

## Rainfall-yield relationships in rainfed sorghum in India

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**सार**— वर्षा में उतार-चढ़ाव और इसके बंटन के कारण वर्षाश्रित खेती के अन्तर्गत उत्पादन व उत्पादकता में बहुत अधिक उतार-चढ़ाव आता है। बारानी खेती के लिए अखिल भारतीय समन्वित परियोजना के द्वारा पिछले दशक में प्राप्त आंकड़ों को पैदावार व वर्षा के संबंध को विकसित करने के लिए प्रयुक्त किया गया है।

कुल वर्षा तथा उसका वितरण पैदावार को प्रभावित करते हैं। साप्ताहिक वर्षा व पैदावार के बीच सह-संबंध को आधार मानकर बीज की बुवाई के समय बड़वार के मौसम को विभिन्न समयान्तरों में बांटा गया है। प्रागुक्ति के लिए विभिन्न निदर्शों को आजमाया गया था। हैदराबाद, झांसी, उदयपुर तथा अकोला इन चार स्थानों की मानसूनी ज्वार फसल का अध्ययन किया गया था।

बीजारोपण में विलम्ब से ज्वार की पैदावार कम होती है। हैदराबाद में 8 से 10, झांसी में 6 से 12, उदयपुर में 3 से 6 तथा अकोला में 11 से 13 सप्ताह विशेष रूप से वर्षा होती है। उदयपुर में 9 से 11 सप्ताह के दौरान अत्यधिक वर्षा से पोलन-वाश और या/पतन के कारण पैदावार कम होती है। आजमाए हुए निदर्शों से इस फसल की पैदावार के संबंध में काफी हद तक प्रागुक्ति की जा सकती है।

**ABSTRACT.** The variation in rainfall and its distribution causes high fluctuations in production and productivity under rainfed agriculture. The data generated during last decade by All India co-ordinated Project for Dryland Agriculture were used for developing yield rainfall relationships.

Total rainfall and its distribution affected the yield. Based on the correlations between yield and weekly rainfall from time of seeding, the growing season was divided into different periods. Various models were tried for prediction. The study was carried out for monsoon sorghum crop for four locations, viz., Hyderabad, Jhansi, Udaipur and Akola.

Delayed seeding reduces the yield of sorghum. The crucial periods for rainfall are 8-10, 6-12, 3-6, 11-13 weeks for Hyderabad, Jhansi, Udaipur and Akola respectively. At Udaipur, high rainfall during 9-11 weeks reduces the yield possibly due to pollen wash and/or lodging. With the models tried, it is possible to predict the yield of this crop with higher degree of predictability.

### 1. Introduction

Seasonal variations in production and productivity of dryland crops, in general, are high. The major factor causing the variation is rainfall—its quantity and distribution. Knowledge of rainfall-crop yield relationships helps in stabilising and increasing the production by developing suitable management practices. However, availability of experimental data under rainfed conditions is highly restricted. It is not feasible to arrive at models with high predictability based on historical data as the cultivars and management vary from year to year. The yield levels vary considerably between experimental farm and farmers' fields. However, the trends in production would be similar if the same cultivars and management techniques are adopted. Therefore, the research data generated during the last one decade by the All India Co-ordinated Research Project for Dryland Agriculture, India, have been used for analysis. The objectives of the present study are (i) to identify the important periods during which rainfall

affect the yield and (ii) to develop some suitable agronomic manipulations to stabilise yield.

It is well known that moisture variations at certain critical stages of crop growth cause variations in yield. Day-to-day moisture fluctuations definitely have some effect on biological system. The best relationships can be obtained by monitoring soil moisture but it is difficult to do so in the monsoon season because of intermittent rains. However, soil moisture fluctuations are directly related to rainfall.

For comprehensive analysis of crop-weather relationships, multiple regression techniques have been used right from 1924 onwards. Fisher (1924) in studies of influence of rainfall on yield of wheat assumed that the effect of change in weather variations in successive weeks would not be an abrupt or erratic change but follows some mathematical law. In his paper, Fisher reduced the number of variables to seven by assuming the effect of weeks are composed of the terms of a

TABLE 1  
Characteristics of the centres

Location	Soil type	Normal rainfall (mm)
Jhansi	Red-shallow to medium	930
Akola	Black-medium to deep black	830
Hyderabad	Red-shallow to medium	770
Udaipur	Black-light to medium	635

polynomial function of time. Hendrics and Scholl (1943) modified Fisher's technique by assuming second degree polynomials and thus reducing the independent variables to 4. Hendrics and Scholl (1943) and Runge (1968) have used this model for studying the joint effect of temperature and rainfall on crop yield. Huda *et al.* (1975) have studied the effect of individual climatic factors on rice and maize yield using the above model.

