Impact of Climate on Sugarcane Yield over Gorakhpur District, U.P. using Statistical Model

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ABSTRACT

The impact of climate on agriculture could result in problems with food security and may threaten the livelihood activities upon which much of the population depends. In the present study, the development of a statistical yield forecast model has been carried out for sugarcane production over Gorakhpur district using weather variables of crop growing season and past observed yield data for the period of 1971 to 2010. The study shows that this type of statistical yield forecast model could efficiently forecast yield 5 weeks and even 10 weeks in advance of the harvest for sugarcane within acceptable limit of error.The performance of the model in predicting yields at district level for sugarcane crop is found quite satisfactory for both validation (2007 and 2008) as well as forecasting (2009 and 2010). In addition to the above study, the climate variability of the area has also been studied and hence, the data series was tested for Mann Kendall Rank Statistical Test. The maximum and minimum temperatures were found to be significant with opposite trends (decreasing trend in maximum and increasing in minimum temperature) while other three are found insignificant with different trends (rainfall and evening time relative humidity with increasing trend andmorning time relative humidity with decreasing trend).

Keywords: *Climate impact, Regression analysis, Yield and Forecast model.*

1. Introduction

Weather and climate are considered as basic input or resources in agricultural planning. Every plant process related to growth development and yield of a crop is affected by weather. Sugarcane is one of the several species of tall perennial true grasses and the main sugar-producing crop that contributes nearly 78.2% to the total sugar pool at the global level andis also a commercial crop for India on which economy depends. Sugarcane yield depends on several natural and unique succession of daily weather during the growing season and management factors. It is considered as a tropical plant but it can grow in sub-tropics too as in north India. It is a long duration crop and thus it encounters all the seasons, viz., rainy, winter and summer during its life cycle. Principal climatic components that control cane growth, yield and quality are temperature, light and moisture availability.

Previous studies show that most works have been done on cereal crops but almost few studies has been done for sugarcane crop in India (Agrawal, 2003; Shekh and Rao, 1996). The statistical modeling for yield forecast has been done by some workers (Gupta and Singh, 1988, 1990, 1991). Palanisamy et al. (1995) used an ORYZA1 model to determine the relative performance of short duration rice genotypes across the state of Tamilnadu. Agrawal and Kalra (1994) developed the WTGROWS model to analyze the effect of climatic variable and crop management on productivity of wheat in tropical and sub-tropical regions of India. Agrawal *et al.* (2000) concluded that yield of wheat is declining in Indo-Gangetic plain, whereas yield of rice do not show any trend by using crop growth model. Mall and Singh (2000) observed that small changes in the temperature of growing season over the years appeared to be the key aspect of weather affecting yearly wheat yield fluctuations. Yields of rice and wheat in the Indo-Gangetic plains (IGP) of India were studied by Pathak *et al.* (2003). They concluded that the negative trends in solar radiation and an increase in minimum temperature, resulting in declining trends of probable yields of rice and wheat over IGP. A number of statistical techniques viz. multiple regression, principal componentanalysis, Markov chain analysis, Discriminant function and agro-meteorological models (Rai, 1999; Ram Subramanian and Jain, 1999; Baweja, 2002; Muralidhara and Rajegowda, 2002; Ravi Kiran and Bains, 2007; Bazgeer et al. 2008) have been used toquantify the response of crops to weather. Jain et al (1980) and Agrawal et al (1986) studied the effects of weather on rice yield. Weather indices and principal components of weather variables were used in the models developed by Agrawal et al. (1980). Agrawal et al (2001) developed yield forecast models for wheat and rice using weather variables and agricultural inputs on the basis of agro-climatic zone. Four different approaches, two onoriginal weather variables and two on generated weather variables were used by Khistariaet al. (2004) and Varmola et al. (2004). By coupling technology trend with weather variables, models were developed by Mallick et al. (2007). Tripathi et al (2016) developed the techniques of estimating the productivity of maize crop based on past weather and yield for Jaunpur district of Eastern Uttar Pradesh.

Geographically, Gorakhpur (Lat. 26°13′N and 27°29′N and Long. 83°05′E and 83°56′E) is situated on the left bank of river Rapti at the convergence of the river Rapti and Rohin. With the establishment of various institutions, organizations and other infrastructural developments, major changes have taken place in every sector after the 1970s. The city is a major center of socio-economic commercial, cultural and administrative activities of North Eastern U.P. and as sugarcane is the most important commercial crop of the region on which most of the farmers depends for their livelihood. This will ultimately help in the economy because India is the second major sugar producing country in the World. Hence, there is a need of this type of study that could help various decision makers, farmers, traders, exporters and importers and most importantly the government (can plan their strategic actions well in advance (in the light of the model forecast) of import or export in the case of shortage or surplus production to maintain the availability of sugarcane and to control the prices in the market). The present study aims at the development of a statistical yield forecast model for sugarcane production over Gorakhpur district (Lat. 26°13′N and 27°29′N and Long. 83°05′E and 83°56′E) using different weather variables viz. temperature (maximum and minimum), 24 hourly rainfall, relative humidity (morning and evening) of crop growing season and past observed yield data for the period of 40 years i.e. from 1971 to 2010.

