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Managing the impact of seasonal rainfall variability through response farming at a semi-arid tropical location

U. S. Victor, N. N. Srivastava, A. V. M. Subba Rao and B. V. Ramana Rao

Central Research Institute for Dryland Agriculture, Hyderabad 500 059, India

A method of Response Farming Programme for managing risks associated with variable seasonal rainfall was developed for a semi-arid location using daily rainfall records for the period 1971–94. The risks are intense rains threatening soil erosion, prolonged heavy rains threatening water logging, prolonged low rainfall periods, early cessation of rains long before the maturity of crops and too little rainfall in relation to crop water requirements. Onset relations, i.e. relations between season rainfall parameters (amount, duration and average rainfall per day) and date of onset of the rainy season are determined. It has been demonstrated how these relationships can be used in the selection of crops/cropping systems, fertilizer application rates, plant population, etc.

In rainfed agriculture, farmers must cope with rainfall variability both within and between seasons. If rainfall were uniform every year, farmers would choose a single management plan. Crops, planting date, seeding rate, fertilizer and insecticide would be planned for that anticipated single rainfall pattern. Obviously, this is not the case and variability of rainfall creates major problems. Response Farming is a means of coping with this seasonal rainfall variability which provides a method of identifying and quantifying seasonal rainfall variability and its related risks and of addressing the latter at the farm level. This is accomplished through improved prediction of expected rainfall behaviour in the approaching cropping season enabling improved decisions at the field level. The date of onset acts as a rainfall (amount, duration, average rainfall per day) predictor for the remainder of the season. Current rainfall is used to determine the management strategies which are responsive to the weather patterns. Stewart[1] developed Response Farming Strategies by studying the relationship between

onset of the rainy season versus duration of the rainy season and onset versus rainfall amount during the rainy season for two locations, Niamey and Bouza. In order to assess the rainy season potential for crop growth, Siva Kumar[2] has determined the relationship between duration and onset for 58 locations in the Sahelian and Sudanian Zones of Niger and Burkina Faso. In the present study, two types of analysis were done. The first analysis provides a general characterization of historical rainfall behaviour for purposes of determining cropping potential in new development areas or presently farmed lands. Analysis two simulates historical water supply conditions for crops of specified types and maturities. This type of analysis assumes that final decisions are based on date of onset but the effective cropping season begins at germination.

Materials and methods

The daily rainfall data for the period 1971–94 recorded at Hayatnagar Research Farm of Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad (17°27′N, 78°28′E) were utilized in the present study. The farm situation represents semi-arid tropical region of Peninsular India, with an average annual rainfall of 733 mm and potential evapotranspiration of 1754 mm. Nearly 70% of the total precipitation is received during the southwest monsoon season (June to September). Post-monsoon rains are not uncommon and occur around 18% of average annual rainfall. The monthly normal potential evapotranspiration values given by Rao *et al.*[3] were utilized in the present study.

Soils of the experimental site are shallow alfisols. Moisture storage in the profile is only 24% by volume and permanent wilting point is 14% by volume. The soils are low in nitrogen and extremely low in phosphorus. The yields of sorghum (CSH-6), pearlmillet (BJ-104), castor (Aruna), pigeonpea (HY-2) and sunflower (68415) were simulated (1971–94) using the water production functions developed by Victor *et al.*[4].

The following assumptions were made to identify beginning, end and duration of the rainy season to characterize the rainy season behaviour[5,6]. The date of onset of rains is defined as that date after 28 May, when rainfall accumulated over two consecutive days is at least 20 mm. The date of ending of the rains is taken as that date after 1 September following which no rainfall occurs over a period of 30 days. The duration of the rainy season is taken as the difference between beginning and ending of rainy season. Frequency distribution of dates of beginning and ending of the rains and duration of the rainy season were estimated by fitting a normal distribution. Then the probabilities for different durations of the rainy season for early, normal and delayed onset of rains were obtained.

A computer-based Response Farming Programme which incorporates a bare soil water balance algorithm[7] was developed to simulate historical water supply conditions based on which the date of onset, germination and duration of the crop growing season were identified. The following are the inputs to this analytical programme.

