PRE-HARVEST FORECASTING OF RICE (*Oryza sativa* L.) YIELD BASED ON WEATHER PARAMETERS IN KHEDA DISTRICT OF GUJARAT

A
THESIS
SUBMITTED TO THE

ANAND AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF SCIENCE
IN
AGRICULTURAL STATISTICS

BY
GHANSHYAMBHAI BHAGWANDAS PATEL
B.Sc., PGDCA

DEPARTMENT OF AGRICULTURAL STATISTICS
B.A. COLLEGE OF AGRICULTURE
ANAND AGRICULTURAL UNIVERSITY
ANAND-388 110 (GUJARAT)

March 7, 2005

REGISTRATION NO.: 04-4641-2000

Dr. P.R. Vaishnav
Associate Professor
Department of Agricultural Statistics
B.A. College of Agriculture
Anand Agricultural University
Anand-388 110, Gujarat

CERTIFICATE

This is to certify that the thesis entitled **"PRE-HARVEST FORECASTING OF RICE (*Oryza sativa* L.) YIELD BASED ON WEATHER PARAMETERS IN KHEDA DISTRICT OF GUJARAT"** submitted by **Shri Ghanshyambhai B. Patel** in partial fulfilment of the requirements for the degree of **Master of Science** in **Agricultural Statistics** of the Anand Agricultural University is a record of bonafide research work carried out by him under my guidance and supervision. The thesis has not previously formed the basis for the award of any degree, diploma or other similar title.

Place : Anand
Date : 07-03-2005

(P.R. Vaishnav)
Major Advisor

LIST OF TABLES

PRE-HARVEST FORECASTING OF RICE (*Oryza sativa* L.)
YIELD BASED ON WEATHER PARAMETERS
IN KHEDA DISTRICT OF GUJARAT

Name of Student **Major Advisor**

G.B. Patel ***Dr. P.R. Vaishnav***

Department of Agricultural Statistics
B.A. College of Agriculture
Anand Agricultural University
Anand -388 110

ABSTRACT

A timely and reliable forecast of yield of crop needs little emphasis for monsoon dependent country like India and where, the economy is mainly based on agricultural production. Weather is a major factor, affecting crop production in advanced agricultural systems in our country. The large variation in yield is predominantly due to weather parameters. In view of fluctuating weather effects, a timely and reliable forecast of crop yield could help in deciding the policies. Rice is an important staple food of masses in the country. The present study has been taken up to identify the nature of the effect of weather parameters and technological advancement on rice crop and thereby to suggest suitable pre-harvest forecast models for Kheda district of Gujarat state.

To estimate the effect of weather variables and technological advances, 33 years yield data from 1967-68 to 2001-02 were collected. The weekly averages of weather variables viz., bright sunshine hours, rainfall, maximum and minimum temperature and morning relative humidity from 23rd to 42nd standard meteorological week of the respective year, were considered in the study.

The week-wise and crop stage-wise approaches were used with original weather variables, whereas generated variables with week number and correlation coefficients as weight were tried. Time trend was also included as independent variables in all the approaches. To provide early forecasts different (12 to 18) weeks intervals were considered. Three sets of multiple linear regression equations consisting of 27, 28 and 29 years data for each model were tried.

The results revealed positive and significant effect of time trend in rice productivity.

The effects of all the weather variables in relation to their quantum and direction differed over the approaches. However, they were found important for prediction point of view in rice productivity. The effect of weather variables also differed within the crop stage, indicating that small interval of crop period results in higher R^2 value and thereby minimizes the error of predicting the rice yield. Week-wise approach using original weather variables was found superior over the other approaches. This approach provided suitable pre-harvest forecasting model of Kheda district, four week before expected harvest (i.e. 3rd week of September).

The selected model for pre-harvest forecast explained more than 75 per cent of total variation in rice yield. The errors of simulated forecast were below 20 per cent for the selected model.

The pre-harvest proposed forecast model is

$Y = 546.13 + 22.49\ T - 35.64\ X_1w_{31} - 85.10\ X_4w_{28} + 10.53\ X_5w_{38} + 24.49\ X_5w_{32} - 44.33\ X_1w_{27}$ ($R^2 = 75.40$ %)

ACKNOWLEDGEMENT

I express my deep sense of gratitude to my guide Dr. P.R. Vaishnav, Associate Professor, Department of Agricultural Statistics, B.A. College of Agriculture, Anand Agricultural University, Anand for his keen interest and inspiring guidance during the course of this investigation and preparation of the manuscript.

I take this opportunity to render my profound gratitude to Dr. S.K. Dixit, Professor & Head, Department of Agricultural Statistics, B.A. College of Agriculture, AAU, Anand and one of the member of my advisory committee for his learned counsel and meticulous guidance from the conception to the logical end of this arduous task.

I express my gratitude to the other members of my advisory committee Dr. B.D. Bhatt, Professor & Head, Department of Agricultural Economics, Dr. R.H. Patel, Associate Professor, Department of Agronomy, B.A. College of Agriculture, AAU, Anand for their valuable guidance and suggestions during the course of study.

I am also thankful to the Vice-Chancellor, Registrar and Director of Research and Dean, PG Studies, GAU, Sardar Krushinagar (Now AAU, Anand) for providing me an opportunity as an in-service candidate for master degree course.

My sincere gratitude is also recorded to Dr. A.M. Shekh, Principal & Dean, Faculty of Agriculture, B.A. College of Agriculture and

R.S. Parmar, Data Processor, Department of Agricultural Meteorology, BACA, AAU, Anand for providing computerized weather records.

My grateful thanks are due to Dr. J.S. Patel for providing assistance while in giving a final stage to the draft of the thesis and H.M. Bhatt, SRA, for their sincere help during the course of investigation.

It's my pleasure to express a word of thanks to Dr. N.P. Patel, Prof. L.P. Purohit, U.J. Upadhyay, P.S. Pandya, D.K. Patel, V.B. Darji, B.K. Bhatt, Prof. A. Rajrathinam and M.C. Dabhi for their ready help in time without any expectations.

My grateful thanks are due to Mr. M.M. Parekh for his sincere help in preparing thesis on computer.

I would find no words to express my heartful gratitude to my beloved late father whose love, affection and emotive blessing brought me up to this stage.

Finally, I wish to express my love and affection to my mother, wife DEVINA, daughter BROMA and son KARNISH who even in their own inconvenience and difficulties gave their full moral support and encouragement throughout the course of my study. I also extend my cordial thanks to one and all that either directly or indirectly helped in this task.

Anand
March 7, 2005 **(G. B. PATEL)**

1. INTRODUCTION

Among the various production commodities of basic importance, agricultural production is the one which subject to wide and irregular fluctuations of output.

Indian economy is mainly based on agriculture. India has made considerable progress in agriculture since independence in terms of production, productivity and area under cultivation with respect to many crops. The demand of any staple food is inelastic for long term whereas, supply of agricultural production for short term is elastic.

The importance of timely and reliable forecasts of area and yield of principal crops need not be over-emphasized for the country like India where, the economy is mainly based on agricultural production. The pre-harvest estimates of crop yields are considered mainly as an aid to conjecture the final production and therefore, sufficient attention needs be paid towards their improvement. Pre-harvest yield forecasts are of considerable help in taking policy decisions with greater confidence in matters relating to the food procurement and distribution, price policies, export-import policies and for exercising several administrative measures for storage and marketing of agricultural commodities.

There are broadly three approaches for forecasting the crop yields (Singh *et al*., 1977). They are,

(i) Forecasts based on eye observations of the growing crop.

(ii) Forecasts based on observations on weather and other input parameters.

(iii) Forecasts based on observations on biometrical characters made on the growing crop.

These approaches are complementary to one another and may be combined. The most frequently used approach is based on crop weather relationship studies in which, the historical data of crop yields and weather variables are utilized. The forecast based on such relationship is objective in nature and do not require survey.

Weather is a major factor affecting crop production in advanced agricultural systems**.** Weather is a primary determinant of agricultural production. There are many weather variables like temperature, relative humidity, wind speed, rainfall and sunshine hours that constitute the major climatic influence contributing to the growth and development of the crop directly or indirectly. The resultant response is manifested in the final yield. Other factors which are not related to weather are variation in seed, fertilizer application, cultural practices and management techniques. They are summed up as effects of technological advances. These effects are of paramount importance in the crop productivity.

Rice is a staple food of masses in India. India ranked first in area and second in production over the world (Anon., 2000a). Among the major rice growing states, Gujarat ranked 15th in area (0.58 million hectare) as well as in production (0.47 million ton) (Anon., 2000b). Kheda being the major rice growing district of middle Gujarat was selected for the present study. The area under the crop was 0.17 (million ha) with total production of 0.3 (million ton) and average productivity of 1800 kg/ha (Anon., 2000c).

Since there is no work has been reported on the pre-harvest forecasting of rice yield in Gujarat, therefore, the present study was undertaken with a view to develop appropriate model for pre-harvest forecasting of rice yield in Kheda district of Gujarat. The specific objectives of present study were,

(1) To identify the nature of the effect of weather variables and technological advancement on rice yield in Kheda district of middle Gujarat.

(2) To explore the possibility of suggesting suitable model for pre-harvest forecasting of rice yield in Kheda district of middle Gujarat.

2. REVIEW OF LITERATURE

Several studies have been carried out in the past in India and abroad on crop weather relationship using different approaches to pre-harvest forecast of crop yield. The review is divided in two parts.

2.1 METHODOLOGICAL REVIEW

2.2 APPLICATION REVIEW

2.1 METHODOLOGICAL REVIEW

The present study is concerned with the effect of weather parameters and time trend on rice yield. Hence, an attempt has been made to review the literature on the basis of effect of weather parameters on rice crop and similar type of work for other crops.

Fisher (1924), was the first person who assumed that in wheat crop, the effects of change on weather variable in successive weeks would not be an erratic change but an orderly one that follows some mathematical law. He assumed that these effects are composed of the terms of a polynomial function of time.

Hendricks and Scholl (1943), modified Fisher's technique. They divided the crop season into 'n' weekly intervals with the assumption that a second degree polynomial in week number would be sufficiently flexible to express the relationship.

Since the data for such studies extended over a long period of times, an additional variate **T** representing the year was included to make allowance for time trend. Hendricks and Scholl (1943), Stacy *et al.* (1957) and Runge (1968) have used this model to study joint effects of temperature and rainfall on crop yields.

Ranjana *et al.* (1980), developed two models for forecasting of rice yield. For convenience, weighted accumulation of weather variables was replaced by corresponding weighted averages. The models developed were,

$$Y = A_0 + \sum_{i=1}^{p}\sum_{j=0}^{2} a_{ij} Z_{ij} + \sum_{i \neq i'=1}^{p}\sum_{j=0}^{2} b_{ii'j} . Q_{ii'j} + c\,T$$

Model - I

where,

Y = crop yield (kg/ha)

T = Year number included to correct long term upward or downward trend in yield (Time trend)

$\mathbf{A_0}$ = Constant

a_{ij}, $b_{ii'j}$ and **c** are partial regression coefficients associated with each $\mathbf{Z_{ij}}$, $\mathbf{Q_{ii'j}}$, and T, respectively.

p = No. of weather variables

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

$$Z_{ij} = \sum_{w=1}^{n} w^j . X_{iw} \Big/ \sum_{w=1}^{n} w^j \quad \text{and} \quad Q_{ii'j} = \sum_{w=1}^{n} w^j . X_{iw} . X_{i'w} \Big/ \sum_{w=1}^{n} w^j$$

Where,

n = number of weeks up to the time of forecast.

w = week identification

X_{iw} = value of the i[th] weather variable in the w[th] week

Model - II

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} Z'_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=0}^{2} b_{ii'j} . Q'_{ii'j} + c\,T$$

Where,

Y = crop yield (kg/ha)

T = Year number included to correct long term upward or downward trend in yield (Time trend)

A_0 = Constant

a_{ij}, $b_{ii'j}$ and **c** are partial regression coefficients associated with each **Z'_{ij}**, **$Q'_{ii'j}$**, and T respectively. (i,i' = 1,2,….,p; and j=0,1,2)

p = No. of weather variables

Z'_{ij} and **$Q'_{ii'j}$** are generated first and second order variables defined as,

$$Z'_{ij} = \sum_{w=1}^{n} r_{iw}^j . X_{iw} \Big/ \sum_{w=1}^{n} r_{iw}^j \quad \text{and} \quad Q_{ii'j} = \sum_{w=1}^{n} r_{ii'w}^j . X_{iw} . X_{i'w} \Big/ \sum_{w=1}^{n} r_{ii'w}^j$$

Where,

n = number of weeks up to the time of forecast.

w = week identification

$\mathbf{X_{iw}}$ = value of the i^{th} weather variable in the w^{th} week ($i \neq i'=1,2, \ldots,p$ and $j=0,1,2$)

r_{iw} = correlation coefficient between yield and the i^{th} weather variable in the w^{th} week.

$r_{ii'w}$ = correlation coefficient between yield and the product of the i^{th} and i'^{th} weather variable in the w^{th} week.

This was a modified form of Model-I, where respective correlation coefficients were used as weights in place of week numbers.

2.2 APPLICATION REVIEW

Forecasting the yield of Paddy/Rice in India on the basis of weather was studied by Das (1970). He developed separate regression equation for each region. He found that rainy days from 16th September to 15th October and maximum temperature from 16th August to 15th September had significant effect on yield in West Bengal, while in Andhra Pradesh, rainy days and rainfall distribution in August and September were highly correlated with yield.

Das and Sajnani (1970), investigated critical periods on the basis of weather elements having significant influence on crop yield.

They concluded that the precipitation at different stages of growth of rice crop in Telengana region of Andhra Pradesh had significant contribution in prediction of yield.

Das and Ramachandran (1971), developed a forecasting model for bajra yield for Ahmedabad district of Gujarat state. They found that it could be possible to give final estimate of yield of bajra by third week of October.

Bhargava *et al.* (1974), studied the recurrence of rainfall deficiency in relation to rice crop in Raipur. They reported that, rainfall during July, September and the total rainfall during the crop season in the district was highly correlated with yield of paddy.

