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Evaluation of crop production potential using long term simulated soil moisture in drought prone region of Bihar

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ABSTRACT

The quantum of plant available moisture storage in the soil profile plays a vital role in crop growth and development under rainfed condition. Understanding the variability of available Soil Moisture (SM) in the root zone on both spatial and temporal scales would be a reliable guide in effective and sustainable crop production program in rainfed region. In this paper, weekly available soil moisture in medium and fine textured soils in seven chronically drought prone districts, *viz.* Gaya, Aurangabad, Jahanabad, Kaimur, Nalanda, Nawada and Rohtas of Zone IIIB (part of south Bihar alluvial plains) of Bihar has been simulated through climatic water balance technique employing weekly total rainfall data for the period from 30 to 55 years, normal weekly Potential Evapotranspiration (PET) and Available Water Holding Capacity (AWC). Probabilities of available SM for 25, 50 and 75% of AWC m^{-1} depth have been estimated for these soils in various districts. Results revealed that under medium textured soil when SM at 50% of AWC was considered, Jahanabad district recorded the longest crop growing period among all the seven districts indicating greater degree of moisture availability and thus favouring greater crop production potential, whereas shortest growing period with least crop production potential was observed in Auranagabd and Nawada districts. In the fine textured soil, the highest crop production potential in terms of SM availability seemed to be achieved also in Jahanabad district and the lowest in Nalanda district. Significant negative correlations of dry spell with rainfall and SM were observed. Crop planning based on available SM has been suggested under various SM scenarios for this drought prone zone of Bihar. Findings of the study could be useful for scheduling supplemental irrigation. In most vulnerable districts such as Nalanda and Gaya having lesser availability of SM, intercropping of pigeon pea with maize sown in paired rows could be more remunerative cropping system.

Key words:
Crop production potential,
Drought,
Probability,
Soil moisture,
Water balance

1. INTRODUCTION

Rainfed agro-ecosystem plays a very important role in Indian agriculture (Venkateswarlu and Prasad, 2012). Currently, about 56% of the total cropped area of India is rainfed and even after realizing the full irrigation potential, about 50% of the total net sown area will still remain under rainfed agriculture in the country (NRAA, 2012). A number of risks are involved in crop production in the rainfed regions due to uncertainty of rainfall and occurrence of recurrent droughts (Misra, 2005). Moisture regime is considered one of the important determinants of crop growth and development, and hence it plays a vital role in food sufficiency status of any nation (Mwale *et al.,* 2007). The amount of rainwater stored in the soil profile is the primary source of available water for crop production in the drought prone tract. Rainfall distribution is a very important characteristic that affects the crop productivity in the rainfed regions (Subhas *et al.,* 2012).

Of all the agroclimatic zones of Bihar, Zone III B, which covers south Bihar alluvial plains is considered as chronically drought prone region and is traditionally regarded as the dry zone of Bihar. Apparently, the primary climatic constraint in this zone is the limited and variable moisture supply to the crops, due to low and variable rainfall, which hampers crop growth during growing period and consequently low crop productivity becoming a common feature of agriculture in this region. Available SM which is defined as the quantity of SM lying between field capacity and permanent wilting point is extracted by plant roots (Jensen *et al.,* 1990). Plant water stress commences when the SM falls below a threshold of 50% of available SM (Raper *et al.,* 2012). Ramana Rao *et al*. (1979 a) worked out SM availability to crop plants in different soils at Bijapur district of Karnataka state under rainfed conditions using climatic water balance model and suggested planting schedule for different crops. While studying the feasibility of growing *rabi* crops through stored SM characterization in Sibsagar district of Assam, Dutta *et al.* (2014) observed that light soils could supply water for a period of 10 to 13 days, medium soils for 29 to 33 days and heavy soils for 28 to 37 days, and as a result light soils would suffer from severe water stress in the initial stage and the other soils at latter part of the growing periods causing failure of crops. Results of several studies involving rainfall pattern for crop planning have been reported (Sarker *et al.,* 1982; Manorama *et al.,* 2007; Sattar and Khan, 2013), where the role of stored SM in the root zone after cessation of rains has been underestimated. Measurement of SM over a large area on a long term basis is not possible. Further, there are practical limitations for routine SM measurements like monitoring of meteorological parameters in the agromet observatory. Recognizing the importance of SM for crop planning, many water balance methods have been developed. The water balance method of Thorthwaite and Mather (1955) is one of the most widely used methods for estimation of SM storage, actual evapotranspiration, water deficit and water surplus. In Bihar, work on available SM *vis-a-vis* crop production potential is practically sparse. Considering the above realities in respect of water availability in rainfed ecosystems of drought prone region and available SM stored in one meter depth of soil which is vital for crop growth and yield, it has been attempted to study the crop production potential in medium and fine textured soils of drought prone zone of Bihar on the basis of simulated SM and thereby to suggest suitable crops and varieties that can withstand and efficiently produce under moderate to low available SM conditions (Laary *et al.*, 2012). In the present study, empirical probabilities of available SM greater than or equal to 25, 50 and 75% of AWC m^{-1} depth in medium and fine textured soils have been estimated for identifying water availability period for crop planning under rainfed condition in seven drought prone districts of Bihar.

2. MATERIALS AND METHODS

The Zone IIIB (part of South Bihar alluvium plains) is drought prone agroclimatic zone of Bihar (Fig.1). Seven districts, *viz.* Aurangabad, Gaya, Jahanabad, Kaimur, Nalanda, Nawada and Rohtas of this dry zone which are most vulnerable to occurrence of drought condition have been selected for characterization of available SM *vis-a-vis* evaluation of rainfed crop production potential. Weekly total rainfall data of three locations from each of the seven districts for different time periods were utilized and averaged out for district level analysis (Table 1). Monthly normal PET data of Rohtas were collected from India Meteorological Department, Pune (Rao *et al.,* 1971), whereas PET values of remaining districts were calculated using PET Calculator software (V 3.0) developed by ICAR-Central Research Institute for Dryland Agriculture, Hyderabad. Monthly PET data were converted into weekly total values by interpolation method as followed by Rao and Vyas (1983). AWC m^{-1} depth of soil was estimated for medium and fine textured soils considering the layer wise soil textural classes up to one meter soil depth for each district as reported by ICAR-National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Nagpur (Haldar *et al.,* 1996) and following the procedures described by Saxton and Rawls (2006). As the soils of the region are predominantly medium and fine textured, these two types of soil from each district were considered for the study (Haldar *et al.*, 1996).

