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Response of sorghum yield to weather under semi-arid conditions in Dhule region of Maharashtra

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ABSTRACT

A long-team agroclimatic analysis of rainfed sorghum (*Sorghum bicolor(L)* under semiarid conditions in Dhule region of Western Maharashtra Scarcity Zone (WMSZ) was carried out using Fisher's technique. The mean sorghum yield in the region has a very high coefficient of variability of 61.5%; time trend alone explained 61% interannual variability in sorghum yields. Rainfall distribution, wind speed and minimum temperature accounted for 77,42 and 34% of the interannual variance in grain yield. That yield is related to transpiration is evident but water shortages at critical times have profound effect on yield and therefore, make linear or curvilinear relationships unreliable. Wind protection is proposed in order to reduce advective energy supply and turbulent transport from the transpiring crop surface, as well as dehydration and leaf senescence of the sorghum crop.

Key words : Yield response, Fisher method, Rainfed sorghum.

Sorghum is the major rainfed crop cultivated in *kharif* season in the northern part of the Western Maharashtra Scarcity Zone (WMSZ) where mean annual rainfall varies between 500 and 700 mm. However, the probability of 500 mm of rainfall is only 40% (Sarker and Biswas, 1986). Sorghum remains an important crop, although its average water use is about 10% greater than that of pearl millet (Kanemasu *et at*, 1984). There is, therefore, considerable interest and economic importance in the crop. A detailed agrometeorological investigation was undertaken in order to determine the effect of climatic variability on sorghum yields and to consider some possible agrotechnologies that can be attempted to stabilize and possibly increase crop yields in the northern part of the WMSZ.

MATERIALS AND METHODS

Meteorological data for the period 1965-90 of Dhule observatory collected from the IMD, Pune and the sorghum yield data for the same period obtained from the Directorate of Agriculture, Maharastra State were analyzed on a weekly basis and according to phenological stages of the crop raised on medium deep (30 to 60 cm depth) and deep (0.6 to 1 meter depth) vertisols and planted mostly with CSH-5 and CSH-9 sorghum varieties. The crop requires some 15 weeks to reach maturity, is usually sown in the last week of June. After detailed scrutiny and verification, 20-year data set of sorghum yields and climatic data was used in this study.

Standard statistical analysis such as simple linear, non-linear regressions, multiple regressions was carried out to relate the climatic data to the sorghum yields. Fisher's orthogonal polynomial of the fifth degree was used which has also been applied by Gangopadhyay and Sarker (1965), Lomas and Shashoua (1973), Sarker (1984) and Lomas (1998). The method computes partial regression equations for various meteorological distribution constants, which are correlated with the yield. A partial regression was then fitted to the data of yield deviations as dependent variates and similar deviations of rainfall distribution constants as independent variates. Finally coefficients ('a') of response curve are calculated and the resultant equations are plotted. The response curves indicate effect of an additional increment of a unit of weather element above average on the yield during its growing season.

RESULTS AND DISCUSSION

The mean sorghum yield in this region is 657 kg ha^{-1} ± 404 kg with very high coefficient of variation of (61.5%) indicating extreme inter-annual yield variability. During the period under study (1967-1990) there has been a significant increase in sorghum yields from 300 kg ha^{-1} to some 1500 kg ha^{-1}. Thus time trend accounted for about 61% of the inter-annual variability of crop yields and was highly significant at 1% level. The relationship between average climatic conditions during the sorghum-growing season and sorghum yields was very poor (Table 1), for example, growing season rainfall accounted for only 4-7% of inter-annual yield variability depending upon the statistical method of analysis used. The only statistically significant result between climatic elements and sorghum yields obtained on a crop seasonal basis are those with minimum temperature Tmin (r=0.58), wind speed (r=0.65) and the mean daily duration of sunshine hours (r=0.37). Dividing the sorghum growth and development period into 5 phytophases brought out the significant relationships between Tmin and vegetative development and wind speed and grain filling stages.

Effect of rainfall on sorghum yield

Surprisingly poor results obtained between rainfall and sorghum yields led to a more detailed examination of the effect of rainfall distributoin on crop yields. This was achieved by considering the linear relationship of weekly amounts to sorghum yields (Table 2). A significant relationship to crop yield with rainfall during week 14 (physiological maturity stage) accounted for 31% of the inter-annual variability. In spite of the fact that 14 out of the 15 weekly rainfall periods were not significantly related to sorghum yields, a multiple regression between all 15 weekly rainfall periods and the yield, gave good results (R^2=0.77).