Huda *et al.* (1975), studied the contribution of climatic variables in predicting rice yield in Pantnagar. They used a second degree polynomial multiple regression equation. They reported that average weekly total rainfall is beneficial during the nursery period but weekly total rainfall more than the average has the adverse effect.

Jain *et al.* (1980), studied the effect of climatic variables on rice yield and its forecast in Raipur district, M.P. for the period from 1947 to 1971. The effect of total weekly rainfall was found beneficial throughout the crop season. The reliable forecast was possible after about two months of sowing, assuming that weather would be remaining normal thereafter.

Agrawal and Jain (1982), developed composite model for forecasting the yield of rice in Raipur district. The additional contribution of agricultural inputs over the trend was found negligible, suggesting that inclusion of trend as a variable in the model takes care of agricultural inputs and change in technology. The weather variables along with trend explained more than 70 % of the variation in yield at about 2.5 months before the harvest in comparison to weather variables alone.

Agrawal *et al*. (1983), studied the joint effects of climatic variables on rice yield at different stages of crop growth in Raipur district, M.P. Beneficial effect of above average maximum temperature on yield increased with rise in humidity during active vegetative phase while detrimental effect decreased in other phases of crop growth. The rise in humidity has small beneficial effect in general throughout the crop season. The effect increased with increase in temperature. Rise in temperature associated with high rainfall had beneficial effect during growth phase of the crop.

Huda *et al*. (1985), concluded that rainfall, mean temperature and their product for three growth stages together explained 68% yield variation in sorghum crop.

Agrawal *et al*. (1986), observed that above average maximum daily temperature had beneficial effect during ripening stage and detrimental effect during reproductive stage of the rice crop while in the initial growth, active and lag vegetative phase effects were fluctuating. The effect of increase in minimum temperature was beneficial during initial, lag vegetative and reproductive stages, detrimental during ripening stage and fluctuating during active vegetative stage. Above average relative humidity and rainfall had beneficial effect throughout the growth and detrimental effects during ripening phase of the crop in general. Effects of increase in sunshine hours were detrimental during initial growth, active vegetative and reproductive stages, fluctuating during lag vegetative and beneficial during ripening stage of the crop.

Shanker and Gupta (1987), fitted a multiple regression equation using weather variables as an independent variables and yield data as dependent variable, to forecast the yield of paddy at Chinsurah, in West Bengal, India. The weather element (rainfall) was useful for yield forecasting during establishment and vegetative phases. The actual estimated and forecasted yields agreed very well.

Khan and Chatterjee (1987), studied the influence of weather on forecasting the yield of autumn rice in West Bengal through multiple linear regression technique**.** The data of rice yield of 25 years (1958-1982) were taken as dependent variable and the data of weekly rainfall covering the growing period 18^{th} to 35^{th} standard week as the independent variables**.** Prediction model developed by selected rainfall variables was helpful in forecasting the yield of rice within a deviation of

12 per cent from actual yield. The coefficient of determination was 0.95.

The influence of weather variables on sorghum yield was studied by Vyas and Gupta (1990) in Surat district of Gujarat state. They observed that weather variables like rainfall, maximum and minimum temperature, relative humidity and duration of sunshine influenced the sorghum yield significantly.

Hoa and Singh (1993), reported that the effect of maximum temperature, minimum temperature and relative humidity was beneficial at the end of the seedling stage. During the vegetative growth stage, relative humidity and total rainfall were found beneficial, while increase in minimum temperature was found harmful. The forecasting model using weather data upto 13th week (the third week of August) was appropriate for forecasting rice yield as it explained 85 per cent variation in yield.

Pandey and Singh (1993), developed pre-harvest forecasting model for wheat at Pantnagar. The forecasting model based on week numbers as weight was found superior (R^2 = 0.87). It was possible to forecast yield in 15th week after sowing the crop i.e. February, almost two months before the harvest. The weather index based on correlation coefficient as weights was also found superior and explained more variation in the yield.

Prasad and Jain (1995), reported that reliable forecast of sorghum yield was possible one month before harvest using curvilinear method.

The influence of agroclimatic elements on the yield of rice at Raipur was studied by Singh *et al.* (1996). The data were used for the periods of 1951-1952 to 1988-1989. The crop period considered was 19 weeks (26^{th} to 44^{th} standard weeks). This period was divided into different phenological phases of rice. The bright sunshine hours, maximum and minimum temperature were negatively correlated with yield in all the phases. The yield variation explained by afternoon relative humidity was maximum, followed by those of rainfall, maximum temperature, bright sunshine hours, minimum temperature and morning relative humidity.

Rai and Chandrahas (1997), studied that relative humidity and number of rainy days were beneficial upto early growth phase whereas sunshine and maximum temperature in addition to relative humidity contributed positively towards rice yield upto the vegetative phase. At the reproductive phase, minimum temperature and rainfall have the deleterious effect on the yield of rice.

Chaurasia and Minakshi (1997), studied wheat crop yield and climatological data for the period 1961-1995. Yearly fluctuations were discussed and regression equations were developed to predict the wheat yield in the central part of Punjab state. The multiple regression equation using maximum and minimum temperature, morning and evening relative humidity, sunshine hours and wind speed resulted high coefficient of determination (R^2 = 0.88).

Rai and Chandrahas (1999), observed that temperature (maximum and minimum) and sunshine hours were effective at the growing phase whereas sunshine hours found ineffective during early growth phase. All the variables under study at active vegetative phase explained about 87% of the total variation in rice yield.

Kokate *et al*. (2000), developed a statistical model for forecasting the yield of rice in Ratnagiri district of Maharashtra for the varieties Jaya, Ratna for the period 1981-1995 and RTN-1 for the period 1986-1995. Seven ancillary characters and weather variables were considered for the study. Results revealed that, use of either plant characters or climatological parameters alone could not fulfill the requirement of prediction model for forecasting yield of rice. However, integrating plant characteristics and climatological factors together in the same model gave reliable and predictive model for forecasting yield in rice which was evident from increased R^2 values.

Pathak *et al*. (2003), studied the trends of climatic potential and on farm yields of rice and wheat in the Indo-Gangetic plains for the period 1985-1999 of nine districts. They concluded that maximum temperature had detrimental effect during reproductive stage of the crop.

They reported that rise in maximum temperature above normal was beneficial effect in general. They also reported that increase in bright sunshine was beneficial in general throughout the crop growth period.

Varmora *et al*. (2004), studied the influence of weather parameters and time trend on wheat crop of Junagadh district of Gujarat state with the objective to develop regression equation to predict the yield of wheat. The stepwise regression approach was used taking weather parameters and time trend (T) as independent variables and crop productivity as dependent variable. They observed positive and significant influence of time trend (T), total rainfall, maximum temperatures of 7th and 10th weeks and morning relative humidity of 10th week. Negative significant influence of maximum temperatures of 3rd, 5th and 9th weeks and sunshine hours of 9th week was observed on wheat yield. The R^2 value was 98%. The predicted yield showed 5.85 to 9.05 per cent deviations from observed yield of Junagadh district.

Varmora *et al*. (2004), fitted a pre-harvest forecast model for wheat yield based on weather parameters using stepwise regression technique. Models based on original weather variables with week-wise and the crop stage-wise approach and the generated variables taking week number and correlation coefficient as weight were tried. They identified the model based on generated weather variables using correlation coefficient as weight to predict the wheat yield at the end of 12th week after sowing.

3. MATERIALS AND METHODS

The present study was undertaken to explore the possibility of forecasting the yield of rice by using combined effects of weather parameters and technological advancement. Kheda being the major rice growing district of middle Gujarat was selected for the study.

3.1 SOURCE OF DATA

Considering the specific objectives of the study, rice yield data for Kheda district for the years 1967 to 2001 were extracted from Annual Season and Crop Reports, Directorate of Agriculture, Gujarat state. The complete meteorological data set of Main Rice Research Station, Nawagam was not available hence the historical weather data for the same periods of Anand station, a representative center of the Kheda district were collected from the Department of Agricultural Meteorology, Anand Agricultural University, Anand for the present study.

The records for the years 1976 and 1979 were not available and hence, were not included in the study. Weekly averaged data of weather variables *viz.,* (1) bright sunshine hours (2) maximum temperature (3) minimum temperature (4) morning relative humidity and weekly total rainfall were collected for the period of the growing season of rice in Kheda district for the years under consideration.

3.2 DELINEATION OF PHENOLOGICAL STAGES OF RICE CROP

The transplanting of rice is mainly concentrated around the second week of June in Kheda district. Hence, the data pertaining to weather parameter for the period 23rd to 42nd standard meteorological weeks were included in the present investigation.

For studying the effect of weather variables on the crop effectively, the 18 weeks of crop growth period was divided into five different phenological stages. The details on meteorological standard weeks (MSW), their corresponding periods and crop phenological stages are given in Table 3.2.1.

Table 3.2.1 : Meteorological standard weeks (MSW) and phenological stages of rice crop

Week No.	Std. week No. (MSW)	Month	Date	Crop stage description	Crop stage code
1	23	June	4-10	Seedling	S
2	24		11-17		
3	25		18-24		
4	26		25-1 July		
5	27	July	2-8	Active tillering	A
6	28		9-15		
7	29		16-22		
8	30	August	23-29	Vegetative lag	V
9	31		30-5 Aug.		
10	32		6-12		
11	33		13-19		
12	34	Sept	20-26	Flowering	F
13	35		27-2 Sept.		
14	36		3-9		
15	37		10-16		
16	38	Oct	17-23	Grain development	G
17	39		24-30		
18	40		1-7 Oct.		

Source: Book on efficient use of irrigation water; Reddi & Reddy (1995), 219-252.

3.3 METHODOLOGY

For studying the effect of important weather variables on yield of rice crop, following weather variables with time trend were considered.

Variables	Description
Y	Average rice yield of the district in kg/ha
T	Time trend, year number included to correct upward or downward trend in yield
X_1	Bright sunshine hours/day
X_2	Rainfall (mm)
X_3	Maximum temperature (ºC)
X_4	Minimum temperature (ºC)
X_5	Morning relative humidity (%)

For selecting the best regression equation among number of independent variables, the stepwise regression procedure was adopted (Draper and Smith, 1966). SPSS Computer Software was used for the analysis of the data with probability level of 0.1 to enter and 0.2 to remove the variables. Three sets of multiple linear regression equations were obtained separately for 27, 28 and 29 years data for each model. Since the variables entered in the individual model were not consistent over the models, a full regression model was fitted considering common significant variables obtained from individual stepwise regression analysis and rice yield for the subsequent years were predicted.

The various approaches employed were as under.

3.3.1 Week-wise approach using original weather variables

3.3.2 Crop stage-wise approach using original weather variables

3.3.3 Week number as weight using generated weather variables

3.3.4 Correlation coefficient as weight using generated weather variables.

3.3.1 Week-wise approach using original weather variables

In this approach, weekly averaged data of different weather variables were considered in original from for 23rd to 42nd meteorological standard weeks. With a view to have forecasts before actual harvest, different models based on 12, 14, 16 and 18 weeks crop periods were fitted. The descriptions of variables included in the model upto 18 weeks of crop period are given in Table 3.3.1.

Table 3.3.1 : Description of variables included in week-wise approach

Std. week No.	Crop week No.	Bright sunshine hours (X_{1j})	Rainfall (X_{2j})	Temperature		Relative humidity (X_{5j})
				Max. T. (X_{3j})	Min. T. (X_{4j})	
23	1	X_{101}	X_{201}	X_{301}	X_{401}	X_{501}
24	2	X_{102}	X_{202}	X_{302}	X_{402}	X_{502}
25	3	X_{103}	X_{203}	X_{303}	X_{403}	X_{503}
26	4	X_{104}	X_{204}	X_{304}	X_{404}	X_{504}
27	5	X_{105}	X_{205}	X_{305}	X_{405}	X_{505}

28	6	X_{106}	X_{206}	X_{306}	X_{406}	X_{506}
29	7	X_{107}	X_{207}	X_{307}	X_{407}	X_{507}
30	8	X_{108}	X_{208}	X_{308}	X_{408}	X_{508}
31	9	X_{109}	X_{209}	X_{309}	X_{409}	X_{509}
32	10	X_{110}	X_{210}	X_{310}	X_{410}	X_{510}
33	11	X_{111}	X_{211}	X_{311}	X_{411}	X_{511}
34	12	X_{112}	X_{212}	X_{312}	X_{412}	X_{512}
35	13	X_{113}	X_{213}	X_{313}	X_{413}	X_{513}
36	14	X_{114}	X_{214}	X_{314}	X_{414}	X_{514}
37	15	X_{115}	X_{215}	X_{315}	X_{415}	X_{515}
38	16	X_{116}	X_{216}	X_{316}	X_{416}	X_{516}
39	17	X_{117}	X_{217}	X_{317}	X_{417}	X_{517}
40	18	X_{118}	X_{218}	X_{318}	X_{418}	X_{518}

The mathematical expression of this model was,

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=1}^{w} a_{ij} X_{ij} + bT$$

Where,

Y = Average rice yield of the district (kg/ha)

A_0 = Constant

X_{ij} = Observed value of i^{th} weather variable in j^{th} week, i=1, 2,....p=5 and j=1,2,... w= 12,14,16 and 18

T = Year number included to correct the long term upward or downward trend in rice yield

a_{ij} and b are partial regression coefficients associated with each X_{ij} and time trend respectively.

3.3.2 Crop stage-wise approach using original weather variables

The eighteen weeks of crop period were divided into 5 important crop stages and average value for the respective stages were considered to fit the model. The crop stage-wise variables included in the model are given in Table 3.3.2.

Table 3.3.2 : Description of variables included in crop stage-wise approach

Std. week No.	Crop week No.	Bright sunshine hours (X_{1j})	Rainfall (X_{2j})	Temperature		Relative humidity (X_{5j})	Crop stage code
				Max. T. (X_{3j})	Min. T. (X_{4j})		
23-26	1-4	X_{11}	X_{21}	X_{31}	X_{41}	X_{51}	S
27-29	5-7	X_{12}	X_{22}	X_{32}	X_{42}	X_{52}	A
30-33	8-11	X_{13}	X_{23}	X_{33}	X_{43}	X_{53}	V
34-37	12-15	X_{14}	X_{24}	X_{34}	X_{44}	X_{54}	F
38-40	16-18	X_{15}	X_{25}	X_{35}	X_{45}	X_{55}	G

Three models were fitted considering the data upto 3rd, 4th, and 5th crop stages i.e. vegetative lag (V), flowering (F) and grain development (G) stages, respectively.