2. Data and Methodology

The crop yield data of sugarcane including production (Metric tons), area (Hectare), and productivity (Quintal/hectare) for the period of recent 40 years (1971-2010) for Gorakhpur District were collected from Directorate of Agriculture, Lucknow, U.P. Long period daily weather data were collected from India Meteorological Department, New Delhi. Daily data on weather parameters during the crop growth period were taken and arranged in weeks starting from 14^{th} to 50^{th} week of each year using cumulative value for rainfall and weekly average value for other parameters like maximum and minimum temperature, morning and evening relative humidity.

Multiple linear stepwise regression procedure has been developed for selecting the best regression equation among number of independent variables. To select significant variables stepwise regression (Ghosh et al, 2014) was used. Statistical Package for Social Science (SPSS) computer software was used for the analysis of data with probability level of 0.05 to enter and 0.1 to remove the variables. To predict the yield of sugarcane for the subsequent years, the entered variables obtained from individual stepwise regression analysis are considered in the regression model. Further, analysis was carried out including significant generated variables only. Weather variables used for this model are maximum temperature (T_{max}) in ^{0}C, minimum temperature (T_{min}) in ^{0}C, morning (8:30 IST) and evening (17:30 IST) relative humidity (RHI and RHII respectively) in percentage and 24 hourly rainfall (RF) in millimeter. Combination of weather variables for weather indices, thus generated are presented in Table1.

Table 1. Notations of various weather indices used in model

Indices	Notation for unweighted index (Z_{ij})	Notation for weighted index(Z_{iij})
T_{max}	Z10	Z11
T_{min}	Z20	Z21
RF	Z30	Z31
RH I	Z40	Z41
RH II	Z50	Z51
T_{max}-T_{min}	Z120	Z121
T_{max}-RF	Z130	Z131
T_{max}-RHI	Z140	Z141
T_{max}-RHII	Z150	Z151
T_{min}-RF	Z230	Z231
T_{min}-RHI	Z240	Z241
T_{min}-RHII	Z250	Z251
RF-RHI	Z340	Z341
RF-RHII	Z350	Z351
RH I-RHII	Z450	Z451

In order to study the consistency of forecast, predicted yield values of subsequent years were worked out. Yields of subsequent years were forecasted two months before harvest. For forecasting, observed weather was used up to the time of forecast andnormal values of weather variables for the remaining period up to harvest. The best agro-meteorological indices were selected to develop agro meteorological yield model for the district, on the basis of examination of determination coefficients (R^2), Standard Error of estimates (SE) as well as relative deviation (RD) values resulted from different weather variables.

Test criteria have been separated into two groups, called summary measures and difference measures. The difference measures include the mean bias error (MBE) and the root mean square error (RMSE). The summary measures describe the quality of simulation while, the difference measures try to locate and quantify the errors. These were calculated according to Willmott (1982) as follows and were based on the terms (P_i - O_i):

$$MBE = \sum_{i-1}^{n} [P_i - O_i]/n$$

$$RMSE = \left[\sum_{i=1}^{n} (P_i - O_i)^2 /n \right]^{1/2}$$

RMSE indicate the magnitude of the average error, irrelative of the size of the average difference between predicted yield (P) and observed yield (O). The value of MBE is related to the magnitude of the values under investigation. The statistic MBE describes the direction of the error bias. Negative MBE indicates that the predictions are smaller in values than those of the corresponding observations.

Further, the statistical analyses were performed over all the time series data of maximum temperature, minimum temperature, morning and evening relative humidity, 24 hourly rainfall, actual and predicted yield of sugarcane over Gorakhpur district to find out fluctuations and presence of trend if any. The statistical significance of 40 years trend in the

