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Using agroclimatic approach for crop planning under rainfed condition in Darbhanga district of Bihar

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सार – इस समय बदलते जलवायविक परिदृश्य में सतत फसल उत्पादन के लिए प्रभावशाली निर्णय लेने के उद्देश्य को पूरा करने के लिए वर्षा वाली स्थितियों में फसल विभव का मूल्यांकन करने के लिए ऐतिहासिक मौसम ऑकड़ों के साथ कृषि जलवायविक विश्लेषण किए गए है। बिहार के दरभंगा जिले में कृषि जलवायविक अध्ययन 1980 - 2012 के डाटा बेस का उपयोग करते हुए सक्षम फसल योजना, हल्के, मध्य और उच्च कोटि को मृदा के लिए तीन स्थानों जैसे दरभंगा, हयाघाट और जाले को लिया गया। इनसे प्राप्त हुए परिणामों से पता चला है कि औसत वार्षिक वर्षा 1109.8 ± 340.7 मि. मी. आकलित की गई। प्रति सप्ताह 30 मि. मी. से अधिक वर्षा 24 से 36 एस एम डब्ल्यू (11 जून - 9 सिंतबर) दौरान हुई और 26 से 36 एस एम डब्ल्यू (25 जून - 9 सिंतबर) के दौरान प्रति सप्ताह 50 मि. मी. से अधिक वर्षा आकलित की गई। हल्के संगठन मृदा के लिए 23 से 43 एस एम डब्ल्यू (4 जून - 28 अक्तूबर) के दौरान 483 मि. मी. तथा 26 से 42 एस एम डब्ल्यू (25 जून - 21 अक्तूबर) के दौरान, 408 और 375 मि. मी. क्रम में क्रमश: मध्यम और उच्च कोटि की मृदा की कुल वार्षिक जल बचत मान रहे। नमी का पर्याप्त सूचकांक (Ima) के आधार पर वर्षावार बढ़ती अवधियों का पता लगाया गया। Ima के आधार पर जिले के औसत एल जी पी 143 ± 19 दिनों का रहा, मध्यम रूप से 180 ± 30 और 209 ± 36 दिन अति उत्तम कोटि की मृदा रही। दरभंगा, हयाघाट और जाले ब्लाक में क्रमश 161, 177 और 167 दिनों का एल जी पी रिकार्ड किया गया। हरग्रीव नमी उपलब्धता सूचकांक (MAI ≥ 0.34) 25, 50, 75 प्रतिशत पर बढ़कर 19 से 42 (7 मई - 21 अक्तूबर), 23 से 40 (4 जून - 7 अक्तूबर) और 26 से 38 एस एम डब्ल्यू (25 जून - 23 सितंबर) रहा जबकि MAI ≥ 0.75, 25, 50, 75 प्रतिशत संभावता स्तर पर 23 से 42 (4 जून - 21 अक्तूबर), 28 से 39 (9 जुलाई - 30 सितंबर) और 27 से 35 एस एम डब्ल्यू (2 जुलाई - 2 सितंबर) रहा। वर्षा वाली स्थितियों के अंतर्गत सतत वाली फसल उत्पादन के लिए जिलों में विभिन्न प्रकार की मृदाओं के लिए एल जी पी के आधार पर फसल योजना तैयार की गई।

ABSTRACT. Agroclimatic analysis with historical weather data for assessment of crop potential under rainfed condition is called for effective decision making purposes for sustainable crop production under changing climatic scenario. An agroclimatic study was conducted for Darbhanga district of Bihar using database of 1980-2012 comprising three locations, *viz*., Darbhanga, Hayaghat and Jale for efficient crop planning in coarse, medium and fine textured soils. Results revealed that average annual rainfall computed was 1109.8 ± 340.7 mm. More than 30 mm rainfall per week was found to occur during 24 standard meteorological week (SMW) to 36 SMW (11 June - 9 September) and more than 50 mm per week occurred during 26 to 36 SMW (25 June - 9 September). Total annual water surplus values were 483 mm during 23 to 43 (4 June - 28 October), 408 mm during 26 to 42 (25 June - 21 October) and 375 mm during 26 to 42 SMW (25 June - 21 October) in coarse, medium and fine textured soils, respectively. Year-wise lengths of growing periods (LGP) were worked out based on index of moisture adequacy (I_{ma}). Mean LGP of the district based on I_{ma} was 143 ± 19 days in coarse, 180 ± 30 days in medium and 209 ± 36 days in fine textured soils. Darbhanga, Hayaghat and Jale blocks recorded LGP of 161, 177 and 167 days, respectively. Hargreaves' moisture availability index (MAI) ≥ 0.34 extended from 19 to 42 (7 May - 21 October), 23 to 40 (4 June - 7 October) and 26 to 38 SMW (25 June - 23 September) at 25, 50 and 75% probability levels, whereas MAI ≥ 0.75 prevailed from 23 to 42 (4 June - 21 October), 28 to 39 (9 July-30 September) and 27 to 35 SMW (2 July - 2 September) at 25, 50 and 75% probability levels, respectively. Crop planning based on LGP has been suggested for the district in different soils for sustainable crop production under rainfed condition.