The mathematical model for the approach was

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=1}^{s} a_{ij} X_{ij} + bT$$

Where,

Y = Average rice yield of the district (kg/ha)

A_0 = Constant

X_{ij} = Observed value of i^{th} weather variable in j^{th} crop stage
i=1, 2,....p=5 and j=1,2…s=3, 4 & 5

T = Year number included to correct the long term upward or downward trend in rice yield

a_{ij} and b are partial regression coefficients associated with each X_{ij} and time trend.

3.3.3 Week number as weight using generated weather variables

Here in these approach new variables (Z_{ij}) and ($Q_{ii'j}$) were generated from original weekly averaged weather variable data (Agarwal *et al.*) as per the formula given below

$$Z_{ij} = \sum_{w=1}^{n} w^j . X_{iw} \Big/ \sum_{w=1}^{n} w^j \quad \text{and} \quad Q_{ii'j} = \sum_{w=1}^{n} w^j . X_{iw} . X_{i'w} \Big/ \sum_{w=1}^{n} w^j$$

Z_{ij} and $Q_{ii'z}$ are generated first and second order variables defined as,

Where,

n = number of weeks up to the time of forecast

w = week identification (w=1,2,… n=12, 14, 16 and 18)

X_{iw} = value of the i^{th} weather variable in the w^{th} week ($i \neq i'$ = 1,2… 5 and j=0,1,2)

The weighted averages of weekly weather variables and their interactions using powers (0, 1 and 2) of week number as a weights were used. The details of first order (Z_{ij}) and second order ($Q_{ii'j}$) generated variables included in the analysis are presented in Table 3.3.3.

Table 3.3.3 : First and second order generated variables using week number as weight

First order generated variables (Z_{ij})

Z_{ij}	Z_{1j}	Z_{2j}	Z_{3j}	Z_{4j}	Z_{5j}
Z_{i0}	Z_{10}	Z_{20}	Z_{30}	Z_{40}	Z_{50}
Z_{i1}	Z_{11}	Z_{21}	Z_{31}	Z_{41}	Z_{51}
Z_{i2}	Z_{12}	Z_{22}	Z_{32}	Z_{42}	Z_{52}

Second order generated variables ($Q_{ii'j}$)

$Q_{ii'j}$	$Q_{ii'0}$	$Q_{ii'1}$	$Q_{ii'2}$	$Q_{ii'j}$	$Q_{ii'0}$	$Q_{ii'1}$	$Q_{ii'2}$
Q_{12j}	Q_{120}	Q_{121}	Q_{122}	Q_{13j}	Q_{130}	Q_{131}	Q_{132}
Q_{14j}	Q_{140}	Q_{141}	Q_{142}	Q_{15j}	Q_{150}	Q_{151}	Q_{152}
Q_{23j}	Q_{230}	Q_{231}	Q_{232}	Q_{24j}	Q_{240}	Q_{241}	Q_{242}
Q_{25j}	Q_{250}	Q_{251}	Q_{252}	Q_{34j}	Q_{340}	Q_{341}	Q_{342}
Q_{35j}	Q_{350}	Q_{351}	Q_{352}	Q_{45j}	Q_{450}	Q_{451}	Q_{452}

Fourty five explanatory generated variables along with time trend variable were subjected to stepwise regression analysis for developing forecasting model.

The mathematical expression of the fitted model was

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} Z_{ij} + \sum_{i \neq 1'}^{p} \sum_{j=0}^{2} b_{ii'j} Q_{ii'j} + cT$$

Where,

Y	=	Average rice yield of district kg/ha
A_0	=	Constant
T	=	Year number included to correct the long term upward or downward trend in rice yield
p	=	No. of weather variables (p=1,2,...5)

a_{ij}, $b_{ii'j}$ and c are partial regression coefficients associated with each Z_{ij}, $Q_{ii'j}$, and time trend respectively (ii' = 1,2….p and j=0,1,2)

Using these variables, forecasting models were developed for 12, 14, 16, and 18 weeks crop periods to explore the possibility of early forecast before harvest.

3.3.4 Correlation coefficients as weight using generated weather variables

The correlation coefficients between rice yield and different weather variables were worked out week-wise and they were used as weight and new variables Z'_{ij} and $Q'_{ii'j}$ (taking interaction of variables) were generated (Agarwal *et al.*) using following formula

$$Z'_{ij} = \sum_{w=1}^{n} r^{j}_{iw}.X_{iw} \Big/ \sum_{w=1}^{n} r^{j}_{iw} \quad \text{and} \quad Q'_{ii'j} = \sum_{w=1}^{n} r^{j}_{i'iw}.X_{iw}.X_{i'w} \Big/ \sum_{w=1}^{n} r^{j}_{ii'w}$$

Z'_{ij} and $Q'_{ii'z}$ are generated first and second order variables defined as,

Where,

n	=	number of weeks up to the time of forecast
w	=	week identification (w=1,2,… n=12, 14, 16 and 18)
X_{iw}	=	value of the i^{th} weather variable in the w^{th} week ($i \neq i'$ = 1,2… p and j=0,1,2)
r_{iw}	=	correlation coefficient of yield with the i^{th} weather variable in the w^{th} week
$r_{ii'w}$	=	correlation coefficient of yield with the product of the i^{th} and i'^{th} weather variable in the w^{th} week.

The details of first order (Z'_{ij}) and second order ($Q'_{ii'j}$) generated variables obtained from this way and included in analysis are given in Table 3.3.4.

Table 3.3.4 : First and second order generated variables using correlation coefficients as weight

First order generated variables (Z'_{ij})

Z'_{ij}	Z'_{1j}	Z'_{2j}	Z'_{3j}	Z'_{4j}	Z'_{5j}
Z'_{i0}	Z'_{10}	Z'_{20}	Z'_{30}	Z'_{40}	Z'_{50}
Z'_{i1}	Z'_{11}	Z'_{21}	Z'_{31}	Z'_{41}	Z'_{51}
Z'_{i2}	Z'_{12}	Z'_{22}	Z'_{32}	Z'_{42}	Z'_{52}

Second order generated variables ($Q'_{ii'j}$)

$Q'_{ii'j}$	$Q'_{ii'0}$	$Q'_{ii'1}$	$Q'_{ii'2}$	$Q'_{ii'j}$	$Q'_{ii'0}$	$Q'_{ii'1}$	$Q'_{ii'2}$
Q'_{12j}	Q'_{120}	Q'_{121}	Q'_{122}	Q'_{13j}	Q'_{130}	Q'_{131}	Q'_{132}
Q'_{14j}	Q'_{140}	Q'_{141}	Q'_{142}	Q'_{15j}	Q'_{150}	Q'_{151}	Q'_{152}
Q'_{23j}	Q'_{230}	Q'_{231}	Q'_{232}	Q'_{24j}	Q'_{240}	Q'_{241}	Q'_{242}
Q'_{25j}	Q'_{250}	Q'_{251}	Q'_{252}	Q'_{34j}	Q'_{340}	Q'_{341}	Q'_{342}
Q'_{35j}	Q'_{350}	Q'_{351}	Q'_{352}	Q'_{45j}	Q'_{450}	Q'_{451}	Q'_{452}

In order to explore the possibility of early forecasts before 8, 6, 4 and 2 weeks of harvest of rice crop, four models were fitted using generated weather variables for the period of 12, 14, 16 and 18 weeks crop periods.

Fourty six explanatory variables comprising of 15 first order generated variables (Z'_{ij}), 30 second order generated variables ($Q'_{ii'j}$) along with time trend variable (T) were subjected to stepwise regression analysis using following model.

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} Z'_{ij} + \sum_{i\neq 1'}^{p} \sum_{j=0}^{2} b_{ii'j} Q'_{ii'j} + cT$$

Where,

Y	=	Average rice yield of the district kg/ha
A_0	=	Constant a_{ij}, $b_{ii'j}$ and c are partial regression coefficients associated with each Z'_{ij}, $Q'_{ii'j}$ and time trend respectively. ($i \neq i'$ = 1,2…p and j = 0,1,2)
T	=	Year number included to correct for the long term upward or downward trend in rice yield
p	=	No. of weather variables (p=1,2,...5)

3.4 SIMULATED FORECAST

Using these fitted prediction equations, simulated forecasts were obtained for the subsequent years which were not included in the model. The per cent deviations of forecasted yields and reported yields were worked out to assess the suitability of these models as pre-harvest forecast models. Finally, the model which provided the early forecast before harvest of rice crop, accounted higher variation in rice yield with least deviation from the observed yield of the district, was considered to be the pre-harvest forecast model.

The information on different sets, number of years, their period included in the prediction model and corresponding simulated forecast periods are given in Table 3.4.

Table 3.4. : Details of the number of years included for prediction equations and the period of simulated forecasts

Set No.	The period of prediction equations		The period of simulated forecasts	
	No. of years	From …. To ….	From …. To ….	No. of years
1	27	1967-68 1995-96	1996-97 2001-02	6
2	28	1967-68 1996-97	1997-98 2001-02	5
3	29	1967-68 1997-98	1998-99 2001-02	4

4. RESULTS AND DISCUSSION

Forecast of crop yields well in advance has its own importance in policy decision regarding export and import, food procurement and distribution, price policies and for exercising several administrative measures for storage and marketing of agriculture commodities. Such forecast depends on crop weather relationship. To estimate the effect of weather variables and technological advances on production of rice of Kheda district, a major rice producing and growing district of middle Gujarat, 33 years yield data from 1967-68 to 2001-02 were collected. For assessing joint influence of weather variables, different approaches were considered. The approaches employed were.

1. Week-wise approach using original weather variables
2. Crop stage-wise approach using original weather variables
3. Week number as weight using generated weather variables
4. Correlation coefficient as weight using generated weather variables.

In order to investigate the possibility of yield forecasts before 8, 6, 4 and 2 weeks of harvest, the weather variables related to 12, 14, 16 and 18 weeks crop period were considered in the model of 1st, 3rd and 4th

approaches. In case of crop stage-wise approach weather variables were considered upto 3rd, 4th and 5th stages to provide forecasts before 9, 5 and 2 weeks of harvest, respectively. In case of each of the model the variables included were determined based on stepwise regression procedure utilizing 29 years data. Subsequently, 27, 28 and 29 years data were used for fitting separate multiple regression equations, to have the idea about the stability of the model based on coefficient of determination and standard error.

The variables included in the models corresponding to the three periods differed. Thus, a common model for all the three periods was fitted using multiple regression approach. This model included all those independent variables, which appeared in one or the other models corresponding to three periods.

Apart from this, simulated forecast of rice yield for 3 to 5 subsequent years were also made. The results for different approaches are presented and discussed in the subsequent section.

4.1 WEEK-WISE APPROACH USING ORIGINAL WEATHER VARIABLES

In this approach, original week-wise weather variables were utilized. The fitted equations, coefficients of multiple determinations and the standard errors, for four different models corresponding to 12, 14, 16 and 18 weeks crop periods are presented in Tables 4.1.A.1, 4.1.B.1 and 4.1.C.1. The corresponding simulated forecasts for the subsequent years which were not considered for fitting the models and their per cent deviations from actual district average yields are presented in Tables 4.1.A.2, 4.1.B.2 and 4.1.C.2**.**

The results related to 12 and 14 weeks crop period were same and hence presented in one table (Table 4.1.A.1). The set of explanatory variables observed to enter in the equations consisted time trend (T) and weekly weather variables viz., X_{212}, X_{209}, X_{412}, X_{406} and $X_{503.}$ These variables explained around 68.00% variation in yield of rice in all the three models. The results indicated that the partial regression coefficients for time trend (T) and rainfall of 12th week (X_{212}) were positive and significant. The effect of minimum temperature of 6th week (X_{406}) was negative and significant. The simulated forecasts of rice yield for fitted equation (Table 4.1.A.2) showed deviations from observed yield ranging from -201.47 to 24.63 per cent.

In fitted model for 16 weeks crop period (Table 4.1.B.1), the set of explanatory variables entered in the equations consisted time trend (T) and weekly weather variables viz., X_{109}, X_{406}, X_{516}, X_{510} and X_{105}. These variables explained around 75 per cent variation in yield of the rice crop. The results indicated that the partial regression coefficients for time trend (T) and morning relative humidity of 10th week (X_{510}) were positive and significant, whereas partial regression coefficients for bright sunshine hours of 5th week (X_{105}) was observed negative and significant. The simulated forecasts of rice yields for the fitted equation (Table 4.1.B.2) showed deviations from observed yields ranging between -154.97 to -18.16 per cent.

Table 4.1.A.1 : Partial regression coefficients of rice yield on trend and different original weather variables in week-wise approach (12 and 14 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	3654.74 (1743.51)	3548.16 (1720.64)	3501.99 (1702.96)
Trend	17.78** (6.50)	19.56** (6.00)	18.45** (5.77)
X_{212}	1.58* (0.67)	1.46* (0.64)	1.24* (0.57)
X_{209}	2.04 (0.96)	1.96 (0.95)	1.76 (0.90)
X_{412}	129.69 (92.68)	121.37 (91.12)	135.78 (88.26)
X_{406}	-247.83** (64.77)	-238.21** (62.90)	-250.33** (60.26)
X_{503}	6.03 (6.10)	6.73 (5.97)	7.20 (5.88)
S. E.	249.57	247.09	244.70
R^2 (%)	67.70	67.20	67.10

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.1.A.2: Simulated forecasts based on the fitted equations

Year	Observed Yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1448.18 (12.92)		
97-98	1758	1996.23 (-13.55)	2008.00 (-14.22)	
98-99	1952	2107.21 (-7.95)	2116.47 (-8.43)	2076.77 (-6.39)
99-00	2152	1621.90 (24.63)	1671.67 (22.32)	1683.87 (21.75)
00-01	652	1919.83 (-194.45)	1938.78 (-197.36)	1965.55 (-201.47)
01-02	1795	1887.80 (-5.17)	1922.14 (-7.08)	1936.69 (-7.89)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.1.B.1: Partial regression coefficients of rice yield on trend and different original weather variables in week-wise approach (16 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	278.53 (2282.67)	262.07 (2209.45)	546.13 (2006.48)
Trend	22.95** (5.86)	23.03** (5.56)	22.49** (5.23)
X_{109}	-34.41 (25.69)	-34.45 (25.06)	-35.64 (24.31)
X_{406}	-78.75 (54.63)	-78.38 (52.93)	-85.10 (48.17)
X_{516}	11.57 (11.56)	11.63 (11.24)	10.53 (10.55)
X_{510}	24.37* (10.62)	24.38* (10.36)	24.19* (10.14)
X_{105}	-46.51* (21.30)	-46.36* (20.62)	-44.33* (19.36)
S. E.	221.08	215.77	211.4
R^2 (%)	75.20	75.00	75.40

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.1.B.2: Simulated forecasts based on the fitted equations.