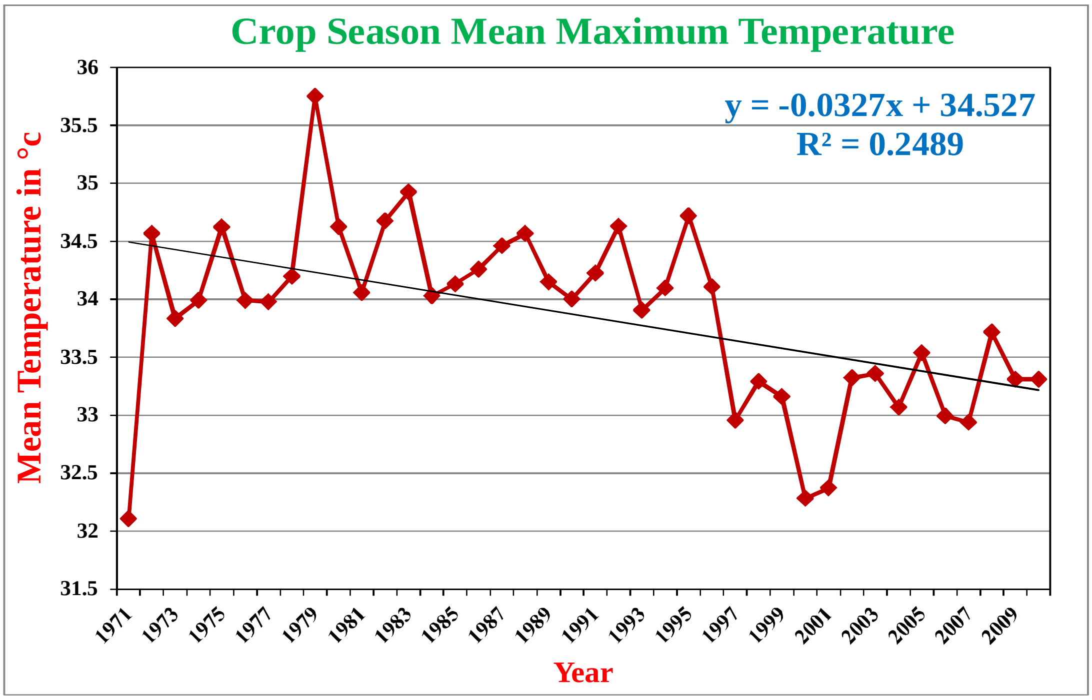

Figure 1: Crop season mean maximum temperature for the period 1971-2010

above climatic and crop data were tested by non- parametric Mann- Kendall Rank statistics (WMO, 1966).

3. Results and Discussion

3.1 Contribution of various weather variables

District level yield forecast model was developed using independent weather variables i.e. temperature (maximum and minimum), rainfall, relative humidity (morning and evening) during the crop growing season (period from planting of crop to the harvesting) and past observed yield over the Gorakhpur region of Eastern Uttar Pradesh with the help of statistical techniques for sugarcane crop and the results were analyzed. Changes and Contribution of various weather variables (maximum and minimum temperature, morning and evening relative humidity and 24 hourly rainfalls) and observed yield of sugarcane are studied and discussed below. These weather parameters along with the observed yield and predicted yields so generated were further statistically tested for their significance of trend using Mann Kendall Rank statistics at 95% level of significance. All the results of the study are discussed below:

Figure 1 shows the interannual variations in crop season (the duration from planting to harvesting) mean maximum temperature for the entire period of study i.e. 1971-2010. The crop season mean maximum temperature shows a significant decreasing trend with a rate of 0.03^{o}C/year with R square value 0.2489. This is very peculiar as well as interesting and alarming to the concerned scientists and environmentalists as well as for sugarcane growers. However, the data series is tested for Mann Kendall Rank statistics and the maximum temperature was found to be significant. The lowest crop season mean maximum temperature was seen 32.1^{0}C (1971) and the highest crop season mean maximum temperature was observed 35.7^{0}C (1979). The temperature was remarkably down during the period 1997-2001. The whole period may be divided into two block of time one earlier period from 1971-1996 with a mean value 34.3^{0}C and the other as later period from 1997-2010 with a mean value 33.1^{0}C, which clearly shows a change in climate over the study area.