In all the models used by earlier workers equal weightage was given for the weeks of growing period. However, it is well known that there are specific growth stages during the growing season when a high or low rainfall would drastically affect the total yield. The final yield is a resultant of the responses at different crop growth stages to meteorological factors. In rainfed agriculture, where moisture is one of the most limiting factors, the crop yields are all the more affected by the fluctuations in rainfall at critical stages.

In this paper, attempts are made to study the relationship of the amount of rainfall received at different stages of crop growth with the yield.

## 2. Materials and methods

The analysis is carried out using data from four locations, *viz.*, Hyderabad, Jhansi, Udaipur and Akola where sorghum is grown as a monsoon crop. The characteristics of the locations are presented in Table 1.

Sorghum under rainfed conditions was grown at all the four locations. Depending on the rain and water holding capacity of soil, the varieties differed in duration from 90 to 110 days.

The yield data for the analysis have been computed from different experiments under high management for the same variety at a particular centre. The number of years varied from location to location.

Since seeding of dryland crops depends essentially upon the onset of monsoon, the time of seeding varied from year to year in each location. Therefore, while computing the rainfall for different weeks the average date of seeding of the experiments considered for analysis was used as the starting point.

The study was confined to a single cultivar at any given location. Weekly rainfall from the date of seeding was determined for each location. Correlation and regression techniques were adopted. Correlations between yield and weekly rainfall were worked out

Based on the correlations between weekly rainfall and yield and the physiological stages of crop, the growing season was divided into different periods. The following models were tried for predicting the yield:

$$Y = \alpha + \sum_{i=1}^k \beta_i < p_i \quad (1)$$

$$Y = \alpha + \beta_1 W + \sum_{i=1}^k \beta_i + {}_1 p_i \quad (2)$$

$$Y = \alpha + \sum_{i=1}^k \beta_i p_i \quad (3)$$

$$Y = \alpha + \beta_1 W + \sum_{i=1}^k \beta_i + {}_1 p'_i \quad (4)$$

$$Y = \alpha + \beta I \quad (5)$$

$$Y = \alpha + \beta_1 W + \beta_2 I \quad (6)$$

Where,

$p_i$  is rainfall in the  $i^{\text{th}}$  period.  $p'_i$  is  $\log p_i$ .  $W$  stands for week of sowing (Meteorological standard week) and

$$I = \sum_{i=1}^k \log_e p_i$$

In the models tried, the seeding week was introduced as a variable because with late seeding, pests such as shootfly and earhead bug take a heavy toll of yield (All India Co-ordinated Research Project for Dryland Agriculture, Hyderabad 1978). Since the higher rainfall would not cause proportionate increase in yield, logarithmic transformation of rainfall was used in models 3 and 4. In order to give weightage to low rainfall in any period and to reduce the number of variables an index is developed and used (models 5 and 6).

## 3. Results and discussion

Maximum and minimum rainfall received during crop growth period and corresponding yield on one hand and the maximum and minimum yield recorded and the corresponding rainfall received in different locations on the other hand are presented in Table 2. A perusal of the table indicates that the total rainfall is not the only important factor. For example, at Udaipur centre, maximum yield of 6480 kg/ha was recorded with a rainfall of 255.1 mm, while with the highest rainfall of 471.6 mm, only 3800 kg/ha was harvested. In fact with heavy rainfall, water logging would be a problem and may even reduce yields drastically. This means that in heavy black soils, a major portion of the rainfall is not utilised by the crop. On the other hand, in the light red soils, the maximum yield corresponds with the highest rainfall (*e.g.*, Hyderabad).

The correlations between yield and seeding time and weekly rainfall have been worked out. Based on these

TABLE 2

Maximum and minimum rainfall received with corresponding yield and maximum and minimum yields with corresponding rainfall in different centres

Centre	Maximum rainfall (mm)	Yield (kg/ha)	Minimum rainfall (mm)	Yield (kg/ha)	Maximum yield (kg/ha)	Rainfall (mm)	Minimum yield (kg/ha)	Rainfall (mm)
Hyderabad	372.9 (4-10)	4740	22.7 (4-10)	1360	5370	299.8 (4-10)	960	129.7 (4-10)
Jhansi	695.2 (6-12)	2240	25.2 (6-12)	290	2470	307.1 (6-12)	0	78.5 (6-12)
Udaipur	471.6 (3-11)	3800	194.3 (3-11)	2830	6480	255.1 (3-11)	2490	246.5 (3-11)
Akola	437.5 (6-13)	3980	137.9 (6-13)	3320	4100	420.0 (6-13)	2200	217.0 (6-13)

Figures in parantheses are week numbers of crop growth.