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1649 (0.86)		
97-98	1758	1843 (-4.84)	1846 (-5.01)	
98-99	1952	2063 (-5.66)	2065 (-5.80)	2036 (-4.33)
99-00	2152	1921 (10.73)	1924 (10.60)	1908 (11.33)
00-01	652	1661 (-154.71)	1662 (-154.97)	1652 (-153.39)
01-02	1795	2119	2121	2105

		(-18.07)	(-18.16)	(-17.27)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.1.C.1: Partial regression coefficients of rice yield on trend and different original weather variables in week-wise approach (18 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	1349.00 (1733.96)	1361.66 (1684.76)	1539.65 (1582.31)
Trend	22.30** (4.56)	22.54** (4.33)	21.99** (4.00)
X_{108}	70.77** (22.05)	70.31** (21.36)	69.45** (20.74)
X_{109}	-70.15** (22.92)	-69.76** (22.22)	-69.46** (21.68)
X_{218}	-10.11** (2.98)	-10.15** (2.89)	-10.21** (2.82)
X_{406}	-88.35* (39.71)	-86.72* (38.08)	-90.56* (35.90)
X_{414}	-106.49 (63.74)	-109.56 (60.81)	-110.87 (59.26)
X_{417}	66.58* (29.64)	66.83* (28.80)	66.95* (28.11)
X_{515}	12.46 (8.31)	12.82 (7.95)	12.69 (7.76)
X_{510}	22.85* (10.12)	22.60* (7.79)	22.20* (9.50)
X_{105}	-28.01 (15.97)	-27.34 (15.31)	-25.78 (14.42)
S. E.	159.26	154.81	151.11
R^2 (%)	89.50	89.60	89.70

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.1.C.2 : Simulated forecasts based on the fitted equations

Year	Observed Yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1617.40 (2.74)		
97-98	1758	1822.29 (-3.66)	1827.99 (-3.98)	
98-99	1952	2193.87 (-12.39)	2197.19 (-12.56)	2173.78 (-11.36)
99-00	2152	1772.78 (17.62)	1775.47 (17.50)	1761.12 (18.16)
00-01	652	1728.99 (-165.18)	1734.29 (-165.99)	1725.97 (-164.72)
01-02	1795	2045.49 (-13.95)	2046.31 (-14.00)	2028.34 (-13.00)

Figures in parenthesis are per cent deviation from observed yield.

In fitted model for 18 weeks crop period, the set of explanatory variables observed to enter in the equations consisted time trend (T) and weekly weather variables viz., X_{108}, X_{109}, X_{218}, X_{406}, X_{414}, X_{417}, X_{515}, X_{510} and X_{105}. The variation explained by these variables were around 90 %. The results (Table 4.1.C.1) indicated that the partial regression coefficients for time trend (T), bright sunshine hours of 8th week (X_{108}), minimum temperature of 17th week (X_{417}) and morning relative humidity of 10th week (X_{510}) were positive and significant, whereas partial regression coefficients for bright sunshine hours of 9th week (X_{109}) and rainfall of 18th week (X_{218}) and minimum temperature of 6th week (X_{406}) were significant and negative. The simulated forecast (Table 4.1.C.2) showed 2.74 to 18.16 per cent deviations from the actual yield. Here negative deviation relates to over estimation while positive deviation indicates under estimation.

The year 2000-01 was characterized by very low and erratic rainfall, which resulted in abnormally low productivity. Thus, this year was dropped for calculating the simulated forecast in all the subsequent approaches. While giving range of deviations absolute values are presented hereafter.

Among the equations fitted under this approach, in model of 12 and 14 weeks crop period, R^2 was low and deviations of simulated forecasts was ranging from 5.17 to 24.63 per cent. In case of 16 and 18 weeks models R^2 was reasonably high (> 75%) but the simulated forecast for the 16 weeks model deviate from 0.80 to 18.16 per cent which was less than the 18 weeks model. Thus, 16 weeks model could be considered as a pre-harvest forecast model under this approach.

4.2 CROP STAGE-WISE APPROACH USING ORIGINAL WEATHER VARIABLES

Crop stage-wise original weather variables were used in this approach and two models related to 3rd and 5th crop stages were fitted. The fitted equations, coefficients of multiple determinations and standard errors for three different models corresponding to 3rd and 5th crop stages are depicted in Tables 4.2.A.1 and 4.2.B.1, respectively. The corresponding simulated forecasts for the subsequent years, which were not considered for fitting the models and their per cent deviation from actual district average yield are presented in Tables 4.2.A.2 and 4.2.B.2.

The results (Table 4.2.A.1) related to 3rd and 4th crop stages were same and the explanatory variables entered in the models were time trend (T) and weather variables viz., X_{53}, X_{42}, and X_{43}. The variation explained by these variables ranged from 69.00 to 69.70 per cent in yield of rice. The results revealed that the partial regression coefficients for time trend (T) and morning relative humidity of vegetative lag (V) stage (X_{53}) were found positive and significant. The partial regression coefficients corresponding to the variable minimum temperature of active tillering (A) stage (X_{42}) was found negative and significant. The simulated forecasts of rice yield for the obtained regression equations (Table 4.2.A.2) showed deviation from 4.10 to 20.98 per cent from observed yield.

Table 4.2.A.1: Partial regression coefficients of rice yield on trend and different original weather variables in crop stage-wise approach (3rd & 4th stages)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	-3370.91 (3849.16)	-2993.27 (3719.10)	-3086.73 (3634.53)
Trend	13.90* (6.51)	15.18* (5.92)	15.64* (5.60)
X_{53}	61.52** (16.94)	59.87** (16.38)	60.05** (16.05)
X_{42}	-296.36** (76.41)	-282.97** (70.76)	-281.21** (69.15)
X_{43}	265.62 (14015)	242.28 (130.60)	243.34 (128.04)
S.E.	232.87	229.14	224.74
R^2 (%)	69.00	69.10	69.70

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.2.A.2 : Simulated forecasts based on the fitted equations

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1523 (8.43)		
97-98	1758	1663 (5.38)	1686 (4.10)	
98-99	1952	1700 (12.89)	1716 (12.09)	1726 (11.56)
99-00	2152	1701 (20.98)	1722 (19.96)	1732 (19.50)
01-02	1795	2015 (-12.28)	2033 (-13.28)	2043 (-13.83)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.2.B.1: Partial regression coefficients of rice yield on trend and different original weather variables in crop stage-wise approach (5th stage)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	1696.05 (2141.89)	1782.02 (2070.52)	1741.97 (2055.61)
Trend	22.04** (6.13)	21.56** (5.74)	19.58** (5.19)
X_{53}	38.74** (10.08)	38.47** (9.80)	38.14** (9.73)
X_{42}	-196.84** (58.12)	-200.06** (55.60)	-211.35** (53.55)
X_{24}	1.38 (1.15)	1.35 (1.12)	1.28 (1.11)
X_{45}	110.29* (43.92)	110.61* (42.92)	106.68* (42.37)
X_{31}	-46.00 (37.56)	-45.48 (36.67)	-32.26 (32.84)
S.E.	217.54	212.68	211.21
R^2 (%)	75.40	75.70	75.50

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.2.B.2 : Simulated forecasts based on the fitted equations

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1728 (-3.90)		
97-98	1758	1999 (-13.73)	1983 (-12.8)	
98-99	1952	1892 (3.09)	1879 (3.72)	1835 (5.99)
99-00	2152	1880 (12.64)	1869 (13.14)	1815 (15.68)
01-02	1795	2265 (-26.17)	2254 (-25.57)	2188 (-21.88)

Figures in parenthesis are per cent deviation from observed yield

The results related to 5th crop stage model (Table 4.2.B.1) indicated that the set of explanatory variables found to enter in the equations consisted time trend (T), X_{53}, X_{42}, X_{24}, X_{45} and X_{31}. These variables explained around 75.50 per cent variation in yield of the rice crop. The partial regression coefficients were positive and significant for time trend (T), morning relative humidity for vegetation lag (V) stage (X_{53}) and minimum temperature for grain development (G) stage (X_{45}) whereas, negative and significant for minimum temperature of active tillering (A) stage (X_{42}). The simulated forecast (Table 4.2.B.2) showed 3.09 to 26.17 per cent deviation from the actual yield.

Under this approach for 3rd and 4th crop stages, the models were same and explained around 69 per cent variation and simulated forecasts deviated from 4.10 to 20.98 per cent whereas 5th crop stage model explained around 75.50 per cent variation and simulated forecasts deviated from 3.09 to 26.17 per cent from actual yield. Therefore, none of the model could be considered as pre-harvest forecast model under this approach.

4.3 WEEK NUMBER AS WEIGHT USING GENERATED WEATHER VARIABLES

In this approach, generated weather variables (week number as weight) were used. The fitted equations, coefficients of multiple determination and standard errors of four different models corresponding to 12, 14, 16 and 18 weeks crop periods are presented in Tables 4.3.A.1, 4.3.B.1, 4.3.C.1 and 4.3.D.1, respectively. The corresponding simulated forecasts for the subsequent years which were not included for fitting the equations and their per cent deviations from actual district average yields are presented in Tables 4.3.A.2, 4.3.B.2, 4.3.C.2 and 4.3.D.2, respectively.

The results of 12 weeks model (Table 4.3.A.1) indicated that out of 46 generated explanatory variables, time trend (T), Q_{251}, Z_{41} and Q_{241} were entered in the equations. These variables explained 56.30 to 57.00 per cent variation in the yield of the rice crop. Only time trend (T) and linear weight of week number to minimum temperature influenced the yield of rice significantly. The simulated forecast (Table 4.3.A.2) showed 0.28 to 29.34 per cent deviations from the observed yield.

In fitted model of 14 weeks crop periods (Table 4.3.B.1), the explanatory variables observed to enter in the equation consisted time trend (T), Q_{340}, Z_{52} and Q_{352}. These variables explained 58.40 to 60.00 per cent variation in the yield of rice crop. The result indicated that the second order generated variable Q_{340} (zero weight of week number to cross product of maximum temperature and minimum temperature) and time trend (T) significantly influenced the rice yield. The simulated forecasts of the model (Table 4.3.B.2) showed 0.05 to 19.77 per cent deviations from the actual yields.

The regression equations (Table 4.3.C.1) obtained on 16 weeks model, indicated that explanatory variables entered in the equations were time trend (T), Q_{340} and Q_{352}. The variation explained by these variables ranged from 63.30 to 60.90 per cent. Time trend (T), Q_{340} and Q_{352}

significantly influenced the yield of rice. The simulated forecasts of this model (Table 4.3.C.2) showed 0.85 to 23.79 per cent deviations from the observed yields.

Table 4.3.A.1 : Partial regression coefficients of rice yield on trend and different original weather variables in week number as weight (12 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	9245.91 (3228.85)	9099.53 (3176.27)	9219.42 (3070.60)
Q_{251}	-0.41 (0.30)	-0.41 (0.30)	-0.42 (0.29)
Trend	29.33** (7.12)	27.90** (6.63)	27.53** (6.30)
Z_{41}	-337.61* (128.27)	-331.27* (126.11)	-335.71* (122.14)
Q_{241}	1.74 (1.13)	1.72 (1.11)	1.76 (1.08)
S. E.	276.09	272.33	266.90
R^2 (%)	56.50	56.30	57.00

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.3.A.2 : Simulated forecasts based on the fitted equations.

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1873.52 (-12.66)		
97-98	1758	2048.86 (-16.54)	1963.58 (-11.69)	
98-99	1952	1595.08 (18.28)	1542.41 (20.98)	1379.31 (29.34)
99-00	2152	1808.24 (15.97)	1759.65 (18.23)	1759.10 (18.26)
01-02	1795	1849.50 (-3.04)	1789.89 (0.28)	1786.76 (0.46)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.3.B.1 : Partial regression coefficients of rice yield on trend and different original weather variables in week number as weight (14 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	4533.53 (26.90.58)	4607.73 (26.30.13)	3716.64 (2577.18)
Trend	24.84** (8.13)	23.76** (7.36)	21.21** (7.20)
Q_{340}	-7.77* (2.83)	-7.93** (2.74)	-6.69* (2.61)
Z_{52}	-28.46 (38.11)	-31.65 (36.26)	-19.03 (35.46)
Q_{352}	2.02 (2.30)	2.15 (1.22)	1.70 (1.19)
S. E.	264.61	259.49	263.28
R^2 (%)	60.00	60.30	58.40

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.3.B.2 : Simulated forecasts based on the fitted equations

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1662 (0.05)		
97-98	1758	2106 (-19.77)	2101 (-19.54)	
98-99	1952	1828 (6.34)	1829 (6.31)	1758 (9.94)
99-00	2152	1794 (16.62)	1777 (17.42)	1739 (19.20)
01-02	1795	2103 (-17.18)	2088 (-16.30)	2012 (-12.11)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.3.C.1 : Partial regression coefficients of rice yield on trend and different original weather variables in week number as weight (16 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	2071.15 (1625.69)	1893.20 (1556.17)	1792.73 (1551.62)
Trend	21.95* (8.11)	20.44** (7.34)	18.53* (7.07)
Q_{340}	-5.84** (1.34)	-5.78** (1.32)	-5.52** (1.29)
Q_{352}	1.40* (0.56)	1.45* (0.54)	1.41* (5.54)
S.E.	256.48	252.3	252.11
R^2 (%)	60.70	60.90	60.30

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.3.C.2 : Simulated forecasts based on the fitted equations

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1649 (0.85)		
97-98	1758	1990 (-13.20)	1966 (-11.81)	
98-99	1952	1710 (12.38)	1690 (13.41)	1645 (15.75)
99-00	2152	1722 (19.98)	1691 (21.44)	1640 (23.79)
01-02	1795	1992 (-11.0)	1958 (-9.06)	1894 (-5.51)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.3.D.1 : Partial regression coefficients of rice yield on trend and different original weather variables in week number as weight (18 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	-382.14 (2260.52)	-543.99 (2212.63)	-560.37 (2263.29)
Trend	24.79** (7.42)	23.28** (6.88)	20.42** (6.74)
Z_{52}	46.93** (16.43)	47.67** (16.15)	44.89* (16.40)
Q_{340}	-9.19* (3.31)	-9.26** (3.26)	-7.89* (3.20)
Q_{342}	6.34* (3.05)	6.56* (2.98)	5.48 (2.96)
S.E.	252.58	249.02	254.73
R^2 (%)	63.60	63.50	61.10

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.3.D.2 : Simulated forecasts based on the fitted equations.