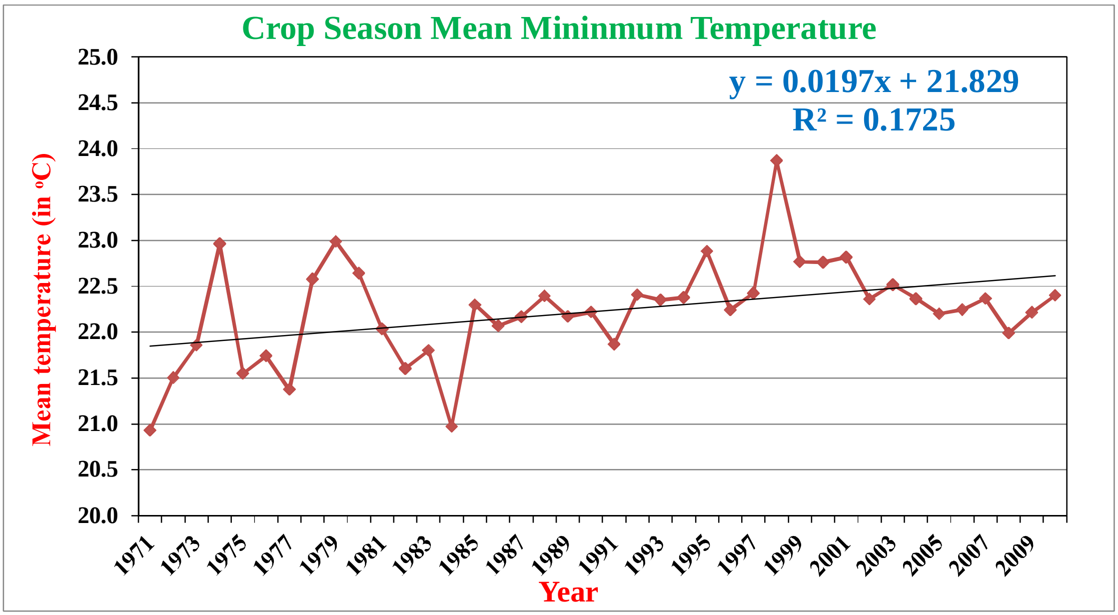

Figure 2:Mean minimum temperature of crop growing season over the period 1971-2010

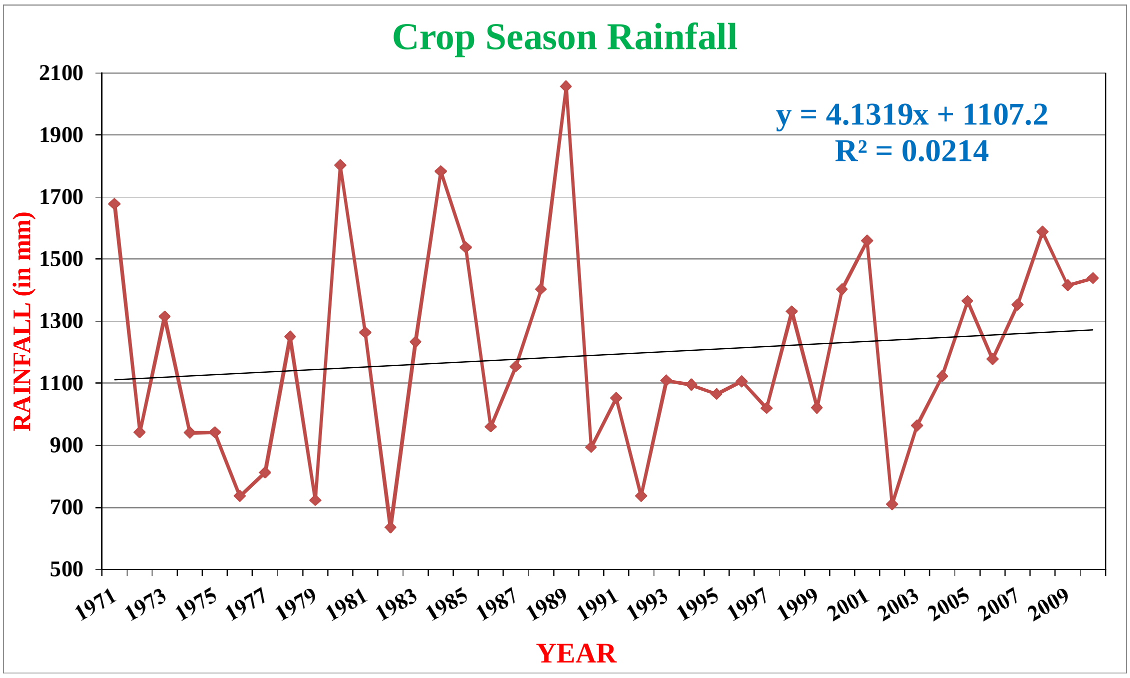

Figure 3: Variation of total rainfall of crop growing season over the period 1971-2010

