 1% level

Table 7(b) Zero order correlation coefficients of the generated variables Z'_{ijk}'s and Q'_{ijk}'s under model 2 with yield of PTB 5 in the autumn season

No. of fortnights after sowing.	Total rainfall (R)	No.of rainy days (D)	Maximum temperature (T)	No.of hours of sunshine (S)	Minimum humidity (H_1)	RD	RT	RS	RH_1	DT	DS	DH_1	TS	TH_1	SH_1
1	0.0583	-0.1399	-0.0215	-0.2893	-0.0936	0.1343	0.0401	-0.4334*	0.0726	-0.1958	-0.5119*	-0.0985	-0.2563	-0.1811	-0.7263**
	0.3377	-0.3864	-0.3103	-0.4649*	-0.2636	0.3758	0.4889*	-0.5545**	0.3964	-0.3985	-0.6293**	-0.3445	-0.4529*	-0.2463	-0.5196*
	0.2793	-0.2036	-0.0389	-0.4781*	-0.1575	0.3033	0.0498	-0.6330**	0.1994	-0.3410	-0.6629**	-0.1495	-0.4666*	-0.2659	-0.5267*
2	-0.0593	0.0126	0.0074	-0.2345	-0.0943	0.0278	-0.0659	-0.3845	-0.0700	-0.0115	-0.3610	0.0096	-0.2051	-0.1536	-0.3230
	0.4135	0.4389*	-0.5267*	-0.4962*	-0.4589*	0.4041	-0.5004*	-0.5116*	-0.5202*	0.4495*	-0.6513**	0.4925*	-0.4879*	-0.2903	-0.5175*
	0.0252	0.0276	0.1459	-0.4759*	-0.1385	0.1123	-0.0878	-0.6134**	-0.0739	-0.1881	-0.6505**	0.4101	-0.4608*	-0.2475	-0.5171*
3	-0.1911	0.2580	0.0213	-0.1815	-0.1511	-0.0961	-0.1976	-0.3586	-0.1981	0.2805	0.1919	0.1598	-0.1628	-0.2556	-0.2483
	-0.5479*	0.5395**	-0.4975*	-0.5190*	-0.4454*	-0.4789*	-0.5839**	-0.5288*	-0.6054**	0.5672**	-0.7130**	0.5148*	-0.5086*	-0.3687	-0.5186*
	-0.1481	0.3061	-0.0181	-0.4698*	-0.0134	-0.0359	-0.2451	-0.5996**	-0.2722	-0.0301	-0.5833**	0.4423*	-0.4569*	-0.3482	-0.5184*
4	-0.3261	0.0950	0.0878	-0.0365	-0.2020	-0.2710	-0.3315	-0.3583	-0.3252	0.0203	-0.1208	-0.0621	-0.0278	0.3247	-0.0903
	-0.6537**	0.7202**	0.6139**	0.6193**	-0.4735*	-0.6479**	-0.6747**	-0.5333*	-0.7083**	0.7047**	-0.7140**	-0.6644**	0.4986*	-0.3950	-0.5917**
	-0.4632*	-0.1094	0.0364	-0.3245	-0.0694	-0.4543*	-0.5078*	-0.5983**	-0.5522**	-0.1162	-0.5727**	0.1368	-0.3097	-0.0258	-0.4092
5	-0.2549	0.1396	-0.0695	-0.1598	-0.1366	-0.1809	-0.2661	-0.3939	-0.2601	0.1288	-0.1902	0.0633	-0.1522	-0.2426	-0.2149
	-0.6748**	0.6389**	-0.2381	-0.6561**	-0.5117*	-0.6667**	-0.6871**	-0.5492**	-0.6943**	0.6846**	-0.7376**	0.6578**	-0.6466**	-0.3850	-0.6174**
	-0.4287	-0.0027	-0.4948*	-0.4209	-0.1964	-0.4126	-0.4919*	-0.6043**	-0.5442*	-0.0685	-0.5961**	0.1884	-0.4119	-0.3659	-0.4619*
6	-0.2849	0.0950	-0.0693	-0.0274	-0.2288	-0.2099	-0.2976	-0.4129	0.1382	0.0817	-0.0764	0.0552	-0.0281	-0.3659	-0.0803
	-0.6999**	-0.5326*	-0.2439	-0.6837**	-0.5469*	-0.7059**	-0.6996**	-0.5585**	-0.7362**	0.6929**	-0.7534**	-0.6813**	-0.6762**	-0.5449*	-0.6471**
	-0.4882*	-0.0279	-0.4886*	-0.2782	-0.4042	-0.4655*	-0.5327*	-0.6077**	-0.6022**	-0.0706	-0.5706**	0.1692	-0.2904	-0.5620**	-0.3852

* Significant at 5% level

** Significant at 1% level

Table 8(a) Zero order correlation coefficients of the generated variables Z_{ijk}'s and Q_{ijk}'s under model 1 **with yield of PTB 12 in the winter season.**

No.of fortnights after sowing	Total rain-fall (R)	No. of rainy days (D)	Maximum tempera-ture (T)	No. of hours of sunshine (S)	Maximum humi-dity (H_2)	RD	RT	RS	RH_2	DT	DS	DH_2	TS	TH_2	SH_2
1	0.1815	0.2732	-0.0315	-0.0646	0.3222	0.2295	0.1807	0.2521	0.1942	0.3134	0.3543	0.2881	-0.0676	-0.0602	-0.0273
	0.1767	0.2233	-0.2932	0.0314	0.3746	0.2234	0.1871	0.3213	0.1885	0.2396	0.3992	0.2245	-0.0209	-0.0073	0.0780
	0.1565	0.1813	-0.1785	0.0843	0.3550	0.1167	0.1929	0.3710	0.1864	0.1988	0.4066*	0.1949	0.0332	0.0269	0.1278
2	0.2902	0.4563*	-0.0615	-0.1994	0.3417	0.3313	0.2823	0.3505	0.3053	0.4742*	0.4388*	0.4700*	-0.2459	-0.0105	-0.1579
	0.3053	0.4332*	-0.3904	-0.1876	0.3046	0.3391	0.3061	0.3631	0.3291	0.4223*	0.3793	0.4486*	-0.2228	0.0304	-0.1511
	0.2911	0.3804	-0.3724	-0.2016	0.2883	0.0579	0.2769	0.3017	0.3026	0.3639	0.2909	0.3948	-0.2288	0.0829	-0.1853
3	0.2209	0.3286	-0.1058	-0.1887	0.3358	-0.1312	0.2125	0.2351	0.2336	0.3449	0.3209	0.3455	-0.2432	0.0892	-0.1037
	0.2323	0.1944	-0.4754*	-0.1629	0.3129	0.1295	0.1375	0.1191	0.1593	0.1714	0.2158	0.2146	-0.2149	0.1345	-0.0561
	0.0623	0.0666	-0.4756*	-0.1432	0.3004	-0.0370	0.0492	0.0006	0.0709	0.0422	0.0012	0.0892	-0.1964	0.1345	-0.0217
4	0.2549	0.2823	-0.1421	-0.1229	0.3979	0.2005	0.2465	0.2814	0.2669	0.2969	0.2550	0.3012	-0.2048	0.2232	0.0785
	0.1754	0.1164	-0.5099*	-0.0170	0.3875	0.0889	0.1887	0.1853	0.2123	0.1098	0.1866	0.1517	-0.1130	0.2839	0.3349
	0.1405	0.0344	-0.4977*	0.0771	0.3835	-0.0522	0.1267	0.1104	0.1512	0.0208	0.0064	0.0522	-0.0227	0.2992	0.4732*
5	0.1911	0.1838	-0.1634	-0.0649	0.3606	0.1549	0.1817	0.2185	0.1973	0.2187	0.1738	0.2075	-0.1485	0.2116	0.1420
	0.0698	-0.0188	-0.4838*	0.0390	0.3362	-0.0004	0.0679	0.0913	0.0927	-0.0349	0.0743	0.0011	-0.0451	0.2387	0.3966
	0.0219	-0.1728	-0.4526*	0.0825	0.2941	-0.0692	-0.0278	0.0027	0.0368	-0.1424	-0.0959	-0.1176	0.0086	0.2382	0.4088*
6	0.2317	0.2297	-0.2337	-0.1908	0.3637	0.1764	0.2218	0.2405	0.2420	0.2569	0.2171	0.2470	-0.2873	0.1929	0.0613
	0.1132	0.0779	-0.5504**	-0.1844	0.3449	0.0526	0.1562	0.1806	0.1849	0.0605	0.0722	0.0905	-0.2868	0.2026	0.1759
	0.1361	0.0258	-0.6273**	-0.2022	0.3441	-0.0583	0.1200	0.1461	0.1328	0.0109	-0.0077	0.0301	-0.3010	0.1908	0.2043

*Significant at 5% level

** Significant at 1% level

Table 8(b) Zero order correlation coefficients of the generated variables Z_{ijk}'s and Q_{ijk}'s under model 1 with yield of PTB 20 in the winter season

No.of fort-nights after sow-ing	Total rain-fall (R)	No.of rainy days (D)	Maxi-mum temper-ature (T)	No.of hours of sun-shine (S)	Maxi-mum humi-dity (H_2)	RD	RT	RS	RH_2	DT	DS	DH_2	TS	TH_2	SH_2
1	0.3207	0.0636	-0.0298	-0.1734	0.1940	0.2765	0.3153	0.4081*	0.3255	0.3854	0.4116*	0.3534	-0.1724	-0.1807	-0.1547
	0.2468	0.2298	-0.3353	-0.0785	0.2797	0.1919	0.2616	0.4033*	0.2497	0.2480	0.3967	0.2397	-0.1235	-0.1229	-0.0432
	0.1661	0.1351	-0.2257	-0.0032	0.2599	0.0312	0.2089	0.3882	0.1899	0.1524	0.3492	0.1424	-0.0595	-0.0931	0.0281
2	0.4806*	0.4694*	-0.0568	-0.2067	0.2668	0.4018*	0.4774*	0.5692**	0.4861*	0.4911*	0.4913*	0.4747*	-0.2548	-0.0981	-0.1832
	0.4542*	0.3675	-0.3806	-0.1339	0.2338	0.3512	0.4596*	0.5269**	0.4686*	0.3563	0.3796	0.3783	-0.1748	-0.0433	-0.1024
	0.4012*	0.2896	-0.3536	-0.1151	0.2163	-0.0135	0.3888	0.4216*	0.1342	0.2269	0.2583	0.2984	-0.1495	-0.0318	-0.1027
3	0.3447	0.3169	-0.0912	-0.1260	0.2160	0.2943	0.3373	0.3697	0.3516	0.3359	0.1662	0.3316	-0.1794	-0.0454	-0.0618
	0.3090	0.1253	-0.4299*	-0.0364	0.1812	0.1585	0.1905	0.1774	0.2110	0.0941	0.2051	0.1415	-0.0906	-0.0037	0.0754
	0.0815	-0.0183	-0.4195*	0.0024	0.1609	-0.0817	0.0313	0.0193	0.0909	-0.0473	-0.0509	0.0049	-0.0508	0.0031	0.0939
4	0.3522	0.2759	-0.1301	-0.0679	0.2845	0.2618	0.3421	0.3682	0.3601	0.2916	0.2709	0.2932	-0.1496	0.0753	0.0835
	0.1821	0.0673	-0.5129**	0.0796	0.2736	0.1099	0.1972	0.1806	0.2253	0.0581	0.1919	0.1046	-0.0911	0.1354	0.3685
	0.1140	-0.0125	-0.5137**	0.1580	0.2733	-0.1027	0.0944	0.0649	0.1263	-0.0353	-0.0239	0.0062	0.0558	0.1559	0.4549*
5	0.2904	0.1699	-0.1470	0.0267	0.2632	0.2115	0.2799	0.3436	0.3210	0.2087	0.1880	0.1906	-0.0568	0.0805	0.1484
	0.0950	-0.0741	-0.5027*	0.1808	0.2463	0.0120	0.0923	0.1101	0.1198	-0.0922	0.0788	-0.0549	0.0957	0.1150	0.4762*
	0.0704	-0.1243	-0.4858*	0.2182	0.2421	-0.1238	-0.0305	-0.0024	0.0445	-0.1993	-0.1220	-0.1735	0.1438	0.1228	0.4688*
6	0.3199	0.2143	-0.2107	-0.0836	0.2655	0.2296	0.3080	0.3103	0.3274	0.2449	0.2259	0.2307	-0.1829	0.0572	0.0823
	0.0992	0.0209	-0.5267**	-0.0391	0.2521	0.0543	0.1525	0.1667	0.1919	0.0004	0.0408	0.0342	-0.1498	0.0696	0.2377
	0.0935	-0.0339	-0.6223**	-0.0676	0.2499	-0.1155	0.0763	0.0940	0.0982	-0.0513	-0.0549	-0.0282	-0.1739	0.0593	0.1968

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

Table 9(a) Zero order correlation coefficients of the generated variables Z'_{ijk}'s and $Q'_{ii'jk}$'s under model 2 with yield of PTB 12 in the winter season.

No. of fort-nights after sow-ing.	Total rain fall (R)	No. of rainy-days (D)	Maxi-mum tempera-ture (T)	No. of hours of sun-shine (S)	Maximum humi-dity (H_2)	RD	RT	RS	RH_2	DT	DS	DH_2	TS	TH_2	SH_2
1	0.1815	0.2732	-0.0315	-0.0646	0.3222	0.2295	0.1807	0.2521	0.1942	0.3134	0.3543	0.2881	-0.0676	-0.0662	-0.0273
	0.3882	0.3594	-0.4494*	-0.1304	0.4239*	0.2647	0.4145*	0.5703**	0.3918*	0.3770	0.6282**	0.3713	-0.2362	-0.2500	0.2308
	0.2615	0.3513	-0.4589*	-0.1710	0.4401*	0.2723	0.2726	0.4824*	0.2819	0.3559	0.6018**	0.3515	-0.2269	0.1419	-0.0805
2	0.2902	0.4563*	-0.0615	-0.1994	0.3417	0.3313	0.2823	0.3505	0.3053	0.4742*	0.4388*	0.4700*	-0.2459	-0.0105	-0.1579
	0.4726*	0.5619**	-0.5448**	-0.2894	0.3879	0.4390*	0.4852*	0.6353**	0.4829*	0.5648**	0.2229	0.5699**	-0.3840	-0.3017	-0.3663
	0.4057*	0.5457**	-0.5663**	-0.3283	0.3955*	0.4211*	0.4079*	0.5805**	0.4233*	0.5329**	0.5877**	0.5563**	-0.3755	-0.0649	-0.2718
3	0.2209	0.3286	-0.1058	-0.1887	0.3358	-0.1312	0.2125	0.2351	0.2336	0.3449	0.3209	0.3455	-0.2432	0.0892	-0.1037
	0.5439**	0.6414**	-0.5696**	-0.3316	0.3519	0.5209**	0.5575**	0.6544**	0.5477**	0.6648**	0.3154	0.6629**	-0.4012*	0.2739	-0.4260*
	0.3317	0.3572	-0.5982**	-0.3295	0.3718	0.3244	0.3258	0.6015**	0.3545	0.3123	0.3752	0.4035*	-0.3858	0.0639	-0.1295
4	0.2549	0.2823	-0.1421	-0.1229	0.3979*	0.2005	0.2465	0.2814	0.2669	0.2969	0.2550	0.3012	-0.2048	0.2232	0.0785
	0.5786**	0.6415**	-0.5969**	-0.4405*	0.4279*	0.5015**	0.5929**	0.6947**	0.5794**	0.6733**	0.6967**	0.6644**	-0.4612*	0.4032*	0.5621**
	0.3696	0.3583	-0.6283**	0.0886	0.4161*	0.3239	0.3608	0.6279**	0.3902*	0.3121	0.3765	0.4033*	-0.1997	0.3548	0.4631*
5	0.1911	0.1838	-0.1634	-0.0649	0.3606	0.1549	0.1817	0.2185	0.1973	0.2187	0.1738	0.2075	-0.1485	0.2116	0.1420
	0.6079**	0.6567**	-0.6056**	-0.5095**	0.4488*	0.5319**	0.6203**	0.6831**	0.6069**	0.6769**	0.7171**	0.6564**	-0.5119**	0.4093*	0.6305**
	0.2354	0.2326	-0.6234**	0.1961	0.4306*	0.1587	0.2366	0.5546**	0.2603	0.1680	0.2759	0.2386	0.0151	0.3692	0.5351**
6	0.2317	0.2297	-0.2337	-0.1908	0.3637	0.1764	0.2218	0.2405	0.2420	0.2569	0.2171	0.2470	-0.2873	0.1929	0.0613
	0.6262**	0.6837**	-0.6397**	-0.6441**	0.4591*	0.6265**	0.6466**	0.7143**	0.6285**	0.6920**	0.7379**	0.6933**	-0.6468**	0.3785	0.7187**
	0.2792	0.2739	-0.7363**	-0.3858	0.4061*	0.1969	0.2772	0.5822**	0.2959	0.1829	0.3044	0.2727	-0.4949*	0.3628	0.0467

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

Table 9(b) Zero order-correlation coefficients of the generated variables Z'_{ijk}'s and Q'_{ijk}'s under model 2 with yield of PTB 20 in the winter season.

No.of fortnights after sowing	Total rainfall (R)	No.of rainy days (D)	Maximum temperature (T)	No.of hours of sunshine (S)	Maximum humidity (H_2)	RD	RT	RS	RH_2	DT	DS	DH_2	TS	TH_2	SH_2
1	0.3207	0.0636	-0.0298	-0.1734	0.1940	0.2765	0.3153	0.4081*	0.3255	0.3854	0.4116*	0.3534	-0.1724	-0.1807	-0.1547
	0.3417	0.3327	-0.4973*	-0.2799	0.3456	0.2997	0.3448	0.4635*	0.1960	0.2215	0.5358**	0.3734	-0.0112	-0.3474	-0.3339
	0.3257	0.1215	-0.5221**	-0.2835	0.3753	0.2991	0.4936*	0.4731*	0.3295	0.3713	0.4699*	0.3723	-0.3079	-0.3599	-0.2707
2	0.4806*	0.4694*	-0.0568	-0.2067	0.2668	0.4018*	0.4774*	0.5692**	0.4861*	0.4911*	0.4913*	0.4747*	-0.2548	-0.0981	-0.1832
	0.5674**	0.5968**	-0.5527**	-0.3183	0.3002	0.5205**	0.6004**	0.7116**	0.2906	0.6179**	0.6674**	0.6145**	-0.3205	-0.4675*	-0.3074
	0.5624**	0.2962	-0.3935	-0.3127	0.3376	0.5498**	0.6302**	0.6919**	0.6293**	0.6189**	0.6251**	0.6296**	-0.3443	-0.2775	-0.2584
3	-0.3447	0.3169	-0.0912	-0.1260	0.2160	0.2943	0.3373	0.3697	0.3516	0.3359	0.1662	0.3316	-0.1794	-0.0454	-0.0618
	0.6498**	0.6917**	-0.5578**	-0.3629	0.2450	0.6042**	0.6476**	0.7240**	0.6494**	0.6965**	0.6288**	0.6937**	-0.3712	-0.4877*	-0.4258*
	0.5242**	0.3748	-0.6028**	-0.2835	0.3117	0.5412**	0.5488**	0.6747**	0.5684**	0.3241	0.3229	0.4208*	-0.2573	-0.2705	-0.2105
4	0.3522	0.2759	-0.1301	-0.0679	0.2845	0.2618	0.3421	0.3682	0.3601	0.2916	0.2709	0.2932	-0.1496	0.0753	0.0835
	0.6453**	0.6984**	-0.6099**	-0.3944	0.3537	0.6024**	0.7032**	0.7619**	0.6783**	0.7028**	0.7154**	0.6991**	-0.3935	0.5035*	0.5028*
	0.4889*	0.3742	-0.6559**	-0.0486	0.4111*	0.5109**	0.5461**	0.6683**	0.5832**	0.3258	0.3227	0.4205*	-0.2578	0.1483	-0.0502
5	0.2904	0.1699	-0.1470	0.0267	0.2632	0.2115	0.2799	0.3436	0.3210	0.2087	0.1880	0.1906	-0.0568	0.0805	0.1484
	0.6663**	0.7161**	-0.6328**	0.5699**	0.3900	0.6518**	0.7095**	0.7564**	0.6985**	0.7287**	0.7379**	0.7189**	-0.5429**	0.5147**	0.6771**
	0.4259*	0.1694	-0.6651**	0.2855	0.4096*	0.2461	0.4948*	0.6392**	0.5132**	0.1381	0.2349	0.2491	0.1990	0.1561	0.4483*
6	0.3199	0.2143	-0.2107	-0.0836	0.2655	0.2296	0.3080	0.3103	0.3274	0.2449	0.2259	0.2307	-0.1829	0.0572	0.0823
	0.6919**	0.7082**	-0.7011**	-0.6429**	0.3670	0.6176**	0.7143**	0.7611**	0.3249	0.7469**	0.7521**	0.7458**	-0.6297**	0.5499**	0.7279**
	0.4415*	0.0418	-0.1532	-0.0839	0.3969	0.4092*	0.5019*	0.6448**	0.5180**	0.3929	0.2479	0.2555	-0.2275	0.1379	0.2055

* Significant at 5% level

** Significant at 1% level

The simple linear correlation coefficients between the generated variables of the various fortnights and the yields of PTB varieties in the two seasons are presented in Tables 6-9. In the above mentioned tables the three entries in each cell indicate the correlation coefficients between yield and the relevant weather indices with the exponent of the weighting coefficient 'j' assuming values 0,1, and 2 respectively.

