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Original Article

Role of Meteorological Models in Estimating Yield of Sugarcane Based on Weather Variables

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Abstract

A field study was conducted at G.B.P.U.A.&T., Pantnagar to investigate the feasibility of estimating the yield of sugarcane crop based on weather variables. Five years (2004 to 2009) crop management data (sowing/harvest/irrigation etc.) for sugarcane were collected from Agricultural farm, Pantnagar. The development of multiple variable regression models employs that the dependent variable (yield) of multiyear is related with independent weather variables. SPSS (Statistical Package for the Social Sciences) software was used for the statistical analysis and development of multiple regression models based on fortnightly meteorological parameters. A total number of 8 models were developed using different combinations of fortnightly weather variables at different crop growth stages. Among all models, the performance of the model 8 was superior as compared to other models. The predicted yield by this model ranged between 349.39q ha-1 to 803.76q ha-1 with the value of R2 as 0.668, while the observed values ranged from 221.80q ha-1 to 824.16q ha-1. The RMSE between observed and predicted yield of sugarcane by model 8 was 15.49%, while the value of F test was 7.32 which is significant at 1% probability level. Hence, it can be concluded that the observed and predicted values were close enough in model 8 as compared to other meteorological models. The reason is obvious because model 8 used more number of weather variables.

Keywords

Weather parameters; Coefficient of correlation and Yield prediction models.

Introduction

Sugarcane (*Saccharum officinarum* L.) is a long duration tropical crop covering all the seasons' *viz., kharif,* rainy and *zaid* during its life cycle. A total of 1100mm-1500mm rainfall is adequate provided the distribution is right and abundant in the months of vegetative growth followed by a dry period for ripening. Optimum temperature for sprouting (germination) of stem cuttings is 32 to 38°C. Principal climatic components that control cane growth, yield and quality are temperature, light and moisture availability. Agriculture and climate are closely linked to crop growth, development and production[1] and is affected by both long term meteorological factors (the climate) and short term meteorological events (the weather). Forecasting of crop production is one of the most important aspects of agricultural statistics system. At present, yield forecasts are based on quite subjective estimates and the final crop production estimates based on objective crop cutting surveys become available long after the harvests. Crop weather models act as useful tools to predict crop yields in a vast country like India for planners and policy makers.[2] The weather parameters play an important role both in biology and control of pest.[3] There are numerous studies based on Fisher's (1924) techniques *viz.,* linear, curvilinear and multiple regression techniques for prediction of yield. The relationship between crop yields and weather parameters is generally carried out with the help of multiple regression models.[4] The production of crop and prediction of crop yields have direct impact on national and international economy and thus, play an important role in the food management.[5] Therefore, the present study was undertaken to

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investigate the feasibility of estimating yield of sugarcane crop based on weather variables.

Materials and Methods

Field study was conducted at H and I block of Agricultural Farm of G. B. Pant University of Agriculture and Technology, Pantnagar. Geographically, this centre is situated at 29°N latitude and 79.3°E longitude. The elevation of this place from mean sea level is 216 meters. The soil of the present experimental site belongs to Beni silty clay loam series. Plant and management data (sowing/harvest date/irrigation scheduling, etc.) related to sugarcane form the year 2004 to 2009 were collected from Agriculture Farm of G. B. Pant University of Agriculture and Technology, Pantnagar.

The daily weather data of crop seasons such as temperature, relative humidity, wind speed, bright sunshine hours, evaporation and rainfall used in the study as indicators in crop yield prediction and were collected for a period of five years (2004 to 2009) from the agrometeorological observatory located at Norman E Borlaug Crop Research Centre (NEB-CRC), G.B. Pant University of Agriculture and Technology, Pantnagar. The daily values of the meteorological parameters were converted in to the fortnightly weather data. These fortnightly weather variables were taken after six to seven months from the date of sowing. Number of fortnightly were varied (increase or decrease) because sowing dates of the sugarcane is not same in all the fields during the study period. This resulted into the varying crop duration of sugarcane in the different fields.