Water stored in the soil after rainfall or irrigation reaches field capacity, which can be considered equivalent

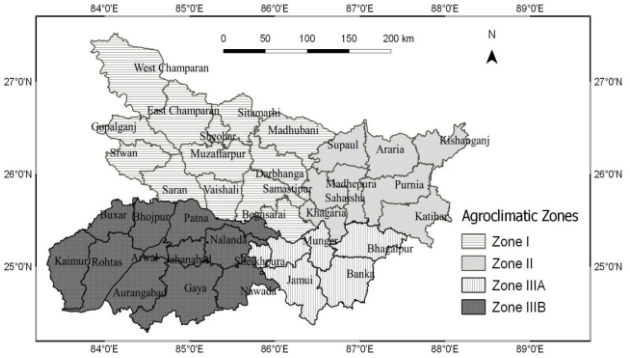

Fig. 1. Location of agroclimatic Zone IIIB of Bihar

Table: 1
Details study locations of Bihar

S.No.	Districts	Rainfall stations	Duration of data (yrs)
1	Gaya	Gaya, Attri, Sherghati	1959-2013
2	Auranagabd	Aurangabad, Daudnagar, Deo	1975-2012
3	Jahanabad	Jahanabad, Makdampur , Kako	1984-2013
4	Kaimur	Bhabua, Mohania, Kudra	1972-2013
5	Nalanda	Asthwa , Biharsharif , Nursarai	1974-2013
6	Nawada	Gobindpur,Sirdala, Hisua	1982-2013
7	Rohtas	Bikramganj, Dehri, Sasaram	1974-2012

to one irrigation. Stored SM could be effective to the extent of 40 to 90% depending upon soil texture, time and meteorological conditions (Doorenbos and Pruitt, 1977). The magnitude of available SM depletion at which irrigation is to be scheduled are 25, 50 and 75% (Misra and Ahmed, 1987) depending upon type of crops and stages of their growth (Singh and Sahu, 1981). Recognizing rainfall as the most variable element, Chang (1968) suggested for rainfall probability analysis for crop planning. SM is also a variable element and, therefore, probabilities of having different threshold amounts of SM need to be estimated in the analysis. By using weekly total rainfall, normal weekly total PET and AWC m^{-1} soil depth (Table 2), year wise weekly SM storage for medium and fine textured soils in each district was worked out following the procedure given by Thornthwaite and Mather (1955). Experimental findings of previous works suggest that available SM content equivalent to 75% of AWC is the value for obtaining potential yield, while 50 and 25% of AWC are considered as drought with little moisture stress, and severe moisture stress respectively (Singh and Sahu, 1981). Consequently, empirical probabilities of having SM of 25, 50 and 75% of AWC for two types of soils have been determined. Although scheduling of irrigation is made at different specified levels of SM depletion depending upon crops, it has not hitherto been applied for identifying water availability period for crop planning under rainfed condition. As suggested by Virmani *et al.* (1982), dry spell has been worked out by considering a week receiving less than 5 mm rainfall.

3. RESULTS AND DISCUSSION

The weekly simulated available SM m^{-1} soil depth in medium and fine textured soils based on entire data base of rainfall, PET and AWC for seven chronically drought prone districts of Zone IIIB (part of south Bihar alluvial plains) of Bihar showed that at least 50% of AWC could be expected during the period from 27th - 28th to 43rd Standard Meteorological Week (SMW) in medium textured soil and 28th to 43rd-5th SMW in fine textured soils across various districts (Table 3). Higher level of SM in fine textured soil as compared to medium textured soil during *rabi* season (41st to 12th SMW) could be utilized for growing rainfed *rabi* crops like rainfed wheat, gram *etc.* On an average, the lowest magnitude of SM occurs at 21st SMW, whereas SM abruptly increases at 25th SMW in all the districts. The period of water availability in terms of average SM extended from 34th SMW at Gaya, Aurangabad, Nalanda, Nawada and Rohtas to 35th SMW at Kaimur and to 37th SMW at Jahanabad district. Weekly average rainfall pattern in various districts have been presented in Table 4. When monthly rainfall was considered, out of seven districts, three districts such as Jahanabad, Nalanda and Nawada recorded the highest rainfall in the month of July, whereas in the remaining districts, the highest rainfall was observed in the month of August (Table 5). Rainfall during September varied from 157.1 mm in Nalanda to 177 mm in Rohtas district. The results on distribution of monthly rainfall led us to conclude that none of the districts are suitable for rainfed transplanted rice because only two months received rainfall > 200 mm. Morris and Zandstra (1979) estimated that areas with monthly rainfall greater than 200 mm consecutively for four months are suitable for growing rainfed transplanted rice.

Table: 2
Available water holding capacity (mm per meter soil depth) for different soils in various drought prone districts of Bihar

S.No.	Districts	Available water holding capacity (mm per meter soil depth)	
		Medium textured soil	Fine textured soil
1	Gaya	132	165
2	Auranagabd	136	166
3	Jahanabad	143	170
4	Kaimur	129	167
5	Nalanda	141	165
6	Nawada	137	165
7	Rohtas	134	168

Annual and *kharif* season dry spell, average weekly SM and rainfall, and dates of monsoon onset in the different districts of drought prone region of Bihar are presented in Table 6. It is observed that average *kharif* season rainfall was highest (932.8 mm) in Aurangabad district and the lowest (762.2 mm) in Nalanda district. Dry spell was found to occur for 3 to 4 weeks during *kharif* season across different districts. Average SM was found to vary from 73.6 mm in Nawada district to 85.4 mm in Jahanabad district. The lowest average annual rainfall (873.1 mm) was observed in Nalanada district as against the highest of 1018.6 mm in Auarangabad district. The annual average number of dry spell varied from 31 in Gaya to 34 weeks in Nalanda district. Annual average SM ranged from 35.6 mm in Rohtas to 43.4 mm in Jahanabad district. The onset of monsoon was recorded in 25 SMW (18-24 June) in all districts except Nawada, where it occurred during 26th SMW (25th June - 1st July). Although seasonal and annual rainfall differed significantly among the districts, such variation was not observed in SM storage. Aurangabad district recorded the highest annual and seasonal rainfall, but SM storage was lesser than that recorded by several other districts receiving less rainfall, which was due to difference in available water holding capacity (Table 2). The districts having greater water holding capacity tended to store more moisture (Ramana Rao *et al.,* 1979b). The values of simple correlation coefficients determined following the procedure of Gomez and Gomez (1984) have been presented in Table 7. Correlation coefficients between dry spell and rainfall, and dry spell and SM on annual and seasonal basis were found to be negative in all districts, being highly

significant in most of the districts except Jahanabad and Rohtas. Thus, it is evident that greater dry spell durations are associated with lower rainfall and SM.

