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A study on the characterization of monsoon rainfall for sorghum (*Sorghum Vulgare Pers*) and its response to typical rainfall patterns

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सार — नागपुर में पिछले अट्ठाईस वर्षों (1962-1989) में हुई वर्षा का विश्लेषण किया गया तथा ज्वार की फसलों के लिए आवश्यकता के विभिन्न स्तरों पर वर्षा की अनुकूलता का अध्ययन किया गया है। खरीफ की फसल (25-39 वां एम. डब्ल्यू.) के दौरान कुल वर्षा 861.50 मि. मी. हुई थी। बारह सप्ताहों (25-36 वां एम. डब्ल्यू.) के दौरान सामान्य वर्षा/सप्ताह 50 मि. मी. से अधिक हुई। इसके उपरांत तीन सप्ताह (37-39 एम. डब्ल्यू.) तक वर्षा में उत्तरोत्तर कमी आई। विभिन्नता का गुणांक 74.3 प्रतिशत (25 वें एम. डब्ल्यू.) से 144.7 प्रतिशत (39 वां एम. डब्ल्यू.) के बीच पाया गया। बारह सप्ताहों (25-36 एम. डब्ल्यू.) के दौरान आवश्यकता की 50 प्रतिशत वर्षा का वितरण अच्छा रहा। यह वितरण 44.5 से 36.3 मि. मी. के बीच रहा, जो कि ज्वार की फसलों की साप्ताहिक मांग (21-35 मि. मी./सप्ताह) को देखते हुए सही व पर्याप्त (20 मि.मी./सप्ताह से अधिक) था।

इस स्थिति से संबंधित विशेष वर्षा प्रणालियों को उनकी पुनरावृत्ति के आधार पर परिभाषित किया गया है। जिन चार विशेष वर्षा प्रणालियों का अध्ययन किया गया है उनमें से सबसे कम वर्षा (458.4 मि.मी./ऋतु और 30.56 मि.मी./सप्ताह) वाली प्रणाली सबसे अधिक (865.0 कि.ग्रा./हैक्टा) उपज हुई जिससे कि इस बात का पता चलता है कि फसल के पकने के समय को छोड़कर फसल की शेष विभिन्न अवस्थाओं के दौरान, पर्याप्त वर्षा हुई। इस प्रत्येक अवस्था के दौरान फसल की किसी भी अवस्था में न तो अधिक वर्षा (100 मि. मी./सप्ताह से अधिक) हुई और न ही वर्षा की कमी(20 मि.मी./सप्ताह से कम) रही। कम से कम 30.56 मि.मी./सप्ताह की वर्षा सबसे अधिक पर्याप्त वर्षा थी।

ABSTRACT. Twenty eight years (1962-89) rainfall of Nagpur was analysed and the rainfall suitability at various probability levels for sorghum crop was studied. The total rainfall during kharif season (25-39th MW) was 861.50 mm. Normal rainfall/week exceeded 50 mm during 12 weeks (25-36th MW) which declined successively for three week (37-39th MW). The coefficient of variation (CV) ranged between 74.3% (25th MW) to 144.7% (39th MW). The rainfall at 50% probability level was well distributed during 12 weeks (25-36th MW) ranging between 44.5 to 36.3 mm being adequate and sufficient (>20 mm/week) for sorghum crop considering its weekly demand (21-35 mm/week).

Typical rainfall patterns representing the situation were defined on the basis of their repetitiveness. Out of four typical rainfall patterns studied, the one with lowest rainfall (458.4 mm/season and 30.56 mm/week) fetched the highest yield (865.0 kg/ha) which ensured adequate rains during the various growth stages except maturity. Excessive rainfall (>100 mm/week) and deficient rainfall (<20 mm/week) during every stage were inadequate. Rainfall atleast 30.56 mm/week was most adequate.

Key words — Sorghum yield, Probability, Monsoon rainfall. Crop growth stages, Rainfall pattern

1. Introduction

Sorghum (*Sorghum Vulgare Pers*) is a moisture - sensitive crop and is grown over large areas in semi-arid tropics (SAT) under dryland agriculture. Moisture stress, especially during critical stages, *viz*., initial seedling, preflowering, flowering and grain formation is the principal limiting constraint in the yield determinations (Michael 1978). Though most of the soils in the SAT, falling under monsoon in India, have high moisture holding capacity, the erratic and uneven distribution of rainfall destabilizes the yield despite the low water requirement of the crop (Ghadekar and Patil 1990). Therefore, it was thought necessary to assess the probability of weekly rainfall during the normal growth phases. The study was undertaken further to investigate the response of

sorghum yield to various typical rainfall patterns and to evolve a suitable cropping pattern for the best yield of the crop in the region.