The two main factors affecting crop yield are inputs and weather. Use of these factors forms one class of models for forecasting crop yields. Weather plays a very important role in crop growth and development and hence, can be conveniently used as an indicator of change in the crop yield. Weather variables like rainfall, temperature, bright sunshine hours and relative humidity were used as indicators in the development of empirical statistical models using multiple linear regression techniques.[6-7] The development of multiple variable regression models employs that the dependent variable usually multiyear yield is related with the independent weather variables. Multiple regression models were developed with the help of SPSS software by using different sets of independent variables. The forward stepwise parameter selection approach was used which describes F range criteria. An example of multiple regression equation is given below.

$$\mathbf{Y = a + bx_1 + cx_2 + dx_3 + \ldots}$$

Where,

Y = Crop yield (q ha^{-1})

a = Multiple régression constant

b, c, d... = Slope of the curve

x_1, x_2, x_3 ….. = Average weather parameters.

Results and Discussion

Yield prediction of sugarcane

Each crop cultivar requires a set of weather conditions for its potential growth, development and finally economic yield. However, it may be noted that the variation in weather conditions introduce the year to year variability in yield. Sugarcane is a long duration crop which requires different types of weather conditions at its various phenophases. Even under optimum conditions small variations in weather influences growth and development of the crop. A total number of 8 models were developed using different combinations of meteorological parameters. All the models developed in the present study have been listed in Table 1.

Yield prediction of sugarcane: Model 1

Observed and predicted yield of sugarcane crop at H and I block of Agricultural Farm of G.B. Pant University of Agriculture and Technology is depicted in fig. 1. It was found that observed yield ranged from 221.80q ha-1 to 824.16q ha-1 and yield predicted by model 1 ranged from 457.02q ha-1 to 755.71q ha-1, respectively. The model 1 was developed using the weather variable wind speed of 13th fortnight from 6 to 7 month of sowing. Co-efficient of determination (R2=0.344) shows that about 34 per cent variability in yield of sugarcane may be addressed by the single weather variable of wind speed.

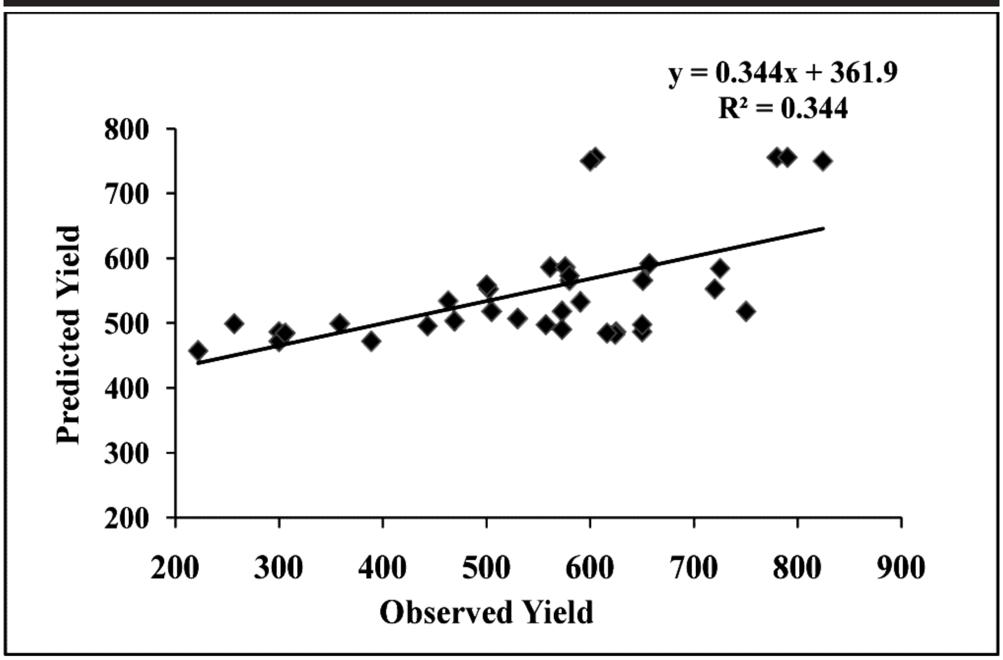
The RMSE (Root Mean Square Error) between observed and predicted sugarcane yield was 21.64 per cent while the value of F test was 18.91 which is significant at 1% probability level. Results show that wind speed is the most important factor in deciding sugarcane yield though it doesn't influence directly. But indirectly it supplies CO2 which is an important gas required during photosynthesis. Wind increases the turbulence in atmosphere, thus increasing the supply of carbon dioxide to the plants resulting in higher photosynthetic process.[8]