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1809 (-8.77)		
97-98	1758	2264 (-28.79)	2249 (-27.93)	
98-99	1952	1869 (4.27)	1856 (4.93)	1792 (8.17)
99-00	2152	1875 (12.87)	1851 (14.01)	1798 (16.44)
01-02	1795	2255	2230	2130

		(-25.64)	(-24.22)	(-18.67)

Figures in parenthesis are per cent deviation from observed yield.

The regression equations related to 18 weeks model indicated (Table 4.3.D.1) that the variables entered in fitted equations were time trend (T), Z_{52}, Q_{340} and Q_{342}. The variation explained by these variables together ranged from 61.10 to 63.60 per cent. The results further indicated that all partial regression coefficients were significant in case of all models of 27 and 28 years. The simulated forecasts (Table 4.3.D.1) obtained from this model, showed 4.27 to 28.79 per cent deviations from observed yields of the district.

Thus, it was observed from the results that the variation explained by fitted models, ranged from 56.30 to 63.60 per cent. Simulated forecasts and observed yields differed widely in most of the cases. The deviations were 0.05 to 29.34 per cent. Therefore, none of the models could be considered as pre-harvest forecast model under this approach.

4.4 CORRELATION COEFFICIENT AS WEIGHT USING GENERATED WEATHER VARIABLES

In this approach, generated variables (correlation coefficient as weight) were utilized. The fitted equations, coefficients of multiple determination and the standard errors of four different models corresponding to 12, 14, 16 and 18 weeks crop periods are presented in Tables 4.4.A.1, 4.4.B.1, 4.4.C.1 and 4.4.D.1, respectively.

Table 4.4.A.1 : Partial regression coefficients of rice yield on trend and different original weather variables in correlation coefficients as weight (12 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	9101.88 (2973.45)	9852.95 (3129.91)	11806.48 (3583.25)
Z'_{52}	-98.29* (39.91)	-103.25* (40.54)	-117.08* (47.81)
Q'_{251}	0.44* (0.18)	0.41* (0.16)	0.31 (0.17)
Trend	11.2* (5.91)	12.71* (5.44)	13.06* (5.77)
Z'_{42}	-464.49** (111.09)	-496.14** (119.52)	-580.08** (139.15)
Q'_{451}	5.64** (1.71)	5.85* (1.75)	6.51* (2.06)
Q'_{231}	-1.23* (0.55)	-1.15* (0.53)	-0.88 (0.54)
S. E.	191.33	190.24	201.09
R^2 (%)	81.00	80.50	77.80

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.4.A.2 : Simulated forecasts based on the fitted equations.

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1465 (11.90)		
97-98	1758	1817 (-3.38)	1860 (-5.78)	
98-99	1952	1655	1668	1694

		(15.24)	(14.57)	(13.23)
99-00	2152	1635	1720	1770
		(24.02)	(20.06)	(17.75)
01-02	1795	2054	2101	2040
		(-14.45)	(-17.07)	(-13.62)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.4.B.1 : Partial regression coefficients of rice yield on trend and different original weather variables in correlation coefficients as weight (14 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	286.17	416.02	295.32
	(2586.53)	(2655.22)	(2691.75)
Z'_{52}	17.14	4.02	23.71
	(29.10)	(33.02)	(32.54)
Z'_{21}	14.78	14.23	10.03
	(7.05)	(7.62)	(7.57)
Z'_{20}	14.82	12.17	-3.09
	(22.39)	(23.87)	(21.82)
Z'_{41}	-382.79**	-483.06**	-508.77**
	(127.78)	(140.31)	(146.39)
Z'_{40}	285.04	407.27*	451.09*
	(166.32)	(167.67)	(165.44)
Q'_{351}	6.62	5.50	3.18
	(3.91)	(3.55)	(3.18)
Q'_{231}	-0.62	-0.59	-0.51
	(0.40)	(0.41)	(0.41)
Trend	9.92*	10.41*	15.28*
	(8.013)	(7.33)	(7.09)
Q'_{230}	-0.42	-0.31	0.18
	(0.54)	(0.58)	(0.50)
Q'_{352}	-6.00	-4.73	-3.10
S. E.	197.35	204.86	211.73
R^2 (%)	83.80	81.70	79.80

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.4.B.2 : Simulated forecasts based on the fitted equations.

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1344		
		(19.16)		
97-98	1758	1145	1151	
		(34.88)	(34.50)	
98-99	1952	1084	1178	679

		(44.49)	(39.64)	(65.22)
99-00	2152	1355	1393	1316
		(37.02)	(35.28)	(38.85)
01-02	1795	1370	1405	1092
		(23.67)	(21.70)	(39.18)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.4.C.1 : Partial regression coefficients of rice yield on trend and different original weather variables in correlation coefficients as weight (16 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	-2498.10	-994.90	-94.06
Z'_{52}	58.78	31.31	20.09
Z'_{21}	11.13**	11.44**	12.05**
Q'_{240}	-1.02	0.32	1.68
Q'_{242}	-1.30	-1.06	-1.42
Q'_{252}	0.27	0.20	0.27
Q'_{351}	8.29	8.18*	7.20
Z'_{41}	-240.47	-374.43*	-448.17**
Q'_{230}	-0.40	-0.63	-1.67
Q'_{352}	-8.54	-7.67*	-6.22
Z'_{40}	213.71	297.71	327.57*
S. E.	182.88	190.08	196.89
R^2 (%)	86.10	84.30	82.60

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.4.C.2: Simulated forecasts based on the fitted equations.

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1139 (31.53)		
97-98	1758	1157 (34.19)	1255 (28.63)	
98-99	1952	575 (70.57)	766 (60.76)	653 (66.53)
99-00	2152	1375 (36.10)	1439 (33.12)	1457 (32.28)
01-02	1795	1281 (28.66)	1371 (23.63)	1405 (21.74)

Figures in parenthesis are per cent deviation from observed yield.

Table 4.4.D.1 : Partial regression coefficients of rice yield on trend and different original weather variables in correlation coefficients as weight (18 weeks)

Variables in the equation	Years		
	67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
Constant	888.46	5489.37	5335.35
Z'_{52}	-59.06	-21.57	42.74
Z'_{21}	15.06**	15.50**	15.98**
Q'_{120}	-2.57	-2.81*	-3.17**
Q'_{351}	10.20	12.72*	11.92*
Z'_{41}	-298.05	-295.51	-301.74
Q'_{352}	-8.69	-11.18*	-10.78*
Z'_{40}	138.18	-60.71	-55.4
Q'_{231}	-0.45*	-0.51*	-0.54*
Q'_{122}	15.57	1.83	2.19
Q'_{121}	0.37	0.47	0.51
Q'_{451}	0.39	3.50	4.42
Z'_{51}	49.89	-63.05	-134.36
S. E.	187.64	175.86	185.27
R^2 (%)	87.20	88.10	86.30

* Significant at 5 % and ** Significant at 1 % level of significance
Figures in parenthesis indicates standard error

Table 4.4.D.2 : Simulated forecasts based on the fitted equations.

Year	Observed yield (kg/ha)	Simulated forecasts (kg/ha)		
		67-68 to 95-96	67-68 to 96-97	67-68 to 97-98
96-97	1663	1021 (38.59)		
97-98	1758	1024 (41.75)	849 (51.68)	
98-99	1952	928 (52.48)	863 (55.81)	925 (52.59)
99-00	2152	1200 (44.24)	1140 (47.01)	1261 (41.38)
01-02	1795	1293 (27.96)	1223 (31.89)	1264 (29.59)

Figures in parenthesis are per cent deviation from observed yield.

The results related to 12 weeks crop period generated data (Table 4.4.A.1), the variables entered were time trend (T), Z'_{52}, Q'_{251}, Z'_{42}, Q'_{451} and Q'_{231}. The variation explained by these explanatory variables ranged from 77.80 to 81.00 per cent. The results revealed that time trend (T), Z'_{52} (Quadratic weight of correlation coefficients to morning relative humidity), Z'_{42} (Quadratic weight of correlation coefficient to minimum temperature) and Q'_{451} (linear weight of correlation coefficients to cross products of minimum temperature and morning relative humidity) significantly influenced the yield of rice for 27, 28 and 29 years model. Second order generated variables Q'_{251} and Q'_{231} were also significantly influenced the yield of rice for 27 and 28 years model whereas time trend (T) was significantly influenced the yield of rice for all the three models. The simulated forecasts for this model (Table 4.4.A.2) showed 3.38 to 24.02 per cent deviation from the actual yields.

The results related to 14, 16 and 18 weeks crop period generated data, the entered variables explained variation ranged from 79.80 to 88.10 per cent (Tables 4.4.B.1, 4.4.C.1 and 4.4.D.1). The per cent deviations from the observed yields were very high in all these models which were ranged from 19.16 to 70.57 per cent in simulated forecasts (Tables 4.4.B.2, 4.4.C.2 and 4.4.D.2).

It could be observed from the above results that in all the models R^2 ranged from 79.80 to 88.10 but simulated forecasts deviated much more from observed yields. Therefore, none of the models could be considered as pre-harvest forecast model under this approach.

4.5 GENERAL DISCUSSION

The examination of the results in the previous sections (4.1, 4.2, 4.3 and 4.4) of this chapter brings out the following points.

4.5.1 The effect of time trend (T)

The perusal of the results indicated that effect of the time trend was positive and significant on rice yield in all the approaches, except in 16 and 18 weeks models of generated variables, using correlation coefficients as weight. This suggested significance influence of the advances in rice production technology. This involved adoption of the high yielding varieties, improved agronomic practices, use of mechanized implements, control of diseases and pests, increased consumption of chemical fertilizers and other modern farming techniques. They are summed up as effect of technological advances. The quantum of influence of the time variable differed over the models fitted.

4.5.2 The effects of weather variables (X_{ij})

In order to investigate the effects of week-wise and crop stage-wise weather variables on the rice yields, the variables which appeared in the equations and had significant partial regression coefficients were considered to have influence on the rice productivity. The overall look on the results showed favourable as well as detrimental effects of weather variables on rice yields.

Generated variables did not show any improvement in the yield forecasting of rice yield in comparison to week-wise and stage-wise approaches. Hence, they were not discussed.

4.5.2.1 The bright sunshine hours

The effect of bright sunshine hours was found beneficial during 8th week (X_{108}), which corresponded to vegetative lag (V) crop stage. Rai and Chandrahas (1997) also reported similar effect of sunshine hours on rice yield. The effect was found unfavourable during 5th week (X_{105}) which corresponded to tillering crop stage. Rai and Chandrahas (1999) found similar effect of variables on the rice yield. The effect was also found unfavourable during 9th week (X_{109}), which corresponded to vegetative lag (V) stages.

4.5.2.2 The rainfall

The effect of rainfall was found beneficial during 12th week (X_{212}), which corresponded to flowering (F) stage, whereas it was detrimental in 18th week (X_{218}), which correspondence to grain development (G) stage. Agrawal *et al*. (1986) studied the models for rice crop weather relationship at Puri district of Orissa. They found that the effect of rainfall was beneficial during reproductive (flowering (F)) stage and detrimental during grain development (G) stage of the crop. Singh *et al*. (1996) also found that rainfall was favourable for the rice yield upto the initial maturity phase. Thus, the present findings are in agreement with these works. The effect of rainfall could not be observed in seedling, active tillering and vegetative lag which might be due to supplementary irrigation provided through well and canals which were not considered in the prediction models.

4.5.2.3 The maximum temperature

In the present investigation, the effect of maximum temperature was not observed in week-wise as well as stage-wise approaches on rice yield.

4.5.2.4 The minimum temperature

The positive response of minimum temperature on rice yield was observed during 17th week (X_{417}) in week-wise approach, which correspond to grain development (G) stage. Same was also observed during grain development (G) stage in crop stage-wise approach. The effect was observed detrimental during 6th week (X_{406}) which correspond to the active tillering (A) stage and also same was observed during the active tillering (A) stage in crop stage-wise approach. Findings reported by Hoa *et al.* (1993), are in agreement with the present findings. While studying the effect of weather variables on rice yield at Pantnagar at different stages, they reported that positive impact of increase in minimum temperature on rice yield during grain development (G) stage.

4.5.2.5 The morning relative humidity

The beneficial effect of the morning relative humidity was reflected during 10th week (X_{510}) in week-wise approach, which corresponded to the vegetative lag (V) stage. Jain *et al.* (1980) studied effect of climatic variables on rice yield at Raipur district of Madhya Pradesh. They reported that rise in relative humidity (at 7 hr.) above average was beneficial during tillering and early part of reproductive stage. Agrawal *et al.* (1986) also reported beneficial effects for above average relative humidity throughout the growth phase of the crop in general.