Growing Period under Varying Levels of Soil Moisture

The lengths of rainfed *kharif* crop growing period in medium and fine textured soils under severe and low moisture stress at SM of 25 and 50% of AWC, respectively and no crop moisture stress conditions with SM of 75% of

Table: 3
Average simulated weekly available SM (mm m^{-1} depth) in medium textured (MT) and fine textured (FT) soils in different drought prone districts of Bihar

SMW	Gaya		Aurangabad		Jahanabad		Kaimur		Nalanda		Nawada		Rohtas	
	MT	FT	MT	FT	MT	FT	MT	FT	MT	FT	MT	FT	MT	FT
1 (1-7 Jan)	20.8	36.4	23.34	37.2	29.4	44.4	19.7	36.8	27.3	39.4	23.1	36.3	20.5	34.5
2 (8-14 Jan)	18.7	33.4	21.11	34.3	26.8	41.1	17.7	33.9	25.2	36.8	20.4	32.8	18.4	31.7
3 (15-21 Jan)	18.3	32.1	20.02	32.5	24.9	38.5	16.6	31.9	24.7	35.8	20.0	31.6	17.9	30.4
4 (22-28 Jan)	17.8	30.9	19.69	31.4	24.4	37.2	16.2	30.6	24.5	35.0	19.8	30.6	17.8	29.5
5 (29 Jan-4 Feb)	16.3	28.6	17.42	28.4	21.9	34.0	14.6	28	22.2	32.1	17.0	27.0	15.5	26.3
6 (5-11 Feb)	14.4	25.8	15.55	25.8	19.3	30.5	14.8	27.3	19.5	28.7	14.6	23.7	14.0	24.0
7 (12-18 Feb)	13.0	23.4	14.82	24.2	16.8	27.2	16.3	27.9	19.7	28.2	12.3	20.5	13.6	22.8
8 (19-25 Feb)	11.1	20.4	13.00	21.5	14.2	23.6	14.1	24.6	16.8	24.5	10.2	17.6	11.7	19.9
9 (26 Feb-4 Mar)	9.0	17.3	10.99	18.6	11.8	20.2	12.4	22	14.9	22.1	8.2	14.7	9.5	16.9
10 (5-11 Mar)	8.3	15.5	8.70	15.3	9.4	16.7	10.0	18.5	12.7	19.1	6.4	12.0	7.5	14.0
11 (12-18 Mar)	6.4	12.6	6.71	12.4	7.3	13.5	7.9	15.4	10.7	16.2	4.9	9.7	5.9	11.4
12 (19-25 Mar)	4.8	10.0	5.35	10.1	5.7	11.0	6.1	12.5	9.1	13.9	3.7	7.7	4.5	9.3
13 (26 Mar-1 Apr)	3.6	7.9	3.93	7.9	4.4	8.9	4.5	9.9	7.0	11.1	2.8	6.0	3.4	7.3
14 (2-8 Apr)	2.6	6.1	2.86	6.0	3.2	6.8	3.3	7.8	5.2	8.6	2.0	4.6	2.5	5.7
15 (9-15 Apr)	2.6	5.4	2.02	4.5	2.4	5.2	2.3	6	4.5	7.3	1.4	3.5	1.8	4.4
16 (16-22 Apr)	2.4	4.6	1.42	3.4	1.7	4.0	1.8	4.7	5.2	7.6	1.0	2.6	1.3	3.4
17 (23-29 Apr)	1.6	3.4	0.99	2.5	1.3	3.1	1.3	3.6	4.7	6.8	0.7	1.9	0.9	2.6
18 (30 Apr-6 May)	1.2	2.6	0.66	1.8	0.9	2.4	0.9	2.7	3.4	5.1	0.5	1.4	1.1	2.4
19 (7-13 May)	0.8	1.9	0.45	1.3	0.7	1.8	0.6	2	2.8	4.2	0.8	1.5	0.8	1.8
20 (14-20 May)	0.6	1.4	0.31	1.0	0.5	1.4	3.5	4.7	2.1	3.3	0.6	1.2	1.4	2.3
21(21-27 May)	0.5	1.2	0.22	0.7	0.4	1.1	2.4	3.5	1.6	2.6	0.5	0.9	1.3	2.0
22 (28 May-3 Jun)	1.4	1.9	0.15	0.5	2.3	2.9	1.7	2.7	3.7	4.5	1.6	2.0	1.0	1.6
23 (4-10 Jun)	6.8	7.3	4.00	5.0	6.6	8.0	6.0	7.7	7.4	8.1	4.8	5.2	5.1	6.3
24 (11-17 Jun)	17.2	18.5	10.12	11.1	7.6	9.0	6.3	7.9	9.7	10.5	7.2	7.7	10.1	11.3
25 (18-24 Jun)	23.5	25.8	28.07	30.1	18.9	20.2	21.9	24.3	23.9	24.7	13.1	13.7	22.9	25.2
26 (25 Jun-1 Jul)	38.3	43.0	41.92	46.1	41.6	45.2	39.7	44.6	49.8	52.8	31.0	32.9	43.3	46.4
27 (2-8 Jul)	51.1	57.8	58.37	65.1	62.4	68.9	55.1	64.3	74.0	79.5	46.3	50.7	67.2	72.7
28 (9-15 Jul)	72.3	82.5	74.82	85.1	92.2	102.2	83.8	98.8	89.6	98.3	74.7	82.0	89.9	102.5
29 (16-22 Jul)	95.3	110.3	101.37	114.8	101.2	114.1	100.5	120.3	104.3	115.9	90.1	100.6	107.4	125.9
30 (23-29 Jul)	105.7	125.0	118.11	135.8	111.3	127.8	112.5	136	108.9	121.9	101.3	114.8	117.8	139.5
31(30 Jul-5 Aug)	110.4	133.8	119.31	140.1	115.3	133.4	115.7	143.5	109.9	124.1	109.9	127.2	124.0	148.7
32 (6-12 Aug)	115.1	141.0	124.28	148.0	115.0	135.0	120.1	150.9	112.1	128.3	111.1	131.9	123.2	150.3
33 (13-19 Aug)	118.6	145.0	127.96	153.5	124.1	145.8	121.8	154.2	116.0	132.9	110.9	131.8	130.1	159.3
34 (20-26 Aug)	122.3	150.1	131.71	158.2	125.0	148.8	121.8	154.9	121.0	139.4	120.9	142.8	131.8	162.1
35 (27 Aug-2 Sep)	118.8	147.1	127.88	154.5	126.5	151.7	121.0	155.8	113.9	132.5	117.8	139.8	126.5	156.9
36 (3-9 Sep)	119.5	148.8	125.16	152.1	125.8	151.6	120.0	155	115.4	134.4	118.5	142.9	123.1	153.4
37 (10-16 Sep)	117.3	147.5	125.70	152.7	130.4	156.3	119.6	154.9	117.7	137.3	115.5	139.9	122.4	152.6
38 (17-23 Sep)	111.1	141.0	115.54	143.1	127.3	153.2	115.1	150.3	118.2	138.3	114.2	139.9	116.3	146.8
39 (24-30 Sep)	109.2	139.5	106.92	134.1	120.5	146.1	109.5	144.4	112.8	133.0	109.3	134.7	109.7	139.8
40 (1-7 Oct)	101.5	132.1	96.79	123.3	111.8	137.2	98.6	132.9	104.3	124.7	98.5	123.4	97.5	126.9
41 (8-14 Oct)	88.4	118.2	86.35	111.9	103.4	128.2	86.3	119.5	95.1	115.1	91.9	116.1	84.0	112.2
42 (15-21 Oct)	75.7	104.3	74.18	98.7	91.3	115.3	75.5	107.4	85.5	105.0	82.1	105.6	74.4	101.3
43 (22-28 Oct)	66.3	93.5	66.58	90.0	79.6	102.7	63.4	93.7	73.8	92.6	74.5	97.0	62.8	88.2
44 (29 Oct- 4 Nov)	56.8	82.6	57.54	79.8	68.7	90.7	54.2	82.7	64.1	82.0	63.5	85.0	53.1	77.0
45 (5-11 Nov)	50.0	74.3	51.13	72.1	61.6	82.8	47.4	74.3	59.1	76.3	56.5	76.9	46.2	68.6
46 (12-18 Nov)	43.4	66.3	44.71	64.6	54.9	75.1	41.3	66.7	53.1	69.6	51.6	71.1	39.9	60.9
47 (19-25 Nov)	37.8	59.5	39.28	58.0	49.6	68.9	36.2	60.1	47.3	63.1	45.1	63.5	34.7	54.4
48 (26 Nov-2 Dec)	34.3	54.7	35.57	53.3	44.6	63.0	33.1	55.7	42.5	57.5	39.6	57.0	33.6	52.1
49 (3-9 Dec)	30.3	49.6	31.67	48.4	40.6	58.3	29.2	50.5	38.6	53.0	34.8	51.3	29.6	47.0
50 (10-16 Dec)	27.2	45.4	28.80	44.7	37.8	54.7	26.1	46.2	35.4	49.2	31.0	46.5	26.5	42.9
51(17-23 Dec)	24.8	42.1	26.17	41.3	34.7	50.9	23.6	42.6	32.7	45.9	27.9	42.5	23.6	39.1
52 (24-31 Dec)	23.0	39.5	24.98	39.5	32.2	47.6	21.9	40.1	30.3	42.9	25.7	39.6	22.5	37.3