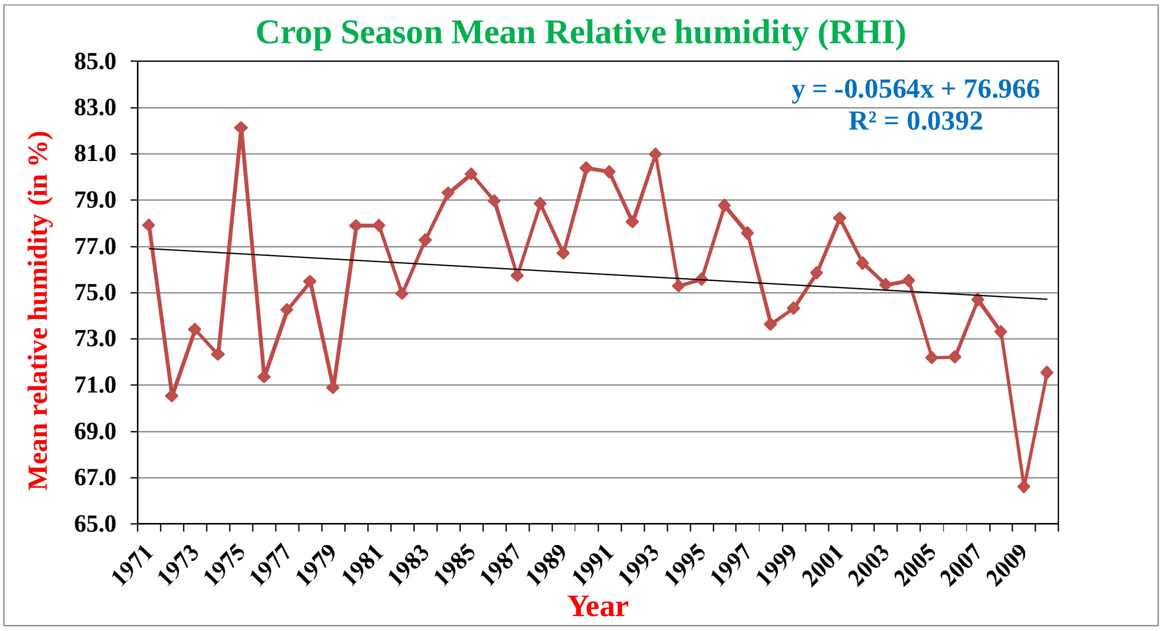

Figure 4: Variation of mean relative humidity at morning (RHI) of crop growing season for the period 1971-2010

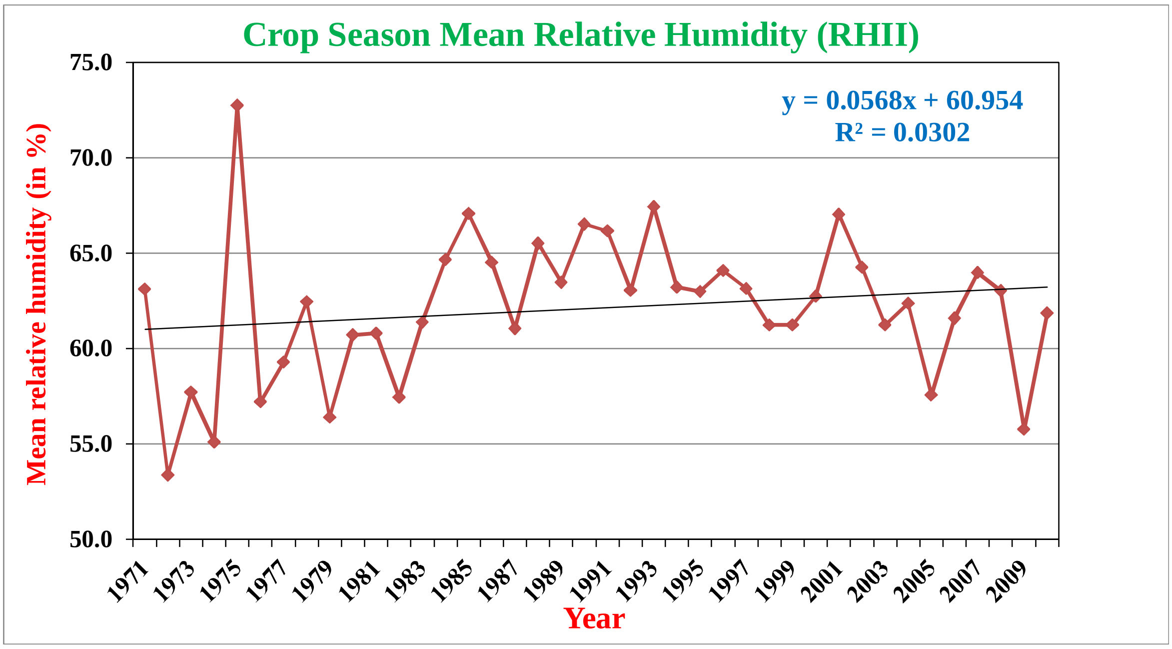

Figure 5: Variations in Crop growing season mean relative humidity at evening (RHII) for the period 1971-2010

Figure 2 represents the variation of mean minimum temperature of crop growing season over Gorakhpur district for the period of 40 years i.e. from 1971 to 2010 is showing a increasing trend with a rate of 0.01^{0}C/year with R square value 0.1725. The data series is showing very small variations except at few years and therefore any notable trend is not observed. A high crop season mean minimum temperature was seen i.e. 23.9^{0}C in the year 1998 and the lowest crop season mean minimum temperature was noticed 20.9^{0}C in the year 1971 and 1984. The data series was however tested for Mann Kendall Rank statistics and was found to be significant. From the graph it can be seen that there is not much fluctuations in the year wise mean minimum temperature and shows a regular trend over the period from 1971 to 2010.