Correlating the rainfall distribution constants with yields by Fisher's method (Table 3), gave fairly good results (R=0.53 significant at 5%level) and using the 'A' values obtained by equation given in table 4, a respo nse curve was drawn (Fig.1) showing the expected average effect on sorghum yield (kg ha^{-1} mm^{-1} during the first 3 weeks to approximately 0.1 kg ha^{-1} mm^{-1} during the next 3 weeks. However, during the grain filling period additional rainfall above the mean value has a very beneficial effect increasing sorghum yields by 0.1 - 0.3

Table 1: Correlation coefficients between the climatic elements and sorghum yield

Climatic elements	Emergence I	Vegetative II	Anthesis III	Grain filling IV	Maturity V	Seasonal Linear	Quadratic
Tmax (°C) Mean	34.3	33.2	31.4	31.2	32.8	32.4	
SD	2.48	0.98	1.0	1.37	1.8	0.78	
r	-0.08	0.12	-0.02	-0.01	-0.13	-0.26	-0.26
Tmin (°C) Mean	25.7	24.1	22.9	22.5	21.7	23.2	
SD	0.71	0.54	1.47	0.95	1.49	0.54	
r	-0.03	0.41#	0.23	0.24	0.25	0.58*	0.73*
RHI (%) Mean	79.9	82.6	85.1	86.6	84.9	84.2	
SD	4.96	3.29	3.2	3.08	4.61	2.55	
r	0.02	0.003	0.031	0.02	0.09	0.34	0.66
RHII(%) Mean	53.7	59.2	64.6	62.3	52.0	59.4	
SD	6.69	5.59	4.67	8.24	10.63	3.84	
r	0.001	-0.001	0.078	0.036	0.17	0.3	0.56$
Wind Mean	9.7	8.6	7.9	6.8	6.1	7.7	
(km hr^{-1}) SD	1.65	1.11	1.46	1.25	1.28	0.75	
r	-0.25	-0.22	-0.05	-0.52$	-0.01	-0.65*	-0.69*
Sunshine Mean	4.9	4.0	3.5	4.5	6.7	4.6	
(Hr) SD	1.31	0.92	1.05	1.63	1.72	0.67	
r	-0.17	0.0	-0.05	-0.08	-0.09	0.37	0.38#
Rainfall Mean	123.8	150.2	85.6	129.2	46.7	537.0	
(mm) SD	87.46	68.86	82.34	79.73	53.07	123.0	
r	-0.2	-0.001	0.001	0.02	0.17	0.18	0.28
PET (mm) Mean	34	120	114	147	53	468	

Significance at 1% (*), 2% ($) and 10% (#) level.

kg ha^{-1} mm^{-1}. Thus the timing of the importance of soil moisture as affected by rainfall, the percentage of variance of inter-annual crop yields explained by most methods of analysis is surprisingly low (Table 5). This indicates that rainfall is not the only climate elements affecting yield and indeed for most of the first 6 to 7 weeks of the growth, above normal rainfall has a negative effect on final yield. As can be seen, the best relationship has been obtained by the use of a multiple regression between weekly rainfall amounts and sorghum yields.

Effect of temperature on sorghum yield

There was no significant relationship between mean Tmax and sorghum yields. All correlation coefficients were negative with the exception of the relationship during

Table 2 : Correlation between weekly rainfall and sorghum yields.

Phases	Rainfall weeks	Correlation coefficient {r}
Emergence	1	-0.16
	2	0.05
Vegetative	3	0.03
	4	-0.04
	5	0.04
	6	-0.09
Anthesis	7	0.35
	8	0.11
	9	-0.24
Grain filling	10	-0.24
	11	0.09
	12	0.18
	13	0.05
Maturity	14	0.56*
	15	0.01

* significant at 1% level

the vegetative period (Table 1). The mean Tmin during the entire growing season showed a significant relationship ($r = 0.58$ significant at 1% level) with yields indicating that the better yields were obtained at the higher mean Tmin. For the phytophases the only significant relationship between mean Tmin and sorghum yields was during the vegetative period ($r = 0.41$ significant at 10% level).

