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Prediction of Pearl Millet Yield Using Crop Water Balance Model for Different Agroclimatic Zones of Gujarat State

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Abstract Water requirement satisfaction index (WRSI) was worked out using a crop water balance (CWB) model in respect of pearl millet crop in various agroclimatic zones of Gujarat State. Different regression models were tried to find out a best fit model to predict and estimate pearl millet productivity at different stations. The best fit curves explained variation in pearl millet yield ranging from a maximum of 94% at Jamnagar to 57% at SK Nagar. A single equation could not predict yield at all the stations, may be because of significant type of climatic conditions prevailing at each place. Statistical attributes like coefficient of determination (R^2) and correlation coefficient (r) between estimated and actual yield indicated that the concept of WRSI could be utilized to predict pearl millet yield in low and erratic rainfall stations of Gujarat state.

Key words water requirement satisfaction index, yield prediction model, pearl millet

The problem of low and erratic rainfall prevails all over arid and semi-arid climates of Gujarat but the degree of problem varies depending upon the amount, distribution and variability of rainfall during rainy season. The concept of Water Requirement Satisfaction Index (WRSI), introduced by Frere & Popov (1979), considers this condition and monitors water availability for a crop on weekly basis taking into account actual rainfall, potential evapotranspiration (PET) and water holding capacity of the soil of the region. Popov (1984) demonstrated the relationship between the WRSI and the yield of groundnut at Bambay, Senegal. Victor *et al.* (1988) have utilized this concept in quantification of pearl millet yields under rainfed conditions of Jodhpur district (Rajasthan), and Srivastava *et al.* (1989) identified commencement of growing season in order to determine the risk of low productivity of groundnut in Rajkot district of Gujarat state. In the present study an attempt has been made to identify the utility of WRSI in predicting pearl millet yield and to find out a suitable prediction model for different agroclimatic zones of Gujarat state.

Materials and Methods

The rainfall data from 1965 to 1989 were collected from the agrometeorological observatories located at Anand, SK Nagar, Rajkot, Jamnagar and Junagadh, the main agricultural research stations of Gujarat Agricultural University (GAU). WRSI based on the Crop Water Balance Model of Frere & Popov (1979) was computed using the values of PET obtained using modified radiation method of Doorenbos & Pruitt (1979). A computer programme was developed for working out WRSI on weekly basis considering total life cycle of the crop as 13 weeks. The whole period was divided into four stages, viz., (a) sowing & establishment (2 weeks), (b) tillering (4 weeks), (c) flowering & earhead emergence (2 weeks), and (d) grain filling & maturity (3+2=5 weeks). Crop coefficients (Kc), viz., 0.5, 0.7, 0.9, 0.7 (for initial 3 weeks of grain filling period) and 0.4 (for last 2 weeks of grain filling period) for different phenophases, respectively, were used to estimate weekly water requirements. The available water holding capacity of the soil profile at 50 cm depth (the effective root zone for the crop) was assumed to be 100 mm for all the stations. The commencement of the growing season, at each station, in each season, was identified as the week in which the rainfall received was higher than the estimated water requirement of the crop. This procedure takes care of the observed yearly variation in actual monsoon onset rather than using a fixed calendar week for sowing period. Thus the WRSI, starting with 100 at sowing and thereafter decreasing as and when water deficit

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Table 1 *Rainfall, yield and WRSI for pearl millet at various stations of Gujarat state*

Station	Rainfall (mm)		Yield (kg ha^{-1})		WRSI (%)		Correlation coefficient (r) yield x WRSI
	Mean	CV (%)	Mean	CV(%)	Mean	CV (%)	
Anand	704	40	1110	26	93	13	0.365
S K Nagar	366	48	559	52	71	39	0.584*
Rajkot	326	55	660	29	85	26	0.862**
Jamnagar	490	48	394	32	81	29	0.836**
Junagadh	726	47	982	35	93	17	0.530**

*,** = Significant at 5 % and 1 %, respectively

(WD) occurred was obtained till the end of the crop period. These values were used to correlate with pearl millet yield data to develop the regression models for predicting yield. The average yield of the district for 25 years(1965 to 1989) were collected from "Agricultural Situation in India" (Government of India, New Delhi). A set of 25 different equations was worked out. Out of these equations the best fit equation identified was one with coefficient of determination (R^2) which indicates the degree of predictability of dependable variable (Productivity).

Results and Discussion

Rainfall, WRSI and yield of pearl millet

The mean and coefficient of variation (CV%) of rainfall, WRSI and productivity were estimated for each station (Table 1). The total rainfall received during the cropping period (13 weeks) was estimated starting from the week receiving rainfall more than the requirement of water for the crop during the week. The mean values of rainfall range from 366 mm at SK Nagar to 726 mm at Junagadh, with a high variability of 40-55 % at all the stations. The average productivity of pearl millet worked out to be 559 kg ha^{-1} at SK Nagar to 1110 kg ha^{-1} at Anand with a coefficient of variation of 52 and 26 %, respectively. The average growing season was found to commence ranging from 25th week at Anand to 29th week at SK Nagar in North Gujarat Agroclimatic Zone. The mean values of WRSI for pearl millet varied from 71 to 93 % depending on the rainfall and water availability to the crop at the individual station. The variation in WRSI values was low at Anand and Junagadh, and higher at SK Nagar, Jamnagar and Rajkot which are low rainfall stations. The relationship between pearl millet yield and WRSI was significantly high at all the stations except at Anand (Table 1).