- Daily rainfall (mm).
- Mean monthly potential evapotranspiration (PET) (mm).
- Daily PET values were calculated/assumed as follows[8,9]:
  PET = (Mean monthly PET) * 1.1/30 on days with no rainfall
  4 mm/day on days with 1–10 mm rainfall
  3 mm/day on days with 11–20 mm rainfall
  2 mm/day on days with > 20 mm rainfall.
- Field capacity of the soils of the experimental site is 0.24 by volume.
- Permanent wilting point is 0.14 by volume.
- Air dry water content is 0.04 by volume.
- 1 May to begin search.
- First accepted date of onset for cropping, 1 June.
- *Onset criterion*: 20 mm of stored water in the 30 cm soil profile from the new rains. Evaporation assumed to continue throughout the soil–water accumulation process. Losses to runoff assumed zero.
- Planting to begin after a minimum delay of three days provided the rainfall is less than 5 mm/day.
- *Germination criterion*: 15 mm of water stored in the 30 cm soil profile to effect germination. Usually occurring on the first day following planting.
- Last search date for season end rains is the crop maturity date.
- *Final rain date criterion* is to sum rainfall backward from the maturity date to accumulate 50 mm, then proceed forward toward the maturity date until average daily rainfall fell below 2.5 mm/day.

The analysis was done for 90, 100 and 150 days maturity crops which corresponds to sorghum [(CSH-6) and pearlmillet (BJ-104)], sunflower (68415) and [pigeonpea (HY-2) and castor (Aruna)] respectively.

Results and discussion

General characterization of rainy season behaviour

Quantification of risks due to variable seasonal rainfall. The following risks, viz. (a) rainfall intensity, (b) prolonged heavy rainfall periods, (c) prolonged low rainfall periods were quantified. The following conclusions were drawn from the analysis.

Intense rains threatening erosion of the basic soil resource: Based on the frequency distribution of daily rainfall data, the chance of occurrence of 75 mm or

more is very low (0.5%) and the probability of getting the rainfall in the range 50–75 mm per day is only 0.3%. However, the occurrence of low rainfall amounts (< 25 mm/day) is very high (98%). Considering the analysis for shallow alfisol, it was judged that the erosion hazard in the present rainfall circumstances is moderate.

Prolonged wet and dry spells: A first order Markov chain probability model was fitted to daily rainfall data to calculate initial and conditional probabilities for two rainfall limits (2.5 mm and 10 mm)[10,11]. Using these probabilities of dry and wet spells and, conditional dry spells, which is the length of a dry spell conditional on the day prior to the beginning of the period being rainy, were calculated and are given in Table 1. These data are presented from 3rd week of May to last week of October (21–44 standard meteorological weeks) which is the period during which rains are received. These data provide quick overview of risks due to dry spells during the rainy season.

It is evident from the analysis that wet spells in the current cropping season exceeding 10 mm per day continuously for five days or more in a week are infrequent (< 1%). It is seen from Table 1 that mid-season dry spell during August (32–35 weeks) exceeding five days is in the range of 16–35%. The conditional dry spell length five days during 23–26 week is in the range of 12–25%. However, if the onset is earlier than 23rd week, the probability of getting conditional dry spell of five days increases (more than 46%), which indicates that sowing field crops with first rains before 23rd week is fraught with considerable risk while the period after 23rd week is slightly favourable since the probability of dry spell decreases rapidly, indicating significantly reduced risks to the emergence and subsequent growth of crops.

Table 1. Probabilities (%) of dry spell and conditional dry spell lengths during different weeks at Hayatnagar, Hyderabad

Standard meteorological week	Dry spell (days)			Conditional dry spell* (days)		
	> 3	> 5	> 7	3	5	7
21	79	67	58	85	73	62
22	65	49	36	61	46	34
23	57	39	27	54	37	25
24	42	23	13	38	21	12
25	58	41	28	38	26	18
26	55	37	25	35	24	16
27	35	18	9	26	13	7
28	49	31	19	41	25	16
29	51	33	21	32	21	13
30	45	26	15	33	19	11
31	39	21	11	34	18	10
32	42	24	13	31	18	10
33	34	16	8	24	12	6
34	54	35	23	49	32	21
35	49	31	19	37	73	15
36	64	48	36	46	34	25
37	58	40	28	43	30	21
38	50	31	20	27	17	11
39	60	43	30	42	30	21
40	52	33	21	33	21	14
41	70	56	44	41	32	25
42	83	73	65	54	48	42
43	72	58	47	40	32	26
44	71	57	46	44	35	28

*Calculation of dry spell conditional on the day before the start of the period under consideration being rainy.