The negative effect of weekly mean Tmax is confirmed by Fisher's analysis (Fig 2-a) throughout the crop grouth. This is

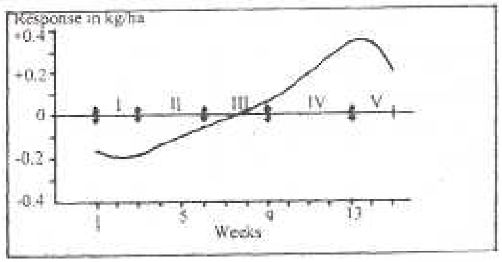

Fig. 1 : Response of rainfall to sorghum yield

more evident at sowing and germination and at the end of the grain filling period. At germination, mean Tmax are 34.3 ± 2.5°C which may be outside the optimum temperature range of 21-35 °C (Peacock, 1982). A yield reduction of 0.4 to 0.5 kg ha^{-1} $°C^{-1}$ at temperatures above 36 °C may be the result. The negative effect of Tmax at the end of grain filling period (week 13-14) when temperatures are at the range of 32-33 °C and gradually rising, could be due to the fact that at air temperatures above 30 °C the rate of grain fill does not increase while the duration of filling is reduced (Chowdhury and Wardlaw, 1978).

There is a significant positive response to increase in the Tmin (Fig. 2-b), particularly during the vegetative stage. Fisher's analysis indicates an increase in yield of 32-35 kg ha^{-1} $°C^{-1}$. Higher mean Tmin, particularly during the vegetative period, will on the one hand increase respiration (Mahalaxmi, 1978) by about 15% for every 1 °C (Eastin, 1982) but at the same time enhances growth and leaf area development (Logan, 1981). On balance this may have a beneficial effect on net photosynthesis.

Table 3 : Correlation coefficients of yield with meteorological distribution constants

Weather Parameter	A`	B`	C`	D`	E`	F`
Rainfall	0.15	0.30	-0.01	0.13	-0.28	-0.15
Tmax	-0.28	-0.04	-0.31	0.20	-0.17	0.27
Tmin	0.61	0.51	-0.30	0.29	0.31	0.21
RH II	0.22	0.14	0.15	-0.05	0.16	-0.37
RH I	0.32	0.31	0.20	0.0	0.15	-0.17
Sunshine	-0.39	-0.16	-0.21	0.34	-0.05	0.29
Wind	-0.65	0.08	0.03	0.04	0.43	0.20

The series of six constants (A`, B`..) for weekly meteorological elements obtained from Fisher and Yates (1943) represent the amount and distribution of an element in each season

Table 4: Equations of response curve

Rainfall	$A=0.046+0.0408\xi_1+0.00052\xi_2-0.00067\xi_3-0.00014\xi_4-0.000035\xi_5$
Tmax	$A=-3.714-0.0207\xi_1-0.0317\xi_2+0.00418\xi_3+0.000823\xi_4+0.000148\xi_5$
Tmin	$A=33.671-0.325\xi_1-0.0298\xi_2+0.0322\xi_3-0.00384\xi_4-0.000195\xi_5$
Wind	$A=-16.0315+0.4226\xi_1+0.0227\xi_2+0.0271\xi_3+0.00454\xi_4+0.000292\xi_5$
Sunshine	$A=-13.3984+0.2812\xi_1-0.02938\xi_2+0.01746\xi_3-0.001855\xi_4+0.000199\xi_5$
RH II	$A=1.857+0.097\xi_1+0.00881\xi_2-0.0027588\xi_3-0.000275\xi_4-0.00022\xi_5$
RH I	$A=1.646+0.043\xi_1+0.00356\xi_2+0.000403\xi_3+0.000193\xi_4-0.0000117\xi_5$

ξ is an orthogonal polynomial of fifth degree obtained from the statistical tables given by Fisher and Yates (1943). `A' is a continuous function of time and represent the average increase in yield for unit increase in the meteorological factor at any time of the period considered.