Key words – Water balance, Length of growing period, Moisture adequacy index, Moisture availability index, Crop planning.

1. Introduction

Rainfall is the most important determinant for crop production under rainfed condition. About 50% of the total net cropped area in Bihar is rainfed. Crop production under rainfed condition depends on rainfall pattern and stored moisture in the soil. Due to variation in rainfall amounts and its distribution and available water holding capacity in different soils, the water availability period in a given location varies from year to year and from soil to soil and influences the crop production differently (Khan and Chatterjee, 1987). Thus, precise evaluation of water availability period is an important pre-requisite for successful rainfed crop production. The water balance is a widely used method for determination of growing period length under rainfed condition. It is a unique tool for assessing agricultural potential of a region (Pandey and Sheikh, 1999). Analysis of historical rainfall data through modern agroclimatic methods such as Thorthwaite and Mather (1955) water balance model will be useful for developing strategies such as selection of suitable crop or a variety under a crop matching with length of growing period and water availability pattern in terms of moisture adequacy during *kharif* and *rabi* seasons. A number of workers have studied water balance technique to assess water availability, water deficiency and length of growing period for agricultural planning. Bishnoi (1980) estimated the probability of index of moisture adequacy (I_{ma}) for different stations of northwest India and compared different values of I_{ma} ranging from 0.4 to 0.9 over crop growing period and suggested extent of water availability for different crops. Debnath (1996) identified periods of recharge, surplus, moisture utilization, and sowing and cropping pattern based on climatic water balance parameters in Bhubaneshwar region of Odisha. Dey (2008) studied climatological water balance for estimating soil moisture, actual evapotranspiration, length of crop growing period and rainwater balance for determining effective rainfall, water surplus and deficit during different growth phases of transplanted *kharif* rice in West Bengal. Water balance studies have also been carried out at Ranchi region of Jharkhand by Singh *et al.* (2009) to assess the drought situation. Verma *et al.* (2012) studied monthly climatic water balance of selected locations of India and emphasized the need for proper crop selection with limited moisture. The study involving water balance, length of growing period and crop planning in Bihar is meager and for Darbhanga district, the availability of such information is practically nil. In this paper, an attempt has been made to assess the components of climatic water balance and length of growing period of three blocks in Darbhanga district of Bihar for potential productivity evaluation under rainfed condition.

2. Data and methodology

The agroclimatic study was conducted for Darbhanga district under North-west Alluvial Plain Zone of Bihar. Rainfall data for the period of 33 years (1980-2012) of three blocks of the district, *viz.*, Darbhanga, Hayaghat and Jale were used in the study for district level analysis. The water holding capacity of soil was estimated considering the layer wise soil textural classes up to one meter soil depth. Available water holding capacity (AWHC) per meter depth of all soil series falling under the district as reported by NBSS & LUP, Nagpur was calculated and accordingly on the basis dominant soil texture of each series, AWHC of coarse, medium and fine textured soils was worked out as the difference between field capacity and permanent wilting point following the procedure of Saxton and Rawls (2006). AWHC per meter depth of the soil so determined was 60 mm for coarse, 138 mm for medium and 175 mm for fine textured soils in the district. Weekly total potential evapotranspiration (PET) were collected from IMD, Pune (Rao *et al.*, 1971; Rathore and Biswas, 1991; Khambete and Biswas, 1992). Year wise weekly water balance computation was carried out by using weekly total rainfall, normal weekly total PET and AWHC of 60 mm, 138 mm and 175 mm per meter soil depth following the procedure given by Thornthwaite and Mather (1955). Output components of water balance method were soil moisture storage (SMS), actual evapotranspiration (AET) water surplus and water deficit. The derived parameters were moisture adequacy index (Im_a) which is the ratio between AET and PET and soil moisture index (the ratio between SMS and AWHC). Where rainfall was greater than PET, AET was considered as equal to PET. When rainfall was below PET, the AET was calculated as the sum of rainfall and change in soil moisture storage between two successive weeks.