Relationship between date of onset and rainfall amount and date of onset and rainy season duration. Seasonal rainfall amount, duration and average rainfall per day are linked to the date of onset. For predictive purposes, onset was divided into three distinctive time periods, viz. early (May 28–June 10), middle (June 11–30), and late (July 1 onwards).

Table 2 shows the median values of monsoon rainfall attributes at Hayatnagar Research Farm for the entire 24-year record studied and then for each of the three groupings of seasons defined by the prediction criteria outlined above. It is evident from Table 2 that over all median cropping season rainfall of 581 mm persisting 150 days with an average rainfall of 4.5 mm per day. Seasons with early onset show higher rainfall amount, longer duration and higher average rainfall per day. Seasons with middle period onset have lower rainfall, same duration and less average rainfall per day. Late onset seasons have the least rainfall and shortest durations, but paradoxically the highest average rainfall per day of all. The importance of the differences among the predicted groupings in Table 2 is more easily grasped when ranges of values within each of the categories are seen in addition to the median values. Table 3 presents the ranges, starting with the 24-year record as if no predictions were involved. Rainfall amount ranged from low of 327 mm to a high of 1077 mm. Duration is 79 to 167 days and average rainfall per day is as low as 2.2 mm per day and as high as 6.8 mm per day. If the onset is early (by June 10), the rainfall was never less than 395 mm but fell to 327 mm with middle period onset and to 448 mm in the late seasons. Similarly, duration never fell below 120 days for the early onset seasons and decreased to 92 days for middle period onset and 79 days for late onset seasons. The average rainfall per day for the early and middle onset periods ranges from 2.2 to 6.8 mm per day. However, the late onset seasons show high average rainfall per day.

Selecting crops/cultivars and cropping systems based on predicted duration. Actually, crop/cultivar selection based on predicted duration requires consideration of (a) length of growing season (maturities) of different crops and cultivars in the planning site environment, (b) rapidity of planting (no. of days it takes to plant following onset), (c) soil depth and water-holding

capacity, (d) crop coefficients for the estimation of water requirements, and (e) evaporative rates through the season.

The goal of planning exercise is to select crop/cultivars that will reach maturity within the rainy period or within a time period following the final rain date but before completely running out of extractable soil water.

For example, from the data in Table 4, it is seen that in 38% of years only more than 150 days duration is possible if the onset is normal. However, this length of the season does not support sequence cropping even with short duration crops and varieties as the soil has low water-holding capacity. The long duration crops like castor or pigeonpea occupy complete growing season. Any intercrop reduces the yield of castor. With short duration cereal crops like sorghum and pearlmillet, quite a good length of growing season is left unutilized. Therefore intercropping of sorghum/or pearlmillet with pigeonpea is the best system suited for this region.

Characterization of rainy season behaviour with reference to specific crops. The analysis was done for 90, 100 and 150-day crops. The relationship between rainy period duration and date of onset, average crop season rainfall and date of onset, and total rainfall in 30 days after germination and date of onset are presented for sorghum and castor in Figures 1 and 2. The following important conclusions can be drawn from these figures.

Rainfall duration of 80 and 110 days or more is sufficient to permit a 90 and 150 days sorghum and castor cultivars respectively to produce yields greater than 75% of the maximum. Both sorghum and castor can be seeded till the end of July. However, if sorghum is seeded beyond June, its yields will be reduced drastically due to shootfly attack. As an alternative, pearlmillet can be seeded up to mid-July. With later seedings, this crop matures in cool weather and results in ergot infection. Under delayed seeding conditions up to the end of August, minor millets like fingermillet, foxtail millet can be seeded. As a last chance horsegram can be seeded up to the end of September.