Table 1 : Meteorological yield models of sugarcane crop based on fortnightly weather data

Model No.	Meteorological model equation	R^2
1	$Y = 401.708+36.875*(x_1)$	0.344
2	$Y = 523.577+39.524*(x_1)+(-24.5280)*(x_2)$	0.468
3	$Y = 438.79+41.767*(x_1)+(-19.234)*(x_2)+0.236*(x_3)$	0.515
4	$Y = 323.865+46.471*(x_1)+(-23.9150)*(x_2)+0.229*(x_3) +21.457*(x_4)$	0.544
5	$Y = 391.953+40.59*(x_1)+(-20.314)*(x_2)+0.3*(x_3)+43.693*(x_4)+(-66.977)*(x_5)$	0.586
6	$Y = 402.155+43.211*(x_1)+(-29.919)*(x_2)+0.41*(x_3)+ 51.274*(x_4) +(-109.027)*(x_5)+19.197*(x_6)$	0.620
7	$Y = 351.034+46.648*(x_1)+(-35.979)*(x_2)+0.418*(x_3)+ 54.718*(x_4) +(-100.479)*(x_5)+22.302*(x_6)+4.8*(x_7)$	0.648
8	$Y = -33.078+46.729*(x_1)+(-32.191)*(x_2)+0.549*(x_3)+58.828*(x_4) +(-156.253)*(x_5)+26.286*(x_6)+4.745*(x_7)+6.485*(x_8)$	0.668

Where, Y = Yield (q ha-1), X1 = Average wind speed of 13th fortnight, X2 = Average Bright Sunshine Hours (BSS) 1st fortnight, X3 = Sum of 2nd fortnight rainfall, X4 = Average Bright Sunshine Hours (BSS) 12th fortnight, X5 =Average evaporation of 6th fortnight, X6 = Average evaporation of 2nd fortnight, X7 = Sum of 11th fortnight rainfall and X8 = Average Relative Humidity of 6th fortnight.