2. Materials and methods

The daily rainfall data of 28 years (1962-89) recorded at the Agrometeorological Observatory, P.K.V., Agriculture College, Nagpur (21° 09′ N, 79° 21′ E, 321 m above mean sea level) were used to work out the weekly means of rainfall. The data were further analysed statistically to find out the highest rainfall in a week, seasonal means, coefficient of variation and rainfall at various probability levels. The coefficient of variation was worked out by the formula,

$$CV = \frac{\text{Standard deviation}}{\text{mean rainfall}} \times 100 \qquad (1)$$

Rainfall at various probability levels in the different weeks was calculated. The rainfall in a particular week for 28 years was arranged in descending order and each week was assigned ranking number '*m*' (Doorenbos and Pruitt 1975). The ranking numbers are then given probability levels *Fa (m)* which was calculated as follows.

$$Fa\ (m) = \frac{100m}{n+1} \qquad (2)$$

where, n = number of weeks and m = ranking number. For example, in the case of 25th MW, for the rainfall amount of 43.2 mm, the ranking position is m = 14. Since n = 28, the probability of getting 43.2 mm rains in that week {*Fa(m)*} is 48.3%. This can also be done by plotting positions *Fa(m)* on the 'X' axis (which is the probability level) and the corresponding rainfall (mm) on the 'Y' axis for a particular meteorological week (MW), e.g., 25th MW, on the log normal probability graph and then the rainfall at any probability level can be obtained from the graph.

The sorghum yield data recorded at the P.K.V. Agriculture College farms was used. The normal sowing date for sorghum in the region is 28th June (Ghadekar *et al.* 1985). The various growth phases and their durations were ascertained from the background information available from the various research programmes. The seasonal yields were divided into 4 categories on the basis of their deviations from the mean sorghum yield (603 kg/ha) as follows:

Yield diviation from mean	*Category*
>20%	Best
-19 to 19%	Normal
-20 to -59%	Deficient
<-60%	Worst

All the years in a particular category were clubbed (*eg.*, number of years under best, normal, deficient and worst category respectively were 7,12,5 and 4 only in the total of 28 years) and the mean, and standard deviation in a particular week were calculated for each category. Similarly corresponding mean and standard deviation for yield under each category were also calculated.

Rainfall generally less than 25 mm/week is insufficient to meet the water requirement of the crop and therefore such weeks were designated as deficient weeks and the rainfall greater than 100 mm/week is "excessive" causing over-saturation of the soil and water-logging. Both, deficient and excessive rains, as these do not favour growth were then designated as 'unfavourable' Rainfall between 25 and 100 mm/week being sufficient to meet the weekly demand of the crop without any edaphic problems was termed 'favourable' or 'normal'. Then, from the clubbed data, in each category the repetitiveness of favourable or unfavourable rains in each week was decided (for example, in the best yield category the 25th MW has 5 times repetitiveness out of 7 years for the rains to be normal, thus showing the general nature). Thus a generalized pattern for 25th to 39th MW for the rains to be favourable or unfavourable with highest repetitiveness was constituted. Then in an individual year, each week representing the generalized pattern character was marked as '*R*' meaning representative. The year with highest '*R*' value count was reckoned as representative "typical pattern". For best, normal, deficient and worst category by following this procedure, the 'typical patterns' were decided.

3. Results and discussion

Normally the monsoon arrives in the region in the 25th MW (18-24 June) and the crop is sown when the sowing rains build up assured moisture in the soil. The sowing rains in the region using criterion by Ashok Raj (1979), *i.e.*, $R \geq 5E+10$ mm where, R=rainfall and E=daily evaporation, amounts to 55 mm/week. Hence the crop is sown in the 25th MW normally as this week receives normal rainfall of 58.95 mm. The life cycle of the crop extends over 90-105 days in the region, roughly a period of 15 weeks, a period of kharif or rainy season in the region.