Following determinations of cultivar maturities to be grown, the next selection is type of crops themselves. This is done by relating average season rainfall to daily water requirements of crops of interest. Average season rainfall per day is calculated by dividing the total season rainfall by the maturity of the crop. For example, for sorghum, it is seen from Figure 1 *b* that average season rainfall per day ranges from just above 1.9 mm per day to just below 8.0 mm/day. Season water supply averaging at or above 5 mm/day should be capable of producing yields greater than 75% of maximum provided the

Table 2. Median values of monsoon cropping season onset dates and rainfall amount, duration and average rainfall per day

No. of years	Onset period	Monsoon rainfall			
		Onset date	Amount (mm)	Duration (days)	Avg. ppt. (mm/day)
			Median values		
24	All onsets (May 28–July 13)	6–13	581.0	150	4.5
	Three groupings of seasons				
10	Early: By June 10	6–13	706.0	152	4.75
13	Middle: June 11–30	6–15	540.0	150	3.70
1*	Late: July 1 onwards	7–13	448.0	79	5.70

* Actual values; Avg. ppt. = Average precipitation.

Table 3. Ranges of monsoon cropping season onset dates and rainfall amount, duration and average rainfall per day

No. of years	Onset period	Monsoon rainfall		
		Amount (mm)	Duration (days)	Avg. ppt. (mm/day)
		Ranges of values		
24	All onsets (May 28–July 13)	327–1077	79–167	2.2–6.8
	Three groupings of seasons			
10	Early: By June 10	395–1077	120–165	2.8–6.8
13	Middle: June 11–30	327–874	92–167	2.2–6.5
1	Late: July 1 onwards	448	79	5.7

Avg. ppt. = Average precipitation.

fertility is not lacking; competing weeds, pests and diseases are controlled and water losses are minimal. 50–75% of the maximum yields can be expected until the average daily water supply falls to about 4 mm after which subsistence level production is expected (50–25% of the maximum yields). When the daily water supply falls below 2 mm, the yields less than 25% of the maximum can be expected.

Table 4. Probabilities (%) of growing season length exceeding specified durations for different dates of onset of rains at Hayatnagar, Hyderabad

	Length of the growing season (days) exceeding			
Date of onset	90	100	130	150
23 May	100	100	100	76
2 June	100	99	89	58
12 June*	100	96	76	38
22 June	99	89	58	21
2 July	96	76	38	9

*Mean date of onset of rains.

The relationship between total rainfall in the next 30 days after germination and date of onset enables the farmers to take decisions for the second time in deciding fertilizer rates and plant population. Here, it is assumed that water supply up to 30 days after germination is adequate to provide low risk guidance on whether to add fertilizer for high rainfall conditions or to thin and reduce the plant populations for low rainfall conditions. For example, it is evident from Figure 1 *c* that if total rainfall in 30 days after germination exceeds 100 mm, sorghum yields greater than 75% of the maximum can