4.5.3 Evaluation of models for pre-harvest forecasting

For assessing joint influence of weather variables and suggesting suitable model for pre-harvest forecasting of rice yield, four different approaches were employed. For the selection of the pre-harvest forecast model from different approaches, the fitted regression equations which accounted more than 75 per cent of the total variation in rice yield and had lower deviation of simulated forecasts yield from the observed ones, was proposed as the pre-harvest forecast model.

For better understanding, the independent variables in case of proposed model, the subscripts of crop week numbers were replaced by corresponding meteorological standard weeks (eg. bright sunshine hours of 1st week, X_{101} could be replaced by the bright sunshine hours of 23rd meteorological standard week; X_1w_{23}).

Out of the four approaches, generated variables using (1) week number as weight and (2) correlation coefficient as weight approaches were used for fitting of the models. Agrawal *et al*. (1980) developed two models for forecasting of rice yield. They generated the variables by using (1) week number as weight and (2) correlation coefficient as weight. They found that the forecasting model based on correlation coefficient as weight was superior. However, in the present study none of the above approaches could be identified because of the high deviation of simulated forecasts from the observed yields.

For remaining two approaches which were used for fitting the models i.e. week-wise and stage-wise, models fitted with stage-wise approach could not be identified as acceptable models. Models fitted with week-wise approach, 16 and 18 weeks models were finally identified, which explained > 75% variation in productivity but the deviation of simulated forecast was observed smaller for the 16 weeks model. So out of these two models, the model (16 weeks) which provided earlier forecast (4 weeks before harvest) is preferred. Thus, the recommended pre-harvest forecast model for Kheda district of Gujarat is

$$Y = 546.13 + 22.49\,T - 35.64\,X_1w_{31} - 85.10\,X_4w_{28} + 10.53\,X_5w_{38} + 24.49\,X_5w_{32} - 44.33\,X_1w_{27} \qquad (R^2 = 75.40\ \%)$$

5. SUMMARY AND CONCLUSION

This chapter aims to briefly summarize the outcome of the investigation and conclusion drawn in the context of objectives set forth.

Indian economy is mainly based on agricultural production. In advance planning, pre-harvest forecasting of crop yield is of great importance. A reliable estimate of crop production available in advance of harvest is helpful in taking policy decisions with greater confidence in matters relating to food procurement and distribution, price policies, export-import policies and exercising several administrative measures for storage and marketing of agricultural commodities. Rice is a staple food of masses in India. Large number of weather parameters influences the rice productivity hence, an attempt was made to identify the weather factors and to suggest suitable pre-harvest forecasting models for rice crop for the Kheda district of the Gujarat state.

For achieving the objectives of the investigation, the weather data used, were, the weekly averages of bright sunshine hours, rainfall, maximum and minimum temperatures and morning relative humidity. The past weather records from 1967 to 2001 were obtained from the meteorological observatory of AAU, Anand. The data were collected only for the period of the growing season of rice. The cropping season in the district is mostly 23rd to 42nd Meteorological Standard Week. In order to provide the pre-harvest forecast of rice yield, the weather data were considered from 23rd MSW to 40th MSW in the present investigation (approximately two weeks before expected harvest). The time trend was also considered as explanatory variables in the study. The time series data of rice yields for Kheda district was obtained from Annual Season and Crop Reports and Final Forecast Reports of the respective years, published by Directorate of Agriculture, Gujarat State, Ahmedabad.

Four broad approaches were used for predicting the productivity of rice, out of which two by using original weather variables (week-wise approach and crop stage-wise approach) and two by using generated variables (week number as weight and correlation coefficients as weight). With a view to provide early rice yield forecasts, weather variables related to 12, 14, 16 and 18 weeks were considered for fitting the regression models which provide the forecast before 8, 6, 4 and 2 weeks of harvest respectively, in case of week-wise approach as well as for generated variables approach. In case of crop stage-wise approach, weather variables were considered up to 3rd, 4th and 5th stages to get forecasts 9, 5 and 2 weeks before expected harvest of rice, respectively. The stepwise regression procedure was employed to determine a set of explanatory variables, which satisfied the equation and explained maximum variation in yield. To give the idea about the stability of the model based on R^2 and standard errors, 27, 28 and 29 years data set were used for fitting separate multiple regression equations. Among the models fitted, the simulated forecasts for corresponding equations were worked out to explore the possibility of suggesting a suitable model. The fitted regression equations which accounted more than 75 per cent of the total variation in rice yield were identified. Finally, the model, which provided the early forecast, with simulated forecast errors not more than 20 per cent from the observed average yields of the district was proposed as the forecast model.

The major findings of this investigation are as under:

(1) Positive and significant effect of the time trend was observed in all the models of different approaches except two models of generated variables using correlation coefficient as weight. This suggested paramount influence of technological advancement in rice productivity.

(2) The effects of all the weather variables (eg. bright sunshine hours, rainfall, maximum and minimum temperature and morning relative humidity) in general, showed an important role in predicting the rice yield except maximum temperature which did not showed any effect in the present investigation. However, differential effects of weather variables were found in different approaches.

(3) The effect of weather variables also differed within the crop stage, suggesting thereby, smaller period than a crop stage improved the predictability of rice productivity. This was the reason that in week-wise approach the relative performance of predictability was found higher as compared to crop stage-wise approach.

(4) Over the approaches, week-wise approach using original weather variables was found superior.

(5) The pre-harvest forecast model, which accounted > 75 per cent of total variation in rice yield and one that gave the earliest forecast, having narrow deviation from the reported yields, was proposed as pre-harvest forecast model. The proposed model is

$$Y = 546.13 + 22.49\ T - 35.64\ X_1w_{31} - 85.10\ X_4w_{28} + 10.53\ X_5w_{38} + 24.49\ X_5w_{32} - 44.33\ X_1w_{27} \qquad (R^2 = 75.40\ \%)$$

REFERENCES

Agrawal, Ranjana and Jain, R.C. (1982). Composite model for forecasting rice yield. *Indian. J. Agric. Sci*., **52** (3) : 177-81.

Agrawal, Ranjana; Jain, R.C. and Jha, M.P. (1983). Joint effects of weather variables on rice yield. *Mausam*, **34** (2) : 189-194.

Agrawal, Ranjana; Jain, R.C.; Jha, M.P. (1986). Models for studying rice-crop weather relationship. *Mausam*, **37** (1) : 67-70.

Agrawal, Ranjana; Jain, R.C.; Jha, M.P. and Singh, D. (1980). Forecasting of rice yield using climatic variables. *Ind. J. Agric. Sci.,* **50**(9) : 680-84.

Anonymous (2000a). International Conference on Managing Natural Resources; Invited papers: page: 10.

Anonymous (2000b). http://agricoop.nic.in/statistics2003/chap4a.htm page: 8-20.

Anonymous (2000c). Sixth meeting of ZREAC and ZTC Report, Deputy Director of Agriculture (Extn.), Middle Gujarat Zone.

Bhargava, P.N.; Asha Pradhan and Das, M.N. (1974). A study of the recurrence of rainfall deficiency in relation to rice crop. *J.N.K.V. Res. J.*, **8** (3-4): 206-9.

Chaurasia, R. and Minakshi (1997). Wheat yield prediction using climatic parameters. *Ind. J. of Soil Conservation*, **25**(2) : 147-50.

Das, J.C. (1970). Forecasting the yield of principal crops in India on basis of weather-paddy/rice; Part 1, Punjab and Haryana, I.M.D., Sci. Rep. No. 120.

Das, J.C. and Ramachandran, G. (1971). Forecasting the yield of bajra on the basis of weather parameters of Ahmedabad district. I.M.D. Sci. Rep. No. 140.

Das, J.C. and Sajnani, P.P. (1970). Locating critical periods when weather elements have significant influence on crop yield. I.M.D. Sci. Rep. No. 130.

Draper, N.R. and Smith, H. (1966). Applied regression analysis. John Wiley & Sons, New York.

Fisher, R.A. (1924). The influence of rainfall on the yield of wheat at Rothamsted Roy. Soc. (London), Phil. Trans. Ser. B. **213** : 89-142.

Gupta, B.S.; Mathur, B.K. and Rao, J.S. (1990). Forecasting yield of pearlmillet in Jodhpur district. *Jour. Ind. Soc. Ag. Stat.*, **42** (3) : 352.

Hendricks, W.A. and Scholl, J.C. (1943). Techniques in measuring joint relationship. The joint effect of temperature and precipitation on corn yield. N.C. Staff Agri. Exp. Tech. Bull., 74.

Hoa, T.V. and Singh, J.B. (1993). Pre-harvest forecasting of rice yield at Pantnagar on the basis of weather parameters. *Jour. Ind. Soc. Ag. Stat.,* **45** (1) : 102.

Huda, A.K.S.; Ghildyal, B.P.; Tomar, V.S. and Jain, R.C. (1975). Contribution of climatic variables in predicting rice yield. *Agric. Meteorol.*, **15**(1) : 71-86.

Huda, A.K.S.; Virmani, S.M. and Sekran, J.K. (1985). Simple models for predicting sorghum grain yield using environmental factors. *Jour. Ind. Soc. Ag. Stat.,* **37**(2) : 184-91.

Jain, R.C.; Ranjna Agrawal and Jha, M.P. (1980). Effect of climatic variables on rice yield and its forecast. *Mausam*, **31** (3) : 591-96.

Khan, S.A. and Chatterjee, B.N. (1987). Crop weather analysis for forecasting the yield of autumn rice in West Bengal. *Ind. J. Agric. Sci.,* **57** (11) : 791-94.

Kokate K.D.; Sananse S.L. and Kadam J.R. (2000). Pre-harvest Forecasting of Rice Yield in Konkan Region of Maharashtra. *J. Maharashtra agric. Univ*., **25** (3) : 289 -293.

Pandey, A.K. and Singh, J.B. (1993). Pre-harvest forecasting of wheat in Tarai Region of U.P. on the basis of weather variables. *Jour. Ind. Soc. Ag. Stat.*, **45**(1) : 100.

Pathak, H.; Ladha, J.K.; Aggarwal, P.K.; Pengs, S.; Das, S.; Singh, Y.; Singh, B.; Kamra, S.K.; Mishra, B.; Sastri, A.S.R.A.S.; Aggarwal, H.P.; Das, D.K. and Gupta, R.K. (2003). Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic plains. *Field Crops Res.,* **80**(3) : 223-234.

Prasad, Rajendra and Jain, R.C. (1995). Yield forecast using curvilinear study of yield and Bio-metrical characters. *Jour. Ind. Soc. Ag. Stat.,* **47**(3) : 253-261.

Rai, T. and Chandrahas (1997). Composite weather index for the forecast of rice yield. *Jour. Ind. Soc. Ag. Stat.,* **50** (3) : 328.

Rai, T. and Chandrahas (1999). Forecasting of rice yield using linear discriminate score of weather parameters and input variables. *Jour. Ind. Soc. Ag. Stat.,* **52**(1) : 96.

Runge, E.C.A. (1968). Effect of rainfall and temperature interactions during growing season of corn crop yield. *Agron. J.,* **60** : 503-07.

Shanker, Upendra and Gupta, B.R.D. (1987). Forecasting the yield of paddy at Chinsurah in West Bengal, using multiple regression technique.

Singh, A.K.; Rai, S.K.; Baghel, S.S. and Satri, R.A.S. (1996). Influence of Agroclimatic elements on the yield of rice at Raipur, *Mausam,* **47** (2) : 196-97.

Singh, D.; Jha, M.P.; Krishnan, K.S.; Iyer, V.N. and Rajana Agrawal (1977). Crop forecasting methodology. Report of I.A.R.S.

Stacy, S.V.; Stemson, O.; Jones, L.S. and Foreman, J. (1957). Joint effect of maximum temperature and rainfall on crop yields. *Agron. J.,* **40** : 26-28.

Varmora, S.L.; Pandya, H.R. and Parmar, B.A. (2004). Prediction of wheat yield on the basis of weather variables in Junagadh district of Gujarat State. *J. Agrometerol.,* **6** (sp. issue) : 204-206.

Varmora, S.L.; Dixit, S.K.; Patel, J.S. and Bhatt, H.M. (2004). Forecasting of wheat yield on the basis of weather variables. *J. Agrometerol.,* **6** (2) : 223-228.

Vyas, Pandey and Gupta, B.R.D. (1990). Influence of weather variables on the sorghum yield in Surat district. Annals of Agril. Zone, **29** (4) : 251-57.