The variation in the rainfall pattern during crop growing season over Gorakhpur district from 1971 to 2010 is highly fluctuating and is shown in Fig. 3.

be increasing during the first two decades (1971-1990) and then decreasing during the latter two decades (1991-2010), however, the trend of humidity RHI over the entire period is decreasing with a rate of 0.05 percent/year and the R square value is 0.0392 which states that this trend equation is statistically not able to predict for future years. The maximum humidity is 82.1 in the year 1975 and minimum humidity is 66.6 in the year 2009. Whereas, the data series was tested for Mann Kendall Rank test and was found to be

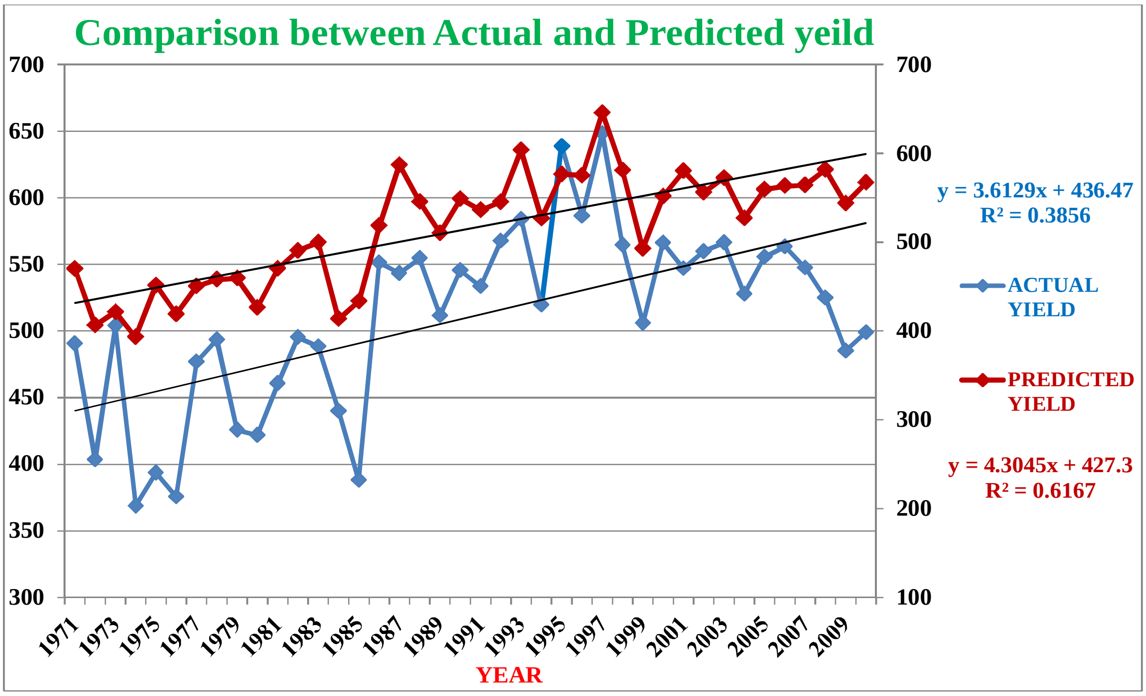

Figure 6: Comparison between actual and predicted yield over Gorakhpur district for the period 1971-2010

The rainfall pattern shows an increasing trend with the rate of 4.13 mm/Year. R square value is 0.0214 which indicates that this trend equation is statistically not predictable for future years. The maximum rainfall received in the year 1989 (2056.6 mm) and minimum in the year 1982 (634.5 mm). During the years 1974-1977, 1982, 1990-1997, 2002, the rainfall was decreased with more fluctuations. The rainfall data series was tested for Mann Kendall Rank statistics and was found to be insignificant. There are some sharp increases in the rainfall in the years 1980, 1984 and 1989.

Figure 4 shows the variations in the average morning (8:30 IST) relative humidity (RHI) during 1971 to 2010. The mean RHI is seen to

insignificant.

Figure 5 displays the variations in evening (17:30 IST) relative humidity (RHII) during crop growing period of sugarcane crop, where a small increasing trend is seen, along the years 1971 to 2010 over Gorakhpur district. The graph shows an increasing trend with a rate of 0.05 percent/year and the R square value is 0.0302 which states that this trend equation is statistically not predictable for future years. The maximum RHII is 72.7 percent in the year 1975 and minimum RHII is 53.4 in the year 1972. It is observed that trend for evening relative humidity (RHII) is of opposite nature (increasing) when compared with the morning relative humidity (RHI). This data series of humidity was however tested for Mann Kendall Rank statistics and was found to be insignificant. The actual yield and predicted yield over the period 1971 to 2010 are compared in the Fig.6, showing an increasing trend with the rate of 3.61 and 4.30 Q/Ha per year respectively.