SMW-Standard meteorological week

Table: 4
Average weekly rainfall (mm) in different drought prone districts of Bihar

SMW	Gaya	Aurangabad	Jahanabad	Kaimur	Nalanda	Nawada	Rohtas
1 (1-7 Jan)	1.3	2.3	0.9	1.8	0.6	1.4	1.6
2 (8-14 Jan)	1.1	0.8	0.6	1.2	1.2	0.3	1.7
3 (15-21 Jan)	3.4	2.6	1.5	2.8	3.2	4.3	3.5
4 (22-28 Jan)	5.4	4.4	3.6	3.7	4.8	4.4	4.8
5 (29 Jan-4 Feb)	4.6	3.0	1.6	3.4	1.9	1.3	2.1
6 (5-11 Feb)	3.3	3.6	2.6	6.2	2.2	2.4	4.6
7 (12-18 Feb)	3.6	3.8	3.1	8.2	6	1.8	5.7
8 (19-25 Feb)	2.2	3.0	2.0	1.7	2.3	2.0	2.4
9 (26 Feb-4 Mar)	2.3	2.4	1.5	3.1	2.7	1.8	2.8
10 (5-11 Mar)	3.6	1.4	0.2	1.3	3.9	0.7	1.4
11 (12-18 Mar)	1.9	0.8	0.9	1.2	3	1.2	1.4
12 (19-25 Mar)	1.8	2.2	1.0	1.1	5.3	2.0	2.6
13 (26 Mar-1 Apr)	1.5	0.5	0.4	0.4	0.6	0.7	0.8
14 (2-8 Apr)	1.5	0.6	0.8	0.4	0.6	0.4	1.8
15 (9-15 Apr)	3.7	1.0	1.1	0.5	2.6	1.1	2.0
16 (16-22 Apr)	5.1	2.0	1.4	3.4	5.6	2.3	3.9
17 (23-29 Apr)	2.3	1.2	2.1	1.2	5.9	1.5	3.6
18 (30 Apr-6 May)	2.6	1.2	2.9	1.4	3.5	2.9	4.4
19 (7-13 May)	4.9	3.0	2.9	1.5	5	7.8	4.2
20 (14-20 May)	5.3	4.7	6.4	9.3	5.5	7.2	8.9
21(21-27 May)	6.8	5.6	7.9	3.8	8.2	7.5	9.7
22 (28 May-3 Jun)	8.3	3.4	9.5	3.9	11.7	6.8	4.2
23 (4-10 Jun)	19.1	16.6	17.3	17.8	14.6	16.6	19.4
24 (11-17 Jun)	33.8	24.3	15.4	15.9	15.3	18.9	20.7
25 (18-24 Jun)	35.3	49.9	34.1	39.2	37	27.5	40.5
26 (25 Jun-1 Jul)	58.7	56.0	54.5	51.9	56.6	62.7	55.6
27 (2-8 Jul)	57.7	67.6	63.4	53.3	60.9	62.7	62.4
28 (9-15 Jul)	77.3	72.7	86.3	73.1	65.1	88.5	68.3
29 (16-22 Jul)	67.1	72.5	52.3	67.1	63.7	61.6	72.1
30 (23-29 Jul)	56.4	72.7	54.4	60.9	52.9	57.7	69.4
31(30 Jul-5 Aug)	58.4	52.5	40.6	60.9	38.5	49.8	53.7
32 (6-12 Aug)	64.6	64.2	48.0	59.8	44.1	45.2	56.6
33 (13-19 Aug)	60.8	64.0	69.6	64.9	54.1	51.4	71.3
34 (20-26 Aug)	59.8	60.3	50.3	70.5	44.8	65.5	70.2
35 (27 Aug-2 Sep)	42.6	57.2	47.6	59.3	36.8	39.5	50.9
36 (3-9 Sep)	45.0	54.8	44.7	62.4	45.4	49.5	55.4
37 (10-16 Sep)	44.7	59.2	41.4	65.1	38.2	42.8	59.8
38 (17-23 Sep)	36.2	29.8	36.4	34.9	40.1	41.1	35.8
39 (24-30 Sep)	36.4	28.3	35.0	33.1	27.4	36.1	26.0
40 (1-7 Oct)	27.0	19.2	14.0	16.1	16.7	16.4	16.2
41 (8-14 Oct)	12.0	11.5	12.0	10.2	10.3	15.5	7.1
42 (15-21 Oct)	8.1	7.6	6.2	7.3	9.1	10.1	9.5
43 (22-28 Oct)	5.7	9.4	3.6	1.8	3.4	8.8	2.9
44 (29 Oct- 4 Nov)	2.8	3.0	1.3	1.8	2.3	1.5	1.6
45 (5-11 Nov)	2.8	2.8	2.0	2.1	3.5	4.3	2.0
46 (12-18 Nov)	1.3	1.2	0.2	1.2	1.2	4.6	0.6
47 (19-25 Nov)	0.8	0.7	1.6	0.6	0.5	0.8	0.7
48 (26 Nov-2 Dec)	2.0	1.8	0.4	2.6	0.6	0.4	4.2
49 (3-9 Dec)	0.3	0.2	0.2	0.0	0.2	0.0	0.2
50 (10-16 Dec)	0.5	1.1	1.0	0.6	0.5	0.4	0.4
51(17-23 Dec)	1.3	1.2	1.0	0.9	1.1	1.0	0.7
52 (24-31 Dec)	2.0	3.0	2.2	2.4	1.8	2.4	3.0