From the tables it was seen that under model 1 only a few indices could be identified as significant at 5% level of significance whereas in the case of model 2 a large number of generated variables were noticed as significant even at the 1% level of significance. Thus in order to get sufficient number of predictor variables under model 1 to be included in the prediction equations, all the weather indices which had significant linear relationship with yield at 10% level of significance were selected. The level of significance for preliminary screening was restricted to 5% under model 2 because the number of significant contributors at 10% level was too many to be handled in a regression analysis.

Fortnightly prediction equations using the generated variables of the specific fortnights were developed and their relative efficiencies compared on the basis of the values of the adjusted coefficients of determination.

Table 10 (a) Selected yield prediction equations under model 1 for PTB 1 in the autumn season involving generated variables of the particular fortnights

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2440.61 - \underset{(16.14)}{44.49}\overset{*}{Q}_{2401} + \underset{(46.08)}{93.98}Q_{2411}$	0.387
2	$Y = 2635.62 - \underset{(0.28)}{0.61}\overset{*}{Q}_{4502}$	0.199
3	$Y = -1282.88 + \underset{(43.33)}{91.89}\overset{*}{Q}_{2313} - \underset{(0.09)}{0.13}Q_{1403} - \underset{(11.09)}{26.69}\overset{*}{Q}_{2323} - \underset{(527.35)}{1249.75}\overset{*}{Z}_{213}$	0.294
4	$Y = -3203.40 - \underset{(0.41)}{1.34}\overset{**}{Q}_{1324} + \underset{(0.41)}{1.24}\overset{**}{Q}_{1314} - \underset{(0.07)}{0.20}\overset{*}{Q}_{1404} + \underset{(2.46)}{2.63}Q_{3524}$	0.483
5	$Y = 2655.43 - \underset{(0.02)}{0.05}\overset{*}{Q}_{1405}$	0.233
6	$Y = 8837.30 - \underset{(0.07)}{0.14}\overset{*}{Q}_{1406} - \underset{(1.55)}{2.84}Q_{3516}$	0.276

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 10 (b) Selected yield prediction equations under model 1 for PTB 5 in the autumn season involving generated variables of the particular fortnights

Time of fore-cast (No. of fortnights after sowing	Regression equations	Adjusted R^2
1	$Y = 1954.15 - \underset{(17.86)}{61.92}\overset{**}{Q}_{2401} + \underset{(44.35)}{129.13}\overset{**}{Q}_{2411} +$ $\underset{(0.53)}{0.59}Q_{4501}$	0.427
2	$Y = 1918.57 - \underset{(0.09)}{0.16}Q_{1402}$	0.148
3	$Y = -829.95 - \underset{(157.57)}{230.54}\overset{*}{Q}_{2313} - \underset{(3901.6)}{7910.68}\overset{*}{Z}_{223} +$ $\underset{(144.81)}{279.48}Q_{2323} + \underset{(4187.90)}{7000.27}Z_{213}$	0.306
4	$Y = -2767.45 - \underset{(0.46)}{0.87}\overset{*}{Q}_{1324} + \underset{(0.46)}{0.69}Q_{1314} +$ $\underset{(2.88)}{2.26}Q_{3524}$	0.225
5	$Y = 1920.68 - \underset{(0.11)}{0.24}\overset{*}{Q}_{1405}$	0.215
6	$Y = 8450.51 - \underset{(4.47)}{7.60}\overset{*}{Q}_{3516} - \underset{(0.07)}{0.10}Q_{1406} +$ $\underset{(0.33)}{0.36}Q_{3506}$	0.245

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 11 (a) Selected yield prediction equations under model 2 for PTB 1 in the autumn season involving generated variables of the particular fortnights

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2653.15 - \underset{(14.53)}{41.27}Q'^{*}_{2421} - \underset{(3.26)}{5.97}Q'_{4521} + \underset{(3.86)}{5.60}Q'_{4511}$	0.487
2	$Y = 2139.89 - \underset{(15.81)}{33.96}Q'^{*}_{2422} + \underset{(0.08)}{0.18}Q'^{*}_{2512} - \underset{(0.70)}{1.59}Q'^{*}_{4522} + \underset{(1.06)}{1.33}Q'^{*}_{2312} + \underset{(0.14)}{0.30}Q'^{*}_{2402}$	0.525
3	$Y = 1287.63 - \underset{(10.44)}{28.33}Q'^{*}_{2413} + \underset{(57.71)}{178.84}Z'^{*}_{213} - \underset{(0.82)}{1.06}Q'_{4513} + \underset{(0.72)}{0.67}Q'_{1423}$	0.626
4	$Y = 1726.71 + \underset{(1.22)}{5.43}Q'^{**}_{2314} - \underset{(0.19)}{0.81}Q'^{**}_{4514} - \underset{(0.03)}{0.06}Q'^{*}_{1514} - \underset{(9.68)}{30.12}Z'^{**}_{214} - \underset{(0.03)}{0.05}Q'_{2514} + \underset{(0.09)}{0.13}Q'_{1314}$	0.883
5	$Y = 2939.16 - \underset{(4.96)}{23.07}Q'^{**}_{2415} + \underset{(67.64)}{173.48}Z'^{*}_{215} - \underset{(0.05)}{0.11}Q'^{*}_{1315} - \underset{(3.88)}{7.31}Q'_{2315} + \underset{(0.11)}{0.15}Q'_{1215}$	0.816
6	$Y = 1677.39 - \underset{(5.69)}{2.39}Q'_{2416} - \underset{(46.88)}{90.80}Z'_{216} - \underset{(0.001)}{0.001}Q'_{2516} - \underset{(0.10)}{0.32}Q'^{**}_{1216} + \underset{(2.93)}{7.11}Q'^{*}_{2316} - \underset{(0.44)}{1.02}Q'^{*}_{4516} + \underset{(0.68)}{1.01}Q'_{3416}$	0.868

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 11(b) Selected yield prediction equations under model 2 for PTB 5 in the autumn season involving generated variables of the particular fortnights

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2317.13 + \underset{(38.44)}{47.46}Q'_{2421} + \underset{(0.02)}{0.01}Q'_{1311} - \underset{(11.19)}{9.86}Q'_{2401} - \underset{(4.49)}{8.99}Q'_{1421} + \underset{(0.67)}{0.27}Q'_{1401} - \underset{(40.27)}{81.85}Q'_{2411} + \underset{(0.98)}{1.47}Q'_{2411} - \underset{(1.01)}{2.39}Q'^{*}_{4511} + \underset{(36.07)}{99.65}Q'^{*}_{3411} - \underset{(325.36)}{924.53}Z'^{*}_{421} - \underset{(1100.11)}{2374.15}Z'_{411} + \underset{(6.17)}{9.23}Q'_{1411}$	0.693
2	$Y = 3323.95 - \underset{(11.18)}{32.04}Q'^{*}_{2412} - \underset{(9.79)}{22.79}Z'^{*}_{512} - \underset{(2.20)}{5.52}Q'^{*}_{4522} + \underset{(2.29)}{4.66}Q'^{*}_{4512} + \underset{(0.02)}{0.04}Q'^{*}_{2512}$	0.587
3	$Y = 1701.96 - \underset{(3.27)}{8.41}Q'^{*}_{2413} - \underset{(0.01)}{0.02}Q'^{**}_{1513} + \underset{(1.46)}{2.66}Q'_{2313}$	0.655
4	$Y = 2154.93 + \underset{(1.78)}{3.96}Z'^{*}_{214} - \underset{(0.01)}{0.02}Q'^{*}_{1514} - \underset{(1.11)}{2.21}Q'_{2414} - \underset{(0.13)}{0.23}Q'_{4514} - \underset{(0.09)}{0.14}Z'_{414} - \underset{(0.14)}{0.16}Q'_{2514}$	0.780
5	$Y = 1926.62 - \underset{(3.79)}{5.79}Q'_{2415} - \underset{(0.06)}{0.05}Q'_{2515} - \underset{(7.91)}{22.34}Z'^{*}_{215} - \underset{(1.59)}{3.13}Z'_{115} + \underset{(0.21)}{0.30}Q'_{1215}$	0.765
6	$Y = 1816.59 - \underset{(1.39)}{3.37}Q'^{*}_{2416} - \underset{(0.02)}{0.02}Q'_{2516} - \underset{(0.01)}{0.02}Q'_{1516} + \underset{(0.80)}{1.07}Q'_{2316}$	0.746

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 12(a) Selected yield prediction equations under model 1 for PTB 12 in the winter season involving generated variables of the particular fortnights

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = -3703.54 + \underset{(6.73)}{23.94}\overset{**}{Q}_{2411} + \underset{(44.69)}{55.41}Z_{611}$	0.142
2	$Y = 6247.93 + \underset{(0.35)}{0.69}\overset{*}{Q}_{2302} - \underset{(137.59)}{154.87}Z_{312} +$ $\underset{(0.73)}{0.61}Q_{1412}$	0.175
3	$Y = 11107.6 - \underset{(115.49)}{292.96}\overset{*}{Z}_{323}$	0.189
4	$Y = 9232.93 - \underset{(124.33)}{298.66}\overset{*}{Z}_{314} + \underset{(1.52)}{3.26}\overset{*}{Q}_{4624}$	0.333
5	$Y = 10258.40 - \underset{(153.89)}{305.23}\overset{*}{Z}_{315} + \underset{(1.47)}{2.09}Q_{4625}$	0.232
6	$Y = 15736.50 - \underset{(114.40)}{428.76}\overset{**}{Z}_{326}$	0.361

Figures in brackets denote the standard error of partial regression coefficients.

* Significant at 5% level

** Significant at 1% level

Table 12(b) Selected yield prediction equations under model 1 for PTB 20 in the winter season involving generated variables of the particular fortnights

Time for forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 1369.87 + \underset{(6.69)}{13.86}Q^{*}_{2401}$	0.169
2	$Y = 61761.5 + \underset{(1.11)}{0.89}Q_{1402} - \underset{(801.44)}{456.45}Q_{1322} +$ $\underset{(53.83)}{44.95}Q_{2412} + \underset{(1.77)}{3.79}Q_{2302} + \underset{(6.77)}{2.92}Q_{1612} -$ $\underset{(73.13)}{260.01}Z^{**}_{112} + \underset{(4.55)}{11.96}Q^{*}_{1412} - \underset{(27.79)}{4.02}Q_{2402} -$ $\underset{(1.08)}{1.53}Q_{2312} - \underset{(938.70)}{1402.84}Z_{312} + \underset{(0.79)}{0.32}Q_{1312} -$ $\underset{(32.99)}{73.25}Z^{*}_{122} + \underset{(2655.30)}{5508.00}Z_{212} - \underset{(149.43)}{209.25}Q_{2612}$	0.602
3	$Y = 10908.70 - \underset{(158.91)}{296.77}Z^{*}_{323} + \underset{(0.12)}{0.18}Q_{1403}$	0.192
4	$Y = 2132.49 - \underset{(196.35)}{152.84}Z_{324} + \underset{(0.09)}{0.43}Q^{*}_{4624} +$ $\underset{(0.19)}{0.23}Q_{1604} - \underset{(17.92)}{20.82}Z_{104} + \underset{(5.83)}{6.17}Q_{4614}$	0.378
5	$Y = 12827.4 - \underset{(203.97)}{419.32}Z^{*}_{325} + \underset{(2.22)}{3.98}Q_{4615}$	0.298
6	$Y = 20134.80 - \underset{(156.20)}{563.34}Z^{**}_{326}$	0.383

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 13(a) Selected yield prediction equations under model 2 for PTB 12 in the winter season involving generated variables of the particular fortnights

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = -7948.82 - \underset{(45.98)}{72.52Q'}_{2411} + \underset{(640.46)}{382.55Z'}_{321} - \underset{(615.38)}{442.03Z'}_{311} + \underset{(0.95)}{0.29Q'}_{1421} + \underset{(953.80)}{2754.53Z'^{*}}_{621} - \underset{(931.30)}{2637.02Z'^{*}}_{611} + \underset{(30.78)}{69.67Q'^{*}}_{2421} + \underset{(1.01)}{0.99Q'}_{1411}$	0.687
2	$Y = 8793.04 + \underset{(0.37)}{1.16Q'^{**}}_{1412} - \underset{(95.13)}{236.29Z'^{**}}_{322}$	0.495
3	$Y = 8366.94 + \underset{(0.75)}{1.82Q'^{*}}_{1423} - \underset{(630.29)}{955.55Z'}_{313} + \underset{(618.53)}{733.38Z'}_{323}$	0.414
4	$Y = 2304.67 - \underset{(11.78)}{40.16Q'^{**}}_{2414} + \underset{(0.17)}{0.53Q'^{**}}_{4614} - \underset{(126.82)}{41.83Z'}_{314} - \underset{(455.96)}{877.81Z'}_{214} + \underset{(5.04)}{8.57Q'}_{2614}$	0.692
5	$Y = 8498.81 + \underset{(0.36)}{0.52Q'}_{1415} + \underset{(0.34)}{0.84Q'^{*}}_{4615} - \underset{(124.29)}{232.17Z'}_{325} - \underset{(16.47)}{31.82Z'}_{115} + \underset{(0.53)}{0.89Q'}_{1315} + \underset{(0.34)}{0.46Q'}_{2615}$	0.652
6	$Y = 5538.03 + \underset{(0.19)}{0.43Q'^{*}}_{4616} + \underset{(0.28)}{0.60Q'^{*}}_{1416} - \underset{(108.41)}{151.25Z'}_{316} + \underset{(78.83)}{87.07Z'}_{416}$	0.655

Figures in brackets denote the standard error of partial regression coefficients

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

Table 13 (b) Selected yield prediction equations under model 2 for PTB 20 in the winter season involving generated variables of the particular fortnights.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 6856.33 + \underset{(189.14)}{550.13}Q'^{**}_{2411} - \underset{(373.35)}{967.35}Z'_{321} - \underset{(186.33)}{487.72}Q'^{*}_{2421} + \underset{(418.53)}{774.57}Z'_{311}$	0.544
2	$Y = -1368.38 - \underset{(2.78)}{0.91}Q'_{1412} + \underset{(191.28)}{79.67}Z'_{312} + \underset{(2.54)}{5.27}Q'_{1422} + \underset{(5.82)}{19.47}Z'^{**}_{122} + \underset{(0.13)}{0.42}Q'^{*}_{1622} - \underset{(2.16)}{8.05}Q'_{1312} + \underset{(0.43)}{1.68}Q'^{**}_{1402} + \underset{(1.68)}{2.85}Q'_{1222} - \underset{(71.89)}{289.09}Q'^{**}_{2422} + \underset{(17.38)}{35.92}Q'_{2322} + \underset{(58.38)}{166.68}Z'_{112} + \underset{(81.49)}{231.26}Q'^{*}_{2412} - \underset{(20.50)}{25.29}Q'_{2312}$	0.778
3	$Y = 8641.51 + \underset{(0.63)}{1.59}Q'^{*}_{1413} - \underset{(438.78)}{783.44}Z'_{323} + \underset{(456.47)}{549.15}Z'_{313} + \underset{(2.95)}{4.28}Q'_{2313} - \underset{(0.79)}{1.08}Q'_{1313} + \underset{(0.24)}{0.28}Q'_{1613}$	0.603
4	$Y = 17459.00 + \underset{(0.63)}{1.58}Q'^{*}_{1414} - \underset{(147.48)}{488.16}Z'^{**}_{324} + \underset{(191.16)}{516.94}Z'^{*}_{214} - \underset{(3.00)}{6.75}Q'^{*}_{2614} - \underset{(6.46)}{11.56}Z'_{114} + \underset{(0.15)}{0.27}Q'_{1314} - \underset{(1.27)}{1.36}Q'_{1424}$	0.715

(Contd..)

Table 13 (b) Contd.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
5	$Y = 5403.81 + \underset{(0.64)}{1.26}Q'_{1415} + \underset{(0.69)}{1.49}Q'^{*}_{4615} -$ $\underset{(13.41)}{2.16}Q'_{2415} - \underset{(6.09)}{11.74}Z'_{115} + \underset{(39.33)}{60.39}Z'_{215} -$ $\underset{(554.58)}{798.14}Z'_{325} + \underset{(556.80)}{651.19}Z'_{315}$	0.683
6	$Y = 3556.48 + \underset{(0.42)}{1.32}Q'^{**}_{1416} + \underset{(38.79)}{170.23}Z'^{**}_{216} +$ $\underset{(0.49)}{2.07}Q'^{**}_{4616} + \underset{(42.79)}{149.92}Z'^{**}_{416} - \underset{(2.17)}{5.37}Q'^{*}_{2316} -$ $\underset{(94.83)}{144.42}Z'_{316}$	0.880

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

The equation which resulted in maximum amount of predictability in each fortnight was identified. Prediction equations incorporating the important weather indices of all the previous fortnights in addition to those of the relevant fortnight were also developed and their relative efficiencies evaluated on the basis of the values of adjusted coefficient of determination. The selected regression equations for fortnightly yield prediction of the PTB varieties in each of the six fortnights on the basis of the weather indices of the relevant fortnights, together with standard error of regression coefficients and adjusted coefficient of determination are given in Tables 10-13. The selected regression equations for fortnightly yield prediction of PTB varieties in each of the six fortnights on the basis of weather indices of the specific and those of the previous fortnights, together with standard errors of regression coefficients and adjusted coefficients of determination are presented in Tables 14-17. A set of prediction equations other than those already selected and tabulated is also given in Appendix. Some of the equations listed in this table are very subtle and convenient to make reliable predictions with lesser number of variables.

The regression equations fitted under model 1 for PTB 1 in the autumn season in each of the six fortnights after sowing, utilising the generated variables of the particular fortnight of prediction alone, showed that the accuracy of prediction was comparatively high in the fourth fortnight after sowing. The equation of the fourth fortnight with an accuracy of 48% is

$$Y = -3203.40 - 1.34Q_{1324}^{**} + 1.24Q_{1314}^{**} - 0.20Q_{1404}^{*} + 2.63Q_{3524} \qquad - (4.12)$$

The indices Q_{1324} and Q_{1314} represent the cumulative effect of the interaction of total rainfall and maximum temperature starting from one week before sowing upto the fourth fortnight after sowing whereas Q_{1404} represent the cumulative effect of the interaction of total rainfall and number of hours of sunshine and Q_{3524} represent the cumulative effect of the interaction of maximum temperature and minimum humidity. After the fourth fortnight no improvement in the value of $\bar{R}^2$ was noticed. In the case of PTB 5 in the autumn season the forecasting equations fitted in the first fortnight succeeded in explaining about 43% of variation in yield and there after the value of $\bar{R}^2$ was not found to increase in any of the subsequent fortnights. The forecasting equation for PTB 5 in the first fortnight was obtained as

$$Y = 1954.15 - 61.92Q_{2401}^{**} + 129.13Q_{2411}^{**} + 0.59Q_{4501} \qquad -(4.13)$$

Results also indicated the superiority of model 2 over model 1 in predicting the expected yields of the crop in both the seasons. In the case of PTB 1 the maximum precision for the crop forecasts in the autumn season was attained in the fourth fortnight after sowing, under model 2 as it was found under model 1. A regression equation under model 2 in the fourth fortnight could explain about 88% of the variation in yield. The equation is given by

$$Y = 1726.71 + 5.43Q'^{**}_{2314} - 0.81Q'^{**}_{4514} - 0.06Q'^{*}_{1514} - 30.12Z'^{**}_{214} - 0.05Q'_{2514} + 0.13Q'_{1314} \qquad - (4.14)$$

The index Q'_{2314} had beneficial effects on yield while all other indices exerted unfavourable effects on yield. In the third fortnight a prediction equation consisting of Q'_{2413}, Z'_{213}, Q'_{4513} and Q'_{1423} could explain about 63% of the variation in yield. The more important weather indices of this fortnight were Q'_{2413} and Z'_{213}. The regression analysis in the second fortnight singled out five weather indices viz., Q'_{2422}, Q'_{2512}, Q'_{4522}, Q'_{2312} and Q'_{2402} as decisive and a prediction equation involving them could explain about 53% of variation in yield.