Fig. 1 : Comparison between observed and predicted yield: Model 1



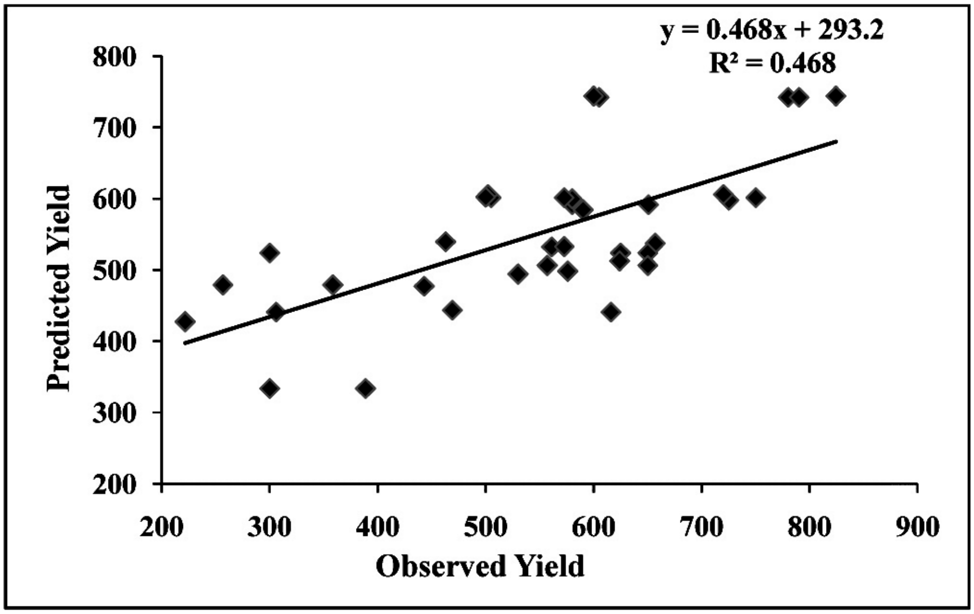
Yield prediction of sugarcane: Model 2

The comparison between observed and predicted yield of sugarcane crop by model 2 has been shown in fig. 2. The yield predicted by model 2 ranged from 333.77q ha-1 to 743.78q ha-1. The RMSE between observed and predicted sugarcane yield was 19.48 while the value of F-test was 15.45 per cent which is significant at 1% probability level. The value of co-efficient of determination (R2=0.468) shows that there is slight improvement in model performance. Higher value of R2 in model 2 reveals that BSS of 1st fortnight from 6 to 7 month of sowing is also a decisive factor in the final yield of sugarcane. The bright sunshine hours allows crop to participate in photosynthetic activities for a longer time. Sugarcane is a tropical plant and responds well to long period of sunlight (12 to 14 hours). A long and warm growing season with adequate long hours of bright sunshine permits rapid growth to build up adequate yield (more tonnage) and a ripening season of around 2-3 months duration having warm days, clear skies, cool nights and relatively a dry weather without rainfall for buildup of sugar are required.[9]

Yield prediction of sugarcane: Model 3

Fig. 3 shows the comparison between observed and predicted yield of sugarcane crop and it was found that yield predicted by model 3 ranged from 310.42q ha-1 to 746.81q ha-1, respectively. The RMSE between observed and predicted sugarcane yield was reported as18.60 per cent while the value of F-test was 12.07 which is significant at 1% level of probability. The value of co-efficient of determination was found to be 0.515 showing the improved performance of the model 3 over the previous two models. The additional parameter considered in model 3 in comparison to model 2 is rainfall, which shows that rainfall will significantly plays an important role in cane development and sugar production. During the active growth period rainfall encourages rapid cane growth, cane elongation and internode formation. Sugarcane is highly dependent on the availability of sufficient amounts of rainfall on a seasonal cycle of wet and dry periods. Without irrigation it grows best in regions with annual rainfall in the range of 1500-2500mm.[10]

Fig. 2 : Comparison between observed and predicted yield: Model 2



Yield prediction of sugarcane: Model 4

The predicted yields by model 4 ranged from 314.81q ha-1 to 770.93q ha-1, respectively. Fig. 4 shows the observed and predicted yield of the sugarcane crop by model 4. The RMSE between observed and predicted sugarcane yield was 18.04 per cent while the value of F-test was 9.85 which is significant at 1% probability level. R2 =0.544 shows that the inclusion of bright sunshine hours of 12th fortnight in the model improved accuracy of the yield prediction. Sugarcane is a sun loving plant and the plant thrives best in tropical hot sunny areas. Being a C4 plant, sugarcane is capable of high photosynthetic rates and the process shows a high saturation range with regards to light. Tillering is affected by intensity and duration of sunshine. High light intensity and long duration promote tillering while cloudy and short days affect it adversely. Stalk growth increases when daylight is within the range of 10-14 hours. Increase in leaf area index is rapid during 3rd to 5th month, coinciding the formative phase of the crop and attained its peak values during early grand growth phase.[11]

Yield prediction of sugarcane: Model 5

Fig.5 shows the comparison between observed and predicted yield of sugarcane crop by model 5. The predicted yields by model 5 ranged from 275.98q ha-1 to 755.28q ha-1, while, observed yield of sugarcane