AWC have been worked out for various districts of Zone IIIB at 50 and 75% probability levels (Table 8). The empirical probabilities of having SM of 25, 50 and 75% of available AWC in medium and fine textured soils have also been presented graphically (Fig. 2 to Fig. 8) for individual districts. Ramana Rao *et al.* (1979b) identified water availability period for Gulbarga region by estimating probabilities for the ratio of AE/PE being equal to or greater than 0.30, 0.60 and 0.75 in case of sandy soils, 0.25, 0.50 and 0.75 for lateritic soils and 0.20, 0.40, 0.60 and 0.80 for medium and deep black soils. As suggested by Misra and Ahmed (1987), in the present study, the length of growing period for crop production under rainfed condition has been evaluated under conditions of low SM availability (at least 25% of

Table: 5
Average monthly rainfall (mm) in various drought prone districts of Bihar

Months	Gaya	Aurangabad	Jahanabad	Kaimur	Nalanda	Nawada	Rohtas
Jan	15.8	13.1	8.2	12.9	11.8	11.7	13.7
Feb	11.4	12.8	9.2	19.2	13.2	8.2	15.5
Mar	8.8	4.9	2.5	4.0	12.9	4.6	6.2
Apr	12.6	4.8	5.4	5.5	9.7	5.3	11.3
May	27.9	17.9	29.6	19.9	32.8	32.2	31.4
Jun	146.9	146.8	121.3	124.8	123.5	125.5	136.2
Jul	258.5	285.5	256.4	254.4	242.6	270.5	272.2
Aug	286.2	298.2	256.2	315.4	218.3	251.4	302.7
Sep	162.3	172.1	157.5	195.5	157.1	169.5	177.0
Oct	52.8	47.7	35.8	35.4	39.5	50.8	35.7
Nov	7.7	7.7	5.1	5.7	7.5	11.2	4.9
Dec	6.1	7.3	4.8	6.5	4.2	4.2	8.5
Total	997.0	1018.8	892.0	999.2	873.1	945.1	1015.3

Table: 6
Average number of annual and *kharif* season dry spell (weeks), average soil moisture (mm), rainfall (mm) and dates of monsoon onset

District	*Kharif* season			Annual			Onset of monsoon during SMW
	Average rainfall (mm)	Dry spell (weeks)	Average soil moisture (mm)	Average rainfall (mm)	Dry spell (weeks)	Average soil moisture (mm)	
Gaya	892.8	3	76.5	997.0	31	40.2	25
Aurangabad	932.8	4	80.2	1018.8	33	41.2	25
Jahanabad	815.8	4	85.4	892.0	33	43.4	25
Kaimur	902.2	4	77.4	999.2	33	39.6	25
Nalanda	762.2	4	76.6	873.1	34	41.4	25
Nawada	848.9	4	73.6	945.1	32	38.9	26
Rohtas	911.4	4	82.0	1015.3	32	35.6	25

Table: 7
Correlation coefficients of number of dry spell with rainfall and SM

District	Dry spell vs. Rainfall		Dry spell vs. soil moisture	
	Annual	*Kharif* season	Annual	*Kharif* season
Gaya	-0.45**	-0.31*	-0.46**	-0.38*
Aurangabad	-0.39*	-0.43**	-0.38**	-0.39**
Jahanabad	-0.18	-0.11	-0.27	-0.30
Kaimur	-0.48**	-0.26	-0.61**	-0.32*
Nalanda	-0.64**	-0.44**	-0.54**	-0.52**
Nawada	-0.51**	-0.46**	-0.57**	-0.52**
Rohtas	-0.14	-0.15	-0.21	-0.34*

*Significant at 5% level, ** significant at 1% level

AWC), medium soil moisture availability (at least 50% of AWC) and high SM availability (at least 75% of AWC).

Growing Period at Low Soil Moisture Availability

In medium textured soil, the rainfed *kharif* crop growing season starts at 27th SMW in all the districts except in Nawada where it begins at 28th SMW at 50% probability level. The growing period terminates during 46th to 50th SMW with the earliest end occurring at 46th SMW in Rohtas and the latest at 50th SMW in Jahanabad district. At this probability (50%), the crop growing period varied from 20 weeks in Rohtas to 24 weeks in Jahanabad district (Table 8, Fig 4 and Fig. 8). In case of 75% probability the earliest onset of growing period was observed at 27th SMW in Rohtas and Nalanda districts with Length of Growing Period (LGP) ranging from 16th weeks in Auranagabad to 21st weeks in Jahanabad and Nalanda districts (Fig. 2, Fig. 4 and Fig. 6). The earliest end of LGP on the basis of one-fourth of available SM availability was recorded in Aurangabad at 44th SMW, while the latest occurred in Jahanabad district at 48th SMW.