In the case of PTB 5 grown in the autumn season also the best time of prediction as per model 2 was found to be the fourth fortnight after sowing because the value of $\bar{R}^2$ was not found to improve in the later forecasts than that at the fourth. The prediction equation with an accuracy of 78% is given by

$$Y = 2154.93 + 3.96Z'^{*}_{214} - 0.02Q'^{*}_{1514} - 2.21Q'_{2414} - 0.23Q'_{4514} - 0.14Z'_{414} - 0.16Q'_{2514} \quad -(4.15)$$

For the same variety about 69% of the variation in yield could be explained by the weather indices of the first fortnight itself eventhough the number of indices included in the prediction equation was considerably large. Twelve weather indices were used in this context and among them the three statistically significant indices were Q'_{4511}, Q'_{3411} and Z'_{421} . The best prediction equation (4.13) under model 1 for the same variety was also developed in the first fortnight itself. In the second fortnight the value of $\bar{\bar{R}}^2$ under model 2 was decreased ($\bar{\bar{R}}^2$ = 59%) but the regression equation consisted only five indices and the partial regression coefficients of all of them were significant. The relevant indices were Q'_{2412}, Z'_{512}, Q'_{4522} Q'_{4512} and Q'_{2512}. In the third fortnight a regression equation constituted by three indices Q'_{2413}, Q'_{1513} and Q'_{2313} had succeeded in explaining about 66% of the variation in yield.

In the case of the variety PTB 12 grown in the winter season the regression equations fitted under model 1 for each of the six fortnights after sowing, utilising the generated variables of the specific fortnights of prediction alone, showed that only 36% of the variation in yield could be explained by the most efficient equation and this was achieved only in the sixth fortnight after sowing incorporating a single weather index Z_{326} which had negative association with yield. The forecasting equation is of the form

$$Y = 15736.50 - 428.76Z_{326}^{**} \qquad - (4.16)$$

The values of $\bar{R}^2$ for the fitted models in the previous fortnights were relatively small. In the same season and under the same model predictability of the regression equations for PTB 20 attained its maximum value ($\bar{R}^2 = 60\%$) in the second fortnight after sowing at the expense of fourteen generated variables. The regression equation turned out to be

$$\begin{aligned} Y = {} & 61761.5 + 0.89Q_{1402} - 456.45Q_{1322} + 44.95Q_{2412} + \\ & 3.79Q_{2302} + 2.92Q_{1612} - 260.91Z_{112}^{**} + 11.96Q_{1412}^{*} - \\ & 4.02Q_{2402} - 1.53Q_{2312} - 1402.84Z_{312} + 0.32Q_{1312} - \\ & 73.25Z_{122}^{*} + 5508.00Z_{212} - 209.25Q_{2612} \qquad - (4.17) \end{aligned}$$

The significant weather indices seemed to be Z_{112}, Q_{1412} and Z_{122}. A prediction equation developed for the sixth fortnight after sowing utilising a single weather index Z_{326} alone could explain about 38% of the variation in yield.

The most efficient yield prediction equation for PTB 12 in the winter season using the generated variables under model 2 relating to the specific fortnights alone was identified in the fourth fortnight after sowing ($\bar{R}^2$=69%). The relevant regression equation is

$$Y = 2304.67 - 40.16Q'^{**}_{2414} + 0.53Q'^{**}_{4614} - 41.83Z'_{314} - 877.81Z'_{214} + 8.57Q'_{2614} \qquad -(4.18)$$

The important indices were Q'_{2414} and Q'_{4614}. Forecasting equations constructed using the weather indices in the first fortnight had succeeded in explaining 68.7% of variation in yield eventhough the number of indices constituting the equation was very large. Thus forecast of yield of the crop was possible as early as in the first fortnight after sowing with sufficient degree of precision using the generated variables. The significant indices which constituted the equation were Z'_{621}, Z'_{611} and Q'_{2421}. In the second fortnight the two weather indices Q'_{1412} and Z'_{322} together were found to explain about 50% of the variation in yield. For PTB 20 also sufficiently reliable forecasts under model 2 could be obtained through stepwise regression analysis. The best prediction equation was obtained in the sixth fortnight after sowing ($\bar{\bar{R}}^2$= 88%) and is given by

$$Y = 3556.48 + 1.32Q'^{**}_{1416} + 170.23Z'^{**}_{216} + 2.07Q'^{**}_{4616} + 149.92Z'^{**}_{416} - 5.37Q'^{*}_{2316} - 144.42Z'_{316} \qquad -(4.19)$$

It was also found that an early forecast with adequate precision ($\bar{\bar{R}}^2$=78%) could be made in the second fortnight with the help of thirteen weather indices, the most important among them being Z'_{122}, Q'_{1622}, Q'_{1312}, Q'_{1402}, Q'_{2422} and Q'_{2412}.

The above results emphasize that yield forecasting with sufficient degree of accuracy could be done even in earlier stages of crop growth by the use of generated variables.

A glance at the values of $\bar{\bar{R}}^2$ for various prediction equations formed by using the information on the important weather indices of previous fortnights in addition to those on the relevant fortnight of prediction revealed that accuracy of the prediction could be greatly improved by incorporating the supplementary informations on the generated variables of previous fortnights. The optimum time of prediction under model 1 for PTB 1 in the autumn season was found to be the fourth fortnight after sowing. After that period the adjusted coefficient of determination showed a tendancy to decline. The relevant regression equation fitted in the fourth fortnight with a predictability of 73% is given by

$$Y = 263.52 - 4.59Q_{2401} - 0.92\overset{**}{Q}_{1324} + 15.11\overset{**}{Q}_{2313} + 0.79\overset{**}{Q}_{1314} \qquad - \quad (4.20)$$

Table 14 (a) Selected yield prediction equations under model 1 for PTB 1 in the autumn season involving important generated variables of the previous fortnights in addition to those of the specific fortnights of prediction.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2440.61 - \underset{(16.14)}{44.49}Q^{*}_{2401} + \underset{(46.08)}{93.98}Q_{2411}$	0.387
2	Same as that of the first fortnight	
3	$Y = -361.89 - \underset{(4.86)}{11.21}Q^{*}_{2401} + \underset{(39.57)}{93.97}Q^{*}_{2313} -$ $\underset{(13.86)}{29.45}Q^{*}_{2323} - \underset{(841.70)}{1356.32}Z_{213}$	0.408
4	$Y = 263.52 - \underset{(3.37)}{4.59}Q_{2401} - \underset{(0.24)}{0.92}Q^{**}_{1324} +$ $\underset{(4.79)}{15.11}Q^{**}_{2313} + \underset{(0.26)}{0.79}Q^{**}_{1314}$	0.728
5	Same as that of the fourth fortnight	
6	Same as that of the fourth fortnight	

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 14 (b) Selected yield prediction equations under model 1 for PTB 5 in the autumn season involving important generated variables of the previous fortnights in addition to those of the specific fortnights of prediction

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 1954.15 - \underset{(17.86)}{61.92}Q^{**}_{2401} + \underset{(44.35)}{129.13}Q^{**}_{2411} + \underset{(0.53)}{0.59}Q_{4501}$	0.427
2	Same as that of the first fortnight	
3	Same as that of the first fortnight	
4	$Y = 520.25 - \underset{(16.69)}{24.46}Q_{2401} + \underset{(44.64)}{58.84}Q_{2411} - \underset{(0.06)}{0.15}Q^{*}_{1324} + \underset{(6.21)}{12.82}Q^{*}_{2313}$	0.551
5	$Y = 448.63 - \underset{(16.43)}{20.27}Q_{2401} + \underset{(52.26)}{16.59}Q_{2411} - \underset{(0.07)}{0.22}Q^{**}_{1324} + \underset{(6.03)}{13.43}Q^{*}_{2313} + \underset{(0.16)}{0.23}Q_{1405}$	0.580
6	Same as that of the fifth fortnight	

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 15(a) Selected yield prediction equations under model 2 for PTB 1 in the autumn season involving important generated variables of the previous fortnights in addition to those of the specific fortnights of prediction.

Time of fore-cast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2653.15 - \underset{(14.53)}{41.27}Q'^{*}_{2421} - \underset{(3.26)}{5.97}Q'_{4521} +$ $\underset{(3.86)}{5.60}Q'_{4511}$	0.487
2	$Y = 2234.24 - \underset{(72.86)}{132.07}Q'_{2421} + \underset{(0.17)}{0.17}Q'_{2512} -$ $\underset{(1.00)}{1.85}Q'_{4522}$	0.605
3	$Y = 1268.48 - \underset{(7.19)}{15.75}Q'^{*}_{2413} + \underset{(54.65)}{172.83}Z'^{**}_{213} -$ $\underset{(0.88)}{1.56}Q'_{4522} + \underset{(3.73)}{5.15}Q'_{2402}$	0.651
4	$Y = 2654.16 + \underset{(0.59)}{3.79}Q'^{**}_{2314} - \underset{(0.44)}{1.99}Q'^{**}_{4522} -$ $\underset{(0.01)}{0.05}Q'^{**}_{1514} + \underset{(0.08)}{0.23}Q'^{*}_{2512} - \underset{(63.16)}{130.92}Z'^{*}_{213}$	0.883
5	$Y = 2585.58 - \underset{(4.40)}{5.91}Q'_{2415} + \underset{(0.64)}{3.45}Q'^{**}_{2314} +$ $\underset{(0.58)}{1.46}Q'^{*}_{4522} - \underset{(0.01)}{0.04}Q'^{*}_{1514} + \underset{(0.08)}{0.23}Q'^{*}_{2512} -$ $\underset{(62.04)}{120.27}Z'_{213}$	0.889
6	$Y = 2161.99 - \underset{(4.08)}{5.68}Q'_{2415} + \underset{(0.37)}{2.19}Q'^{**}_{2314} -$ $\underset{(0.06)}{0.16}Q'^{*}_{1216} - \underset{(0.54)}{1.17}Q'^{*}_{4522} -$ $\underset{(0.01)}{0.03}Q'^{*}_{1514} + \underset{(0.07)}{0.14}Q'_{2512}$	0.904

Figures in brackets denote the standard error of partial regression coefficients.

* Significant at 5% level

** Significant at 1% level

Table 15(b) Selected yield prediction equations under model 2 for PTB 5 in the autumn season involving important generated variables of the previous fortnights in addition to those of the specific fortnights of prediction.

Time of fore-casts (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2317.13 + \underset{(38.44)}{47.46}Q'_{2421} + \underset{(0.01)}{0.01}Q'_{1311} - \underset{(11.19)}{9.86}Q'_{2401} - \underset{(4.49)}{8.99}Q'_{1421} + \underset{(0.67)}{0.27}Q'_{1401} - \underset{(40.27)}{81.85}Q'_{2411} + \underset{(0.98)}{1.47}Q'_{2411} - \underset{(1.01)}{2.39}Q'^{*}_{4511} + \underset{(36.07)}{99.65}Q'_{3411} - \underset{(325.36)}{924.53}Z'^{*}_{421} - \underset{(1100.1)}{2374.15}Z'_{411} + \underset{(6.17)}{9.23}Q'_{1411}$	0.693
2	Same as that of the first fortnight	
3	Same as that of the first fortnight	
4	$Y = 2132.85 + \underset{(1.37)}{4.95}Z'^{**}_{214} - \underset{(0.02)}{0.01}Q'_{1514} - \underset{(2.60)}{6.94}Q'^{*}_{2413} - \underset{(0.01)}{0.01}Q'_{1513}$	0.778
5	Same as that of the fourth fortnight	
6	$Y = 1973.80 - \underset{(1.13)}{3.57}Q'^{**}_{2416} + \underset{(1.28)}{5.28}Z'_{214} - \underset{(0.01)}{0.01}Q'^{*}_{1513}$	0.789

Figures in brackets denote the standard error of partial regression coefficients

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

Table 16(a) Selected yield prediction equations under model 1 for PTB 12 in the winter season involving important generated variables of the previous fortnights in addition to those of the specific fortnights of prediction.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = -3703.54 + \underset{(6.73)}{23.94}Q^{**}_{2411} + \underset{(44.69)}{55.41}Z_{611}$	0.142
2	$Y = 1272.54 + \underset{(0.58)}{1.46}Q^{*}_{2302}$	0.189
3	Same as that of the second fortnight	
4	$Y = 1592.13 - \underset{(133.49)}{106.75}Z_{314} + \underset{(1.42)}{4.62}Q^{**}_{4624} + \underset{(0.71)}{1.03}Q_{2302} + \underset{(16.35)}{17.74}Q_{2411}$	0.486
5	Same as that of the fourth fortnight	
6	$Y = 5300.59 - \underset{(124.92)}{200.91}Z_{326} + \underset{(15.58)}{17.55}Q_{2411} + \underset{(1.48)}{3.79}Q^{*}_{4624} + \underset{(0.65)}{0.89}Q_{2302}$	0.532

Figures in brackets denote the standard error of partial regression coefficients

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

Table 16 (b) Selected yield prediction equations under model 1 for PTB 20 in the winter season involving important generated variables of the previous fortnights in addition to those of the specific fortnights of prediction.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 1369.87 + \underset{(6.69)}{13.86}Q^{*}_{2401}$	0.169
2	$Y = 1162.99 + \underset{(0.14)}{0.24}Z_{122} + \underset{(7.12)}{8.88}Q_{2401}$	0.195
3	$Y = 13305.01 + \underset{(1.71)}{2.32}Z_{122} - \underset{(213.44)}{372.82}Z_{323} -$ $\underset{(55.41)}{70.59}Z_{112} + \underset{(6.94)}{8.42}Q_{2401}$	0.239
4	$Y = 220.56 + \underset{(1.25)}{2.36}Z_{122} + \underset{(1.66)}{6.75}Q^{**}_{4624} + \underset{(5.47)}{16.58}Q^{**}_{2401} -$ $\underset{(40.61)}{70.41}Z_{112} - \underset{(163.94)}{173.35}Z_{323}$	0.591
5	Same as that of the fourth fortnight	
6	$Y = 9014.21 - \underset{(152.79)}{350.33}Z^{*}_{326} + \underset{(4.93)}{15.81}Q^{**}_{2401} +$ $\underset{(1.64)}{5.44}Q^{**}_{4624} + \underset{(0.99)}{2.34}Z^{*}_{122} - \underset{(32.00)}{70.98}Z^{*}_{112}$	0.670

Figures in brackets denote the standard error of partial regression coefficients

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

Table 17(a) Selected yield prediction equations under model 2 for PTB 12 in the winter season involving generated variables of the previous fortnights in addition to those of the specific fortnights of prediction.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = -7948.82 - \underset{(45.98)}{72.52}Q'_{2411} + \underset{(640.46)}{382.55}Z'_{321} - \underset{(615.38)}{441.03}Z'_{311} + \underset{(0.95)}{0.29}Q'_{1421} + \underset{(953.80)}{2754.53}Z'^{*}_{621} - \underset{(931.30)}{2637.02}Z'^{*}_{611} + \underset{(30.78)}{69.67}Q'_{2421} + \underset{(1.01)}{0.99}Q'_{1411}$	0.687
2	Same as that of the first fortnight	
3	Same as that of the first fortnight	
4	Same as that of the first fortnight	
5	Same as that of the first fortnight	
6	$Y = 1316.85 + \underset{(0.07)}{0.28}Q'^{**}_{4616} + \underset{(4.98)}{19.56}Q'^{**}_{2414}$	0.694

The figures in brackets denote the standard error of partial regression coefficients

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

Table 17 (b) Selected yield prediction equations under model 2 for PTB 20 in the winter season involving generated variables of the previous fortnights in addition to those of the specific fortnights of prediction.

Time of fore-cast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 6856.33 + \underset{(189.14)}{550.13}Q'^{**}_{2411} - \underset{(373.35)}{967.35}Z'_{321} - \underset{(186.33)}{487.72}Q'^{*}_{2421} + \underset{(418.53)}{774.57}Z'_{311}$	0.544
2	Same as that of the first fortnight	
3	Same as that of the first fortnight	
4	$Y = 11439.49 + \underset{(1.47)}{3.20}Q'^{*}_{1414} - \underset{(139.05)}{311.88}Z'^{*}_{324} + \underset{(181.99)}{378.65}Z'^{*}_{214} - \underset{(2.75)}{4.74}Q'_{2614} - \underset{(1.44)}{1.97}Q'_{1413}$	0.686
5	Same as that of the fourth fortnight	
6	$Y = 4683.80 + \underset{(0.34)}{1.03}Q'^{**}_{1414} + \underset{(29.13)}{130.30}Z'^{**}_{216} - \underset{(104.33)}{171.39}Z'_{324} - \underset{(0.65)}{1.27}Q'_{2614} + \underset{(0.53)}{1.84}Q'^{**}_{4616} + \underset{(44.17)}{138.36}Z'^{**}_{416}$	0.875

Figures in brackets denote the standard error of partial regression coefficients

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

The indices Q_{1324}, Q_{2313} and Q_{1314} were found to have greater influence on yield. These three indices together could explain 71% (Appendix-1(a)) of variation in the yield of PTB 1 and hence were decisive in predicting the yield of PTB 1 in the autumn season. In the first fortnight the two indices Q_{2401} and Q_{2411} alone could explain about 39% of variation in yield of PTB 1. There was no significant improvement in the value of $\bar{R}^2$ in the second and third fortnights as compared to that of the first fortnight.

In the case of PTB 5, among the different forecasting equations under model 1, the one in the fifth fortnight after sowing resulted in the maximum amount of predictability ($\bar{R}^2 = 58\%$). The equation is

$$Y = 448.63 - 20.27Q_{2401} + 16.59Q_{2411} - 0.22Q_{1324}^{**} + 13.43Q_{2313}^{*} + 0.23Q_{1405} \qquad - (4.21)$$

The yield forecasts of PTB 5 could also be tried in the fourth fortnight after sowing without much loss of accuracy for the prediction equation ($\bar{R}^2 = 55\%$) by means of the indices viz., Q_{2401}, Q_{2411}, Q_{1324} and Q_{2313}. In the first fortnight the two indices Q_{2401} and Q_{2411} alone could explain as much as 42% of the variation in yield (Appendix-1(b)). After the fifth fortnight no improvement in the value of $\bar{R}^2$ was noticed.

In the case of the prediction equations under model 2 for PTB 1 in the autumn season, the one in the sixth fortnight was found to give maximum value of $\bar{R}^2$. The relevant equation which explained 90% of the total variation in yield was

$$Y = 2161.99 - 5.68Q'_{2415} + 2.19Q^{\prime **}_{2314} - 0.16Q^{\prime *}_{1216} - 1.17Q^{\prime *}_{4522} - 0.03Q^{\prime *}_{1514} + 0.14Q'_{2512} \qquad -(4.22)$$

However a plausible prediction equation with sufficiently high degree of precision could be evolved in the fourth fortnight itself. The form of the equation is

$$Y = 2654.16 + 3.79Q^{\prime **}_{2314} - 1.99Q^{\prime **}_{4522} - 0.05Q^{\prime **}_{1514} + 0.23Q^{\prime *}_{2512} - 130.92Z^{\prime *}_{213} \qquad -(4.23)$$

Just two variables viz., Q'_{2314} and Q'_{4522} representing the equation could explain about 78% (Appendix-2(a)) of variation in yield and so these could be isolated as the major contributors. In the third fortnight four indices viz., Q'_{2413}, Z'_{213}, Q'_{4522} and Q'_{2402} had succeeded in explaining about 65% of variation in yield. Of these Q'_{2413} and Z'_{213} alone could explain about 60% of variation in yield (Appendix-2(a)).

In the case of the forecasting equations under model 2 for PTB 5 maximum value of $\bar{R}^2$ (about 79%) was noted in the sixth fortnight after sowing. The relevant equation which comprised of only three major indices is given by

$$Y = 1973.80 - 3.57Q'^{**}_{2416} + 5.28Z'^{**}_{214} - 0.01Q'^{*}_{1513} \qquad -(4.24)$$

The gain in precision of the prediction equation (4.24) when compared to that of the fourth fortnight after sowing was not appreciable. The regression equation of the fourth fortnight which could explain about 77% (Appendix-2(b)) of variation in yield utilizing three indices was

$$Y = 2153.87 + 4.68Z'^{**}_{214} - 0.03Q'^{**}_{1514} - 6.65Q'^{*}_{2413} \qquad -(4.25)$$

Further among the indices Z'_{214} and Q'_{1514} were the more important contributors for these two indices alone could explain about 70% (Appendix-2(b)) of the variation in yield. A prediction equation attempted as early as in the first fortnight after sowing was successful in explaining as much as 69% of variation in the yield of PTB 5 though at the expense of twelve explanatory variables.

Among the different forecasting equations under model 1 for PTB 12 in the winter season the equation with maximum value of $\bar{R}^2$ (about 53%) correspond to that of the sixth fortnight and is given by

$$Y = 5300.59 - 200.91Z_{326} + 17.55Q_{2411} + 3.79Q^{*}_{4624} +$$
$$0.89Q_{2302} \qquad -(4.26)$$

The contributors of the equation (4.26) included Z_{326}, Q_{2411} and Q_{4624} and they showed 51% of variation in yield (Appendix-3(a)). The value of $\bar{R}^2$ of the prediction equation in the fourth fortnight was found to be 49%. The predictability of the fitted models in the various fortnights prior to the fourth fortnight were negligibly small. In the case of PTB 20 maximum value of $\bar{R}^2$ (67%) for the forecasting equations under model 1 was obtained in the sixth fortnight after sowing. The relevant prediction equation is given by

$$Y = 9014.21 - 350.33Z^{*}_{326} + 15.81Q^{**}_{2401} + 5.44Q^{**}_{4624} + 2.34Z^{*}_{122} - 70.98Z^{*}_{112} \qquad -(4.27)$$

At the same time a simpler model consisting of three indices Z_{326}, Q_{2401} and Q_{4624} accounted for 58% (Appendix-3(b)) of variation in crop yield. A prediction equation with 59% precision could also be developed in the fourth fortnight after sowing with the help of five generated variables viz., Z_{122}, Q_{4624}, Q_{2401}, Z_{112} and Z_{323}. Earlier forecasts than that at the fourth fortnight appeared to be fruitless.