Table 2. Output of SPSS (Statistical Package for Social Science)-generated models with coefficients (unstandardized and standardized, standard error and significance)

Coefficients						
Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
			Std. Error	**Beta**		
1	(Constant)	419.3425	16.96497		24.71813	2.61E-23
	TIME	4.908275	0.799588	0.7250363	6.138502	5.7E-07
2	(Constant)	355.7185	15.03185		23.66432	2.83E-22
	TIME	5.368223	0.542202	0.7929785	9.900781	2.08E-11
	Z11	14.65932	2.25598	0.5204397	6.497981	2.24E-07
3	**(Constant)**	**101.3459**	**87.30168**		**1.16087**	**0.254282**
	TIME	**4.9042**	**0.512956**	**0.7244343**	**9.560669**	**6.73E-11**
	Z11	**11.9548**	**2.228797**	**0.4244232**	**5.363792**	**6.89E-06**
	Z241	**0.042562**	**0.014431**	**0.2380626**	**2.949384**	**0.005909**

R square values of actual yield and predicted yield are 0.3856 and 0.6167 respectively. The actual yield was minimum (368.64 Q/Ha) in the year 1974 and maximum (648.24 Q/Ha) in the year 1997. Similarly, the predicted yield is also minimum (393.09 Q/Ha) in the same year 1974 and maximum (645.57 Q/Ha) in the year 1997.The trends of actual and predicted yield are almost same with fluctuation and are also of similar nature. Abrupt decrease in the actual and predicted yield is seen in years 1974-76, 1979-80, 1984-85 and 2004-2009. There is remarkable increase in both the yields in the year 1987, 1993, 1995 and 1997. The actual and predicted yield is almost equal in the years 1973, 1995 and 1997. However, the actual and predicted yield data were tested for Mann Kendall Rank Statistics and it was found that both the yields are significant. The reason for this increasing trend may be the weather and climatic conditions over the region that may be favorable for the growth and production of sugarcane. The sugarcane production is greatly influenced by weather conditions prevailing during the various crop-growth periods. Sugar recovery is highest when the weather is dry with low humidity; bright sunshine hours, cooler nights with wide diurnal variations and very little rainfall during ripening period. These conditions favor high sugar accumulation. There are many factors which may be responsible for the increase or decrease in sugarcane yield. Some parameters are not considered in the present study like soil (composition, type etc.), fertilizer input, herbicide application (in sugarcane weeds have been estimated to cause 12 to 72 % reduction in cane yield), and most importantly water supply through irrigation.

3.2 Results of yield forecast model

The present model is developed using actual weather variables as well as product of two weather variables at a time during the crop

Table 3. Validation of forecast model for the years 2007 and 2008

VALIDATION			
YEAR	**PREDICTED YIELD (Q/Ha)**	ACTUAL YIELD (Q/Ha)	**%ERROR**
2007	564.04	547.52	2.93
2008	581.63	524.88	9.76
AVERAGE ERROR			6.34

growing season (from planting to harvesting). The agro climatic weather indices were developed in two categories one considered unweighted indices (simple sum of weather variables) and other weighted indices using sum product of weather variables and correlation values of weather variables with their respective past adjusted yield. These agro climatic indices and observed yield were linearly regressed multiple times using SPSS, whose output provides independent weather variables and coefficients (Table 1) and a model equation (Eq. 1), is established.

Table 4. Forecast of sugar cane yield 10 weeks in advance of harvesting for the years 2009 and 2010

FORCASTING			
YEAR	**PREDICTED YIELD (Q/Ha)**	**ACTUAL YIELD (Q/Ha)**	**%ERROR**
2009	558.00	485.00	13.08
2010	571.47	498.80	12.72
AVERAGE ERROR			12.90

The output of SPSS could be used to develop three different models (Table 2) from which the best suited model were chosen and based on that model; forecast equation has been used for predicting the yield of sugarcane over Gorakhpur district.

The third model was chosen for prediction of yield because it is based on more number of variables (three variables viz. time, Z11 and Z241) and associated coefficients, hence supposed to give better results. Only unstandardized coefficients were used in the yield forecast equation. The final yield forecast model equation using important independent weather variables has been given below:

Y = 101.3459(Constant) + 4.9042*T + 11.9548*Z11 + 0.042562*Z241… (Eq.1) **(R^2 = 0.836)**

Where, Y represents the predicted yield, T is the time variable of the corresponding year, Z11 is the weighted agro-climatic weather index obtained from the sum product of maximum temperature and their respective correlation values taken with past adjusted yield, Z241 represents the weighted agro-climatic weather index obtained from the sum product of composite of minimum temperature with morning time relative humidity (Tmin*RHI) and their corresponding correlation values taken with past adjusted yield. R^2 value (measure of goodness of fit) indicates that generated model equation is able to explain 83.6% of variation in the sugarcane yield.