YEAR	YIELD	MSW																	
		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1967-68	1242	8.2	6.9	4.8	4.5	3.9	6.1	5.5	4.2	2.2	3.9	2.5	3.6	2.2	5.2	6.6	9.4	9.9	10.1
1968-69	1256	9.2	8.1	8.9	7.7	5.0	4.4	3.5	7.3	3.7	1.5	2.8	4.9	10.3	9.9	9.2	7.6	8.5	9.9
1969-70	1121	10.0	9.5	9.2	9.5	9.2	8.3	2.9	3.6	2.3	0.4	0.2	0.0	8.7	2.8	5.7	7.3	9.7	9.7
1970-71	1504	10.5	9.3	9.6	0.0	1.9	3.0	5.8	5.9	1.1	5.4	2.5	1.4	1.7	2.3	6.5	8.0	6.9	10.4
1971-72	1265	5.1	7.2	7.1	1.0	3.0	5.4	1.7	2.2	3.0	2.1	6.8	5.6	1.8	6.0	8.0	8.4	4.6	7.8
1972-73	454	9.5	10.3	9.2	4.5	3.0	4.3	6.4	6.9	6.9	3.4	7.8	2.1	4.3	6.9	9.0	9.4	9.9	10.0
1973-74	937	4.7	1.2	3.3	6.0	4.9	2.0	1.3	2.4	4.7	4.1	1.3	2.8	0.0	0.0	5.7	4.9	3.1	6.8
1974-75	714	9.0	8.8	7.7	8.0	6.0	5.6	3.9	5.7	4.0	4.1	6.3	0.0	9.0	9.2	8.7	7.0	5.7	7.1
1975-76	1413	8.6	6.9	4.7	3.2	7.7	5.3	4.0	7.1	4.2	1.3	0.0	2.9	5.9	4.7	4.4	0.0	7.0	6.8
1977-78	1677	9.5	6.8	5.8	2.1	2.0	3.9	3.6	2.2	1.9	3.6	3.1	5.7	3.8	2.9	5.9	7.8	9.8	9.3
1978-79	1716	8.2	5.9	2.8	2.2	1.5	2.6	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980-81	1739	5.4	7.2	5.9	3.0	1.2	4.5	3.8	2.2	2.5	1.6	7.7	4.7	4.7	8.6	6.6	10.1	10.5	10.5
1981-82	1650	11.2	10.7	8.6	2.6	6.5	1.4	2.0	4.0	4.2	1.4	2.0	5.4	7.0	8.9	8.5	9.7	4.8	9.4
1982-83	1555	10.8	8.7	7.8	9.8	8.3	5.1	5.3	2.6	2.1	1.7	1.9	5.4	6.8	8.8	8.2	8.7	9.7	10.1
1983-84	1481	10.3	10.1	4.1	7.8	7.2	6.6	4.5	4.1	3.6	5.5	2.3	3.6	3.0	4.9	6.0	7.1	9.0	8.6
1984-85	1977	10.4	6.7	5.1	8.4	2.7	7.1	6.3	5.8	7.1	3.3	3.8	2.9	2.0	2.6	4.4	5.6	9.9	10.1
1985-86	993	10.5	9.6	9.3	6.6	6.4	4.0	3.4	3.0	2.1	1.9	4.4	4.7	6.1	8.1	9.0	8.9	9.2	6.9
1986-87	1196	10.8	9.2	6.1	4.2	6.8	3.0	2.2	0.7	3.8	3.8	2.0	4.5	7.1	9.2	10.1	10.3	10.2	10.2
1987-88	1017	10.5	6.6	21.0	7.7	7.2	8.1	8.8	7.4	9.2	5.4	8.2	6.7	4.0	8.1	9.8	10.1	10.6	9.1
1988-89	1616	9.5	4.7	10.5	5.5	5.4	2.8	1.4	2.0	1.4	2.8	6.1	2.5	7.8	7.6	8.9	6.4	4.3	6.4
1989-90	1890	9.6	6.2	6.8	7.4	4.6	7.4	6.7	4.1	2.9	3.2	4.2	3.0	5.0	7.8	8.5	7.3	6.8	9.3
1990-91	1963	11.5	11.1	8.8	6.2	0.7	5.4	3.6	6.2	2.4	4.6	2.9	2.3	4.6	7.4	6.5	9.3	5.2	9.4
1991-92	1452	8.4	9.0	8.3	7.0	9.3	3.8	5.4	3.2	2.9	4.7	6.5	2.7	2.3	5.3	10.0	9.1	9.6	10.1

1992-93	1604	11.0	8.8	4.1	8.7	9.4	7.4	3.4	3.2	3.6	4.5	3.3	4.0	3.4	6.0	8.2	10.0	10.2	9.7
1993-94	1747	11.5	6.8	7.9	5.7	4.4	1.8	3.2	6.5	5.7	4.8	4.4	6.4	8.4	7.5	7.1	6.3	3.5	10.0
1994-95	1466	9.9	3.3	5.1	1.2	4.8	2.5	2.7	1.6	1.4	1.5	3.1	5.0	3.0	2.5	5.2	9.0	10.5	10.1
1995-96	1946	10.8	9.5	7.2	6.9	9.3	4.7	1.4	3.6	2.5	4.6	5.6	5.8	3.1	6.3	9.3	10.3	9.3	9.8
1996-97	1663	11.3	8.5	6.6	9.7	9.8	6.6	3.2	1.7	2.7	2.3	5.1	5.8	3.4	2.8	6.2	9.3	9.6	8.4
1997-98	1758	9.6	8.6	6.9	6.6	5.0	3.9	2.8	4.1	2.6	7.5	4.3	2.9	4.3	9.4	5.0	6.0	8.4	9.5
1998-99	1952	10.8	6.6	10.0	6.4	2.9	1.1	4.6	6.7	2.3	1.3	5.4	5.9	3.8	7.7	5.1	5.0	6.4	9.0
1999-00	2152	9.5	6.3	4.1	8.3	5.6	4.1	0.7	2.8	2.6	1.2	5.1	5.5	6.5	6.7	6.4	5.4	7.5	6.1
2000-01	652	6.0	7.9	7.1	8.1	4.5	1.8	0.4	5.3	6.8	6.1	3.3	3.9	4.5	2.2	8.9	10.4	9.2	9.5
2001-02	1795	7.9	4.7	4.8	5.9	2.0	1.6	1.0	3.8	4.6	2.8	3.1	6.6	7.5	6.7	7.7	9.6	8.0	7.7

Appendix-I : Weekly Bright Sunshine (hrs/day) of Anand of Gujarat

Appendix-II : Weekly total rainfall (mm) of Anand of Gujarat

YEAR	YIELD	MSW																	
		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1967-68	1242	0	0	105	136	158	0	9	134	98	6	1	149	103	58	18	2	0	0
1968-69	1256	0	5	0	0	98	48	53	7	54	131	0	4	0	0	0	5	10	14
1969-70	1121	136	0	0	0	0	32	133	58	81	74	59	2	5	37	151	0	0	0
1970-71	1504	0	109	0	66	267	30	20	17	19	12	313	166	97	354	0	3	19	0
1971-72	1265	8	25	27	67	3	36	182	67	69	64	2	5	110	42	40	0	104	0
1972-73	454	0	20	0	18	143	10	0	0	0	25	109	59	2	0	16	0	0	0
1973-74	937	0	79	0	0	6	100	43	3	3	57	74	30	250	200	5	83	111	23
1974-75	714	0	0	3	29	19	92	0	2	4	0	2	9	4	0	0	67	72	0
1975-76	1413	11	0	100	16	4	34	77	2	12	185	96	8	36	119	98	0	0	53
1977-78	1677	0	57	96	363	155	173	21	141	37	59	13	0	97	43	0	22	0	0
1978-79	1716	0	4	16	0	14	116	4	39	6	9	141	100	276	3	0	0	8	0
1980-81	1739	34	2	28	65	118	7	0	45	240	33	25	70	51	0	7	0	0	0
1981-82	1650	0	0	0	138	1	265	26	39	4	173	190	6	33	0	15	6	26	0
1982-83	1555	0	23	0	0	21	11	10	97	82	55	126	127	6	1	0	0	0	0
1983-84	1481	0	6	67	142	130	31	154	132	83	94	68	11	13	64	19	76	5	0
1984-85	1977	4	4	46	0	132	5	45	42	142	159	44	36	8	1	21	39	0	0
1985-86	993	0	0	0	0	0	16	71	116	72	40	4	6	9	0	0	0	0	35
1986-87	1196	0	0	57	71	0	0	14	28	57	31	26	0	2	0	0	0	0	0
1987-88	1017	0	1	0	139	65	0	4	5	0	12	102	76	16	0	0	0	0	0
1988-89	1616	0	16	0	29	64	106	196	176	119	48	0	40	0	2	41	93	71	0
1989-90	1890	3	36	5	82	67	96	65	111	1	17	55	131	12	0	0	21	0	0
1990-91	1963	0	15	0	0	78	1	47	31	19	50	216	343	45	139	15	2	91	1
1991-92	1452	19	4	1	14	0	39	84	281	106	14	2	22	27	30	0	0	0	0
1992-93	1604	0	0	117	0	8	13	16	71	77	92	69	6	20	166	13	0	0	0
1993-94	1747	0	33	1	24	19	313	151	3	0	32	0	87	0	12	0	1	24	0
1994-95	1466	0	59	14	28	53	166	184	93	48	37	26	147	76	248	34	3	0	0
1995-96	1946	0	0	0	0	0	23	198	78	38	10	11	13	96	77	2	0	0	0
1996-97	1663	0	23	75	96	5	10	7	210	59	109	4	0	26	126	122	0	0	2
1997-98	1758	1	33	218	268	1	23	21	56	157	16	6	310	77	0	69	10	16	1
1998-99	1952	71	24	0	44	114	52	26	0	263	42	18	27	31	67	149	51	38	13
1999-00	2152	0	0	165	0	5	33	139	3	10	20	0	0	0	0	7	0	3	4
2000-01	652	36	2	0	12	24	164	32	0	2	18	37	21	13	1	0	0	0	0
2001-02	1795	3	101	18	21	72	90	9	24	35	179	115	0	0	0	0	0	0	0

Appendix-III : Weekly maximum temperature (°C) of Anand of Gujarat

YEAR	YIELD	MSW																	
		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1967-68	1242	38.7	38.3	31.9	33.9	31.0	32.3	32.7	30.8	30.2	30.3	30.4	29.9	30.8	30.7	30.2	32.5	35.6	34.7
1968-69	1256	39.4	36.8	36.4	37.1	33.9	30.8	31.4	32.6	28.9	28.6	29.5	31.0	32.5	32.5	33.5	34.1	34.0	34.9
1969-70	1121	36.5	35.7	34.6	35.4	35.3	35.0	31.5	29.1	30.5	28.8	27.9	30.9	31.0	31.0	28.8	31.4	31.8	33.4
1970-71	1504	35.8	34.0	33.0	32.8	30.1	31.9	31.8	32.4	33.3	31.7	30.0	30.1	28.6	28.8	29.5	30.7	30.6	32.4
1971-72	1265	33.8	34.5	35.0	28.6	32.1	32.8	28.7	29.9	28.4	29.4	29.9	31.7	29.6	30.8	31.1	34.7	32.9	32.1
1972-73	454	37.3	37.2	37.4	33.2	30.5	31.2	33.6	33.8	34.4	31.5	31.1	28.3	32.1	33.6	37.3	37.0	36.2	38.0
1973-74	937	38.6	34.3	36.0	37.2	34.8	30.1	31.6	31.5	33.1	32.0	29.6	29.1	27.6	26.9	30.6	32.9	30.9	33.2
1974-75	714	37.1	39.0	36.6	36.9	33.0	32.7	32.5	33.0	32.8	32.8	32.6	31.5	33.7	33.8	36.1	36.2	32.5	34.5
1975-76	1413	38.5	37.9	36.2	33.3	34.1	32.7	29.7	32.8	32.5	29.8	30.3	30.8	31.7	28.9	28.6	32.1	33.1	30.7
1977-78	1677	39.4	34.4	35.3	29.6	29.8	29.7	31.8	29.8	29.8	28.8	31.0	31.6	31.1	28.7	30.6	31.9	34.6	36.0
1978-79	1716	38.3	36.8	33.1	33.3	32.4	30.5	32.5	31.3	31.8	31.0	29.8	30.8	27.9	32.2	32.7	33.8	33.5	32.9
1980-81	1739	35.0	36.5	33.4	30.6	30.5	32.4	34.7	32.3	30.1	29.9	33.1	31.4	30.7	32.7	32.4	33.9	36.3	35.9
1981-82	1650	39.3	40.3	39.0	31.4	34.2	28.4	31.1	32.2	33.3	28.9	28.5	31.5	31.5	33.3	34.1	36.0	32.1	33.5
1982-83	1555	40.0	36.7	37.2	37.9	36.2	35.4	34.4	31.2	32.3	31.3	29.6	31.4	32.1	33.3	34.2	35.3	36.3	37.4
1983-84	1481	38.2	39.7	33.6	34.2	32.6	35.2	32.4	32.0	30.6	32.5	31.0	30.4	31.5	32.2	32.7	33.3	33.6	34.6
1984-85	1977	38.1	36.3	34.3	36.4	32.5	32.5	32.5	31.9	32.1	29.3	30.3	29.5	29.8	31.2	31.7	31.0	34.8	36.9
1985-86	993	38.8	38.7	38.1	37.5	36.4	35.2	32.0	32.3	30.3	30.5	32.3	32.5	33.3	33.6	34.0	34.7	35.9	37.5
1986-87	1196	41.2	39.4	34.5	32.2	34.4	34.9	33.0	30.0	31.1	31.3	29.8	31.2	32.5	33.1	33.1	35.7	37.3	36.7
1987-88	1017	38.9	36.0	38.0	37.7	35.2	35.6	34.9	35.5	36.5	34.4	36.1	32.1	31.5	33.7	35.1	37.0	37.4	38.0
1988-89	1616	39.7	37.5	37.8	34.7	32.4	32.4	29.9	30.0	30.1	30.0	32.9	32.2	33.6	34.5	34.9	34.4	31.2	32.9
1989-90	1890	37.3	34.3	35.7	33.5	31.3	32.2	33.0	31.1	31.2	30.6	30.5	29.1	31.4	33.3	34.1	34.5	34.2	35.7
1990-91	1963	36.6	37.4	36.9	34.5	30.7	33.9	31.7	31.4	30.3	32.2	30.8	29.5	30.2	31.3	31.7	33.3	31.9	33.7
1991-92	1452	39.9	36.8	37.5	36.2	36.5	34.1	31.8	28.6	29.8	31.8	33.2	30.6	30.9	31.0	33.0	34.8	34.7	36.1
1992-93	1604	40.0	40.4	35.8	35.3	36.3	35.3	32.4	30.2	30.7	32.0	31.4	31.6	31.8	29.2	31.8	33.9	36.5	36.7
1993-94	1747	42.3	35.7	35.5	35.5	33.9	30.8	30.8	33.4	33.0	32.2	33.4	33.6	34.0	33.4	33.6	33.7	32.5	35.6
1994-95	1466	39.8	33.3	34.1	30.9	31.2	30.2	30.8	30.2	29.3	29.6	30.5	31.1	30.3	28.9	30.7	30.4	34.1	36.7
1995-96	1946	40.7	38.3	37.5	38.2	37.6	35.4	30.0	30.5	31.4	32.3	32.4	32.8	32.4	31.1	34.4	34.5	35.0	36.1
1996-97	1663	40.9	38.4	33.4	35.6	34.8	34.7	32.2	29.7	30.6	27.9	31.7	31.9	30.3	29.9	30.1	32.6	34.5	34.7
1997-98	1758	35.5	37.3	31.3	30.3	33.5	32.9	33.0	31.3	30.4	31.2	32.0	30.5	31.7	32.9	31.2	32.4	33.2	33.0
1998-99	1952	38.4	35.1	37.6	35.8	30.8	31.5	32.2	33.7	32.0	30.9	31.5	34.5	31.1	33.6	31.8	30.9	33.5	35.5
1999-00	2152	36.9	37.1	32.6	34.7	34.5	32.3	30.2	30.9	30.7	29.7	32.6	33.2	33.5	33.7	32.5	33.1	34.6	33.5
2000-01	652	36.4	36.8	36.7	36.5	33.5	31.0	29.9	33.0	33.5	33.8	31.5	33.0	32.2	31.0	33.6	35.2	37.9	38.4
2001-02	1795	36.5	32.7	33.2	35.5	30.6	30.0	29.9	30.8	32.0	31.2	30.3	32.4	33.0	33.4	33.7	36.3	37.2	35.8