The weighted regression analysis of crop-weather data under model 2 for PTB 12 in the winter season showed that the value of $\bar{R}^2$ for the prediction equations could not be improved significantly after the first fortnight ($\bar{R}^2 = 0.687$). The prediction equation of the first fortnight was

$$Y = -7948.82 - 72.52Q'_{2411} + 382.55Z'_{321} - 441.03Z'_{311} + 0.29Q'_{1421} + 2754.53Z'^{*}_{621} - 2637.02Z'^{*}_{611} + 69.67Q'^{*}_{2421} + 0.99Q'_{1411} \qquad -(4.28)$$

The significant contributors were Z'_{621}, Z'_{611} and Q'_{2421}. However maximum value of $\bar{R}^2$ was noted in the case of the prediction equation developed at the sixth fortnight after sowing. The equation consisting of two indices could explain 69% of the variation in yield and it was of the form

$$Y = 1316.85 + 0.28Q'^{**}_{4616} + 19.56Q'^{**}_{2414} \qquad - (4.29)$$

The two indices Q'_{2414} and Q'_{4614} having positive relationship with yield (Appendix-4(a)) evolved to be the important predictor variables and had succeeded in explaining about 64% variation in yield. An earlier forecast of precision of 57% was also possible by using the indices Q'_{1412}, Z'_{322}, Z'_{621} and Z'_{611}.

In the case of PTB 20 the maximum value of $\bar{R}^2$ for the forecasting equations under model 2 was obtained in the sixth fortnight after sowing. Six weather indices which had jointly explained about 88% of the variation in yield formed the prediction equation. It is given by

$$Y = 4683.80 + 1.03Q'^{**}_{1414} + 130.30Z'^{**}_{216} - 171.39Z'_{324} - 1.27Q'_{2614} + 1.84Q'^{**}_{4616} + 138.36Z'^{**}_{416} \qquad - (4.30)$$

All the other indices except Z'_{324} and Q'_{2614} had beneficial effects on yield. It was also found that a linear function involving just three indices alone viz., Q'_{1414}, Z'_{216} and Z'_{324} could explain about 76% of the variation in yield (Appendix-4(b)). Yield forecasting could be done with adequate precision ($\bar{R}^2$= 69%) using the indices Q'_{1414}, Z'_{324}, Z'_{214}, Q'_{2614} and Q'_{1413}. Among them, the two indices Q'_{1414} and Z'_{324} alone were capable of explaining about 63% of the variation in yield. The single index Q'_{1413} of the third fortnight also appeared to be a major contributor as it alone could explain about 50% of the variation in yield (Appendix-4(b)).

The regression analysis of generated variables on crop yield indicated the superiority of model 2 over model 1 for the forecasting of rice yield in the two seasons. The optimum time of forecasting of the yield was found to be the fourth fortnight after sowing of the crop in the autumn season. In the case of PTB 12 in the winter season, yield prediction could be done with sufficient accuracy under model 1 in the fourth fortnight after sowing, whereas under model 2 a plausible prediction equation was evolved in the first fortnight after sowing itself. In the case of PTB 20 prediction of yield would be more reliable if it had done in the sixth fortnight after sowing. It was also evident that forecasting of the yield of PTB 1 was expected to be more reliable than that of PTB 5 in the autumn season while in the winter season the yield forecasting of PTB 20 appeared to be more reliable than that of PTB 12. The results also showed the importance of including indices related to the cumulative effects of the interactions of different weather variables in developing prediction equations for rice yield.

4.3.3. Principal Component analysis

The important generated variables identified in the six fortnights after sowing of the crop were used for conducting principal component analysis in the two seasons. The generated variables under model 2 alone were used for this purpose as they were more strongly correlated with yield than those under model 1. Principal component analysis of the data of PTB 1 included the generated variables Q'_{2512}, Q'_{4522}, Z'_{213}, Q'_{1514}, Q'_{2314}, Q'_{2415}, Q'_{1216}, Q'_{2316} and Q'_{4516} and that on PTB 5 included Q'_{1513}, Q'_{2413}, Z'_{214}, Q'_{1514} and Q'_{2416}. In the winter season principal component analysis on PTB 12 was attempted with five indices viz., Q'_{2421}, Q'_{2414}, Q'_{4614}, Q'_{1416} and Q'_{4616} and that on PTB 20 with nine indices viz., Z'_{214}, Q'_{1414}, Q'_{2614}, Z'_{324}, Z'_{216}, Z'_{416}, Q'_{1416}, Q'_{2316} and Q'_{4616}. The eigen values, eigen vectors, vectors of component loadings and percentage variation accounted by the different components as obtained from the analysis of principal components for the varieties in the two seasons are presented in tables 18-21.

Regression equations were also worked out with principal components as explanatory variables. The prediction equations developed in the process are given in Table 22.

Table 18. Principal component analysis using important generated variables of meteorological observations of the autumn season (Variety:PTB 1)

Sl. No.	Variables	Eigen vectors (VI) and vectors of component loadings (FI)									
		V1	F1	V2	F2	V3	F3	V4	F4	V5	F5
1	Q'_{2512}	0.3183	0.5856	0.2683	0.3875	-0.2924	-0.3289	-0.0267	-0.0268	-0.6983	-0.5799
2	Q'_{4522}	-0.3524	-0.6484	0.4189	0.6050	-0.2421	-0.2723	-0.2498	-0.2505	0.2953	0.2452
3	Z'_{213}	0.2235	0.4111	0.4689	0.6773	0.3638	0.4092	-0.1342	-0.1346	-0.3162	-0.2626
4	Q'_{1514}	-0.0796	-0.1465	0.2857	0.4126	0.2156	0.2425	0.8466	0.8488	0.0442	0.0367
5	Q'_{2314}	0.4387	0.8071	0.3127	0.4516	-0.1412	-0.1588	0.0112	0.0112	0.3916	0.3251
6	Q'_{2415}	-0.4109	-0.7561	0.3106	0.4486	-0.1086	-0.1221	0.2416	0.2422	-0.0822	-0.0683
7	Q'_{1216}	-0.0844	-0.1554	0.1364	0.1970	0.7849	0.8828	0.2753	0.2760	0.0501	0.0416
8	Q'_{2316}	0.4498	0.8276	0.2934	0.4238	-0.0717	-0.0806	-0.0238	-0.0239	0.3971	0.3298
9	Q'_{4516}	-0.3839	-0.7064	0.3899	0.5631	-0.1549	-0.1742	-0.2595	-0.2602	-0.0537	-0.0446
	Eigen value	3.3850		2.0861		1.2649		1.0053		0.6897	
	Percentage variation.	37.61		23.18		14.05		11.17		7.66	

(contd..)

Table 18 (contd..)

Sl. No.	Variables	Eigen vectors (VI) and vectors of component loadings (FI) V6	F6	V7	F7	V8	F8	V9	F9
1	Q'_{2512}	0.3486	0.2047	0.3329	0.1382	0.1381	0.0247	-0.0366	-0.0051
2	Q'_{4522}	0.0406	0.0238	0.0448	0.0186	0.6885	0.1229	-0.1198	-0.0168
3	Z'_{213}	-0.4613	-0.2709	-0.5061	-0.2101	0.1047	0.0187	0.0038	0.0005
4	Q'_{1514}	-0.1691	-0.0993	0.3151	0.1308	0.1376	0.0246	-0.0068	-0.0009
5	Q'_{2314}	0.0774	0.0455	-0.0033	-0.0014	-0.2991	-0.0534	-0.6640	-0.0929
6	Q'_{2415}	0.5311	0.3119	-0.5306	-0.2203	-0.3020	-0.0539	0.0541	0.0076
7	Q'_{1216}	0.4329	0.2542	0.2938	0.1219	-0.0287	-0.0051	-0.0717	-0.0100
8	Q'_{2316}	0.1639	0.0963	0.0251	0.0104	-0.0383	-0.0068	0.7206	0.1009
9	Q'_{4516}	-0.3647	-0.2142	0.4040	0.1677	-0.5422	-0.0968	0.1266	0.0177
	Eigen value	0.3449		0.1724		0.0319		0.0196	
	Percentage variation	3.83		1.92		0.35		0.22	

Table 19 Principal component analysis using important generated variables of the meteorological observations of the autumn season (Variety:PTB 5)

Sl. No.	Variables	Eigen vectors (VI) and vectors of component loadings (FI)									
		V1	F1	V2	F2	V3	F3	V4	F4	V5	F5
1	Q'_{1513}	0.4124	0.7331	-0.6383	-0.6338	-0.0243	-0.0201	-0.6466	-0.2457	-0.0621	-0.0101
2	Q'_{2413}	0.4785	0.8506	0.4273	0.4243	0.3493	0.2886	-0.0645	-0.0245	-0.6798	-0.1109
3	Z'_{214}	-0.3393	-0.6032	-0.3597	-0.3571	0.8617	0.7120	0.1095	0.0416	-0.0325	-0.0053
4	Q'_{1514}	0.4770	0.8479	-0.4427	-0.4396	-0.0947	-0.0783	0.7507	0.2853	-0.0624	-0.0102
5	Q'_{2416}	0.5082	0.9034	0.2909	0.2888	0.3549	0.2933	-0.0462	-0.0176	0.7273	0.1186
	Eigen values	3.1603		0.9859		0.6828		0.1444		0.0266	
	Percentage variation	63.21		19.72		13.66		2.89		0.53	

Table 20 Principal component analysis using important generated variables of the meteorological observations of the winter season (Variety: PTB 12)

Sl. No.	Variables	Eigen vectors (VI) and vectors of component loadings (FI)									
		V1	F1	V2	F2	V3	F3	V4	F4	V5	F5
1	Q'_{2421}	0.4421	0.7734	-0.3816	-0.4455	0.8092	0.4504	-0.0285	-0.0123	00568	0.0162
2	Q'_{2414}	0.4723	0.8262	-0.3548	-0.4142	-0.4519	-0.2515	-0.6671	-0.2869	0.0434	0.0124
3	Q'_{4614}	0.3537	0.6188	0.6462	0.7545	0.1466	0.0816	-0.2328	-0.1001	-0.6177	-0.1767
4	Q'_{1416}	0.5096	0.8915	-0.2305	-0.2691	-0.3420	-0.1904	0.6961	0.2993	-0.2928	-0.0837
5	Q'_{4616}	0.4435	0.7759	0.5077	0.5928	-0.0495	-0.0276	0.1247	0.0536	0.7263	0.2077
	Eigen value	3.0604		1.3631		0.3098		0.1849		0.0818	
	Percentage variation	61.21		27.26		3.44		2.05		0.91	

Table 21 Principal component analysis using important generated variabl
observations of the winter season (Variety: PTB 20)

Sl. No.	Variables	Eigen vectors (VI) and vectors of component loadings (FI)									
		V1	F1	V2	F2	V3	F3	V4	F4	V5	F5
1	Z'_{214}	0.3749	0.9076	-0.2749	-0.3259	-0.0991	-0.0842	0.1846	0.1253	0.2431	0.1406
2	Q'_{1414}	0.3608	0.8735	-0.0433	-0.0513	0.4529	0.3848	-0.3649	-0.2476	-0.1020	-0.0589
3	Q'_{2614}	0.3803	0.9207	-0.2370	-0.2810	0.0095	0.0081	0.1258	0.0854	0.2788	0.1613
4	Z'_{324}	-0.2696	-0.6527	-0.3626	-0.4299	-0.3709	-0.3152	-0.7644	-0.5186	0.2370	0.1371
5	Z'_{216}	0.3298	0.7984	-0.2700	-0.3201	-0.4636	-0.3939	0.2066	0.1402	0.2321	0.1342
6	Z'_{416}	-0.2999	-0.7260	-0.4772	-0.5658	0.3947	0.3354	0.2280	0.1547	0.1445	0.0836
7	Q'_{1416}	0.3563	0.8626	0.0430	0.0509	0.4400	0.3739	-0.3278	-0.2224	0.2869	0.1659
8	Q'_{2316}	0.3091	0.7483	-0.3849	-0.4564	-0.1164	-0.0989	-0.1053	-0.0714	-0.7982	-0.4617
9	Q'_{4616}	0.3013	0.7294	0.5332	0.6322	-0.2635	-0.2239	-0.1391	-0.0944	0.0495	0.0286
	Eigen value	5.8609		1.4059		0.7220		0.4603		0.3346	
	Percentage variation.	65.12		15.62		8.02		5.11		3.72	

(contd...)

Table 21 (contd.)

Sl. No.	Variables	Eigen vectors (VI) and vectors of component loadings (FI)							
		V6	F6	V7	F7	V8	F8	V9	F9
1	Z'_{214}	0.3859	0.1495	0.1476	0.0304	-0.2003	-0.0251	0.6856	0.0609
2	Q'_{1414}	0.0146	0.0057	-0.7091	-0.1462	-0.0106	-0.0013	0.1267	0.0113
3	Q'_{2614}	0.4903	0.1899	-0.0015	-0.0003	0.1644	0.0206	-0.6619	-0.0588
4	Z'_{324}	0.1123	0.0435	0.0129	0.0027	0.0667	0.0084	0.0238	0.0021
5	Z'_{216}	-0.6527	-0.2529	-0.2767	-0.0571	0.0055	0.0007	-0.0649	-0.0058
6	Z'_{416}	-0.1268	-0.0491	-0.0093	0.0019	0.6384	0.0799	0.1729	0.0154
7	Q'_{1416}	-0.3889	-0.1507	0.5702	0.1176	-0.0903	-0.0113	-0.0576	-0.0051
8	Q'_{2316}	-0.0285	-0.0110	0.2677	0.0552	0.1457	0.0183	-0.0279	-0.0025
9	Q'_{4616}	0.0613	0.0237	0.0421	0.0087	0.7009	0.0878	0.1921	0.0171
	Eigen value	0.1501		0.0425		0.0157		0.0079	
	Percentage variation	1.67		0.47		0.17		0.09	

The principal component analysis for PTB 1 showed that the first four components could explain about 86% of the total variation in the original data. Further it was found that all the variables except Z'_{213}, Q'_{1514} and Q'_{1216} could be grouped under one single factor which in turn was responsible for 37.61% variation in the original data. Walton (1972) has reported a minimum correlation of 0.45 among characters grouped into a factor. All such variables which were grouped under the same factor were significantly associated among themselves. Thus the first component appeared to be a measure of the joint effects of some of the weather factors viz., number of rainy days, number of hours of sunshine, minimum humidity and maximum temperature. The second component which explained 23% variation was dominated by Z'_{213} which represented the cumulative effect of number of rainy days upto the third fortnight after sowing. The third component was uniquely associated with the joint effect of total rainfall and number of rainy days upto the sixth fortnight after sowing which could explain about 14% of the total variability. It was fairly clear that the fourth component was more correlated with the joint effect of total rainfall and minimum humidity. The remaining components were unimportant as their total extent of contribution towards the divergence is negligibly small. In the case of PTB 5 all the variables were significantly affected by the first component which explained about 63% of the total variability in the original data. The second component was mainly dominated by the cumulative effect of the interaction of total rainfall and minimum humidity upto the third fortnight after sowing (Q'_{1513}) and the total percentage variation explained by the factor was about 19.7%. In the case of PTB 12 the first two components alone had succeeded in explaining about 88% of the total variability. The first factor represented the component of the joint effect of number of hours of sunshine with other weather variables viz., total rainfall, number of rainy days and maximum humidity and this component alone had explained about 61% of the total variability. The principal component analysis for PTB 20 revealed that out of the nine components the first two were able to explain about 80% of the total variability. The first component which accounted for 65% variability in the original data affected all of the generated variables. The second component with a 15.6% contribution in variability was mainly controlled by Q'_{4616} and Z'_{416}.

The regression of yield on principal components of the varieties in the two seasons showed that there was no appreciable amount of increase in the value of $\bar{R}^2$ by choosing the component vectors as explanatory variables. In the case of PTB 1 in the autumn season nine components were used as explanatory variables for the regression of yield and had explained about 90% of the variation in yield. The

Table 22 Regression equations using principal components as explanatory variables for the varieties in the two seasons

Variety	Regression equations	Adjusted R^2
PTB 1	$Y = 2231.21 + \underset{(8.06)}{1.01}F_1 - \underset{(17.36)}{7.96}F_2 - \underset{(15.99)}{4.73}F_3 +$ $\underset{(6.24)}{0.72}F_4 + \underset{(11.35)}{5.06}F_5 + \underset{(15.91)}{2.62}F_6 + \underset{(17.31)}{9.75}F_7 -$ $\underset{(4.95)}{1.06}F_8 - \underset{(1.89)}{3.45}F_9$	0.902
PTB 1	$Y = 2112.69 + \underset{(0.27)}{1.32}F_1^{**} - \underset{(0.27)}{0.21}F_2 - \underset{(0.16)}{0.21}F_3 +$ $\underset{(0.11)}{0.18}F_4$	0.776
PTB 5	$Y = 2066.31 - \underset{(2.32)}{4.18}F_1 - \underset{(2.71)}{3.68}F_2 + \underset{(2.43)}{2.56}F_3 +$ $\underset{(0.41)}{0.84}F_4 + \underset{(9.52)}{0.52}F_5$	0.768
PTB 5	$Y = 911.84 - 0.04F_1^{**}$	0.375
PTB 12	$Y = 1562.53 + \underset{(5.21)}{10.77}F_1 - \underset{(4.36)}{8.29}F_2 + \underset{(11.05)}{0.94}F_3 -$ $\underset{(5.89)}{9.49}F_4 + \underset{(0.82)}{1.28}F_5$	0.661
PTB 12	$Y = 1376.16 + \underset{(0.27)}{1.21}F_1^{**} - \underset{(0.26)}{0.59}F_2^{*}$	0.649
PTB 20	$Y = 965.05 + \underset{(31.30)}{62.09}F_1 - \underset{(42.07)}{147.36}F_2^{**} + \underset{(23.66)}{42.82}F_3 +$ $\underset{(44.68)}{165.21}F_4^{**} + \underset{(28.78)}{77.52}F_5^{*} - \underset{(44.02)}{5.86}F_6 + \underset{(17.03)}{96.04}F_7 +$ $\underset{(23.87)}{96.04}F_8^{**} + \underset{(63.79)}{149.21}F_9^{*}$	0.957
PTB 20	$Y = 1130.91 + \underset{(0.23)}{1.37}F_1^{**} + \underset{(0.38)}{0.15}F_2$	0.719

Figures in brackets denote the standard error of partial regression coefficients

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

first four components alone had succeeded in explaining about 78% of the variation in yield. For PTB 5 about 77% of variation in yield could be explained by using the first five components. Of these, the first component alone had explained about 38% of variation in yield. In the case of PTB 12 in winter season the regression of yield on the five components had resulted in a crop forecast of moderate accuracy ($\bar{R}^2 = 66\%$). The first two components alone had explained about 65% of total variability. For PTB 20 relatively higher degree of precision could be attained for the regression equations using principal components as explanatory variables. Nine components had explained about 96% of variation in yield. Of these the first two components alone could explain about 72% of variation in yield.

4.3.4. Weather Indices

Three simple weather indices P/T, PT and HS where P is the total precipitation, T is the mean temperature, H is the mean humidity and S is the average number of hours of sunshine were calculated for each week of the crop growing period in both the seasons. The simple linear correlation coefficients of these weather indices with yield of the two varieties and their aggregate yield were calculated for all the successive weeks of crop growth starting from the week

Table 23 Zero order correlation coefficients of weekly weather indices P|T, PT and HS with yields of PTB varieties and their mean yield in the two seasons.