From Table 1, it is seen that the normal rainfall/week during the 12 weeks (25-36th MW) is more than 50 mm/week, but in the latter 3 weeks (37 -39th MW) rainfall declines and lies between 44.33 and 23.75 mm week. The highest rainfall amount in every week is also shown in Table 1. The coefficient of variation (CV) during the 25th MW is only 74.3% but increases though not steadily and becomes highest in 39th MW (144.7%) showing the unsteady nature of monsoon during latter phase. Minimum assured rainfall at various probability levels (90,75 and 50%) is also exhibited in Table 1. At 50% probability level, the rainfall re-

TABLE 1

Rainfall characteristics, normal rainfall, highest rainfall, CV (%) and dependability of rainfall at various probability levels at Nagpur for normal data of 28 years (1962-89)

S.No.	Rainfall characteristics	Meteorological weeks during rainy season														
		25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
1.	Normal rainfall (mm)	58.95	58.34	63.99	73.31	63.67	66.78	67.08	65.98	55.02	45.71	63.42	50.79	30.89	44.33	23.75
2.	Highest rainfall (mm)	151.80	170.40	243.30	246.30	206.30	301.70	207.50	252.50	175.40	234.40	353.30	228.00	162.80	200.20	141.00
3.	Coefficient of variation (%)	74.3	81.3	91.9	85.7	85.6	95.9	83.8	92.2	84.6	107.2	110.0	105.2	123.1	125.3	144.7
4.	Dependability of rainfall															
	(a) At 90% probability	4.98	4.39	9.87	4.28	5.50	6.78	11.91	9.11	4.96	0.0	2.39	3.0	1.59	0.0	0.0
	(b) At 75% probability	18.0	14.9	26.6	18.7	28.1	31.8	18.8	23.3	11.2	4.6	26.6	15.2	8.2	2.0	1.0
	(c) At 50% probability	44.5	47.3	40.6	64.0	44.5	53.4	51.2	45.2	44.7	26.5	56.0	36.3	20.2	13.7	8.0

TABLE 2

Mean rainfall and mean CV (%) for different growth stages of sorghum

Stages		Meteorological week	Rainfall		Rainy days	
		(MW)	Amount (mm)	CV(%)	Number	CV(%)
I	Sowing	25	57.13	76.60	3.57	54.20
II	Seedling and vegetative	25-29	259.43	46.28	15.07	27.58
III	Preflowering	30-32	200.78	68.99	11.39	33.69
IV	Flowering	33-34	100.56	56.46	6.68	34.38
V	Grain formation	35-36	114.24	82.10	6.68	46.83
VI	Maturity	37-39	98.97	85.98	6.36	54.50

TABLE 3

Total rainfall, sorghum yields and their percentage departures over the mean value for 28 years (1962-89)

Year	Yield		Rainfall	
	Amount (Kg/ha)	Departure (%)	Amount (mm)	Departure (%)
1962	379	-59.00	994.3	10.6
1963	476	-26.68	739.3	-15.06
1964	592	-10.86	1050.9	17.03
1965	422	-42.00	717.0	-22.56
1966	481	-25.36	888.5	-9.25
1967	844	28.55	974.3	11.57
1968	905	33.37	742.7	-21.38
1969	671	10.13	892.8	23.27
1970	231	-161.03	1116.7	19.63
1971	267	-125.8	907.8	5.10
1972	372	-62.08	522.5	-64.94
1973	433	-39.26	918.9	6.25
1974	757	20.34	721.4	17.30
1975	480	-25.62	937.2	8.05
1976	709	14.95	874.4	1.38
1977	708	14.83	760.4	-12.85
1978	719	16.13	801.3	16.39
1979	689	12.48	872.0	1.18
1980	601	-0.33	658.8	-18.20
1981	635	5.03	1224.6	29.70
1982	865	30.28	458.3	-79.18
1983	686	12.09	1040.5	13.89
1984	533	-13.13	1012.3	10.47
1985	726	16.94	997.5	13.6
1986	709	14.95	873.6	-7.62
1987	841	28.29	635.0	-39.55
1988	824	26.82	1036.3	16.88
1989	807	25.27	593.5	-31.11

ceived in the first 12 weeks (25-36th MW except 34th MW) exceeds the 35 mm/week and therefore is most suitable. The decreased rainfall amounts during 37th MW (20.2 mm), 38th MW (13.7 mm) and 39th MW (8.0 mm) are also most favourable as the crop water requirement also reduces drastically. Thus, on the basis of normal weekly rainfall, coefficient of variation and the rainfall at 50% probability level, the duration of 15 weeks (25-39th MW) can be considered most suitable for growing sorghum in Nagpur region. Minimum assured rainfall at higher probability levels is too meagre to be taken into account.

The moisture sensitivity of the crop to the rainfall differs from stage to stage. The life cycle (15 weeks) of sorghum is divided into six different stages extending over different durations. Thus (*i*) sowing (1 week, 25th MW), (*ii*) seedling and vegetative (4 weeks, 26-29th MW), (*iii*) pre-flowering (3 weeks, 30-32nd MW), (*IV*) flowering (2 weeks, 33-34th MW), (*v*) grain formation (2 weeks, 35-36th MW) and (*vi*) maturity (3 weeks, 37-39th MW) are the most important growth phases. The mean rainfall and rainy days and the corresponding coefficient of variation during these growth phases are shown in Table 2. From the table it is clear that the rainfall quantums during every stage are adequate. However, the CV for rainfall variabilities continuously increases as the crop progresses towards maturity.