Appendix-IV : Weekly minimum temperature (°C)of Anand of Gujarat

YEAR	YIELD	MSW																	
		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1967-68	1242	27.2	27.2	24.9	24.9	25.3	25.7	25.4	24.4	24.3	24.9	24.5	24.5	24.9	23.6	24.0	23.7	25.2	22.4
1968-69	1256	26.6	27.1	27.6	27.8	26.0	26.1	26.2	25.8	25.5	24.7	24.4	24.8	23.6	23.8	24.4	24.8	24.5	23.9
1969-70	1121	26.2	27.3	27.7	28.1	27.6	27.1	26.3	25.3	25.7	24.7	24.4	24.7	25.7	25.2	24.9	23.5	23.1	20.6
1970-71	1504	28.4	25.6	26.6	25.7	25.6	25.9	25.7	26.0	25.8	25.9	26.1	24.8	24.5	24.3	24.0	24.4	23.6	23.3
1971-72	1265	26.8	27.1	26.8	26.2	26.5	26.3	25.4	25.6	25.4	25.3	25.3	26.1	25.1	24.9	24.7	24.5	26.0	23.6
1972-73	454	27.0	26.9	28.2	26.9	25.6	26.5	25.9	26.4	27.5	26.5	25.6	25.2	25.2	25.7	26.0	23.6	21.1	22.6
1973-74	937	27.6	25.6	26.6	27.2	25.9	24.9	25.1	25.1	24.6	25.2	23.8	23.5	22.7	22.1	22.8	22.6	22.3	19.9
1974-75	714	26.8	25.6	27.3	26.9	26.7	26.4	27.5	26.5	26.3	26.1	25.9	25.6	25.2	24.9	25.3	25.9	24.8	24.5
1975-76	1413	24.7	27.1	25.5	25.0	26.2	25.0	24.0	23.8	24.0	23.3	25.0	23.7	23.6	23.8	22.5	24.0	23.6	22.9
1977-78	1677	25.6	24.4	25.5	23.6	23.4	24.3	25.3	24.8	24.6	24.3	23.8	24.2	23.5	23.6	22.6	22.2	22.0	22.4
1978-79	1716	28.2	26.5	25.9	26.3	25.6	24.7	25.6	25.6	25.2	24.9	24.3	24.3	23.8	23.3	23.4	23.6	23.8	23.5
1980-81	1739	26.9	27.3	26.1	25.6	25.1	26.1	26.6	25.7	24.9	25.0	25.4	24.2	24.6	24.2	24.0	24.1	24.9	22.4
1981-82	1650	27.5	28.0	28.4	25.7	26.8	24.3	25.2	25.5	25.5	24.1	24.1	24.8	24.2	24.8	24.4	25.0	25.3	22.9
1982-83	1555	27.3	26.9	27.8	27.1	26.5	26.6	26.3	25.6	25.5	25.0	24.8	24.8	24.1	23.9	25.0	24.2	23.3	22.9
1983-84	1481	27.2	28.0	26.3	25.2	25.2	25.5	25.7	25.2	25.3	24.9	25.2	25.1	24.4	24.7	24.7	23.9	24.7	23.8
1984-85	1977	27.8	27.0	26.7	26.4	23.8	22.2	23.6	23.1	24.7	24.2	24.2	22.2	24.4	23.7	23.8	21.1	23.8	22.5
1985-86	993	27.2	27.5	27.3	28.0	26.9	26.5	24.9	25.4	24.9	25.1	25.3	24.7	24.2	24.4	24.2	24.9	24.9	24.5
1986-87	1196	28.4	28.5	26.1	25.7	27.0	26.9	26.0	24.9	24.7	25.2	24.4	24.1	23.7	24.0	23.2	24.4	24.4	23.9
1987-88	1017	27.7	27.2	27.8	27.5	26.7	27.0	26.4	26.7	26.8	26.1	25.2	25.3	25.4	25.1	24.6	24.3	24.9	23.7
1988-89	1616	28.4	26.6	27.6	26.4	25.8	26.3	25.0	24.8	25.5	25.2	25.2	25.7	26.1	25.8	25.5	25.1	25.2	23.9
1989-90	1890	27.2	26.3	26.4	26.0	25.0	24.9	25.3	25.3	24.9	24.6	25.4	24.3	25.0	24.3	24.5	25.0	25.2	23.7
1990-91	1963	26.8	27.1	26.8	26.7	25.8	26.2	25.4	25.4	25.0	25.4	25.4	24.5	24.8	24.3	24.3	24.4	24.2	24.0
1991-92	1452	27.6	27.4	27.6	27.1	27.6	26.1	25.9	24.1	25.4	25.1	25.2	25.1	24.3	24.4	23.1	23.7	23.9	17.6
1992-93	1604	26.3	28.0	27.0	27.1	26.4	26.7	25.9	25.1	25.0	25.1	24.8	25.3	25.3	24.1	23.3	22.7	22.1	24.3
1993-94	1747	26.7	26.6	26.9	26.8	26.3	25.4	25.4	26.6	26.8	25.7	25.9	25.0	25.8	25.1	24.9	24.9	24.7	24.0
1994-95	1466	28.1	26.5	26.6	25.4	25.6	25.2	24.9	25.2	24.9	24.7	25.2	24.7	25.2	24.3	24.3	22.6	22.1	20.4
1995-96	1946	27.0	28.2	28.4	28.9	27.8	25.3	25.0	25.0	25.7	25.9	25.7	25.7	24.8	24.5	25.3	24.0	24.9	24.3
1996-97	1663	28.2	26.0	25.4	26.5	26.6	26.7	26.2	24.8	24.9	24.3	24.9	25.0	24.4	24.2	24.5	23.6	23.6	23.5
1997-98	1758	25.0	26.7	25.5	25.0	26.4	26.9	25.9	26.1	25.4	25.1	25.1	24.2	24.9	25.2	25.0	25.0	24.5	22.7
1998-99	1952	27.4	26.3	28.3	27.1	26.0	26.4	26.4	26.4	25.5	26.1	25.3	26.2	25.1	24.9	24.6	25.2	25.6	24.9
1999-00	2152	26.6	28.1	25.3	26.6	26.3	26.0	25.6	25.9	25.3	25.1	25.5	25.1	25.0	25.7	25.0	24.6	25.0	24.4
2000-01	652	26.0	27.6	28.5	26.8	26.2	25.0	25.7	25.8	25.6	25.4	24.8	26.2	25.3	24.5	23.5	23.5	25.3	23.7
2001-02	1795	26.8	25.7	26.9	26.4	25.6	25.2	25.3	25.1	25.3	25.2	24.9	25.4	24.8	25.1	24.3	25.5	24.8	25.6

Appendix-V : Weekly relative humidity (%) of Anand of Gujarat

YEAR	YIELD	MSW																	
		23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1967-68	1242	69.8	67.1	89.3	91.9	93.8	78.4	88.6	94.7	96.7	90.7	90.7	91.4	91.1	91.6	89.4	84.3	84.6	82.8
1968-69	1256	70.9	79.8	79.3	70.6	89.8	90.5	86.0	86.5	92.7	94.0	88.3	84.2	80.8	74.2	77.7	82.8	83.0	84.0
1969-70	1121	100.0	76.4	85.3	94.3	96.7	98.6	89.9	94.8	95.9	95.9	98.8	98.0	97.3	98.4	97.2	93.4	90.0	85.1
1970-71	1504	84.2	96.2	90.2	93.1	96.5	95.6	95.4	92.3	86.9	85.3	82.6	96.3	97.8	94.6	94.5	91.0	91.0	80.5
1971-72	1265	77.1	78.2	79.6	84.5	75.6	82.1	88.5	86.4	88.6	87.5	83.0	78.2	91.7	86.1	84.4	77.2	89.4	87.9
1972-73	454	72.3	80.3	73.5	82.3	86.6	81.5	82.1	77.8	71.7	74.6	79.6	82.6	79.8	73.4	81.8	74.5	72.0	64.1
1973-74	937	72.1	82.8	75.6	84.1	93.3	92.9	90.4	87.8	81.1	90.5	91.5	93.1	97.3	97.3	81.1	87.2	97.3	83.7
1974-75	714	77.3	75.3	68.8	78.6	85.9	91.5	85.7	83.5	89.2	76.8	83.0	83.3	84.1	79.7	72.7	84.0	88.6	91.1
1975-76	1413	85.2	80.8	81.8	84.4	83.0	84.3	92.3	85.8	85.5	96.8	93.0	86.4	81.3	93.4	98.0	83.1	90.3	93.1
1977-78	1677	71.1	81.2	82.3	89.6	92.7	91.5	91.7	94.1	88.5	92.3	87.0	84.8	92.3	93.8	87.9	90.1	75.8	75.9
1978-79	1716	73.2	85.5	91.2	83.9	85.7	95.0	87.1	93.1	89.4	87.6	94.2	94.5	96.6	73.5	89.4	83.7	84.5	87.9
1980-81	1739	88.4	86.2	91.5	96.2	98.1	90.5	82.4	89.5	97.5	92.5	92.1	96.4	94.8	89.7	93.5	88.6	87.3	82.9
1981-82	1650	63.1	48.6	48.4	60.7	55.8	60.9	94.0	91.6	85.7	98.2	96.8	95.9	94.1	88.7	92.9	89.7	95.2	90.9
1982-83	1555	72.2	82.6	77.8	76.6	80.6	85.7	89.5	92.9	93.6	94.5	96.8	93.9	93.9	90.5	87.0	89.3	87.3	74.8
1983-84	1481	76.1	78.3	85.9	92.2	92.5	89.9	93.0	93.1	94.6	93.0	93.8	92.9	90.6	94.5	94.9	94.7	89.8	87.8
1984-85	1977	79.2	79.9	82.0	81.7	93.8	87.8	89.2	89.5	90.7	96.5	95.4	90.9	91.2	89.7	91.4	93.1	84.6	79.9
1985-86	993	75.0	76.2	79.9	73.7	77.7	80.0	93.5	91.5	94.5	92.8	89.7	91.0	89.8	88.4	86.2	83.4	81.4	80.4
1986-87	1196	71.8	71.7	95.0	91.5	81.3	78.7	87.3	90.0	92.5	95.5	90.2	89.7	90.9	87.7	85.6	80.3	89.3	81.2
1987-88	1017	72.7	89.2	76.6	78.1	87.1	86.3	82.8	83.1	77.0	84.5	87.9	94.6	87.4	84.6	83.6	79.8	81.0	81.4
1988-89	1616	74.2	83.9	82.2	87.0	92.6	92.8	96.8	93.0	94.6	92.8	90.3	94.7	88.1	89.4	91.6	89.7	96.4	87.9
1989-90	1890	76.6	86.0	83.1	79.5	91.3	94.0	93.7	92.1	87.0	92.1	92.2	96.6	91.6	89.6	87.6	90.3	90.9	81.9
1990-91	1963	75.9	77.1	76.2	81.7	87.1	82.8	89.6	87.1	90.4	89.2	89.1	95.3	93.2	93.6	90.5	87.3	94.9	89.8
1991-92	1452	77.5	77.4	72.7	79.9	77.4	87.9	91.5	96.7	92.5	89.9	87.1	90.8	91.4	89.9	88.7	83.1	82.0	78.3
1992-93	1604	74.0	75.1	85.9	85.1	86.7	88.6	90.8	92.5	94.9	95.6	94.9	91.7	92.6	96.1	94.2	87.2	77.6	82.1
1993-94	1747	68.2	85.3	86.5	87.9	87.4	94.2	94.7	88.2	83.5	88.6	86.5	88.3	86.5	84.3	88.6	86.1	95.1	87.3
1994-95	1466	73.0	87.4	88.9	94.8	93.4	95.2	95.0	94.5	93.4	94.4	92.2	94.0	96.7	96.2	96.5	92.4	87.7	80.8
1995-96	1946	79.1	79.3	79.0	73.1	81.3	89.7	98.1	94.5	95.1	92.3	91.1	91.6	94.1	93.7	88.5	88.0	89.1	82.4
1996-97	1663	70.6	88.0	89.9	87.9	88.4	93.3	91.6	94.9	92.6	95.8	92.6	86.4	94.1	93.2	94.6	90.2	86.7	84.6
1997-98	1758	81.8	82.9	92.2	95.7	92.4	91.4	93.8	92.2	94.4	93.0	91.7	97.4	95.7	91.0	95.0	93.3	90.3	90.2
1998-99	1952	79.2	87.6	80.5	89.4	95.3	92.4	89.5	82.3	95.3	93.9	90.9	93.1	94.8	87.5	96.2	95.0	90.6	90.1
1999-00	2152	76.5	81.1	95.5	85.2	86.3	88.4	94.3	89.7	90.9	93.8	88.4	85.6	87.0	81.8	91.4	89.9	87.4	93.4
2000-01	652	88.6	76.8	77.0	80.8	91.9	94.8	89.2	81.7	85.5	85.3	92.2	92.7	90.0	89.4	86.6	85.0	85.9	88.7
2001-02	1795	83.0	92.3	85.6	84.8	92.9	93.5	90.2	93.2	91.5	95.7	94.1	89.2	87.0	88.1	90.3	85.0	85.1	84.7