Table 5. Forecast of sugar cane yield 5 weeks in advance of harvesting for the years 2009 and 2010

FORECASTING			
YEAR	**PREDICTED YIELD (Q/Ha)**	**ACTUAL YEILD (Q/Ha)**	**%ERROR**
2009	548.96	485.00	11.65
2010	564.38	498.80	11.62
AVERAGE ERROR			11.64

The performance of the sugarcane yield forecast model equation has been tested by comparing the predicted values with the actual yield for the years 2007 and 2008 and is presented in Table 3.

The predicted yield for the year 2007 is 564.04Q/Ha and that of 2008 is 581.63 Q/Ha, their actual yields being 547.52 and 524.88 Q/Ha respectively. The predicted yields for both the validation years are within the acceptable limit of error i.e., 2.93% for 2007 and 9.76% for 2008. The average error of the validation years is 6.34%. The validation results indicate that the model is capable of predicting the sugarcane yield successfully in Gorakhpur district for subsequent years. The validated model was run to forecast the yield, ten and five weeks in advance of harvesting for years 2009 and 2010. For forecasting, observed weather variables were used up to the time of forecast and normal values of weather variables were used for the remaining period up to the time of harvest. The results for both, 10 weeks in advance forecast and 5 weeks in advance forecast were taken for the years 2009 and 2010 and is presented below in table 4.

Based on the developed model, the predicted yield for the year 2009 and 2010 (ten weeks in advance of harvesting) is 558.00 and 571.47 Q/Ha respectively. The actual yield for these forecasting years (2009 and 2010) were 485.00 and 498.80 Q/Ha respectively. The error in the yield forecast was 13.08% and 12.72% in the year 2009 and 2010 respectively. The average error in the forecast model prediction was found to be 12.90% when the forecast was made ten weeks in advance of harvest. The predicted yield (five weeks before harvesting) for the year 2009 and 2010 was 548.96 and 564.38 Q/Ha respectively, were compared with the actual yield 485.00 Q/Ha in year 2009 and that of 498.80 Q/Ha in year 2010. The error worked out to be 11.65% in 2009 and 11.62% in 2010. The average error in the forecast model prediction was found to be 11.64%. This shows that the model is capable of predicting the yield efficiently for 5 weeks and even for 10 weeks in advance. The percentage MBE (-0.0006%) and percentage RMSE (5.5759%) error have been calculated to check the accuracy of the results. Very small percentage errors indicate that predicted values are in good agreement with observed values. The maximum variation of estimation is less than 10 percent.

4. Conclusions

From the present study the following conclusions may be drawn:

- The variability in the weather parameters were analyzed and further they were tested for the significance using Mann Kendall Rank statistics. The maximum and minimum temperatures were found to be significant with opposite trends (decreasing trend in maximum and increasing in minimum temperature) while other three are found insignificant with different trends i.e. rainfall and evening time relative humidity with increasing trend and morning time relative humidity with decreasing trend.

- The study reveals that the observed weather variables viz. maximum temperature, minimum temperature, morning and evening relative humidity, 24 hourly rainfall and observed yield of previous years of sugarcane crop over Gorakhpur district, through multiple linear regression could be used to develop yield forecast model which could be implemented to forecast yield 5 weeks and even 10 weeks in advance of the harvest.
- The performance of the model in predicting yields at district level for sugarcane crop is found quite satisfactory for both validation (2007 and 2008) as well as forecasting (2009 and 2010). The average errors of validation results (6.34%) and forecast results for 10 weeks in advance (12.90%) and 5 weeks in advance (11.64%) are found to be within acceptable limits.
- Model equation developed in this study include independent weather indices Z11 and Z241 along with their coefficients, which indicates the prime dependence of sugarcane yield on maximum temperature and next to it is the combination of minimum temperature and morning time relative humidity which play an important role in deciding the predicted yield. Both the weather indices are weighted one and hence the past productivity record is also of vital concern.

Various decisions could be taken in advance by obtaining accurate pre-harvest estimates of sugarcane crop. The main beneficiaries are farmers (decide their procurement prices), traders, exporters and importers (for planning their logistics, inventories and contracts). The processing companies may also plan in advance about the capacity, manpower and marketing strategy. Government may also plan their strategic actions well in advance (in the light of the model forecast) of import or export in the case of shortage or surplus production to maintain the availability of sugar cane and to control the prices in the market.

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