In fine textured soil, the longest LGP of 25 weeks was recorded in Jahanabad and the shortest of 23 weeks in Rohtas district at 50% probability, with growing season starting during the window of 27th to 28th SMW in all the districts (Table 8). At 75% probability level, the LGP ranged from 19 weeks in Aurangabad to 23 weeks in Jahanabad and Nalanda districts. The LGP terminated during 47th SMW in Auranagabad to 50th SMW in Jahanabad district. Thus it is observed that under low SM condition the LGP in medium textured soil varied from 16 to 21 weeks, with the lowest being in Auranagabd district and the highest in Jahanabad and Nalanda districts at 75% probability level. In case of fine textured soil, the LGP varied from 19 to 23 weeks with the lowest being occurring in Aurangabad and the highest in Nalanda district (Figs. 2 and 6). Hence, considering the length of growing period

Table: 8
Duration of crop growing period based on SM at 25, 50 and 75% of AWC in medium and fine textured soils at various probabilities in various districts

District	Duration in weeks (SMW) with SM at 25% of AWC				Duration in weeks (SMW) with SM at 50% of AWC				Duration in weeks (SMW) with SM at 75% of AWC			
	Medium texture		Fine texture		Medium texture		Fine texture		Medium texture		Fine texture	
	50% prob.	75% prob.	50% prob.	75% prob.	50% prob.	75% prob.	50% prob.	75% prob.	50% prob.	75% prob.	50% prob.	75% prob.
Auranagabd	22 (27-48)	16 (29-44)	24 (27-50)	19 (29-47)	15 (28-42)	12 (29-40)	16 (28-43)	13 (29-41)	11 (29-39)	9 (30-38)	12 (29-40)	9 (30-38)
Gaya	22 (27-48)	18 (29-46)	24 (28-51)	20 (29-48)	16 (28-43)	13 (29-41)	16 (29-44)	13 (30-42)	8 (30-37)	-	15 (30-44)	8 (32-39)
Jahanabad	24 (27-50)	21 (28-48)	25 (27-51)	23 (28-50)	16 (28-43)	14 (29-42)	17 (28-44)	15 (30-44)	12 (29-41)	7 (33-39)	12 (30-41)	8 (33-40)
Kaimur	21 (27-47)	19 (28-46)	24 (28-51)	22 (28-49)	15 (28-42)	13 (29-41)	16 (28-43)	14 (29-42)	12 (29-40)	10 (30-39)	12 (29-40)	10 (30-39)
Nalanda	23 (27-49)	21 (27-47)	25 (27-51)	23 (27-49)	16 (27-42)	12 (30-41)	16 (28-43)	12 (31-42)	12 (29-40)	-	12 (29-40)	-
Nawada	21 (28-48)	18 (29-46)	24 (28-51)	21 (29-49)	15 (28-42)	12 (30-41)	17 (28-44)	13 (30-42)	12 (29-40)	5 (34-38)	12 (29-40)	6 (34-39)
Rohtas	20 (27-46)	19 (27-45)	23 (27-49)	21 (28-48)	16 (27-42)	13 (29-41)	16 (28-43)	14 (29-42)	12 (29-40)	9 (30-38)	12 (29-40)	9 (31-39)

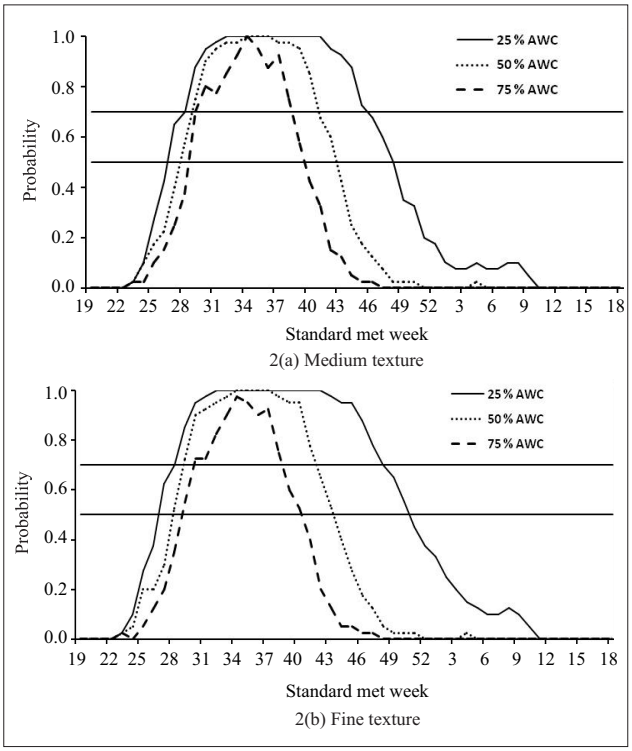

Fig. 2 (a and b). Probabilities of having SM at 25, 50 and 75% of AWC in medium and fine textured soils in Auranagabad district

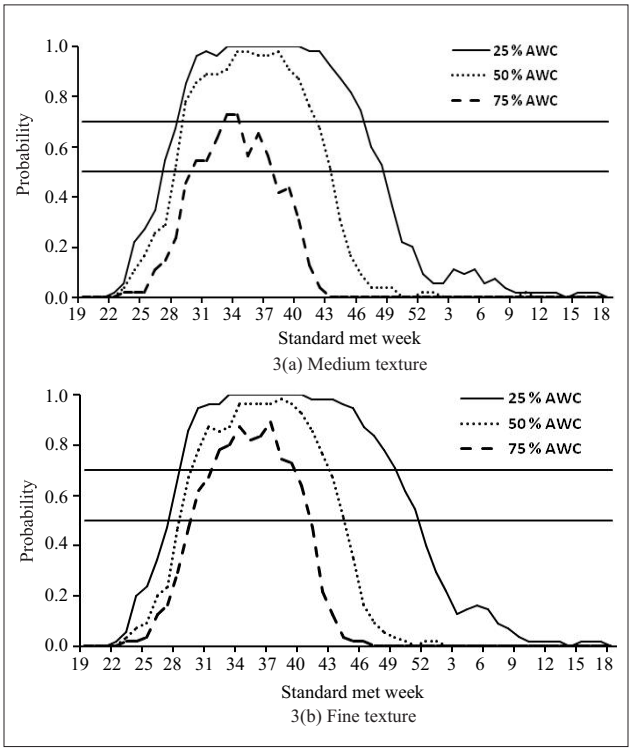

Fig. 3 (a and b). Probabilities of having SM at 25, 50 and 75% of AWC in medium and fine textured soils in Gaya district

based on available soil moisture per meter soil depth, Aurangabad district exhibited the lowest crop production potential with Nalanda and Jahanabad districts showing the highest crop production potential.