In Table 3 the total rainfall quantum, the sorghum yields and their percentage departures over the mean values (mean rainfall 861.5 mm and mean sorghum yield 603 kg/ha) for 28 years (1962-89) are given. It is clearly observed that there are large departures in the year-to-year rainfall, ranging from -79.18% (1982) to +23.27% (1969). Similarly, yields of sorghum too have recorded large departures ranging from -161.03% (1970) to 33.37% (1968). Thus it is clear that the yields in the region are not assured and stabilized ones. A correlation coefficient (r) between total rainfall and sorghum yield was worked out and the value was very less (r= +0.073). This low value of r shows that the total rainfall and sorghum yields are not at all related.

In the year 1982, there was low rainfall (458.3 mm) but the yield was as much as 865 kg/ha, while in the year 1986, rainfall was as high as 873.6 mm but the yield was poor (709 kg/ha). It was well established that the total quantum of rainfall and the yields are poorly related. Therefore, what is important is the rainfall distribution and its timeliness so as to coincide with the growth stages when it is essentially required rather than total amount. Besides this, the criterion based upon favourable or unfavourable rain with the highest repetitiveness and the yields fetched may be more appropriate and reasonable.

Plants are the nature's record of the weather and well grown plants give superior yields indicating the favourable weather enjoyed by the plant. Therefore 28 years rainfall patterns were analysed and considered alongwith the sorghum yields. The typical rainfall patterns alongwith the weekly rainfall distribution and the coinciding critical growth stages of the sorghum are shown in Table 4. Normally observed typical rainfall patterns out of 28 years were only selected for the study. Out of the 4 typical patterns, the best pattern recorded only 458.4 mm rainfall (30.56 mm/week) being lowest of all but giving the highest yield (865 kg/ha). The characteristics of this rainfall pattern is that there is low but regular rainfall upto grain formation stage and no rainfall during maturity. No excessive rains (>100 mm/week) except during seedling stage were observed. The mean and standard deviation of rainfall in the best pattern lay between 27.44 mm (39th MW) & 88.38 mm (30th MW) and 21.95 mm (35th MW) & 80.62 mm (30th MW) respectively.

The seasonal mean rainfall was 706.3 mm. The mean yield for the best pattern was 834.71 kg/ha with standard

TABLE 4

Typical rainfall patterns and their "Normal" Values with mean and standard deviation (SD)

S.No	Meteorological week (MW) / Yield Characteristics	25 (18-24 Jun)	26 (25Jun-1Jul)	27 (2-8 Jul)	28 (9-15 Jul)	29 (16-22 Jul)	30 (23-29 Jul)	31 (30 Jul-5 Aug)	32 (6-12 Aug)	33 (13-19 Aug)	34 (20-26 Aug)	35 (27 Aug-2 Sep)	36 (3-9 Sep)	37 (10-16 Sep)	38 (17-23 Sep)	39 (24-30 Sep)	Rainfall (mm) Average week	Rainfall (mm) Total	Yield kg/ha
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
1.	Best yield (+ 20%)																		
	(a) Typical pattern	43.2	8.6	7.0	106.4	38.0	57.4	12.6	7.2	32.8	2.2	35.4	96.0	7.8	3.8	-	30.56	458.4	865.0
	(b) Normal value																		
	Mean	41.4	78.84	55.64	37.31	55.8	88.38	43.95	40.77	53.18	45.85	31.68	33.1	43.55	29.41	27.44	47.06	706.3	834.71
	SD	22.95	45.29	38.73	38.08	53.39	80.62	27.81	38.34	44.74	56.27	21.99	38.58	51.87	44.50	23.86	41.80	-	6.13
2.	Normal yield (-19 to +19%)																		
	(a) Typical pattern	12.4	65.0	32.4	113.4	123.4	8.0	98.8	13.6	4.0	60.4	111.8	228.0	2.0	-	-	58.24	873.6	709.01
	(b) Normal value																		
	Mean	63.15	69.41	57.23	79.43	73.0	72.82	85.7	89.0	49.81	42.6	52.71	55.50	38.14	34.84	16.0	58.62	879.37	664.83
	SD	49.05	47.50	59.19	64.93	61.80	52.31	64.52	69.16	50.86	38.55	48.14	64.33	37.83	43.43	26.40	51.88	-	16.90
3.	Deficient yield (-20 to -59%)																		
	(a) Typical pattern	66.6	-	4.0	52.4	128.2	125.1	130.4	128.4	100.5	5.0	95.6	52.4	-	-	-	59.24	713.1	481.0
	(b) Normal value																		
	Mean	58.14	30.78	89.88	101.94	63.56	51.02	71.76	60.04	59.74	30.4	70.58	39.52	49.64	30.58	15.68	54.88	823.2	458.4
	SD	51.32	39.35	88.70	64.26	44.77	43.20	59.57	37.41	34.90	21.08	23.71	13.56	49.83	39.42	29.30	42.69	-	11.41
4.	Worst yield (<-60%)																		
	(a) Typical pattern	33.9	29.0	121.8	25.7	28.1	-	21.16	19.0	111.8	23.5	26.6	20.4	18.0	-	-	32.02	480.3	372.0
	(b) Normal value																		
	Mean	65.75	39.3	64.15	57.16	44.67	21.25	29.13	44.55	72.7	69.53	137.35	86.5	16.37	50.05	43.35	56.12	841.81	312.25
	SD	36.62	37.18	35.91	46.45	22.18	21.12	27.61	44.12	39.15	70.02	129.69	54.75	10.69	87.34	57.67	48.03	-	32.28
5.	Growth Stage	Sowing	Seedling and	Vegetative			Pre- flowering		Flowering		Grain formation		Maturity						