TABLE 3

Average yield and correlations with seeding time and log transformed rainfall (mm) in different periods at various locations

Centre	Average yield (kg/ha)	Seeding time (in std. Met weeks)	Period (in weeks) after sowing	Correlations with		No. of sets of data
				Rainfall	log transformed rainfall	
Hyderabad	3552	23-26	—	-0.56	—	9
			4.5	0.58	0.79**	
			6.7	-0.36	0.03	
			8-10	0.84	0.94**	
Jhansi	1548	24-31	—	-0.32	—	11
			6.7	0.31	0.50	
			8.9	0.64*	0.72*	
			10.12	0.61*	0.88**	
Udaipur	4460	25-29	—	-0.73*	—	9
			3.6	0.45	0.45	
			7.8	-0.22	0.04	
			9-11	0.46	0.55	
Akola	3330	26-29	—	-0.66*	—	8
			6.7	0.49	0.78*	
			8-10	-0.63	-0.35	
			11-13	0.68*	0.44	

\*significance at 5% level, \*\*significance at 1% level

correlations, the weeks were grouped into different periods. For all the locations the correlations between yield and rainfall during early weeks are low. This is probably due to high stability in rainfall in the beginning compared to later part of the season and low water requirement by the plants at early stages. The correlations between yield and seeding time, rainfall (mm) during the period and log transformed rainfall are presented in Table 3. A perusal of the results indicates that the seeding time is negatively correlated with yield at all locations and this significantly influences the yields at Udaipur and Akola centres. The rainfall during later stages of crop growth has greater influences on the yield. This stage broadly coincide with the milk stage to grain filling stage. In general, poor or negative correlations were observed with 6-7 weeks of crop

TABLE 4

R<sup>2</sup> values for different yield — rainfall relationships in different centres

Model	Hyderabad	Jhansi	Udaipur	Akola
1. $Y = a + \sum_{i=1}^k \beta_i < p_i$	0.76*	0.75*	0.42	0.61
2. $Y = a + \beta_1 W + \sum_{i=1}^k \beta_i + 1 p_i$	0.80	0.77*	0.83	0.94*
3. $Y = a + \sum_{i=1}^k \beta_i p_i$	0.93**	0.82**	0.71	0.82
4. $Y = a + \beta_1 W + \sum_{i=1}^k \beta_i + 1 p_i'$	0.95**	0.86**	0.83	0.93*
5. $Y = a + \beta I$	0.64**	0.79**	0.50*	0.38
6. $Y = a + \beta_1 W + \beta_2 I$	0.67*	0.84**	0.61	0.57

growth at Hyderabad, Jhansi and 7-8 at Udaipur and 8-10 weeks at Akola. This period mainly coincides with flowering and high rainfall at that stage may result in pollen wash and lodging. By and large, log transformed rainfall improved the correlation coefficients which shows that variation in rainfall does not produce proportionate variations in yield.

The values of coefficient of determination by different models are presented in Table 4. Rainfall quantity transformed to log scale explained much higher variation than the rainfall. Substantial increase in R<sup>2</sup> — value was observed by including time of seeding in case of Udaipur and Akola centres which implies early seeding is a must in these centres. The centrewise results are discussed.



**Hyderabad**—Nine years data from 1972-80 was considered for CSH-6 cultivar for the analysis. The seedings were done during 23-26 standard weeks and the yield varied from 960 kg/ha to 5370 kg/ha. The rainfall during the weeks 4-10 appear to influence the yield (Table 3). Based on the correlations between weekly rainfall and yield, the weeks are grouped into three periods comprising 4-5, 6-7 and 8-10 weeks. About 70% of yield variations are caused by the variations in rainfall in the third period. This period coincides with dough stage and grain filling stage. Even though seeding time is negatively correlated with yield, inclusion of this variable did not improve the predictability substantially. This indicates that some of the ill effects of late seedings are compensated by the subsequent rainfall because the duration of crop is about 90 days only. The best model for predicting the yield is :

$$Y = 4632 - 222W - 155 p_1' - 470 p_2' + 1546 p_3'$$

(222)    (228)    (230)    (372)

$$R^2 = 0.95^{**}$$

where  $Y$  represents yield(kg/ha.)  $W$  represents week of seeding (Meteorological standard week) and  $p_1'$ ,  $p_2'$  and  $p_3'$  represent logarithm of rainfall during 4-5, 6-7 and 8-10 weeks respectively.