No. of weeks after sowing.	autumn season			winter season		
	P|T	PT	HS	P|T	PT	HS
-1	-0.1386	-0.1477	-0.2684	0.1679	0.1573	-0.1958
	-0.0487	-0.2305	-0.1908	0.2441	0.2302	-0.2408
	-0.1819	-0.1918	-0.2335	0.2431	0.2492	-0.2657
1	0.2539	0.2467	-0.4879*	-0.1127	-0.1133	0.0249
	0.2982	0.2854	-0.4997*	-0.0138	-0.0162	0.0111
	0.2114	0.2004	-0.5009*	-0.0817	-0.0575	0.0347
2	-0.0104	-0.0151	-0.1718	0.2072	0.2375	0.2072
	0.0555	0.0572	-0.0541	0.0025	0.0092	0.1685
	0.0210	0.0209	-0.0496	0.2183	0.2258	0.1821
3	0.0032	0.0092	-0.2706	0.3547	0.3512	-0.1101
	0.0026	0.0071	-0.1716	0.2682	0.2687	0.1472
	0.0074	0.0083	-0.3238	0.4183*	0.5295**	-0.1196
4	-0.1339	-0.1313	0.1019	0.1054	0.0709	-0.2144
	-0.2644	-0.2601	0.1729	0.1238	0.0960	0.0312
	-0.1934	-0.1982	0.1389	0.1041	0.0993	-0.1763
5	-0.2769	-0.3008	-0.0267	0.2946	0.3131	-0.0612
	-0.3153	-0.3388	0.0264	0.3329	0.3591	-0.0426
	-0.3051	-0.3252	0.0005	0.3416	0.4844*	-0.0706
6	-0.1694	-0.1762	0.1869	-0.2439	-0.2668	0.2367
	-0.0512	-0.0553	0.0987	-0.1349	-0.1561	0.0545
	-0.1517	-0.1187	0.1485	-0.1851	-0.2364	0.2137
7	-0.2041	-0.1939	0.2786	0.2323	0.1809	0.0330
	-0.1313	-0.1293	0.2913	0.2524	0.2090	0.0483
	-0.1556	-0.1649	0.2890	0.2316	0.1577	0.0053

(contd..)

Table 23(contd..)

No. of weeks after sowing	autumn season			winter season		
	P|T	PT	HS	P|T	PT	HS
8	-0.5659** -0.5202** -0.5413**	-0.5677** -0.5250** -0.5585**	0.2119 0.2542 0.2361	-0.0372 -0.0391 -0.0417	-0.0771 -0.0931 -0.2017	0.3863 0.3187 0.3402
9	0.2059 0.2233 0.2170	0.1876 0.2018 0.1980	-0.2979 -0.2707 -0.2886	-0.3259 -0.1921 -0.3141	-0.3691 -0.1749 -0.3311	0.3342 0.3363 0.4600*
10	0.0091 0.2299 0.1314	0.0556 0.1919 0.1249	-0.1152 -0.2778 -0.1982	0.1002 0.1997 0.1714	0.0938 0.1924 0.1375	-0.0623 -0.0814 -0.0625
11	-0.4273* -0.4801* -0.4102*	-0.4319* -0.4809* -0.3885*	0.2117 0.2826 0.2502	0.1058 0.1423 0.1313	0.1059 0.1429 0.1094	-0.6224** -0.4431* -0.5793**
12	-0.0848 -0.1024 -0.1108	-0.0882 -0.1034 -0.1005	0.1229 0.1637 0.1621	0.2797 0.1735 0.2654	0.2784 0.1680 0.2197	-0.0027 0.0412 -0.0356

*Significant at 5% level

**Significant at 1% level

before sowing upto the twelfth week after sowing of the crop. These correlation coefficients are presented in Table 23. The three entries in each cell of the table represents the correlation coefficients of the weather indices with the yields of the PTB varieties tried in the particular season, in the ascending order of their number and those with their general mean yield.

It appears from the result that the weather indices P/T and PT were not much different with regard to the value of the correlation coefficient in both the seasons. The index P/T of the eighth week (r_1= -0.5659, r_2= -0.5202, r_3 = -0.5413) and eleventh week(r_1 = -0.4273, r_2 = -0.4801, r_3 = -0.4102) showed significant and negative association with yield. The index PT during the above period also had shown significant and negative effect on crop yield. Thus the amount of precipitation per unit temperature during the eighth and eleventh weeks after sowing had adverse effects on crop yield. The other index HS in the first week after sowing (r_1 = -0.4879, r_2 = -0.4997, r_3 = -0.5009) exerted significant and negative effect on crop yield.

The correlation coefficients of the weather indices P/T and PT with yields of the two varieties in the winter season were not found to be significant in any of the weeks of the crop growth period under study. However, the correlation coefficients of these weather indices with aggregate yield were found to be significant and positive in the third week after sowing. The other index HS in the eleventh week after sowing exhibited significant and negative effect on yield ($r_1 = -0.6224$, $r_2 = -0.4431$, $r_3 = -0.5793$) whereas the correlation coefficient of the same index in the ninth week after sowing with aggregate yield was significant and positive ($r_3 = 0.4600$).

A set of regression equations were fitted in different fortnights of plant growth in the two seasons choosing all those weather indices of the different weeks whose correlation coefficients with yield were found to be significant at 20% level of significance. However, in the autumn season a prediction equation of sufficient degree of precision could not be evolved. The specific regression equations for the two varieties in the winter season and the general equation together with the values of adjusted coefficient of determination, standard errors of partial regression coefficients are given in Table 24. The important weather indices which constituted the regression equations are the following.

W_1 = PT of the third week after sowing
W_2 = PT of the fifth week after sowing
W_3 = PT of the sixth week after sowing

W_4 = HS of the eighth week after sowing
W_5 = HS of the ninth week after sowing
W_6 = Hs of the eleventh week after sowing
W_7 = PT of the twelfth week after sowing

A glance at the results furnished in Table 24 revealed that the maximum value of the adjusted coefficient of determination by regressing yield on the weather indices PT and HS of the pertinent weeks was recorded in the sixth fortnight after sowing. The relevant equation for PTB 12 based on three weather indices is given by

$$Y = 3206.69 + 1.21W_1^{**} - 3.06W_6^{**} + 1.42W_7 \qquad - (4.31)$$

The above equation succeeded in explaining as much as 59% variability in the yield of PTB 12. The equation which had explained about 56% variability in the yield of PTB 20 is given by

$$Y = 3125.07 + 1.92W_1^{**} - 3.11W_6^{**} + 1.05W_7 \qquad - (4.32)$$

The same three indices constituted a prediction equation for the aggregate yield and the equation having 58% precision was of the form

$$Y = 3231.21 + 1.53W_1^{**} - 3.08W_6^{**} + 1.26W_7 \qquad - (4.33)$$

The weather indices W_1 and W_6 were the major contributing indices and were decisive in forecasting as they jointly contributed as high as 54% variation in winter crop yield.

Table 24 Regression equations of the weather indices PT and HS on yield of the varieties in the winter season and on their mean yield

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
2	$Y_1 = 1610.76 + 1.29\overset{*}{W}_1$ $(0.52)^1$	0.223
2	$Y_2 = 1518.17 + 1.99\overset{**}{W}_1$ $(0.62)^1$	0.330
2	$Y_3 = 1565.04 + 1.60\overset{**}{W}_1$ $(0.56)^1$	0.280
3	$Y_1 = 1628.33 + 1.08W_1 + 0.42W_2 - 0.41W_3$ $(0.54)^1 \quad (0.44)^2 \quad (0.35)^3$	0.199
3	$Y_2 = 1511.86 + 1.76\overset{*}{W}_1 + 0.54W_2 - 0.39W_3$ $(0.64)^1 \quad (0.52)^2 \quad (0.42)^3$	0.300
3	$Y_3 = 1560.13 + 1.38\overset{*}{W}_1 + 0.52W_2 - 0.39W_3$ $(0.57)^1 \quad (0.47)^2 \quad (0.38)^3$	0.297
4	$Y_1 = 1121.05 + 0.88W_1 - 0.54W_3 + 1.17W_4$ $(0.54)^1 \quad (0.35)^3 \quad (0.73)^4$	0.259
4	$Y_2 = 1195.48 + 1.62\overset{*}{W}_1 + 0.44W_2 - 0.47W_3 + 0.67W_4$ $(0.68)^1 \quad (0.55)^2 \quad (0.43)^3 \quad (0.95)^4$	0.281
4	$Y_3 = 1129.54 + 1.23\overset{*}{W}_1 - 0.51W_3 + 1.05W_4$ $(0.59)^1 \quad (0.38)^3 \quad (0.81)^4$	0.276

(contd..)

Table 24 (contd.)

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
5	$Y_1 = 1001.87 + \underset{(0.45)}{1.15}W_1 - \underset{(0.28)}{0.39}W_3 + \underset{(0.87)}{1.46}W_5$	0.349
5	$Y_2 = 899.99 + \underset{(0.67)}{1.46}W_1^{*} - \underset{(0.41)}{0.42}W_3 + \underset{(1.03)}{1.53}W_5$	0.338
5	$Y_3 = 1015.37 + \underset{(0.61)}{1.12}W_1 - \underset{(0.37)}{0.41}W_3 + \underset{(0.93)}{1.37}W_5$	0.293
6	$Y_1 = 3206.69 + \underset{(0.35)}{1.21}W_1^{**} - \underset{(0.63)}{3.06}W_6^{**} + \underset{(0.69)}{1.42}W_7$	0.591
6	$Y_1 = 3261.17 + \underset{(0.38)}{1.24}W_1^{**} - \underset{(0.68)}{3.04}W_6^{**}$	0.548
6	$Y_2 = 3125.07 + \underset{(0.49)}{1.92}W_1^{**} - \underset{(0.89)}{3.11}W_6^{**} + \underset{(0.97)}{1.05}W_7$	0.555
6	$Y_2 = 3219.99 + \underset{(0.50)}{1.94}W_1^{**} - \underset{(0.89)}{3.09}W_6^{**}$	0.536
6	$Y_3 = 3231.21 + \underset{(0.41)}{1.53}W_1^{**} - \underset{(0.74)}{3.08}W_6^{**} + \underset{(0.81)}{1.26}W_7$	0.583
6	$Y_3 = 3245.73 + \underset{(0.43)}{1.55}W_1^{**} - \underset{(0.77)}{3.06}W_6^{**}$	0.534

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

The weather index $W = R + T\ (80-T)$ proposed by Bean(1964) was also calculated using observations on total precipitation (R) and mean temperature (T) for the crop growing period under study and the indices calculated for weekly intervals starting from the week before sowing to the twelfth week after sowing were correlated with the yield of two varieties and their aggregate yield in the two seasons. The results pertaining to this study are presented in Table 25. As in the previous cases the first two entries in each cell of the table refers to the correlation coefficients of the indices with the yield of the two specific varieties and the third entry refers to that with the general mean yield in the particular season.

On examining the correlation coefficients appeared in the table it could be seen that there was significant and negative relationship between index values of the ninth week ($r_2 = -0.4593$, $r_3 = -0.4287$) and tenth week ($r_1 = -0.4802$, $r_2 = -0.5732$, $r_3 = -0.5354$) after sowing and the yield of PTB varieties in the autumn season. In the winter season the indices pertaining to the week prior to sowing($r_1 = -0.4464$, $r_3 = -0.4352$), eighth week after sowing ($r_1 = -0.4748$, $r_2 = -0.4353$, $r_3 = -0.4567$) and twelfth week after sowing ($r_1 = -0.5557$, $r_2 = -0.5229$, $r_3 = -0.5629$) had shown significant and negative association with crop yield.

Table 25 Zero order correlation coefficients between Bean's weather indices for the successive weeks starting from one week before sowing upto the twelfth week after sowing and the yield of PTB varieties in the two seasons.

(No. of weeks after sowing)	Autumn season	Winter season	(No. of weeks after sowing	Autumn season	Winter season
-1	-0.0817	-0.4464*	7	0.0922	-0.3127
	-0.0345	-0.4000		-0.0386	-0.2833
	-0.0595	-0.4352*		0.0283	-0.2918
1	-0.1776	-0.3206	8	-0.2417	-0.4748**
	-0.2024	-0.1664		-0.2239	-0.4353*
	-0.1932	-0.2324		-0.2371	-0.4567*
2	-0.2665	-0.1086	9	-0.3842	-0.3242
	-0.1809	-0.1668		-0.4593*	-0.2827
	-0.2283	-0.1434		-0.4287*	-0.3043
3	-0.3209	-0.0421	10	-0.4802*	-0.3764
	-0.2859	0.0558		-0.5732**	-0.3682
	-0.3091	0.0067		-0.5354**	-0.3868
4	-0.0158	-0.4001	11	-0.0281	-0.2933
	0.0192	-0.3248		-0.0729	-0.2109
	0.0015	-0.3538		-0.0510	-0.2538
5	-0.2747	-0.2297	12	-0.0945	-0.5557**
	-0.2816	-0.1967		-0.1245	-0.5229**
	-0.2830	-0.2103		-0.1112	-0.5629**
6	-0.1342	-0.2961			
	-0.1291	-0.2490			
	-0.1339	-0.2598			

* Significant at 5% level

** Significant at 1% level

Table 26(a) Regression equations fitted for autumn yield forecast of PTB 1 using Bean's weather indices as explanatory variables

Sl. No.	Regression equations	Adjusted R^2
1	$Y = 15928.31 + \underset{(4.98)}{11.51}W_1^{*} - \underset{(3.71)}{10.62}W_2^{*} - \underset{(4.65)}{14.14}W_5 + \underset{(4.83)}{8.34}W_7 - \underset{(5.15)}{25.78}W_{10}^{**} + \underset{(7.18)}{20.62}W_{11}^{*}$	0.565
2	$Y = 22872.26 + \underset{(5.19)}{12.73}W_1^{*} - \underset{(3.88)}{9.22}W_2^{*} - \underset{(4.89)}{14.09}W_5^{**} - \underset{(5.43)}{25.67}W_{10}^{**} + \underset{(7.56)}{21.18}W_{11}^{*}$	0.518
3	$Y = 19273.59 + \underset{(4.66)}{5.38}W_1 - \underset{(5.36)}{11.88}W_5^{*} - \underset{(5.99)}{23.89}W_{10}^{**} + \underset{(8.29)}{17.89}W_{11}^{*}$	0.399
4	$Y = 18431.17 - \underset{(5.11)}{9.85}W_5 - \underset{(5.42)}{20.81}W_{10}^{**} + \underset{(8.32)}{18.89}W_{11}^{*}$	0.390
5	$Y = 3364.7 - \underset{(5.75)}{20.19}W_{10}^{**} + \underset{(8.84)}{19.10}W_{11}^{*}$	0.311
6	$Y = 18914.62 - \underset{(4.72)}{12.11}W_{10}^{*}$	0.196

The figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 26 (b) Regression equations fitted for autumn yield forecast of PTB 5 using Bean's weather indices as explanatory variables

Sl. No.	Regression equations	Adjusted R^2
1	$Y = 21804.29 + \underset{(4.33)}{13.08 W_1^{**}} - \underset{(3.39)}{8.36 W_2^{*}} - \underset{(4.04)}{15.58 W_5^{**}} + \underset{(3.73)}{7.96 W_8^{*}} - \underset{(4.99)}{32.77 W_{10}^{**}} + \underset{(6.11)}{21.21 W_{11}^{**}}$	0.668
2	$Y = 23953.13 + \underset{(4.58)}{10.69 W_1^{*}} - \underset{(3.43)}{5.54 W_2} - \underset{(4.32)}{13.72 W_5^{**}} - \underset{(4.79)}{27.61 W_{10}^{**}} + \underset{(6.67)}{20.17 W_{11}^{**}}$	0.602
3	$Y = 21796.53 + \underset{(3.84)}{6.28 W_1} - \underset{(4.42)}{12.39 W_5^{*}} - \underset{(4.94)}{26.55 W_{10}^{**}} + \underset{(6.83)}{18.19 W_{11}^{*}}$	0.568
4	$Y = 20816.18 - \underset{(4.35)}{10.02 W_5^{*}} - \underset{(4.61)}{22.95 W_{10}^{**}} + \underset{(7.07)}{19.35 W_{11}^{*}}$	0.532
5	$Y = 5481.68 - \underset{(5.05)}{22.32 W_{10}^{**}} + \underset{(7.77)}{19.57 W_{11}^{*}}$	0.435
6	$Y = 21412.59 - \underset{(4.28)}{14.04 W_{10}^{**}}$	0.298

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 26 (c) Regression equations fitted for autumn mean yield forecast using Bean's weather indices as explanatory variables

Sl. No.	Regression equations	Adjusted R^2
1	$Y = 21389.07 + \underset{(4.53)}{13.95}W_1^{**} - \underset{(3.55)}{10.04}W_2^{**} - \underset{(4.23)}{15.65}W_5^{**} + \underset{(3.89)}{7.49}W_8 - \underset{(5.23)}{31.49}W_{10}^{**} + \underset{(6.39)}{21.66}W_{11}^{**}$	0.635
2	$Y = 3398.59 + \underset{(4.69)}{11.71}W_1^{*} - \underset{(3.51)}{7.38}W_2^{*} - \underset{(4.42)}{13.90}W_5^{**} - \underset{(4.91)}{26.64}W_{10}^{**} + \underset{(6.83)}{20.68}W_{11}^{**}$	0.580
3	$Y = 20528.00 + \underset{(4.09)}{5.83}W_1 - \underset{(4.72)}{12.13}W_5^{*} - \underset{(5.28)}{25.22}W_{10}^{**} + \underset{(2.47)}{18.04}W_{11}^{*}$	0.504
4	$Y = 19616.62 - \underset{(4.57)}{9.93}W_5^{*} - \underset{(4.85)}{21.88}W_{10}^{**} + \underset{(7.44)}{19.12}W_{11}^{*}$	0.479
5	$Y = 4409.10 - \underset{(5.25)}{21.25}W_{10}^{**} + \underset{(8.07)}{19.34}W_{11}^{*}$	0.386
6	$Y = 20156.57 - \underset{(4.39)}{13.07}W_{10}^{**}$	0.219

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 27(a) Regression equations fitted for winter yield forecast of PTB 12 using Bean's weather indices as explanatory variables

Sl. No.	Regression equations	Adjusted R^2
1	$Y = 9549.64 - \underset{(3.69)}{6.05}W_1 + \underset{(4.83)}{12.96}W_2^{*} + \underset{(5.41)}{9.67}W_5 - \underset{(4.46)}{14.03}W_8^{**} - \underset{(2.73)}{8.74}W_{12}^{**}$	0.533
2	$Y = 5204.11 + \underset{(4.94)}{11.31}W_2^{*} + \underset{(5.59)}{8.35}W_5 - \underset{(4.66)}{13.72}W_8^{**} - \underset{(2.83)}{9.30}W_{12}^{**}$	0.487
3	$Y = 8949.57 + \underset{(5.07)}{12.12}W_2^{*} - \underset{(3.26)}{8.42}W_8^{*} - \underset{(2.92)}{9.44}W_{12}^{**}$	0.453
4	$Y = 17625.96 - \underset{(3.25)}{4.95}W_8 - \underset{(2.98)}{6.68}W_{12}^{*}$	0.322
5	$Y = 13143.89 - \underset{(2.79)}{8.57}W_{12}^{**}$	0.278

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 27 (b) Regression equations fitted for winter yield prediction of PTB 20 using Bean's weather indices as explanatory variables

Sl. No.	Regression equations	Adjusted R^2
1	$Y = 7760.28 - \underset{(5.22)}{8.30W_1} + \underset{(5.12)}{15.15W_3^{**}} + \underset{(6.85)}{12.41W_5} - \underset{(6.07)}{14.43W_8^{*}} - \underset{(3.96)}{10.26W_{12}^{**}}$	0.519
2	$Y = 2771.12 + \underset{(5.24)}{13.65W_3^{*}} + \underset{(7.13)}{12.59W_5} - \underset{(6.01)}{17.42W_8^{**}} - \underset{(3.45)}{10.39W_{12}^{**}}$	0.476
3	$Y = 9331.36 + \underset{(5.52)}{13.59W_3^{*}} - \underset{(4.12)}{9.35W_8^{*}} - \underset{(3.63)}{10.32W_{12}^{**}}$	0.417
4	$Y = 5806.38 + \underset{(5.64)}{8.98W_3} - \underset{(3.82)}{12.65W_{12}^{**}}$	0.294
5	$Y = 15438.91 - \underset{(3.64)}{10.24W_{12}^{**}}$	0.240

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Table 27(c) Regression equations fitted for winter mean yield forecast using Bean's weather indices as explanatory variables

Sl. No.	Regression equations	Adjusted R^2
1	$Y = 9069.98 - \underset{(4.38)}{7.85W_{-1}} + \underset{(4.29)}{12.28W_3^{**}} + \underset{(5.75)}{11.12W_5} - \underset{(5.09)}{12.39W_8^{*}} - \underset{(2.78)}{9.45W_{12}^{**}}$	0.558
2	$Y = 4395.19 + \underset{(4.47)}{10.86W_3^{*}} + \underset{(6.09)}{11.29W_5} - \underset{(5.13)}{15.23W_8^{**}} - \underset{(2.94)}{9.57W_{12}^{**}}$	0.502
3	$Y = 10243.22 + \underset{(4.75)}{10.81W_3^{*}} - \underset{(3.54)}{7.99W_8^{*}} - \underset{(3.12)}{9.49W_{12}^{**}}$	0.437
4	$Y = 7244.97 + \underset{(4.85)}{6.87W_3} - \underset{(3.29)}{11.49W_{12}^{**}}$	0.320
5	$Y = 14619.30 - \underset{(3.09)}{9.65W_{12}^{**}}$	0.286