deviation equal to 6.13. In the normal pattern, the total rainfall received was 873.6 mm with mean rainfall 58.24 mm/week recording 709 kg/ha yield. Normal yield giving pattern is associated with excessive rains (>100 mm/week) during seedling, vegetative stage, grain formation stage and with no rains during maturity. These excessive rains have decreased yield to some extent. The mean rainfall and standard deviation for the normal pattern lay between 16.00 mm (39th MW) & 89.00 mm (32nd MW) and 26.40mm (39th MW) & 64.93 mm (28th MW) respectively. The seasonal mean rainfall was 879.37 mm. The mean yield and standard deviation was 664.83 kg/ha and 16.90 respectively.

In the deficient yield, the typical pattern exhibits excessive rains (125.1, 130.4 and 128.4 mm) during the preflowering stage and excessive rains (100.5 mm) during the beginning of flowering stage as against the optimum requirement (50 mm/week). Rainfall amounts during these stages have resulted in decreasing the yield. Most of the rainfall patterns were found to be associated either with too excessive rains or too deficient rains during these stages and finally resulted in deficient yields. The mean and standard deviation of rainfall for this pattern lay between 15.68 mm (30th MW) & 101.94 mm (28th MW) and 13.56 mm (36th MW) & 88.70 mm (27th MW) respectively. The seasonal mean rainfall was 823.2 mm. The mean yield and standard deviation for deficient pattern was 458.4 kg/ha and 11.41 respectively. The pattern giving worst yield is remarkably different from the above 3 patterns. It is associated with deficient rains (<25 mm/week) during preflowering stage, excessive rain (>100 mm/week) during flowering stage and again deficient rains during the grain formation stage with no rains during maturity period. Thus in the last pattern, inadequate rains (excessive > 100 mm/week or deficient 25 mm/week) have resulted in decreasing the yield remarkably (372 kg/ha). The excessive rains during flowering stage (33-34th MW) are to be noted with special attention as these rains affect pollination with less grain formation resulting in lower yield.

The wet spell during grain formation (35-36th MW) is also important as the rains are required for good development of the grains otherwise and grains are sievered resulting in low yields. The mean rainfall and standard deviation for the pattern 16.37 mm (37th MW) & 137.3 mm (35th MW) and 10.69 mm (37th MW) & 126.69 mm (35th MW) respectively.

4. Conclusion

The minimum assured rainfall at 50% probability for the period 25-39th MW is adequate to support the growth of sorghum receiving required quantum of rains during the various growth phases. The coefficient of variation of rainfall was lowest during the second stage (seedling and vegetative) 46.28% (26-29th MW) with highest value of 85.98% during maturity (37-39th MW). These studies have clearly shown that for the best sorghum yields an ideal rainfall pattern must be comprised of adequate wet spells (50 mm/week) till grain formation stage with no rains at maturity. Excessive rains (>100 mm/week) during flowering and deficient rains (<25 mm/week) during grain formation resulted in poor yields. These stages thus form the critical stages in governing the yield and for the best yields, an adequate rain spell (40-60 mm/week) during flowering stage (35-55 DAS) and an additional adequate rain spell (40-60 mm/week) during grain formation stage (70-90 DAS) are essential.

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