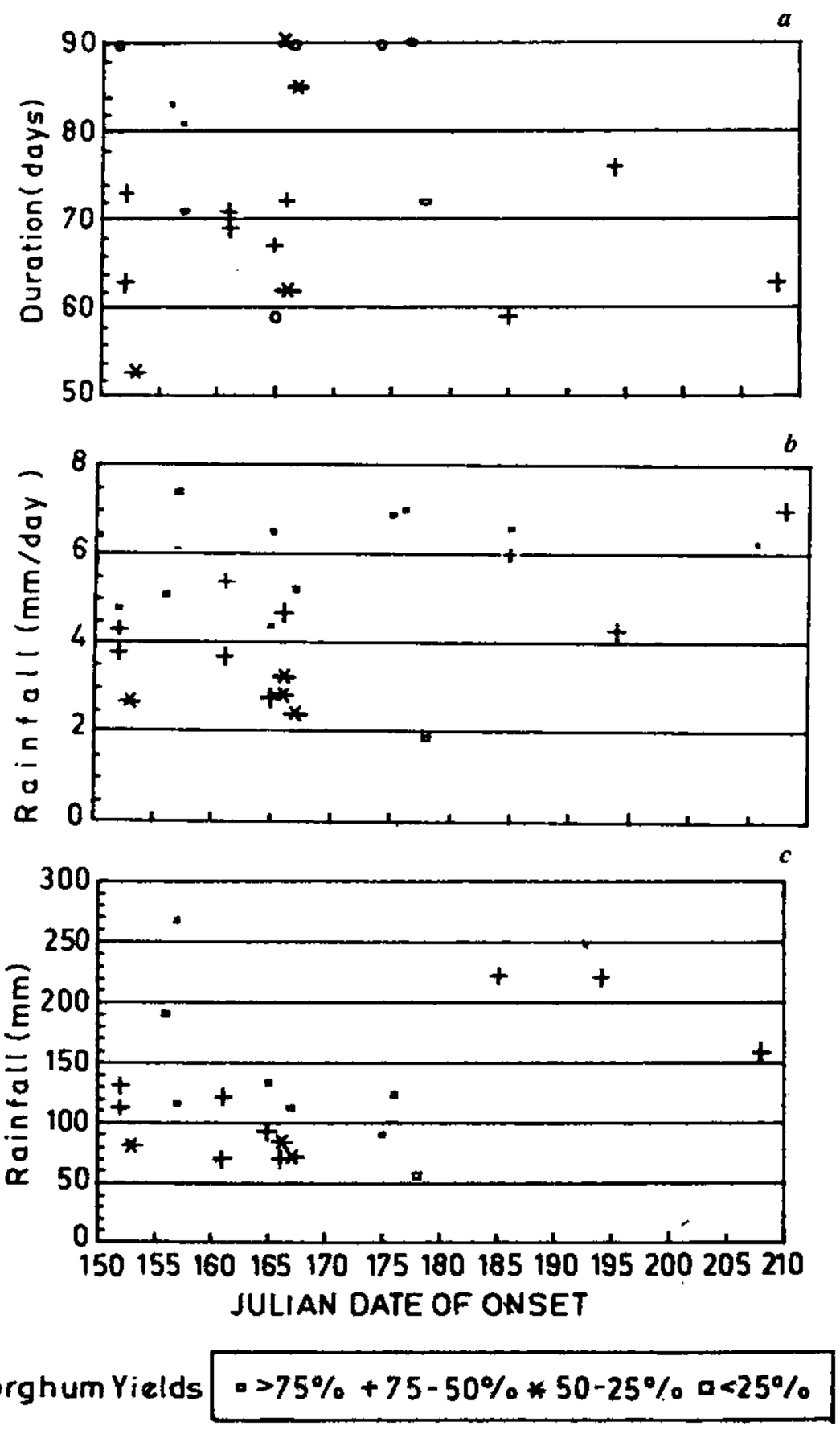

Figure 1 *a–c*. *a*, Relationship between rainy period duration and date of onset at Hayatnagar; *b*, Relationship between average crop season rainfall and date of onset at Hayatnagar; *c*, Relationship between total rainfall in the next 30 days and date of onset at Hayatnagar.