**Jhansi**—Sorghum 302 variety was cultivated from 1974-79. During 1977 and 1978, dates of seeding experiment was conducted with three different dates. Thus, eleven sets of data was considered for the analysis. The yield varied from 0-2470 kg/ha and seeding time varied from 24th to 31st standard week (Table 3). The rainfall during the period 6-12 weeks appear to influence the yield. The weeks were grouped into three periods of two weeks interval, which broadly coincides with physiological stages, viz., flowering, soft dough and grain filling stages. The best model for predicting the yield is

$$Y = -3525 + 102W + 116 p_1' + 197 p_2' + 290 p_3'$$

(82)    (200)    (131)    (85)

$$R^2 = 0.86^{**}$$

where  $Y$  represents yield kg/ha,  $W$  represents week of seeding (Meteorological standard week) and  $p_1'$ ,  $p_2'$  and  $p_3'$  represent logarithm of rainfall during 6-7, 8-9, 10-12 weeks respectively. This implies that rainfall distribution during the period 6-12 weeks is important and any deficit in any week decreases the yield. Rainfall during grain filling stage is much more important for the success of this crop in this region.

**Udaipur**—The data pertain to nine years, i.e., 1974 to 1982 for CSH-5 hybrid sorghum. The yield of this hybrid varied from 2490 to 6480 kg/ha. The seeding time varied from 25th to 29th standard week. The rainfall fluctuation in all the weeks of crop growth are high over seasons. The rainfall during the 3-11 weeks appear to influence the yield. The growing season was divided into three periods, viz., 3-6, 7-8 and 9-11 weeks. Delayed seeding reduces the yield drastically. About 53% of yield variations are caused by the seeding time itself. Substantial increase in predictability was observed whenever the seeding time was also included in the model. The variations accounted by rainfall by using any model is less compared to other locations discussed above. This may be due to the higher mois-

ture holding capacity of the soil or some other environmental factor, probably the temperature. The best model is :

$$Y = 32360 - 1128W + 12.04 p_1 + 2.56 p_2 - 6.92 p_3$$

(361)    (4.94)    (3.14)    (6.01)

$$R^2 = 0.83$$

where  $Y$  represents yield (kg/ha.)  $W$  represents seeding week (Meteorological standard week) and  $p_1$ ,  $p_2$  and  $p_3$  represent rainfall during 3-6, 7-8 and 9-11 weeks respectively. A comparison of regression coefficients reveal that the rainfall is important in earlier period while high rainfall in 9-11 weeks reduces the yield which may be due to lodging or pollen wash.

**Akola**—Eight years yield data for CSH-5 hybrid (1974-77 and 1979-82) was used for the analysis. The yield varied from 2200 to 4100 kg/ha. Seeding time varied from 26-29 standard weeks. Based on the correlations between weekly rainfall and yield, the important period where rainfall is needed are 6th-13th weeks (Table 3). The negative correlation with 8-10 weeks rainfall (-0.63) indicate that the crop yield reduces with high rainfall around 9th week. This may be due to other pollen wash or lodging. About 44% yield variation is caused by seeding time variations. Delayed seeding reduces the yield. Three periods were identified (6-7, 8-10 and 11-13) for model fitting. Substantial increase in predictability was observed by inclusion of seeding time in the model. The best prediction equation is :

$$Y = 14007 - 428W + 80 p_1 - 92 p_2 + 241 p_3$$

(203)    (240)    (119)    (73)

$$R^2 = 0.93^*$$

where  $Y$  represents yield kg/ha,  $W$  represents seeding week (Meteorological standard week) and  $p_1$ ,  $p_2$  and  $p_3$  represents rainfall during 6-7, 8-10 and 11-13 weeks respectively.

A peursal of regression coefficients indicate that good rainfall is necessary during 11-13 weeks (grain filling stage) for good harvest of this crop.

#### 4. Conclusions

Distribution of rainfall rather than total rainfall is important in determining the sorghum yields. The rainfall at grain filling stage is crucial for this crop. Delayed seeding reduces the yield of this crop. By considering the amounts of rainfall during certain crucial stages of crop growth (after transforming to logarithmic scale) it is possible to explain more than 83% of variation in sorghum yield.

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#### References

- 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.
- Hendrics, W.A. and Scholl, J.S., 1943. Techniques in measuring Joint relationships, The joint effects of Temperature and precipitation on crop yield, N. Carolina Agric. Exp. Station, Tech. Bull., 74.
- Huda, A.K.S., Ghildyal, B.P., Tomar and Jain, R.C., 1975, Contribution of climatic variables in predicting rice yield, *Agric. Met.*, 15, 71-86.
- Runge, E.C.A., 1968, Effects of rainfall and temperature interactions during growing season on corn yield, *Agron. J.*, 60, 503-507.