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

The selected regression equations fitted with Bean's weather indices as explanatory variables together with standard errors of the partial regression coefficients and adjusted coefficients of determination are presented in Tables 26 and 27. The symbol W_n in the regression equations indicates the weather index for the n^{th} week after sowing. Among the selected prediction equations, the one with maximum adjusted coefficient of determination ($\bar{R}^2 = 57\%$) for PTB 1 is given by

$$Y = 15928.31 + 11.51\overset{*}{W}_1 - 10.62\overset{*}{W}_2 - 14.14\overset{**}{W}_5 + 8.34W_7 - 25.78\overset{**}{W}_{10} + 20.62\overset{*}{W}_{11} \qquad - (4.34)$$

The prediction equation for PTB 5 with maximum $\bar{R}^2(67\%)$ was obtained in the sixth fortnight after sowing and is given by

$$Y = 21804.29 + 13.08\overset{**}{W}_1 - 8.36\overset{*}{W}_2 - 15.58\overset{**}{W}_5 + 7.96\overset{*}{W}_8 - 32.77\overset{**}{W}_{10} + 21.21\overset{**}{W}_{11} \qquad - (4.35)$$

The same independent variables of (4.35) explained about 64% of the variability in the aggregate data and the relevant equation is

$$Y = 21389.07 + 13.95\overset{**}{W}_1 - 10.04\overset{**}{W}_2 - 15.65\overset{**}{W}_5 + 7.49W_8 - 31.49\overset{**}{W}_{10} + 21.66\overset{**}{W}_{11} \qquad - (4.36)$$

The regression equations fitted in the winter season using Bean's weather indices as explanatory variables showed that yield prediction of PTB 12 could be done in the Sixth fortnight with a precision of 53% by utilizing the following equation

$$Y = 9549.64 - 6.05W_1 + 12.96W_2^{*} + 9.67W_5 - 14.03W_8^{**} - 8.74W_{12}^{**} \qquad - (4.37)$$

At the same time the prediction equation evolved for PTB 20 with 52% precision was of the form

$$Y = 7760.28 - 8.30W_{-1} + 15.15W_3^{**} + 12.41W_5 - 14.43W_8^{*} - 10.26W_{12}^{**} \qquad - (4.38)$$

The same indices of (4.38) could explain about 56% variation in the aggregate yield. The relevant equation is

$$Y = 9069.98 - 7.85W_{-1} + 12.28W_3^{**} + 11.12W_5 - 12.39W_8^{*} - 9.45W_{12}^{**} \qquad - (4.39)$$

4.4. Effect of climatological variables at different phases of crop growth on yield

A perusal of the results in Table 28 brings to focus some findings on the effect of climatological variables at different phases of crop growth on yield. It was found that in the autumn season all the climatic variables other than number of hours of sunshine in various growth phases showed negative correlation with yield though most of them were statistically nonsignificant. Above average maximum humidity during the nursery period exerted significant but negative effect on yield (r_1 = -0.4259). None of the weather variables of active vegetative phase exerted significant influence on yield where as above average maximum humidity during the lag vegetative phase had significant influence on yield (r_1 = -0.4667). The effects of above average total rainfall (r_1 = -0.5097, r_2 = -0.5069) and rainfall range (r_1 = -0.4809, r_2 = -0.4835) during the reproductive phase on yield were significant and negative. The minimum humidity (r_1 = -0.4425) and mean humidity (r_1 = -0.4397) during the same period also had shown negative association with yield. Thus above average total rainfall and maximum humidity during the reproductive phase was expected to cause a considerable reduction in the final crop yield. Number of hours of sunshine during the reproductive phase was not found to limit the crop yield. None of the weather variables of the ripening phase contributed significantly towards crop yield.

The effect of weather indices at different phases of crop growth on the yield of varieties tried in the winter season were more pronounced and statistically significant. It is evident from the results that the effect of above average maximum temperature during the nursery period on yield was negative and significant (r_1 = -0.5743, r_2 = -0.5112). At the same time above average maximum humidity (r_1 = 0.4102), above average minimum humidity (r_1 = 0.4360) and above average

Table 28(a) Zero order correlation coefficients of climatic variables at different phases of crop growth with yield of PTB varieties in the autumn season

Phase	Total rainfall	Rainfall range	No.of rainy-days	Maximum temperature	Minimum temperature	Mean temperature	Maximum humidity	Minimum humidity	Mean humidity	No.of hours of sunshine	Wind velocity
Nursery (I)	-0.0478	-0.1133	-0.0696	-0.0789	-0.0932	-0.1035	-0.4259*	-0.0049	-0.0863	-0.2967	-0.2379
	-0.0573	-0.0323	-0.1628	-0.0268	-0.0684	-0.0584	-0.3499	-0.0862	-0.1721	-0.1762	0.0845
Active vegetative phase II	-0.3322	-0.2942	-0.1571	0.1562	0.0179	0.1054	-0.0705	-0.2782	-0.2644	0.1443	-0.3288
	-0.1716	-0.1803	-0.0781	0.0073	-0.0517	-0.0228	-0.0692	-0.1103	-0.1551	0.0638	-0.1917
Lag vegetative phase III	-0.2394	0.1932	0.0352	-0.1539	-0.0429	-0.1203	-0.4667*	-0.3024	-0.3052	0.1639	-0.0313
	-0.1308	0.2635	0.1263	-0.2775	-0.0911	-0.2275	-0.3962	-0.2463	-0.2787	0.1011	-0.0899
II + III	-0.3439	-0.1349	-0.0442	0.0284	-0.0128	0.0059	-0.1443	-0.3358	-0.3048	0.1806	-0.2349
	-0.1805	-0.0288	0.0654	-0.1452	-0.0747	-0.1342	-0.1758	-0.1949	-0.2029	0.0980	-0.1775
Reproductive phase IV	-0.5097*	-0.4809*	-0.2844	0.2179	0.0907	0.1754	-0.2611	-0.4425*	-0.4397*	0.3771	-0.3135
	-0.5069*	-0.4835*	-0.2306	-0.0236	-0.0039	-0.0116	-0.2227	-0.3775	-0.3752	0.3860	-0.1472
Ripening phase V	-0.0807	-0.1879	-0.2718	0.0797	-0.0104	0.0471	-0.0483	-0.2723	-0.2206	0.3189	-0.4093
	-0.2843	-0.2968	-0.3096	0.0438	0.0513	0.0647	-0.1157	-0.3367	-0.2939	0.3269	-0.2973

* Significant at 5% level

** Significant at 1% level

Table 28(b) Zero order correlation coefficients of climatic variables at different phases of crop growth with yield of PTB varieties in the winter season

Phase	Total rainfall	Rainfall range	No.of rainy days	Maximum temperature	Minimum temperature	Mean temperature	Maximum humidity	Minimum humidity	Mean humidity	No.of hours of sunshine	Wind velocity
Nursery I	0.3953	0.3609	0.1929	-0.5743**	-0.2511	-0.2518	0.4102*	0.4360*	0.4465*	-0.2315	0.0125
	0.3240	0.2917	0.0208	-0.5112**	-0.1228	-0.1801	0.3899	0.3763	0.3979	-0.0603	0.1803
Active vegetative phase II	-0.0585	-0.1709	0.1774	-0.2968	-0.4112*	-0.4415*	0.4546*	-0.0746	0.0434	0.3916	-0.5403*
	0.0073	-0.0253	0.1633	-0.4116*	-0.2992	-0.3784	0.5225**	-0.0295	0.0559	0.2845	-0.4234
Lag vegetative phase III	0.2601	0.1199	0.3933	-0.5926**	-0.2614	-0.5084*	0.4161*	0.1415	0.3061	-0.4787*	-0.5039*
	0.4031*	0.2265	0.4374*	-0.6909**	-0.0793	-0.4085*	0.5823**	0.3331	0.5000*	-0.5943**	-0.5810**
II+ III	0.0834	-0.0922	0.2436	-0.5299**	-0.3343	-0.5148**	0.2815	0.0393	0.3257	-0.0401	-0.6214**
III	0.2289	0.1061	0.2577	-0.6468**	-0.1596	-0.4254	0.2009	0.1986	0.4825*	-0.2019	-0.5936**
Reproductive phase IV	0.3371	0.1577	0.6541**	-0.7941**	-0.1826	-0.5369**	0.3047	0.1322	0.2928	-0.3331	-0.0862
	0.2653	0.2095	0.4526*	-0.7179**	-0.1603	-0.4815*	0.3675	0.0716	0.2832	-0.2440	-0.0976
Ripening phase V	-0.1923	-0.1679	-0.2019	-0.6478**	-0.5861**	-0.7062**	0.2007	-0.3525	-0.1156	0.1143	-0.0858
	-0.0907	-0.0850	-0.1032	-0.5634**	-0.4911*	-0.6050**	0.2939	-0.2639	0.0034	0.1303	-0.3158

* Significant at 5% level

** Significant at 1% level

mean humidity ($r_1 = 0.4465$) during the above period were conducive to get better yield of the crop. An important weather variable in the vegetative phase which had beneficial impact on crop growth seemed to be maximum humidity ($r_1 = 0.4546$, $r_2 = 0.5225$). Maximum temperature ($r_2 = -0.4116$), minimum temperature ($r_1 = -0.4112$) and mean temperature ($r_1 = -0.4415$) during the same phase showed negative association with crop yield. The weather variables of the lag vegetative phase seemed to have relatively greater influence on crop yield. High rainfall ($r_2 = 0.4031$) and frequent rainy days ($r_2 = 0.4374$) exerted beneficial effect on the yield of PTB 20. Maximum humidity during this phase ($r_1 = 0.4161$, $r_2 = 0.5823$)also had positive association with yield. On the contrary maximum temperature ($r_1 = -0.5926$, $r_2 = -0.6909$), mean temperature ($r_1 = -0.5084$, $r_2 = -0.4085$) and number of hours of sunshine ($r_1 = -0.4787$, $r_2 = -0.5943$) during the lag vegetative phase were negatively correlated with yield. Wind velocity of this phase also appeared to have adverse effect on yield ($r_1 = -0.5039$, $r_2 = -0.5810$) The high positive correlation coefficient ($r_1 = 0.6541$, $r_2 = 0.4526$) of number of rainy days during the reproductive phase with yield showed that well distributed rain during the reproductive phase was conducive for better production. The maximum temperature ($r_1 = -0.7941$, $r_2 = -0.7179$) and mean temperature ($r_1 = -0.5369$, $r_2 = -0.4815$) during the reproductive phase were negatively correlated with yield. Further above average maximum temperature ($r_1 = -0.6478$, $r_2 = -0.5634$), above average minimum temperature ($r_1 = -0.5861$, $r_2 = -0.4911$) and above average mean temperature ($r_1 = -0.7062$, $r_2 = -0.6050$) of the ripening period were found to exert significant adverse effects on crop yield.

4.5. Effect of date of sowing on crop yield

As explained in Section 3.4 of Chapter 3 the rank correlation coefficients between the ranks of the series in accordance with date of sowing and seasonal yield were worked out and presented in Table 29. It was found that none of the rank correlation coefficients for the two varieties in the two seasons were significant.

Table 29 Rank correlation coefficients between the ranks of date of sowing and that of the yield data for the varieties in the two seasons

Season	Variety	rank correlation coefficient (ρ)
Autumn	PTB 1	0.2169
	PTB 5	0.1452
Winter	PTB 12	-0.1023
	PTB 20	-0.0741

Hence it can be concluded that crop yield was not significantly influenced by slight changes in the time of sowing for the crops in the two seasons.

When student's 't' test was applied for testing the significance of the difference between mean yields of early sowing years and late sowing years none of the 't' values turned out to be statistically significant (Table 30). Thus it may be concluded that delayed sowing was not found to exert any significant negative effect on the yield of PTB varieties.

Table 30 The calculated values of 't' for the comparison of mean yields of early sowing and late sowing years for the PTB varieties in the two seasons.

Season	Variety	t value
autumn	PTB 1	0.2973
	PTB 5	0.2532
winter	PTB 12	0.7549
	PTB 20	0.5081

DISCUSSION

DISCUSSION

Weather plays a vital role in crop growth and yield. Due to the complex interactions among the climatic parameters themselves, an accurate analysis of the relationships involved in plant growth and yield becomes difficult. As rightly pointed out by Fisher (1924) the inherent complexity of the relationship between yields of farm crops and previous weather which largely controls yields arises primarily from the complexity on the problem of specifying the weather itself. Agriculture being the greatest national industry in India, several studies have been conducted in our country on crop weather relationships. They relate to a closer and deeper analysis of weather data to provide a proper understanding of the direct and indirect effects of the various weather factors on crop growth and yield. Rice being the staple food of most of the Indians advanced estimates on its probable production are of immense use for advanced planning. Such estimates are also useful for working out appropriate agricultural strategies for regional development. As far as the State of Kerala is concerned, paddy occupies the position of the premier food crop of the state and an increase in the output of the crop is closely linked with the agricultural and economic development of the State. In spite of several measures taken by the government from time to time to boost up productivity of paddy in Kerala State, the realised growth rates in the past decades were not substantial. The high reliance of paddy on weather may be one of the reasons for this sluggish growth rate. So far, not much work on these lines have been done in a systematic manner in South India, especially in Kerala. Hence attempts have been made in the present study to examine the nature of the relationship between weather factors and rice yield and to predict yield of medium duration paddy varieties through selected weather parameters, well ahead of harvest. The differential response between the varieties with regard to the effect of the meteorological variables was also examined. Of the four varieties involved in the study, PTB 1 and PTB 5 were confined to the autumn season while PTB 12 and PTB 20 were tried in the winter season. The salient results obtained in the investigation are discussed below.

As a matter of fact, rice crop reacts differently to climatic parameters during different stages of its development. These responses are usually manifested in the final yield of the crop. Therefore not only reliable meteorological data for the whole crop growing season are needed but it is also essential to know their specific influence at each growth stage of the crop. Statistical analysis based on weekly weather data enables one to determine the effect of weather factors on crop yield more accurately than that based on yearly, monthly or seasonal data.

The simple correlation and multiple regression analysis of the weekly weather variables with rice yield helped in understanding the effect of climatic variables at small intervals of crop growth on yield. The results showed that the effect of weather variables at different weeks of crop growth on yield were not similar in the two seasons. However, more or less same values of correlation coefficients of weather variables were observed with the yields of the varieties in the same season and with aggregate yield.

The results illustrate that for the rice varieties tried in the autumn season, above average total rainfall during the first week after sowing was found to be beneficial for crop growth and yield. In the autumn season, dry nursery is our practise and there is likely to be moisture stress. Since there should be necessary soil moisture for the germination of seeds, rains after sowing must be expected to be beneficial. Beneficial effect of premonsoon showers in lowering the maximum temperature to the optimum level for germination of wheat was reported by Sreenivasan (1972). On the contrary, above average number of hours of sunshine during the first week after sowing had adverse effect on yield. A probable desiccation of just sprouted seedlings is attributable to this. Sreenivasan (1974) has reported that any amount of rain received during the germination phase of the wheat crop would be beneficial for better yield. It was evident that above average number of rainy days during the third week after sowing and fifth week after sowing had positive relationship with final grain yield. This may be attributed to the fact that well distributed showers will promote good seedling growth. At the same time, the high rainfall range during the fourth week after sowing and above average total rainfall during the fifth week after sowing had shown detrimental effects on yield. Heavy rains and excessive moisture in a dry nursery are known to cause very fast vegetative growth of seedlings which is not good under a dry nursery system. Such seedlings with excessive growth for two weeks (fourth and fifth) before planting would have formed nodes and hence become physiologically over-aged. The findings of Tanaka et al. (1966) was in agreement with this result. Also the heavy rains during the fifth week after sowing which coincides with the time of land preparation of main field would have resulted in leaching losses of applied inorganics as well as organics. Fisher (1924) also has revealed that it was the distribution of rainfall during a season rather than its total amount which influenced wheat yield. Tomar (1975), Huda et al. (1975), Sreenivasan (1974) and Bhatia (1983) were of the opinion that above average rainfall during the nursery period of kharif rice is beneficial for better yield. This was contrary to the findings of the present study as far as the total rainfall during the end of the nursery period is considered. Above average total rainfall during the sixth and eighth weeks after sowing, number of rainy days during the seventh week after sowing and rainfall range during the eighth week after sowing were found to have negative association with yield. Daily or very frequent rains immediately following transplanting will not allow the planted seedlings to establish well quickly by the disturbances and also will not allow drainage of the field especially during the south west monsoon season. The findings of Sreenivasan (1968) also was in confirmity with this result. Frequent heavy rains in such a period immediately following transplanting will necessitate continuous draining of water and thus result in loss of nutrients through leaching.

Huda et al. (1975) and Tomar (1975) also have reported that above average rainfall during the vegetative phase was detrimental to better rice yield during Kharif season. Bright sunshine hours and above average maximum temperature during the ninth week after sowing, above average maximum and mean temperatures during the tenth week after sowing and bright sunshine hours during the eleventh week after sowing adversely affected the final crop yield. The above mentioned periods coincided with middle of July which is having a high general temperature. With this high temperature an increase in bright sunshine hours could be associated with higher temperature which was very much above the optimum level for rice plant. Huda *et al.* (1975) has found that above average maximum daily temperature during the vegetative growth phase had adverse effect on rice yield. In contrast to the results in the present study Stansel (1966) and Mayr (1967) have got positive association of light energy during the vegetative phases of crop growth with yield of rice. Above average total rainfall and high range of rainfall during the eleventh week after sowing had adverse effect on yield whereas the well distributed rains during the same period were generally beneficial. Extreme rains would create problem of drainage which influences the crop growth negatively. Further, the loss of nitrogenous fertilizers applied as top dressing is also possible due to this excess rain.

The effects of climatic factors on crop growth and yield of PTB rice varieties grown in the winter season was more pronounced. Above average maximum temperature, minimum temperature and mean temperature of the week prior to sowing exerted adverse effect on yield. For the wet nursery of Mundakan crop, only organic manure is applied. Above average temperature might have had influence on the fast loss of nitrogen from the quickly decomposing tender green leaves applied as organic manure in the nursery. Depletion of the nursery plot of its nitrogen might have influenced the seedlings and their initial growth. On the contrary, above average maximum humidity during the presowing period was beneficial for crop. Above average maximum humidity during the second week after sowing also had beneficial effect on final grain yield. This is the period of break of monsoon between the south west and north east monsoons. The humidity as a result of well distributed rain during this period can naturally be beneficial.

Above average total rainfall and more number of rainy days during the third week after sowing was conducive for better yield. Being the seedling stage, the stored food in the seeds might have got exhausted. Hence a well distributed rainfall during this period could have become beneficial in the case of such season bound Mundakan varieties. During the same period, high range of rainfall had shown negative effect on yield which emphasize the importance of well distributed rainfall. More number of rainy days during the sixth week after sowing had detrimental effect on yield. This period synchronizes with the first week after transplanting. The excess water through more rainy days on one hand and the frequent rains on the other would have influenced negatively the quick seedling establishment. Lomas and Shashova (1973) also have reported that, assuming a constant average rainfall, additional rainfall prior to sowing or during the period of germination and during the initial growth stages of the wheat crop was found to be beneficial to the crop whereas additional rainfall during the middle and at the end of the growing season affected it adversely. Above average rainfall and maximum humidity during the seventh week after sowing had shown positive association with yield. This was the second week after transplanting and the period required more water for good growth and yield of the rabi crop. Above average number of hours of sunshine during the ninth week after sowing had significantly and positively related with yield whereas more number of rainy days and above average minimum humidity during the same period had shown adverse effects on yield. North east monsoon with afternoon heavy rains during ninth week could very much reduce the number of hours of sunshine, generally. Under this situation any increase in number of hours of sunshine would be beneficial for better yield. The crop has also passed the maximum tillering stage with more foliage and characteristic long leaves of these varieties with mutual shading. Hence only with bright sunshine for a larger number of hours, adequate quantity of light can be transmitted to more leaf area. This result was in agreement with the findings of Yoshida (1972). Below average maximum temperature, mean temperature and minimum temperature during the period starting from the eighth week to the twelfth week after sowing would also be beneficial for better crop yield. By this time the plant has reached a phase in between maximum tillering and panicle initiation. For the Mundakan varieties, it is the lag vegetative phase and maximum leaf area is attained during this phase. Water has started becoming limited in supply. Increase in temperatures at this stage could cause more respiratory energy loss and transpiratory water loss. The significant and negative association of wind velocity during the tenth week after sowing with rice yield could be attributed to the increased evaporation loss of water at a time when water has started becoming scarce. Above average number of hours of sunshine during the eleventh week after sowing had exerted adverse effect on yield. It might be associated with the negative effect of excess temperature through the long number of hours of bright sunshine which is influencing the plant through excessive transpiration and respiration.