Effect of wind velocity on sorghum yield

Surprisingly, among all the climatic elements wind gave the highest negative correlation with sorgum yields (r = -0.65 significant at 1% level (Table 1); the grain filling period being the most sensitive period (r= -0.52 significant at 2% level). As during this developmental stages the sorghum crop may be water stressed; dry winds (Table1) will have a dessicating effect on the crop. The negative effect of wind can best be seen by Fisher's method of analysis (Fig. 2-c). Wind speed above the mean values by

Table 5: Percentage of variance of sorghum yields accounted for by the different methods of analysis

	Statistical analysis	R^2
1.	Bivariate regressions	
1.1	Linear regression	0.03
1.2	Quadratic regression	0.08
2.	Multiple regression	
2.1	Phenological crop stages rainfall periods	0.04
2.2	15 weekly rainfall periods	0.77
3.	Fisher's orthogonal polynomial 15 weekly rainfall periods	0.28

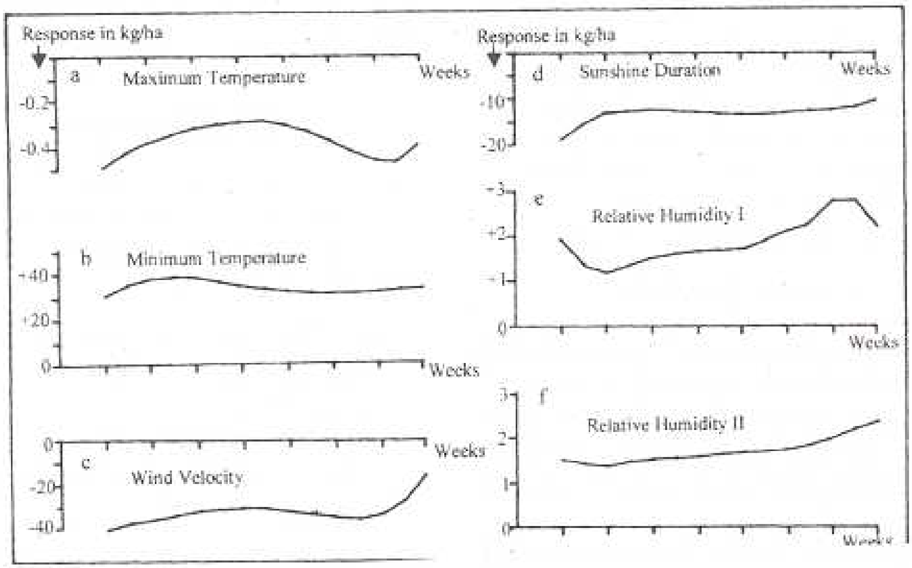

Fig. 2 : Response of temperature, wind velocity, sunshine and relative humidity to sorghum yield

1 km^{-1} will reduce sorghum yields by 15-20 kg ha^{-1} during 13th week of its growth period. The negative impact of wind may be due to a number of effects, such as increased evaporation due to the advective energy load and the enhanced turbulent transport of

vapour, both processes affecting evapotranspiration. Even with a leaf area index of 2, evaporation from the crop field is about 50% of the evapotranspiration (Oswal, 1994). Excessive wind especially in semi-arid regions will also cause dehydration and quicken senescence of the plant thus reducing crop yields.

Effects of sunshine and relative humidity on sorghum yield

Fisher's method indicated a negative response to an additional hour of sunshine above the mean values ranging from 20 kg $ha^{-1}hr^{-1}$ at germination to 12 kg $ha^{-1}hr^{-1}$at maturity, indicating that sunshine duration was not limiting sorghum production (Fig. 2-d). No significant relationship was found between relative humidity and sorghum yields. Fisher's method of analysis showed only a marginal response of 1-2.5 kg ha^{-1} $1\%^{-1}$ humidity (Fig. 2-e and f).

CONCLUSION

The agroclimatic analysis indicates that rainfall distribution, especially at the end of the growing season, wind speeds at the grain filling period and higher minimum temperatures during the vegetative period are the most important climatic factors limiting sorghum yields. That yield is related to transpiration is evident but water shortages at critical times have profound effects on yield, and therefore, make linear or curvilinear relationships unreliable. It is in this context that we consider the negative effect of wind in supplying advective energy for increased transpiration and the removal of vapour by turbulent transport. This would then indicate that wind protection should be investigated in order to reduce the effect of advection of sensible heat from the dry surroundings. Protection should be tailored to the systems and agricultural practices of the semi-arid region. Tall crops could shelter short ones and any such system must be subject to both agronomic and economic testing.

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