Fig. 3 : Comparison between observed and predicted yield: Model 3

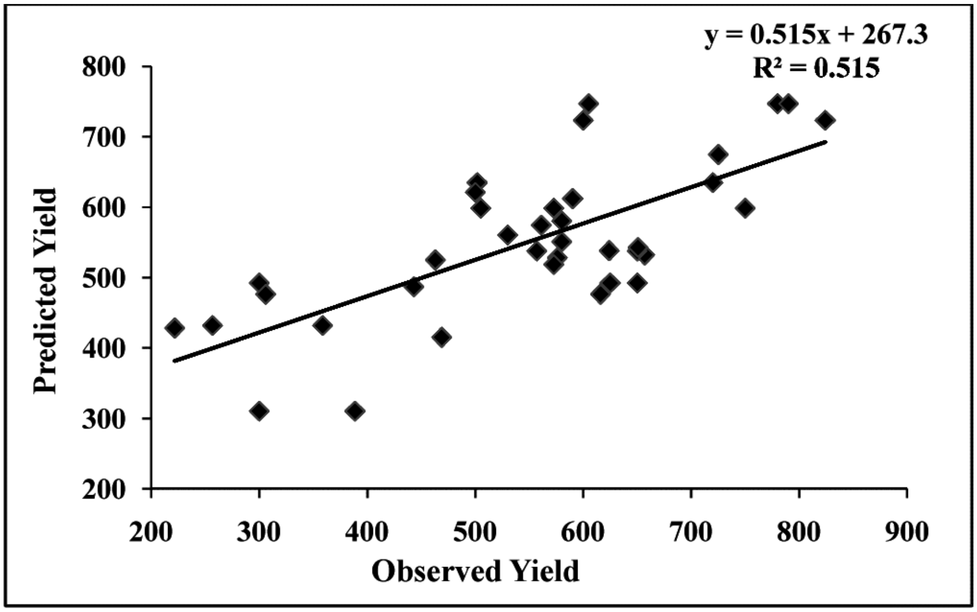
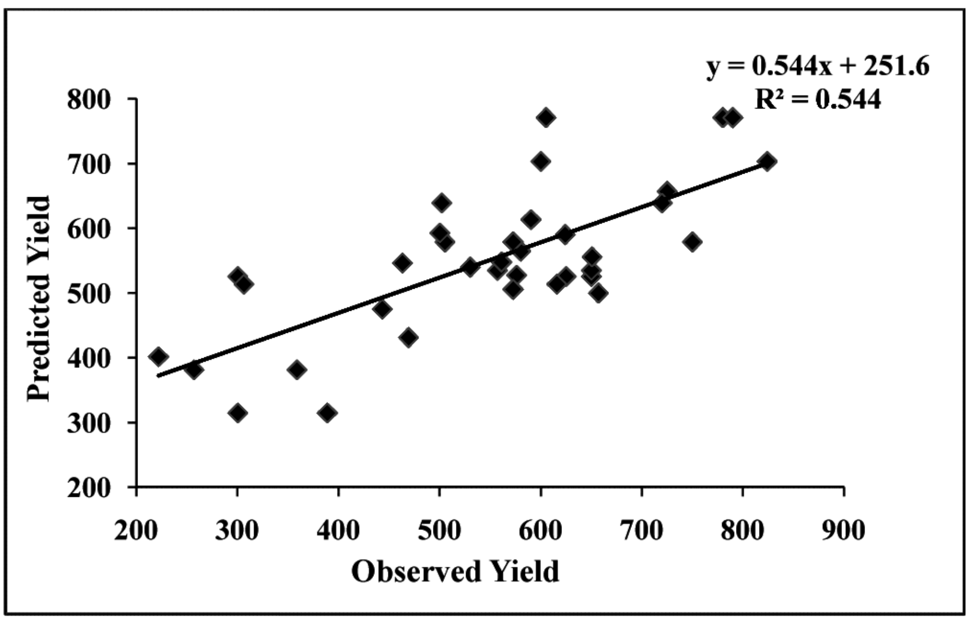