Growing Period at Medium Soil Moisture Availability

In medium textured soil, at 50% probability the rainfed crop growing season starts during 27th to 28th SMW and terminates during 42nd to 43rd SMW in all seven districts with LGP varying from 15 to 16 weeks. LGP extends from 12 to 13 weeks in all the districts except Jahnabad district at 75% probability which had the LGP of 14 weeks. In case of fine textured soil, the LGP ranged from 16 to 17 weeks at 50% probability level to 12

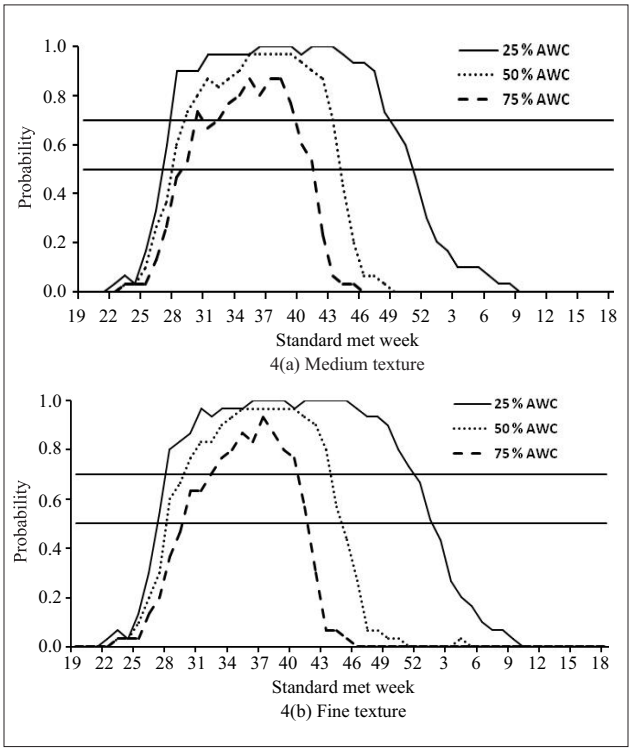

Fig. 4 (a and b). Probabilities of having SM at 25, 50 and 75% of AWC in medium and fine textured soils in Jahanabad district

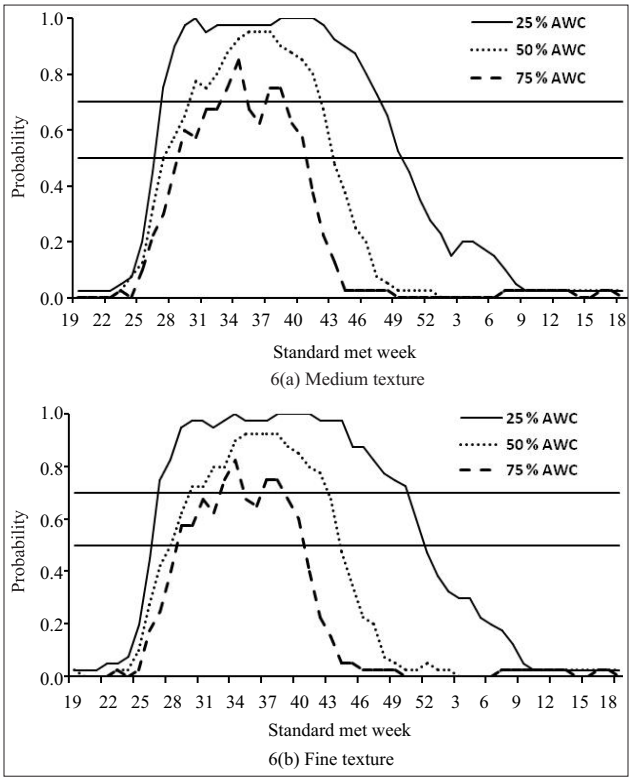

Fig. 6 (a and b). Probabilities of having SM at 25, 50 and 75% of AWC in medium and fine textured soils in Nalanda district

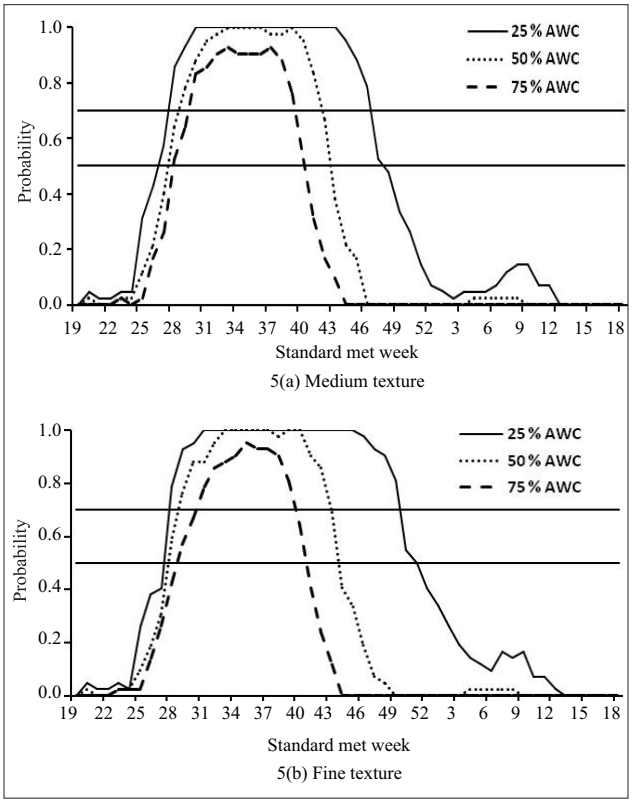

Fig. 5 (a and b). Probabilities of having SM at 25, 50 and 75% of AWC in medium and fine textured soils in Kaimur district

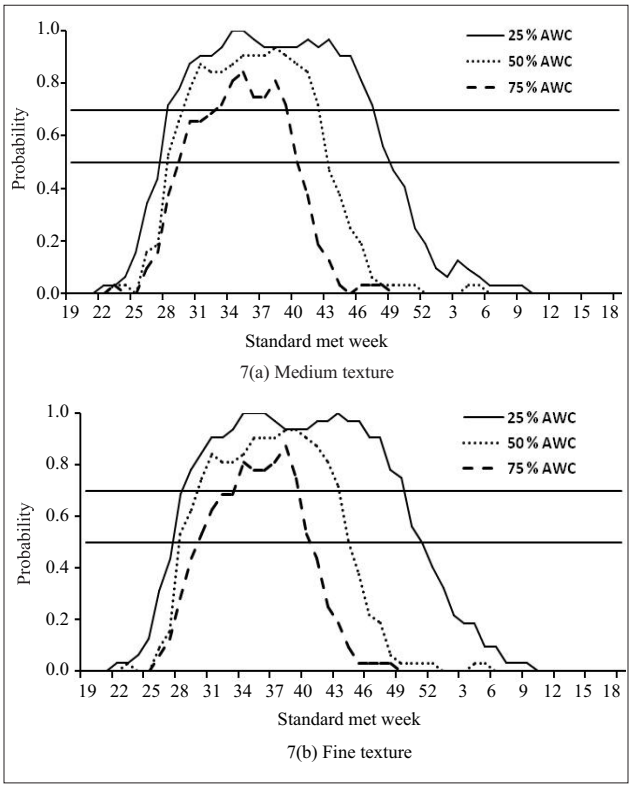

Fig. 7 (a and b). Probabilities of having SM at 25, 50 and 75% of AWC in medium and fine textured soils in Nawada district