Development of prediction models for pearl millet at various stations

The predictive equations which have shown the best fit, as well as, the significantly closer fit, were selected from among 25 equations and presented in Table 2. Four equations such as hyperbola, reciprocal hyperbola, parabola and

Table 2 *Types of equations for predicting pearl millet yield in Gujarat*

Station	Best fit equation types	R^2	R	Significant equation types	R^2	R
Anand	Cauchy	0.4204***	0.6484	–	–	–
Junagadh	Reciprocal hyperbola	0.6555***	0.8096	Reciprocal log	0.6375***	0.7984
Jamnagar	Reciprocal log	0.9416***	0.9704	Reciprocal hyperbola	0.9035***	0.9505
Rajkot	Hyperbola	0.7684***	0.7353	Parabola	0.7810***	0.8837
S K Nagar	Parabola	0.5713***	0.7558	–	–	–

*** Significant at 0.1% level of probability

reciprocal log gave the best fit at various stations. An attempt was made to find out a single model for all the stations. But a single model was not possible, may be due to significant difference in the agroclimatological behaviour of the stations (Table 1). However, one type of equation, either the reciprocal log or reciprocal hyperbola type, can be used for Junagadh and Jamnagar stations without loss of significance, while in respect of Rajkot and SK Nagar, parabola type of equation can be adopted for the estimation of yield. Earlier, Victor *et al.* (1988) and Singh & Ramakrishna (1992) found different types of curves such as exponential and reciprocal hyperbola for the same crop, but for different regions like Jodhpur in Rajasthan and Kutch in Gujarat state, respectively, which are also low and erratic rainfall stations.

Prediction models using WRSI values for pearl millet

Junagadh : The relationship between pearl millet yield in kg ha^{-1} (Y) and WRSI % at the end of the growing period (X) was worked out using data for the period of 1965 to 1989. The predictive equation of reciprocal hyperbola type which has given best fit was obtained as :

$$Y = X/(-0.0002751\,X + 0.1237)$$

with, $R = 0.8096$, significant at 0.1 % level at23df

Using this model the variation in pearl millet yield from Junagadh district in south Saurashtra agroclimatic region can be explained maximum upto 66%.

Rajkot : The regression curve found as best fit for Rajkot in north Saurashtra agroclimatic region is of the hyperbola type :

$$Y = 1736 - 718180/X$$

with, $R = 0.8766$, significant at 0.1% level at 8df

The model explained 77% variation in productivity of pearl millet.

Jamnagar : The relationship between pearl millet yield and WRSI for a period of 14 years (1976-89) was worked out.

The closest association was found by fitting reciprocal log of the following type :

$$Y = 1/(0.0153 - 0.003075/X)$$

with, $R = 0.9703$, significant at 0.1% level at 12df

This model explained for about 94% variation in pearl millet yield for Jamnagar district in north Saurashtra agroclimatic zone.

Sardarkrishinagar (SK Nagar) : SK Nagar is located in north Gujarat agroclimatic region where the cropping season commences very late, i.e., from 29^{th} standard week. The correlation between pearl millet yield of Banaskantha district and WRSI was worked out for the period of 1979 to 1989. The predictive equation of parabola type has given the best fit was obtained as :

$$Y = 609.2 - 15.09\,X + 0.1783\,X^2$$

with, $R = 0.7558$, significant at 0.1% level at 9df

Using this model the variation in pearl millet yield from extreme north Gujarat agroclimatic zone can be explained maximum upto 57%.

Relationship between predicted and actual yield data

The yields of pearl millet were estimated using the above predictive equations and were correlated with the actual yields. The correlation coefficients (r) were very high at Rajkot (r = 0.8807) and Jamnagar (r = 0.8400), significant at 0.1% level and high at SK Nagar (r = 0.7566) and Junagadh (r = 0.6168), significant at 1% level.

The predicted values of yield at different levels of WRSI along with the critical value of WRSI below which yield will be less than average are presented in Table 3. The maximum possible yield of pearl millet with WRSI 100 % at the end of season was worked out to be 1039 kg ha^{-1} at Junagadh to 875 kg ha^{-1} at Jamnagar.

Table 3 *Predicted values of pearl millet yield at different levels of WRSI*

Station	Water requirement satisfaction index (%)						Critical* WRSI
	50	60	70	80	90	100	
			Yield (kg ha^{-1})				
S K Nagar	300	345	426	542	695	883	81
Rajkot	172	433	619	758	867	954	73
Jamnagar	305	368	447	547	682	875	84
Junagadh	455	560	670	787	909	1039	96

* Threshold value of WRSI below which yield is less than average

The correlation coefficient between estimated and actual yields revealed a high degree of association at all the regions. The coefficient of determination (R^2) which happened to be an important attribute to indicate the effectiveness of the relationship between yield and WRSI indicated the influence of soil moisture storage during crop period in relation to rainfall pattern at individual stations. From R^2, it can be inferred that irrespective of the form of the equation, WRSI proved to be able to explain maximum variation in the yield of pearl millet crop at all the low and erratic rainfall regions of Gujarat state.

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