Fig. 4 : Comparison between observed and predicted yield: Model 4



was as discussed earlier. The RMSE between observed and predicted sugarcane yield reduced 17.18 per cent while the value of F-test was 9.09 which is significant at 1% probability level. The scatter plot between observed and predicted sugarcane yield produced R2 as 0.586, which shows that again there is slight improvement in the model accuracy over previous models, which can be attributed to the inclusion of evaporation of 6th fortnight from 6 to 7 month of sowing as independent weather variable. Evaporation does not influence the sugarcane yield directly however it shows the state of atmospheric conditions which will influence sugarcane yield. This stage (Boom stage) is the phase of maximum development in the sugarcane plant and is characterized by increases in stem size, weight and high leaf production. Evaporation at boom stage is the critical climatic factors affecting the variations in crop yield.[12]

Fig. 5 : Comparison between observed and predicted yield: Model 5

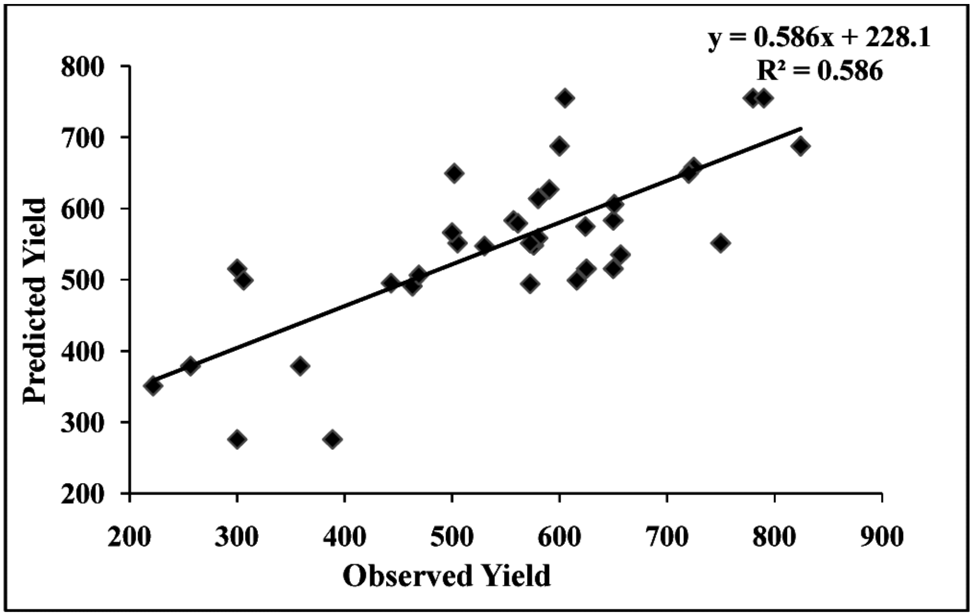
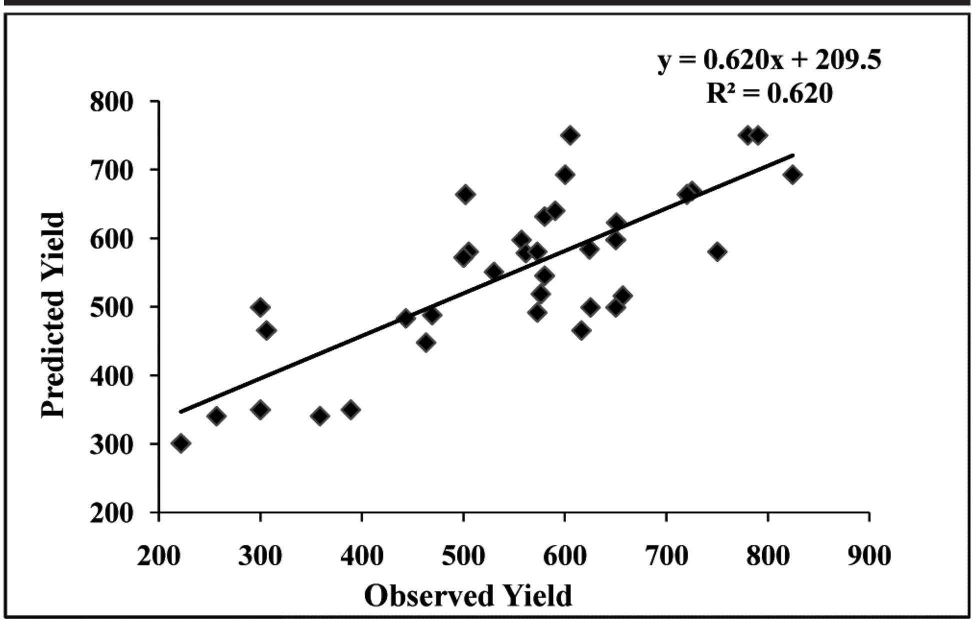