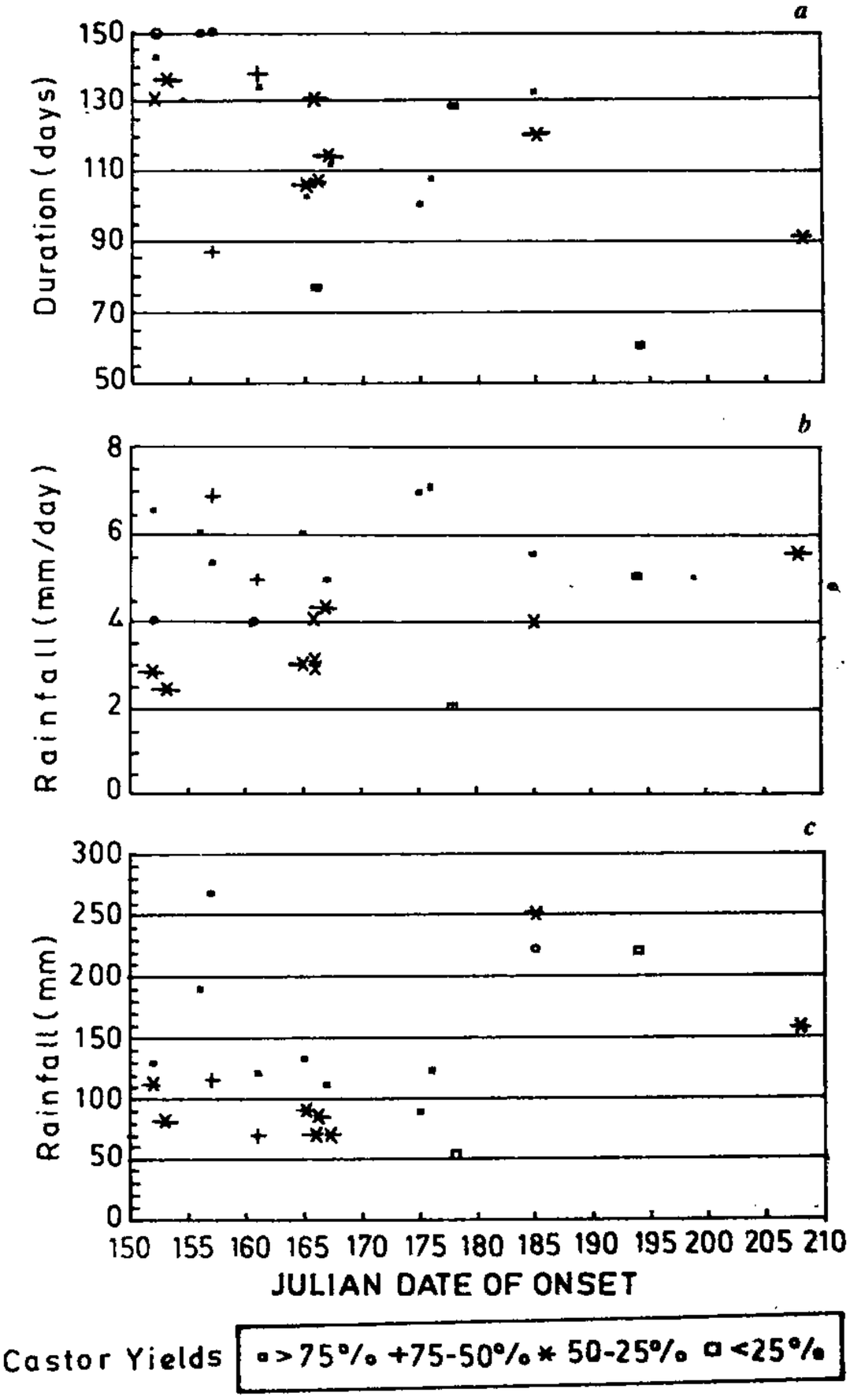

Figure 2 *a–c*. *a*, Relationship between rainy period duration and date of onset at Hayatnagar; *b*, Relationship between average crop season rainfall and date of onset at Hayatnagar; *c*, Relationship between rainfall in the next 30 days and date of onset at Hayatnagar.

be expected. Therefore, if water supply in 30 days after germination exceeds 100 mm, apply fertilizers and if less than 100 mm, reduce the plant population by thinning and leave the fertilizer as before. Actually the 30 day water supply in most years is far above the 100 mm minimum which signals yields greater than 75% of the maximum. This means that the 100 mm rainfall is often reached long before the 30 days have passed. The decision, therefore, for additional nitrogen fertilizer can usually be made well before the action must be taken, thus extending preparation time. The predictive criteria, decisions and recommended actions suggested in this paper are not definitive. These are yet to be tested at field level before using them for operational purpose.

Conclusions

Seasonal variation in rainfall poses the greatest climatic risks to agricultural production in rainfed farming areas. In the variable rainfall zones at least five aspects of seasonal rainfall behaviour need to be evaluated in terms of agricultural production. These are intense rains threatening erosion, prolonged heavy rains threatening water logging, prolonged low rainfall periods within the cropping season, early cessation of rains too long before crop maturity or too little rainfall in relation to crop water requirements. A number of relationships between the onset of cropping season rainfall and such farm relevant rainfall parameters, such as rainfall amount, duration and average rainfall per day are determined by analysing the historical rainfall records. Cursory examination of the rainfall data indicates that risk from prolonged heavy rains is not much, particularly on shallow alfisols. But spells of dryness or exceedingly low rainfall do pose risk during the cropping season. Duration is very much correlated with date of onset of the rainy season, hence is the key factor in selecting maturities of crops/cultivars and cropping systems to be grown. Relating duration to onset dates provides season-by-season guidance. Following determination of cultivar maturities to be grown, the next selection is the type of crops themselves. This is done by relating average water supply per day to daily water requirements of crops of interest. The crux of the management problem with variable rainfall condition is to adopt soil fertility and plant populations to actual rainfall conditions in the season at hand. Fortunately farmers can delay final decisions on these questions until about 30 days after germination. In the case of sorghum if water supply in 30 days after germination exceeds 100 mm, apply fertilizer and if less than 100 mm, reduce plant population by thinning and leave fertilizer as before.

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