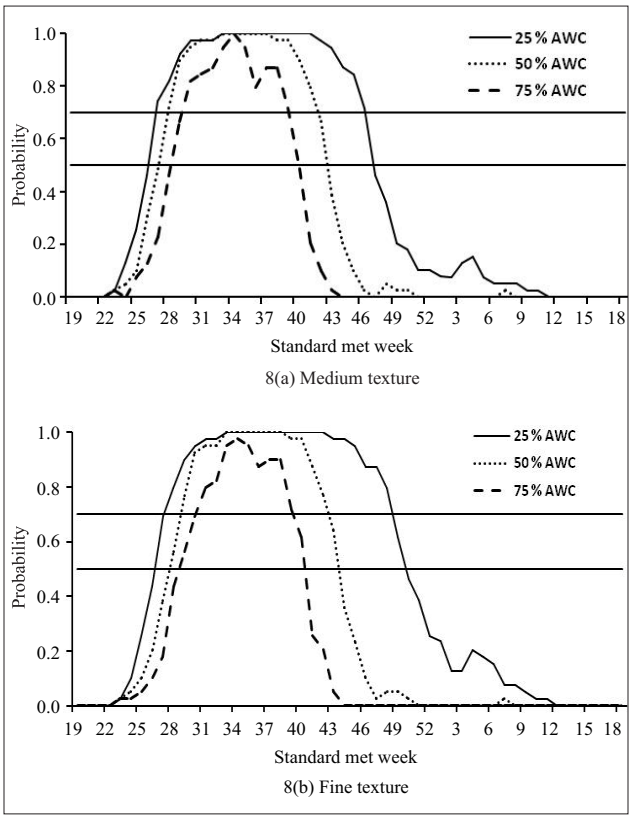

Fig. 8 (a and b). Probabilities of having SM at 25, 50 and 75% of AWC in medium and fine textured soils in Rohtas district

to 15 weeks at 75% probability level. However, at 75% probability level, the highest LGP of 15 weeks was recorded in Jahanabad district as against the lowest of 12 weeks in Nalanda district (Table 8). Hence, on the basis of available SM in both medium and fine textured soils under rainfed condition, the highest crop production potential could be achieved in Jahanabad district and the lowest in Nalanda district in 75 years out of 100 years.

Growing Period at High Soil Moisture Availability

The probability of getting SM greater than or equal to 75% of AWC for medium and fine textured soils have been given in Table 8. In case of medium textured soil, at 50% probability, the duration of rainfed crop growing period varied from 8 weeks in Gaya district to 12 weeks in the remaining districts except Aurangabad district which had a growing period of 11 weeks. The LGP starts during 29th to 30th SMW and ends during 40 SMW in all districts except in Aurangabad, Gaya and Jahanabad districts where LGP ends at 39th, 37th, and 41st SMW, respectively. At 75% probability, the LGP ranged from 5 weeks in Nawada to 10 weeks in Kaimur district (Fig. 5 and Fig. 7) with Gaya and Nalanda districts recording no growing period in 75 out 100 years in medium textured soil (Table 8, Fig. 3 and Fig. 6).).

In fine textured soil, LGP ranged from 12 to 15 weeks at 50% probability and from 6 to 10 weeks at 75% probability level over different districts. Hence, it is to be noted that Nalanda district seems to be the most vulnerable district because it exhibited no scope for crop production under rainfed condition at 75% probability level in both medium and fine textured soils, followed by Gaya district which had no prospect of crop production in medium textured soil at 75% probability level. In fine textured soil, except in Gaya district which has LGP of 8 weeks, the rest of the districts are having LGP of 12 weeks at 50% probability level.

Crop Planning and Irrigation Scheduling

Under low soil moisture condition with at least 25% of AWC, deep rooted and low water requiring rainfed crops like castor, cow pea, sunflower and safflower could be grown. The crops like *kharif* maize, pigeon pea, oil seeds, pulses, vegetables or cowpea can be selected under medium soil moisture condition with 50% of AWC. Where there is no moisture stress under the condition of at least 75% of AWC, short duration varieties of rice (*Prabhat, Rajendra Suhasini, Rajendra Bhagwati*), *kharif* maize, pigeon pea, wheat, rapeseed, chick pea and lentil could be successfully cultivated. Banerjee *et al.* (2010) also suggested SM based crop planning for farmers in Silai sub watershed of West Bengal. Hence, under low SM condition, cropping sequences could be as cowpea-safflower or sunflower followed by vegetables with provision of irrigation or castor as sole crop. Under medium soil moisture condition, the option could be for growing of *kharif* maize-oilseeds or pulses-fallow or *kharif* maize/pigeon pea/cowpea/black gram/green gram-vegetables/fallow. Under assured soil moisture condition (50 to 75% of AWC), short duration rice-wheat/oil seeds/pulses/vegetables or maize-vegetables or *kharif* pigeon pea or sugarcane as sole crop could be grown. In most vulnerable districts such as Nalanda and Gaya with lesser availability of SM, intercropping of pigeon pea with maize sown in paired rows could be more remunerative cropping system than others (Singh *et al.,* 1981).

The depletion of available SM at a specified level which varies from crop to crop and its stages of growth are considered as one of the methods for scheduling irrigation (Doorenbos and Pruitt, 1977). At 75% probability level and under the condition of 50% of AWC, the length of growing period terminates at 42nd SMW in medium textured soil, whereas in fine textured soil, it terminates at 44th SMW, beyond which supplemental irrigation could be applied for better crop prospect. Thus the findings of the present study are useful for scheduling of irrigation.

4. CONCLUSIONS

The study revealed that simulated available SM in medium and fine textured soils could be useful tool for

deciding the types of crops to be grown in a particular area. The crop growing period worked out on the basis of simulated SM has provided scope for identification of suitable rainfed crops under varying level of soil moisture in both medium and fine textured soils. In 75 years out of 100 years the highest crop potential in dry Zone IIIB could be achieved in Jahanabad district and the lowest in Nalanda district in both medium and fine textured soils with SM availability at 50% of available water holding capacity, below which crop water stress may begin in many crops (Singh and Sahu, 1981). When SM status at 75% of AWC was considered, where no crop water stress occurs, Kaimur district seems to be more productive while Gaya district appears to be most vulnerable to produce low in terms of low SM availability. Dry spell showed significant negative correlation with soil moisture.

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