The correlation analysis of climatic variables at different phases of crop growth on yield of autumn rice showed that above average maximum humidity during the nursery period and lag vegetative phase had adverse effects on yield. The nursery period coincides with the period of heavy rains due to the onset of south west monsoon which in turn results in increased humidity. Thus the adverse effect of maximum humidity may be attributed to the indirect negative effect of heavy rainfall on yield. Heavy rains would cause more pronounced growth at the initial stages which is unfavourable for better yield. Above average minimum and mean humidity during the reproductive phase was negatively related with grain yield. High humidity, particularly during the rainy season is likely to affect the plant growth by reducing the transpirational cooling of the plant. The lowering of the yield with the increase in maximum and minimum daily relative humidity may be related to this effect. This hypothesis is further supported by the fact that low humidity is one of the important agrometeorological environmental factors for maximum rice production (De Datta and Zarate, 1970). The adverse effect of above average maximum humidity except during the first two weeks of plant grouth of paddy was reported by Huda et al. (1975). Sreenivasan and Banerjee (1978) had found negative influence of above average relative humidity during the vegetative phase on rice yield. In contrast to the findings of the present study Agrawal et al. (1980) havegot beneficial effect of above average relative humidity during initial growth, lag vegetative and reproductive phases of the crop on rice yield. It was evident from the results that heavy rainfall and high range of rainfall during reproductive phase of the crop were not conducive for better yield. The findings of Tomar (1975) and Huda <u>et al</u>. (1975) also are in confirmity with this result. Above average total rainfall would affect the rate of pollination and fertilization at the time of flowering. Also higher rainfall would reduce the sunshine hours which would affect the rate of photosynthesis.

The correlation analysis of weather variables at different phases of crop growth with the yields of varieties tried in winter season showed that above average maximum temperature through out the crop growing season, had exerted adverse effects on yield. Above average mean temperature except in the nursery period also had negative effect on crop yield. The above average minimum temperature during the active vegetative phase and ripening phase showed significant negative association with yield. Thus in general a reduction in maximum temperature was beneficial for the crop. The minimum temperature available at Pattambi during this crop growing season except during the active vegetative and ripening phases could be considered as optimum for rice growth. The significant negative correlation of high temperatures could be attributed to the adverse effect of transpiratory water loss and respiratory energy loss.

During this season any factor which cause moisture stress would reduce the crop yield. The low night temperature at the later phases influences the panicle number by preventing death of panicle initiated tillers. The high dry matter production at harvest is also favoured by cool nights preventing excessive respiration and conserving maximum photosynthesis. Moreover, the low temperature during the ripening period prolongs the ripening phase which in turn increases the amount of solar energy received by the crop resulting in a high grain yield. Sreedharan (1975) and Nel and Small (1969) also have reported similar results, while De Datta and Zarate (1969) observed a significant and positive correlation between temperature during the ripening period and rice yield. Above average maximum humidity during nursery period and vegetative period had beneficial effect on yield. Moisture availability would solve the problem of water loss through evapotranspiration from the plant. Above average total rainfall during the lag vegetative phase and more number of rainy days during the reproductive phase were conducive for better yield. As the crop reaches the lag vegetative and reproductive phases in the winter season the problem of water scarcity is arising and thus above average total rainfall and number of rainy days during these phases would have great beneficial effects on yield. On the contrary bright hours of sunshine which is above average during the lag vegetative phase seemed to have negative relationship with yield. This may be attributed to the association of this meteorological parameter with temperature which influences plants through excessive transpiration and respiration. Heavy wind along with high temperature during the vegetative phases of crop growth would result in increased evapotranspiration which had unfavourable effect on rice yield. Tullis (1934) has reported that high temperature accompanied by increased wind velocity on clear bright days would cause scald of paddy.

The results of the fortnightly yield prediction of the varieties tried in the autumn season using the weekly weather variables showed that the maximum precision for the yield prediction equations was obtained in the fifth fortnight after sowing. There after the improvement in accuracy for the prediction equations were not substantial. The forecasting equations in the fifth fortnight after sowing, given by (4.2), (4.3) and (4.4) making use of the weather variables viz., number of rainy days, total rainfall, rainfall range and number of hours of sunshine of the pertinent periods of crop growth could explain about 94%, 78% and 90% of the total variation in the yield of PTB 1, PTB 5 and aggregate data respectively. An earlier forecast in the third fortnight after sowing with sufficient degree of precision was also possible. The realised maximum precision of the prediction equations in the third fortnight for PTB 1, PTB 5 and aggregate data were 82%, 67% and 77% respectively. Further, among the different variables, number of rainy days during the third and fifth weeks after sowing, rainfall range during the fourth week after sowing and total rainfall during the eighth week after sowing were decisive in making yield forecast of the varieties tried in the autumn season. Under heavy rainfall condition it seems that every additional amount of rainfall especially during critical periods may be detrimental to the crop. It is for this reason that partial regression coefficient of yield on rainfall in most of the weeks turned to be negative. Jahagirdar and Thote (1983) have reported that total rainfall during Kharif season had diminished the yield of rice. It was also found that PTB 1 was more sensitive to climatic changes than PTB 5.

The prediction equations developed in the present study are more efficient than most of the earlier prediction equations developed by other workers. One of the reasons for low predictability (about 72%) for the regression equation obtained by Sreenivasan (1968) at Pattambi is that he had not taken into account the importance of rainfall range and number of rainy days in building up prediction models.

Now it is an established fact that rice yield is governed not only by the amount of rainfall but also its distribution over the seasons. The prediction equation developed by Sreenivasan and Banerjee (1978) for yield forecast of rice at Aduthurai had a predictability of 65 per cent. This prediction equation involved only two climatological variables viz., number of hours of sunshine and maximum temperature during critical periods of plant growth. Rao (1980) used maximum daily temperature and rainfall averaged for 20 weekly periods during the crop growing seasons as explanatory variables for the prediction equation which could explain about 87% of the variation in yield of tossa jute. Daigo (1943) estimated that about 65% of the yearly deviation in rice yield was attributable to the deviation of air temperature. Das <u>et</u> <u>al</u>. (1971) made use of the monthly weather variables viz., total rainfall, number of rainy days, maximum temperature and occurrence of drought and flood during the crop growing period for predicting the yield of rice. The prediction equation including trend could explain only 90% of the variation in rice yield at coastal Mysore. But when Shrikande and Chaudry (1965) used multiple linear regression analysis with amount of rainfall, number of rainy days and sunshine hours as explanatory variables, they could develop equations with high accuracy (unadjusted R^2 in the range of 83-98%) for predicting rice yield.

On examining the yield prediction equations using weekly weather variables for the varieties tried in the winter season it was evident that the precision of prediction equations is more in the case of PTB 20 when compared to that of PTB 12. In the case of PTB 20 and aggregate yield data, forecasts with sufficiently high degree of precision (81% and 77% respectively for PTB 20 and aggregate data) could be had in the fourth fortnight itself. The equation (4.7) could be used for the yield prediction of PTB 20. The weather variables used as regressors in the regression equation were maximum and minimum temperatures, total rainfall, rainfall range, number of rainy days and maximum humidity of the critical periods of crop growth. The maximum precision (79%) for the yield prediction of PTB 12 could be achieved by the use of the prediction equation (4.9) in the sixth fortnight after sowing and the weather variables viz., minimum humidity and number of hours of sunshine in addition to the above mentioned variables were used.

In contrary to autumn crops, yield of paddy in the winter season was dependent on other limiting factors such as temperature, humidity, number of hours of sunshine in addition to rainfall and number of rainy days. The effect of these variables were more pronounced at later stages of crop growth and the prediction equation involving these variables resulted in high degree of predictability. As in the case of autumn crops, third week after sowing was adjudged to be a critical period for rainfall and number of rainy days for winter crops also. Increase in rainfall during this period would cause a drastic increase in yield whereas frequent occurrence of rainy days at the time of transplanting and during the lag vegetative phase was found to be harmful for the crop. Below average maximum temperature and mean temperature during the tenth week after sowing were found to be beneficial for better crop yield in both seasons. But above average bright hours of sunshine during the eleventh week after sowing had adverse effect on yield.

The crop growth and yield is not only affected by the individual effect of weather factors of the crop growing period but also by the interaction effect of each of these factors during the period. Further, in addition to their effect during a specific period their cumulative effects or carry over effects from previous periods are also equally important. These cumulative effects have to be measured from one week before sowing to the particular stage of crop development. To accomplish these aims, generated variables or weather indices were constructed under two types of models. The correlation analysis of these generated variables under the two models with crop yield showed that the variables under model 2 were more strongly correlated with rice yield. This result was in confirmity with the findings of Agrawal et al. (1980). Eventhough the prediction equations using the generated variables could not improve the value of $\bar{R}^2$ from that of the ordinary regression models using weekly weather variables, earlier prediction with sufficiently high degree of precision was possible. Also efficient prediction equations with less number of generated variables as predictors could be evolved.

As it was seen from the regression analysis using weekly weather variables as predictors, the yield prediction of PTB 1 was more reliable than that of PTB 5 in the autumn season and in the winter season the accuracy of prediction of PTB 20 was more than that of PTB 12.

On examining the prediction equations developed using the generated variables under the two models, it was evident that model 2 was superior to model 1 and could be used conveniently for yield prediction of medium duration varieties of paddy. The gain in precision of the prediction equations under model 2 over those under model 1 using the generated variables of the particular fortnight of prediction was in the range of 28 to 40% for the varieties tried in the two seasons. Among the yield prediction equations developed for the different varieties, the prediction equation for PTB 1 under model 2 had the maximum gain in precision. It was also found that the accuracy of the prediction equations under model 1 could be greatly improved by incorporating the supplementary information on the generated variables of the previous fortnights of prediction in addition to those of the particular fortnight of prediction. Under this model an yield forecast with maximum precision ($\bar{R}^2 = 0.73$) was obtained for PTB 1 in the fourth fortnight after sowing. In the case of model 2 the yield prediction equations developed on the basis of the generated variables of the previous fortnight of prediction in addition to those of the particular fortnight had not shown any substantial improvement in efficiency over those based entirely on the generated variables of the particular fortnight of prediction alone. But the process led to a set of highly efficient prediction models with lesser number of parameters.

In the autumn season the optimum time of yield forecast by making use of the generated variables was found to be the fourth fortnight after sowing. The relevant equations (4.14) with a precision of 88% and (4.15) with a precision of 78% could be used for forecasting the yield of PTB 1 and that of PTB 5 respectively. Further, a forecasting equation developed for PTB 5 in the first fortnight after sowing had a moderate accuracy of 69%. In the winter season also the optimum time of yield prediction ($\bar{R}^2 = 69\%$) of PTB 12 turned out to be the fourth fortnight after sowing and the equation (4.18) could be used for the prediction purpose. However an equally efficient forecasting equation ($\bar{R}^2 = 0.687$), but with larger number of generated variables could be developed as early as in the first fortnight after sowing of PTB 12. This can also be used for getting an early forecast of the crop yield. The sixth fortnight after sowing was adjudged to be an ideal time for making yield forecast of PTB 20 in the winter season and the relavant equation (4.19) could be used for getting a fairly accurate estimate of production ($\bar{R}^2 = 88\%$). The study also revealed the importance of interaction components in defining yield prediction equations on paddy, especially those including relative humidity and number of hours of sunshine.

The results of the regression of yield on generated variables indicated that the value of the coefficient of determination obtained for the prediction equations under the two models in the present study were significantly higher than that recorded by Agrawal et al. (1980). According to them the coefficient of determination was of the order 0.6037 under model 1 and 0.7112 under model 2.

They have also reported that the optimum time of yield prediction of paddy is in the eleventh week after sowing. In the present study forecasting equations with sufficient degree of precision could be developed in the fourth fortnight (eighth week) after sowing itself for all the varieties except for PTB 20 in the winter season. The results are indirectly in agreement with the findings of Agrawal et al. (1980) in the sense that reliable predictions could be made at about 2½ months before final harvest.

The results of the principal component analysis using generated variables of the varieties tried in the two seasons indicated that in the case of PTB 1, out of the nine components the first four were able to explain about 86% of the total variability in the original data. In the case of PTB 5 the first component alone had explained about 63% of the total variability. For PTB 12 the first two components had succeeded in explaining 88% of the total variation and in the case of PTB 20, the first two components were able to explain about 80% of the total variability. Pochop et al. (1975) used daily maximum and minimum temperatures and total rainfall of the crop growing period of wheat for the principal component analysis. Out of 42 components, 31 components were used by them to account 90% of the variability in the original data.

Eventhough the percentage variation in the original data explained by the principal components in the present study was lower than that reported by Pochop _et al_. (1975) the structural description of the data complex could be achieved in the present case with a few components alone.

Mansfield _et al_. (1977) suggested that if the only components deleted are those with small variance then there was very little loss of predictiveness in the regression. While Jeffers (1967) specifically stated that relations between the dependent variable and all of the components should be examined since it is always possible that one of the components with small variance may be related to the dependent variable. In the present study regression equation were fitted using all the principal components as well as using those components which had greater variance. The values of $\bar{R}^2$ for most of the prediction equations fitted using the method of principal components were not found to have any improvement from that of the original equations obtained though usual regression analysis. However for PTB 20 in the winter season regression of yield on principal components had resulted in better prediction equations. In the case of PTB 1 in the autumn season nine components could explain about 90% of the variation in yield. For PTB 5 77% of the variation in yield was explained by five components.

In the case of PTB 12 the value of $\bar{R}^2$ for the forecasting equation using five components was 66%. As indicated above relatively high degree of precision ($\bar{R}^2$=96%) was obtained for the prediction equation of PTB 20, using nine components. The regression equations formed through the components of larger variance also had succeeded in explaining sufficient amount of variation in yield. It was also found that when all the principal components were used as predictor variables, the resulting partial regression coefficients failed to be statistically significant. This may be attributed to the fact that when all the components are used the ordinary least square solution of regression is exactly reproduced. If the characteristic root of any of the principal components is approximately equal to zero the linear function defining that component becomes zero and it acts as the source of multicollinearity in the data. It was also found that the regression coefficients of the components become significant as some components were deleted from the regression analysis. However the accuracy of forecasting models obtained through principal components was higher than that was reported by Agrawal _et_ _al_. (1980) except in the case of PTB 12 in the winter season. According to these authors two principal components obtained through five generated variables could explain about 80% variation in yield. Pochop _et_ _al_. (1975) also had regressed yield on principal components and the equation could explain only 54% of the variation in wheat yield which is considerably lower than that in the present study.

The weekly weather indices P/T, P.T and H.S where P is the total precipitation, T is the mean temperature, H is the mean relative humidity and S is the average number of hours of sunshine were calculated for the two seasons of study. The correlation analysis of the weekly weather indices with rice yield showed that the indices P/T and PT were not much different with regard to the value of the correlation coefficients in both the seasons. Further, yield prediction equations were developed using the weather indices P.T and H.S as explanatory variables. However, in the autumn season a prediction equation of sufficient degree of precision could not be evolved. In the winter season a maximum precision of 59%, 56% and 58% was obtained for the prediction equations for PTB 12, PTB 20 and aggregate data respectively by making use of the indices viz., PT of the third week after sowing, HS of the eleventh week after sowing and PT of the twelfth week after sowing. Another index proposed by Bean (1964) which is given by W = R + T (80-T) is also used in the present study for correlation and regression analysis. From the selected regression equations it could be followed that about 57%, 67% and 64% of the total variation in yield could be explained by regression equations for PTB1, PTB 5 and aggregate data respectively in the autumn season where as in the case of PTB12, PTB 20 and aggregate yield in the winter season about 53%, 52% and 56% of the variation in yield could be explained by means of Bean's weather indices. Thus the joint effect of individual weather variables could be estimated by constructing weather indices and the yield prediction using these weather indices especially using Bean's weather indices would result in sufficiently high degree of precision for the estimates.

The results of the present study also indicated that the yield of PTB varieties tried in the two seasons was not significantly influenced by slight changes in the time of sowing of the crop. Palaniswamy _et al._ (1968) also didn't find any significant effect due to time of sowing on rice yield components except in the number of grains per panicle.

SUMMARY

SUMMARY

A study on forecasting of rice yield well ahead of harvest, using climatological variables was undertaken based on the data related to the co-ordinated crop weather experiments conducted at the Rice Research Station, Pattambi for the period 1949-50 to 1973-74. Meteorological observations on various climatic variables such as total rainfall (mm), number of rainy days, maximum temperature (°C) minimum temperature (°C), maximum humidity (%), minimum humidity (%) total hours of sunshine (h) and wind velocity (km/h) were gathered in addition to the seasonal yield data of four medium duration varieties of paddy viz., PTB 1, PTB 5, PTB 12 and PTB 20. Of these PTB 1 and PTB 5 were tried in the autumn season whereas PTB 12 and PTB 20 had their turn in the winter season. The varieties were grown as rainfed following more or less uniform cultural or managemental practices during the entire experimental period. Linear regression models were developed to get advanced estimates of production on the basis of weekly climatological variables. In addition to simple models, composite regression models involving groups of generated variables and the principal components of these generated variables were also developed through stepwise regression process and their efficiencies compared.

Correlation and multiple regression analysis of the weekly weather factors with yield indicated the major weather factors which governed rice yield. Among the different climatological variables in the autumn season rainfall was found to be the most important factor affecting rice yield. In general isolated spells of heavy rain was detrimental to the crop while uniformily distributed rains especially at the early periods of crop growth was beneficial. Above average maximum temperature during the ninth and tenth weeks after sowing was found to have adverse effect on yield. In the winter season above average temperature and above average relative humidity of the presowing period and those during the subsequent periods of crop growth had shown significant impact on rice yield. In addition to these variables average rainfall during the third week after sowing and above average solar radiation during the ninth week after sowing also had significant positive effect on rice yield. The correlation analysis of the weather variables at different growth phases of the plant viz., nursery, vegetative phase, reproductive phase and ripening phase with yield revealed that above average relative humidity during the nursery, lag vegetative and reproductive phases of the crop growth had adverse effects on yield in autumn season. While during the winter season above average maximum humidity upto the end of vegetative phase of the crop had beneficial effects on yield. Above average rainfall during the reproductive phase of crop growth had significant negative effect on yield in the autumn season where as it had positive effect on yield during the winter season. Above average maximum temperature throughout the crop growing period had shown adverse effects on winter rice yield.

The multiple linear regression analysis of crop yield on weekly weather variables resulted in high degree of predictability. In the autumn season, the maximum precision for the forecasting equations was obtained in the fifth fortnight after sowing. The prediction equation developed included nine independent variables viz., total rainfall during the fifth (X_{12}) and eighth (X_{17}) weeks after sowing, rainfall range during the fourth (X_{10}) and eighth (X_{18}) weeks after sowing, number of rainy days during the third (X_9), fifth (X_{13}) and seventh weeks (X_{15}) after sowing and number of hours of sunshine during the first (X_5) and ninth (X_{21}) weeks after sowing. Using these variables the realised precision for the yield forecast of PTB 1, PTB 5 and aggregate data were 94%, 78% and 90% respectively. An earlier yield forecast in the third fortnight after sowing itself was possible by making use of five explanatory variables viz., X_5, X_9, X_{10}, X_{12} and X_{13}. The relevant forecasting equations for PTB 1, PTB 5 and aggregate data had explained about 82%, 67% and 77% variability in crop yield respectively. In the winter season yield forecast of PTB 20 ($\bar{R}^2 = 81\%$) and aggregate data ($\bar{R}^2 = 77\%$) could be made with moderate degree of precision in the fourth fortnight after sowing. The five important weather factors used for the prediction purpose were maximum temperature during one week before sowing (X_1), total rainfall during the third week after sowing (X_7), rainfall range during the third week after sowing (X_8), number of rainy days during the sixth week after sowing (X_{14}), maximum humidity during the seventh week after sowing (X_{16}) and minimum temperature during the eighth week after sowing (X_{19}). A maximum precision of 79% could be obtained for the yield forecast of PTB 12 in the sixth fortnight after sowing. The six independent variables used were maximum temperature during one week before sowing (X_1), number of rainy days during the sixth week after sowing (X_{14}), maximum humidity during the seventh (X_{16}) and tenth (X_{23}) weeks after sowing, minimum humidity during the ninth week after sowing (X_{22}) and number of hours of sunshine during the eleventh week after sowing (X_{25}).

Composite regression models for the crop yield forecast also had resulted in high degree of predictability. In the first regression model, weighted averages of weekly weather variables and their interactions using powers of week number as weights were used. The respective simple correlation coefficients of weather factors with yield in place of week numbers were taken as weights in the second model. Prediction equations were developed using generated variables computed for the specific fortnights of prediction as well as using generated variables of the previous fortnights of prediction in addition to those of the particular fortnight of prediction. The generated variables under model 2 were superior to those under model 1 for prediction purposes. The generated variables of the particular fortnight of prediction were sufficient to evolve yield forecasting equations with moderate degree of accuracy. And yield forecast with less number of independent variables could be had by incorporating the supplementary information of the generated variables of the previous fortnights in addition to those of the particular fortnight of prediction. Earlier forecasts even in the first fortnight after sowing itself with sufficient degree of precision was possible by the use of generated variables. The optimum time of yield prediction of PTB varieties in the autumn season was found to be the fourth fortnight after sowing. The precision of the relevant prediction equation for PTB 1 and PTB 5 were 88% and 78% respectively. In the winter season also the optimum time of yield prediction of PTB 12 was found to be the fourth fortnight after sowing ($\bar{R}^2$ = 69%). Sixth fortnight after sowing was adjudged to be the ideal time for the yield forecast of PTB 20 ($\bar{R}^2$ = 88%). The study also revealed the importance of interaction components especially those including relative humidity and number of hours sunshine in defining yield prediction equations on paddy. Principal components of the important generated variables under model 2 were also used as independent variables for the yield prediction. But the resulted prediction equations failed to attain higher values of R^2 than those obtained from the other regression equations mentioned earlier except in the case of PTB 20 in the winter season. It was also evident from the results that among the four varieties, PTB 1 and PTB 20 were more sensitive to climatic changes when compared to the other varieties.