Fig. 6 : Comparison between observed and predicted yield: Model 6



Yield prediction of sugarcane: Model 6

The observed and predicted yields of sugarcane crop by model 6 have been depicted in figure 6. The predicted yield by model 6 ranged from 301.09q ha-1 to 750.18q ha-1. The RMSE between observed and predicted sugarcane yield was found to be16.46 per cent, while the value of F-test was 8.45 which is significant at 1% probability level. The value of co-efficient of determination (R2 = 0.620) shows that the evaporation of 2nd fortnight is also an important factor for the growth of crop. On inclusion of evaporation of 2nd fortnight in the forecast model, forecast accuracy significantly improved.

Yield prediction of sugarcane: Model 7

From the fig. 7 it was found that, there is close relationship between the values of observed and predicted yields of sugarcane crop by model 7. The

Fig. 7 : Comparison between observed and predicted yield: Model 7

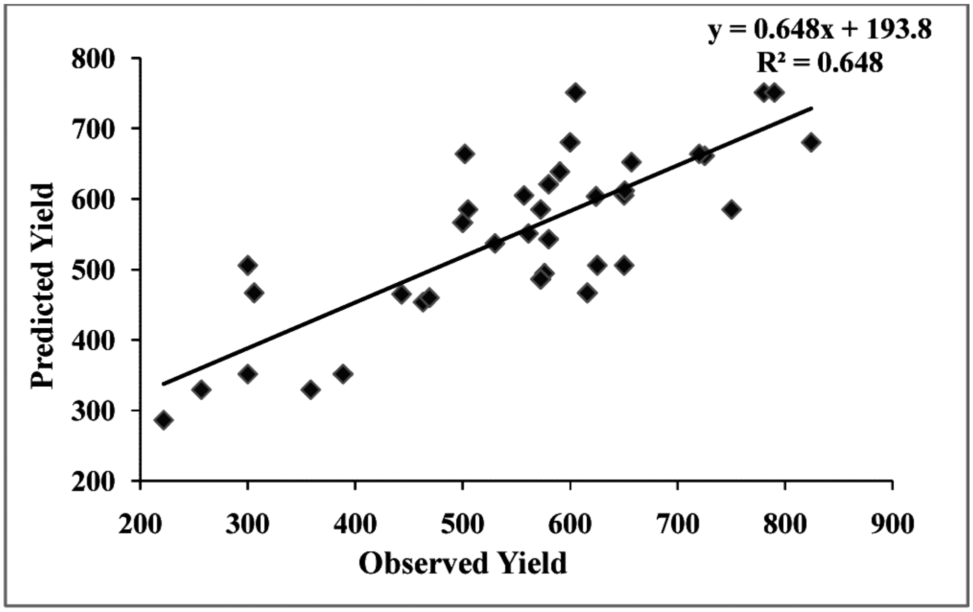
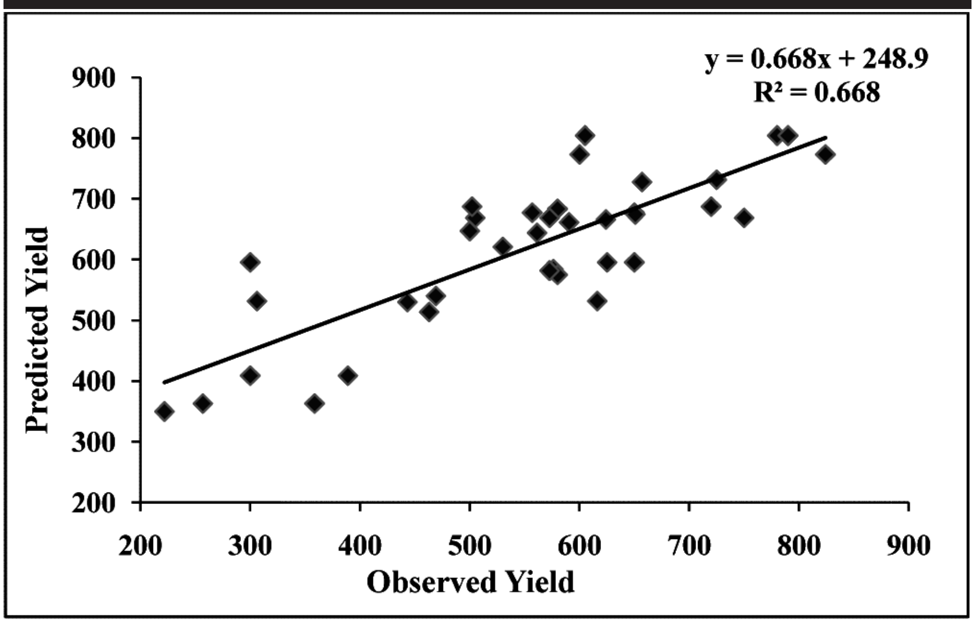


Fig. 8 : Comparison between observed and predicted yield: Model 8



predicted values of sugarcane yield by model 7 ranged from 286.44q ha-1 to 751.35q ha-1 with value of R2 as 0.648. The RMSE between observed and predicted sugarcane yield was reported as15.84 per cent, while the value of F-test was 7.92 (significant at 1% probability level). The addition of weather variable of rainfall of 11th fortnight significantly improved the model performance.

Yield prediction of sugarcane: Model 8