Yield forecasting could also be made with moderate degree of accuracy using weekly weather indices as explanatory variables. Two simple indices 'P.T' and 'H.S' where P is the total precipitation, T is the average mean temperature, H is the average mean relative humidity and S is the average number of hours of sunshine were used. The results were also compared with the regression equations obtained using Bean's weather indices for weekly intervals. It was found that Bean's weather index was more efficient than the other indices and could be used for forecasting yield in the sixth fortnight after sowing with a maximum precision of as much as 67% and 56% in the autumn and winter seasons respectively.

Attempts were also made to study the impact of time of sowing on the yield of medium duration PTB varieties. Results of analysis had not indicated any significant demarcation between years of early sowing and years of late sowing with regard to their impact on productivity.
It appears that rice yield in both the seasons was not seriously affected by slight fluctuations in the date of sowing.

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APPENDIX

Appendix-1 (a) Additional set of yield prediction equations involving generated variables under model 1 for PTB 1 in the autumn season

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2454.04 - \underset{(4.19)}{12.54}Q_{2401}^{**}$	0.284
2	$Y = 319.87 - \underset{(5.08)}{11.48}Q_{2401}^{*} + \underset{(19.00)}{37.34}Q_{2313} - \underset{(14.04)}{23.87}Q_{2323}$	0.352
3	$Y = 652.53 - \underset{(4.10)}{4.70}Q_{2401} - \underset{(0.05)}{0.20}Q_{1324}^{**} + \underset{(5.83)}{14.97}Q_{2313}^{*}$	0.595
4	$Y = -521.56 - \underset{(0.25)}{0.94}Q_{1324}^{**} + \underset{(3.80)}{19.25}Q_{2313}^{**} + \underset{(0.27)}{0.80}Q_{1314}^{**}$	0.713
5	$Y = -57.87 - \underset{(0.25)}{0.99}Q_{1324}^{**} + \underset{(4.52)}{16.75}Q_{2313}^{**} - \underset{(0.28)}{0.89}Q_{1314}^{**} - \underset{(0.06)}{0.06}Q_{1405}$	0.714
6	$Y = -69.34 - \underset{(0.25)}{0.95}Q_{1324}^{**} + \underset{(4.54)}{17.93}Q_{2313}^{**} + \underset{(0.28)}{0.82}Q_{1314}^{**} - \underset{(0.24)}{0.35}Q_{1405} + \underset{(0.25)}{0.31}Q_{1404}$	0.724

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Appendix-1 (b) Additional set of yield prediction equations involving generated variables under model-1 for PTB 5 in the autumn season

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2131.87 - \underset{(15.29)}{51.33}\overset{**}{Q}_{2401} + \underset{(43.65)}{118.51}\overset{*}{Q}_{2411}$	0.419
3	$Y = 2544.46 - \underset{(16.47)}{39.24}\overset{*}{Q}_{2401} + \underset{(46.70)}{8515}Q_{2411} + \underset{(6.21)}{12.82}\overset{*}{Q}_{2313}$	0.426
4	$Y = 2544.46 - \underset{(16.47)}{39.24}\overset{*}{Q}_{2401} + \underset{(46.70)}{85.15}Q_{2411} - \underset{(0.06)}{0.09}Q_{1324}$	0.466
6	$Y = 6978.97 - \underset{(14.66)}{41.24}\overset{*}{Q}_{2401} + \underset{(40.56)}{98.79}\overset{*}{Q}_{2411} - \underset{(1.22)}{2.62}\overset{*}{Q}_{3516} + \underset{(5.81)}{5.96}Q_{2313}$	0.519
6	$Y = 3371.66 - \underset{(17.62)}{28.01}Q_{2401} + \underset{(46.65)}{67.06}Q_{2411} - \underset{(1.62)}{1.19}Q_{3516} + \underset{(6.84)}{10.88}Q_{2313} - \underset{(0.09)}{0.11}Q_{1324}$	0.539
6	$Y = 2281.82 - \underset{(17.74)}{22.85}Q_{2401} + \underset{(56.48)}{24.88}Q_{2411} - \underset{(1.62)}{0.76}Q_{3516} + \underset{(6.77)}{12.14}Q_{2313} - \underset{(0.10)}{0.19}Q_{1324} + \underset{(0.17)}{0.21}Q_{1405}$	0.557

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Appendix-2(a) Additional set of yield prediction equations involving generated variables under model 2 for PTB 1 in the autumn season

Time of forecast (no. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2484.19 - \underset{(14.09)}{41.98}Q'^{**}_{2421}$	(0.419)
2	$Y = 2501.91 - \underset{(11.93)}{27.68}Q'^{*}_{2421} + \underset{(0.14)}{0.29}Q'^{*}_{2512} - \underset{(0.98)}{1.29}Q'_{4522}$	0.542
2	$Y = 315.95 - \underset{(16.96)}{43.13}Q'^{*}_{2421} + \underset{(0.14)}{0.30}Q'^{*}_{2512} - \underset{(0.96)}{1.33}Q'_{4522} + \underset{(4.58)}{5.78}Q'_{2402}$	0.559
3	$Y = 1257.16 - \underset{(4.74)}{16.64}Q'^{**}_{2413} + \underset{(58.44)}{159.62}Z'^{*}_{213}$	0.596
3	$Y = 1546.93 - \underset{(5.79)}{10.59}Q'_{2413} + \underset{(55.87)}{166.31}Z'^{**}_{213} - \underset{(0.91)}{1.51}Q'_{4522}$	0.633
4	$Y = 2190.05 + \underset{(0.40)}{2.59}Q'^{**}_{2314} - \underset{(0.54)}{2.60}Q'^{**}_{4522}$	0.782
4	$Y = 2171.72 + \underset{(0.39)}{2.99}Q'^{**}_{2314} - \underset{(0.49)}{2.18}Q'^{**}_{4522} - \underset{(0.02)}{0.04}Q'^{*}_{1514}$	0.834
4	$Y = 2069.96 + \underset{(0.37)}{2.78}Q'^{**}_{2314} - \underset{(0.48)}{1.92}Q'^{**}_{4522} - \underset{(0.02)}{0.05}Q'^{**}_{1514} + \underset{(0.09)}{0.17}Q'_{2512}$	0.859
5	$Y = 1884.37 - \underset{(4.05)}{18.60}Q'^{**}_{2415} + \underset{(0.45)}{2.04}Q'^{**}_{2314}$	0.770
5	$Y = 2151.77 - \underset{(5.25)}{6.52}Q'_{2415} + \underset{(0.45)}{2.70}Q'^{**}_{2314} - \underset{(0.67)}{1.61}Q'^{*}_{4522} - \underset{(0.02)}{0.03}Q'_{1514}$	0.839
6	$Y = 2064.74 - \underset{(3.63)}{14.12}Q'^{**}_{2415} + \underset{(0.38)}{1.77}Q'^{**}_{2314} - \underset{(0.07)}{0.23}Q'^{**}_{1216}$	0.845

(contd..)

Appendix-2 (a) (contd..)

Time of forecast (no. of fortnights after sowing)	Regression equations	Adjusted R^2
6	$Y = 2277.72 - \underset{(4.44)}{7.35}Q'_{2415} + \underset{(0.35)}{1.97}Q'^{**}_{2314} - \underset{(0.07)}{0.21}Q'^{**}_{1216} - \underset{(0.60)}{1.35}Q'^{*}_{4522}$	0.874
6	$Y = 2260.59 - \underset{(4.43)}{5.11}Q'_{2415} + \underset{(0.39)}{2.33}Q'^{**}_{2314} - \underset{(0.07)}{0.18}Q'^{*}_{1216} - \underset{(0.57)}{1.35}Q'^{*}_{4522} - \underset{(0.01)}{0.02}Q'_{1514}$	0.887

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Appendix-2 (b) Additional set of yield prediction equations involving generated variables under model 2 for PTB 5 in the autumn season

Time of forecast (no. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2145.08 - \underset{(2.12)}{4.72}Q'^{*}_{4511}$	0.394
2	$Y = 4073.21 - \underset{(8.79)}{21.92}Q'^{*}_{2412} - \underset{(8.96)}{21.75}Z'^{*}_{512} - \underset{(0.77)}{1.29}Q'_{4522}$	0.541
2	$Y = 3918.01 - \underset{(11.55)}{31.87}Q'^{*}_{2412} - \underset{(8.99)}{19.28}Z'^{*}_{512} - \underset{(2.25)}{4.03}Q'_{4522} + \underset{(2.32)}{3.01}Q'_{4512}$	0.559
2	$Y = 4151.73 - \underset{(11.77)}{16.13}Q'_{2412} - \underset{(9.34)}{20.82}Z'^{*}_{512} + \underset{(3.52)}{3.33}Q'_{4522} + \underset{(3.24)}{8.67}Q'^{*}_{4512} - \underset{(5.98)}{14.47}Q'^{*}_{4511} + \underset{(0.04)}{0.10}Q'^{*}_{2512}$	0.661
3	$Y = 2231.99 - \underset{(2.99)}{11.43}Q'^{**}_{2413} - \underset{(0.01)}{0.02}Q'^{*}_{1513}$	0.661
3	$Y = 2148.26 - \underset{(3.01)}{11.39}Q'^{**}_{2413} - \underset{(0.01)}{0.02}Q'_{1513} + \underset{(0.03)}{0.03}Q'_{2512}$	0.606
4	$Y = 2117.25 + \underset{(1.49)}{5.82}Z'^{**}_{214} - \underset{(0.01)}{0.04}Q'^{**}_{1514}$	0.700
4	$Y = 2153.87 + \underset{(1.39)}{4.68}Z'^{**}_{214} - \underset{(0.01)}{0.03}Q'^{**}_{1514} - \underset{(2.65)}{6.65}Q'^{*}_{2413}$	0.768
6	$Y = 1769.53 - \underset{(1.18)}{4.82}Q'^{**}_{2416} + \underset{(1.46)}{5.41}Z'^{**}_{214}$	0.723

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Appendix -3(a) Additional set of yield prediction equations involving generated variables under model 1 for PTB 12 in the winter season.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 1416.25 + \underset{(15.63)}{31.91}Q^{*}_{2411}$	0.121
2	$Y = 1238.87 + \underset{(0.79)}{1.16}Q_{2302} + \underset{(20.73)}{11.51}Q_{2411}$	0.163
3	$Y = 1912.50 + \underset{(0.57)}{1.46}Q^{*}_{2302} - \underset{(14.41)}{20.41}Z_{323}$	0.171
3	$Y = 1919.31 + \underset{(0.81)}{1.15}Q_{2302} - \underset{(14.82)}{21.61}Z_{323} + \underset{(21.28)}{11.79}Q_{2411}$	0.143
4	$Y = 1487.69 - \underset{(133.94)}{99.87}Z_{314} + \underset{(1.43)}{4.52}Q^{**}_{4624} + \underset{(0.57)}{1.49}Q^{*}_{2302}$	0.480
5	$Y = 1874.34 - \underset{(141.92)}{108.30}Z_{315} + \underset{(0.52)}{1.56}Q^{**}_{2302} + \underset{(1.53)}{4.33}Q^{**}_{4624}$	0.481
5	$Y = 2003.07 - \underset{(141.44)}{115.70}Z_{315} + \underset{(0.67)}{1.09}Q_{2302} + \underset{(1.52)}{4.42}Q^{**}_{4624} + \underset{(16.34)}{17.76}Q_{2411}$	0.486
6	$Y = 7995.24 - \underset{(117.16)}{268.36}Z^{*}_{326} + \underset{(12.48)}{30.73}Q^{*}_{2411} + \underset{(1.47)}{3.27}Q^{*}_{4624}$	0.511

Figures in brackets denote the standard error of partial regression coefficients.

* Significant at 5% level

** Significant at 1% level

Appendix-3 (b) Additional set of yield prediction equations involving generated variables under model 1 for PTB 20 in the winter season.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
2	$Y = 1365.62 + \underset{(0.13)}{0.31}Z^{*}_{122}$	0.173
3	$Y = 16653.44 + \underset{(1.75)}{2.59}Z_{122} - \underset{(244.21)}{471.57}Z_{323} - \underset{(56.15)}{75.68}Z_{112} + \underset{(7.11)}{9.50}Q_{2401} - \underset{(2.03)}{1.74}Q_{1412}$	0.226
4	$Y = -3797.25 + \underset{(1.06)}{1.65}Z_{122} + \underset{(1.59)}{7.27}Q^{**}_{4624} + \underset{(15.42)}{17.46}Q^{**}_{2401} - \underset{(33.49)}{45.95}Z_{112}$	0.588
6	$Y = 5154.67 - \underset{(158.63)}{234.79}Z_{326} + \underset{(5.43)}{15.05}Q^{*}_{2401} + \underset{(1.81)}{5.39}Q^{**}_{4624} + \underset{(0.11)}{0.14}Z_{122}$	0.598
6	$Y = 7976.88 - \underset{(149.37)}{310.77}Z^{*}_{326} + \underset{(5.23)}{17.26}Q^{**}_{2401} + \underset{(1.82)}{5.08}Q^{*}_{4624}$	0.584

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Appendix-4 (a) Additional set of yield prediction equations involving generated variables under model 2 for PTB 12 in the winter sêason.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = -2152.55 + \underset{(313.94)}{900.05}Z^{\prime **}_{621} - \underset{(320.13)}{864.36}Z^{\prime *}_{611} + \underset{(9.36)}{18.73}Q^{\prime}_{2421}$	0.328
2	$Y = -667.88 + \underset{(0.37)}{1.41}Q^{\prime **}_{1412} - \underset{(102.94)}{124.77}Z^{\prime}_{322} + \underset{(426.98)}{941.98}Z^{\prime *}_{621} - \underset{(415.19)}{879.73}Z^{\prime *}_{611}$	0.570
2	$Y = -2306.54 + \underset{(0.47)}{0.87}Q^{\prime}_{1412} - \underset{(99.39)}{92.78}Z^{\prime}_{322} + \underset{(417.94)}{1121.06}Z^{\prime *}_{621} - \underset{(406.34)}{1053.39}Z^{\prime *}_{611} + \underset{(12.37)}{21.73}Q^{\prime}_{2421}$	0.613
4	$Y = 1005.91 + \underset{(5.11)}{24.17}Q^{\prime **}_{2414} + \underset{(0.17)}{0.57}Q^{\prime **}_{4614}$	0.634
4	$Y = 936.14 + \underset{(7.18)}{18.96}Q^{\prime}_{2414} + \underset{(0.17)}{0.57}Q^{\prime **}_{4614} + \underset{(10.92)}{11.29}Q^{\prime}_{2421}$	0.639

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

Appendix-4 (b) Additional set of yield prediction equations involving generated variables under model 2 for PTB 20 in the winter season.

Time of forecast (No. of fortnights after sowing)	Regression equations	Adjusted R^2
1	$Y = 2128.34 + \underset{(169.35)}{480.12}Q'^{**}_{2411} - \underset{(186.33)}{487.72}Q'^{*}_{2421}$	0.344
2	$Y = 1011.61 + \underset{(17.20)}{42.63}Q'^{*}_{2412} + \underset{(3.52)}{5.56}Z'_{112}$	0.459
2	$Y = 993.78 + \underset{(19.71)}{48.59}Q'^{*}_{2412} + \underset{(44.55)}{34.49}Z'_{112} - \underset{(1.50)}{0.98}Q'_{1312}$	0.441
3	$Y = 1386.99 + \underset{(0.35)}{1.69}Q'^{**}_{1413}$	0.501
3	$Y = 1249.05 + \underset{(0.63)}{1.27}Q'^{*}_{1413} + \underset{(23.58)}{19.33}Q'_{2412}$	0.494
4	$Y = 12127.81 + \underset{(0.36)}{1.32}Q'^{**}_{1414} - \underset{(148.09)}{338.02}Z'^{*}_{324}$	0.634
4	$Y = 12056.15 + \underset{(0.52)}{1.33}Q'^{*}_{1414} - \underset{(141.59)}{330.97}Z'^{*}_{324} + \underset{(182.36)}{328.30}Z'_{214} - \underset{(2.79)}{4.19}Q'_{2614}$	0.671
6	$Y = 11422.21 + \underset{(0.32)}{0.84}Q'^{*}_{1414} + \underset{(25.19)}{84.38}Z'^{**}_{216} - \underset{(120.63)}{317.82}Z'^{*}_{324}$	0.758
6	$Y = 12564.91 + \underset{(0.39)}{1.43}Q'^{**}_{1414} + \underset{(34.67)}{143.82}Z'^{**}_{216} - \underset{(110.09)}{349.58}Z'^{**}_{324} - \underset{(0.79)}{1.80}Q'^{*}_{2614}$	0.802

Figures in brackets denote the standard error of partial regression coefficients

* Significant at 5% level

** Significant at 1% level

FORECASTING OF RICE YIELD USING CLIMATOLOGICAL VARIABLES

By
AJITHA T. K.

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Kerala Agricultural University

Department of Statistics
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Mannuthy - Trichur

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ABSTRACT

Systematic crop and weather observations on autumn and winter paddy at Pattambi Rice Research Station, during 1949-50 to 1973-74 have been analysed in order to evaluate the effect of different climatic factors on rice yield and to develop suitable prediction models for the preharvest forecasting of rice yield with sufficient degree of precision. The varieties under observation were PTB 1 and PTB 5 in the autumn season and PTB 12 and PTB 20 in the winter season. The crop was raised as rainfed through out the entire period of investigation. The meteorological variables included in the study were total rainfall (mm), number of rainy days, maximum temperature (°C), minimum temperature (°C), maximum humidity (%), minimum humidity (%), total hours of sunshine and wind velocity (km/h).

Correlation and multiple regression analysis of crop yield with weekly climatic variables revealed that rainfall was the most important climatic factor which governed rice yield especially in the autumn season. It was the distribution of rainfall rather than its total amount that influenced rice production. Heavy rains especially in the early part of crop growth was unfavourable for yield of autumn paddy. Number of rainy days during the third week after sowing had a significant and positive

effect on the yield of paddy in both the seasons. Sufficient quantity of rainfall uniformly distributed all over the week was found to be more beneficial than isolated showers of heavy rain followed by dry spells of varying lengths. In the winter season moisture availability was the most important limiting factor for crop growth and yield. During this season any meteorological factor which directly or indirectly caused moisture stress brought about a consequent decline in crop yield. Above average maximum temperature during different stages of crop growth had adverse effects on winter rice yield while above average maximum humidity exerted significant beneficial effects on crop growth and yield during the same season.

Regression analysis of yield on weekly meteorological variables further showed that yield prediction equation with sufficient degree of accuracy could be evolved in the fifth fortnight after sowing for the autumn varieties. The $\bar{\bar{R}}^2$ values for the best prediction equations of PTB 1, PTB 5 and that for the aggregate data in the autumn season were 0.94, 0.78 and 0.90 respectively. The optimum time of yield forecast for PTB 20 in the winter season was found to be the fourth fortnight after sowing ($\bar{\bar{R}}^2 = 0.81$) and that of PTB 12 was the sixth fortnight after sowing ($\bar{\bar{R}}^2 = 0.79$).

Composite regression models were also used for predicting rice yield well ahead of harvest. Following Agrawal et al. (1980) a set of generated variables were constructed under two selected models and these were further used as explanatory variables in a multiple regression analysis for developing the forecasting equations. Results showed that model 2 with powers of correlation coefficients as weights was more efficient than model 1 involving powers of week numbers as weights. The optimum time of yield prediction of PTB varieties through generated variables in the autumn season was found to be the fourth fortnight after sowing with a realised precision of as much as 88% and 78% for the yield forecast of PTB 1 and PTB 5 respectively. In the winter season also the optimum time for the yield forecast of PTB 12 ($\bar{R}^2 = 0.69$) was found to be the fourth fortnight after sowing while the ideal time for the yield forecast of PTB 20 ($\bar{R}^2 = 0.88$) was in the sixth fortnight after sowing.

Regression analysis on the basis of generated variables led to more efficient forecasts than those based on weekly climatic variables during the early periods of crop growth. The method also emphasized the importance of considering the interaction effects of various weather factors also in developing prediction equations.

The use of principal components of the generated variables as regressors in yield prediction equations had not brought about any substantial gain in precision for the yield forecasts except that in the case of PTB 20 in the winter season. The study also revealed that PTB 1 and PTB 20 were more sensitive to climatic changes when compared to other variables. A comparison of different weather indices with regard to their power of predictability of the yield fluctuations showed that Bean's index was more efficient than others and could be used for crop forecasting with moderate accuracy.

It was also evident from the study that yield of medium duration varieties of paddy was not significantly affected by slight changes in dates of sowing.