The comparison between the observed and predicted yields of sugarcane crop by model 8 has been depicted in fig. 8. It was found that yield predicted by model 8 ranged from 349.39q ha-1 to 803.76q ha-1. The RMSE between observed and predicted sugarcane yield reduced to 15.49 per cent while the value of F-test was 6.38 (significant at 1% probability level). Inclusion of relative humidity of 6th fortnight from 6 to 7 month after sowing increased the value of co-efficient of determination from 0.648 to 0.668, which is slightly better than the previous meteorological models. Therefore, it can be drawn from the results that the relative humidity of 6th fortnight is also an important weather variable in deciding the final yield of sugarcane in *Tarai* region. High humidities coupled with warm weather favours vegetative growth. Low environmental relative humidity levels can reflect a high vapor pressure deficit (VPD) which directly affects stomatal behavior and transpiration rates. High vapor pressure deficits initially induce high transpiration rates in plants causing them to lose water and turgor and in later stages may result in closure of the stomata and a reduction in the transpiration stream.[13-14-15]

Conclusion

A high degree of variability in the sugarcane yield prediction was observed as shown by the observed yields. Among all models, the performance of the model 8 was superior as compared to other models. The reason is obvious as model 8 incorporated more number of weather variables. These weather variables directly and indirectly affect the growth and development of sugarcane plant. Among all the wind speed of 13th fortnight was most important weather parameter influencing the sugarcane yield in *Tarai* region of Uttarakhand.

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