For determining the length of growing period (LGP), which is also regarded as the water availability period under rainfed condition, the concept of index of moisture adequacy (I_{ma}), which is the ratio between AET and PET, has been considered. Since the study area falls under sub humid climatic condition, the onset of growing season was considered at a week when I_{ma} was greater than or equal to 0.75 (Gupta *et al*., 2010), which is considered as the minimum moisture level for starting the sowing of crops like rainfed rice, maize, pigeon pea and sunflower. The termination of growing period was taken at a week from where I_{ma} was less than 0.33 (Virmani *et al*., 1982; Khan and Saha, 1996) for consecutive three weeks (Krishnan *et al.*, 1980). From the results of water balance, LGP of each individual year during the period from 1968 to 2012 was determined and from this, the average LGP, standard deviation (SD) and coefficient of variation (CV) were calculated. LGPs of individual blocks were determined for coarse, medium and fine textured soils.

Moisture availability index (MAI) which is the ratio between expected rainfall at different probability levels and potential evapotranspiration was estimated with the method given by Hargreaves (1971). Expected weekly rainfall at different probability levels (10, 25, 50, 75 and 90%) was computed with the procedure followed by Sarker and Biswas (1986). According to Hargreaves moisture availability index (MAI) concept, moderately deficient period was considered when MAI was greater than or equal to 0.34 and adequate moisture availability when MAI ≥ 1.0.

3. Results and discussion

3.1. *Weekly water balance parameters*

Results of weekly water balance revealed that weekly rainfall amounting to more than 20 mm was found to occur during 21 to 40 SMW (21 May-7 October) except 22 SMW (28 May-3 June) and more than 30 mm rainfall per week was available during 24 to 36 SMW (11 June-9 September). Weekly rainfall more than 50 mm was recorded during 26 to 36 SMW (25 June-9 September). Weekly total PET was more than 20 mm during the period from 8 to 44 SMW (19 February-4 November) and more than 30 mm during 12 to 27 SMW (19 March-8 July). However, during the months of December and January, PET remained below 20 mm per week. Water surplus which includes run off and deep drainage was found to prevail from 23 to 43 SMW (4 June-28 October). The total surplus in areas having coarse textured soils in Darbhanga district was computed as 482.7 mm as against the total water deficit of 105.5 mm during the corresponding period. However, annual deficit in the district as determined was 735.0 mm. The available water holding capacity for coarse textured soil was 60 mm per meter depth and 50% of this value which comes to be 30 mm prevailed during the period from 29 to 44 SMW (16 July-4 November). Crops growing during this period would be able to produce at potential level under average rainfall condition. Soil moisture index (SMI, the ratio between actual available soil moisture and available water holding capacity) > 0.5 was found to occur during 26 to 41 SMW (25 June - 14 October).

In medium textured soil, total water surplus was computed as 407.5 mm during 26 to 42 SMW (25 June - 21 October). The total deficit during the corresponding period was 35.8 mm. Such information would be useful for selecting low land rice varieties to suit this surplus period under average rainfall condition. The total annual deficit in areas having medium textured soil was 659.5 mm. SMI > 0.5 was found to prevail during 27 to 43 SMW (2 July - 28 October). Available water holding capacity of such soil was calculated as 138 mm per meter depth. At least 50% of this value prevailed during 27 to 44 SMW (2 July - 4 November). In fine textured soil, total surplus during the period from 26 to 42 SMW (25 June - 21 October) was 374.6 mm against the total deficit of 33.9 mm during the corresponding period. Total annual water deficit in the district in fine textured soil was 627.0 mm. SMI > 0.5 was found during the period from 27 to 45 SMW (2 July-11 November). At least 50% of AWHC under such soil was available during 27 to 45 SMW (2 July-11 November) suggesting crops growing during period would be able to produce at potential level.

3.2. *Annual rainfall, water surplus, AET and water deficit*

Year wise water balance parameters during the period from 1980 to 2012 presented in Table 1 for coarse, medium and fine textured soils revealed that the average annual rainfall of the district was recorded as 1109.8 ± 340.7 mm. The C.V. of annual rainfall was 30.7%. Total annual water surplus of 482.7 mm was found to prevail from 23 to 43 SMW (4 June - 28 October) in coarse textured soil, 407.5 mm in medium textured soil during 26 to 42 SMW (25 June-21 October) and 374.6 mm during 26 to 42 SMW in fine textured soil. The mean annual AET in coarse textured soil was recorded as 627.1 ± 94.0 mm. In medium textured soils, annual AET varied from 498.9 to 860.6 mm. The mean annual AET was recorded as 702.6 ± 91.9 mm. In fine textured soil, the highest AET was recorded as 888.0 mm and the lowest 536.6 mm. The variations in AET from various soils have been presented in Fig. 1. The mean annual water deficits were 735.0 ± 94.0, 659.5 ± 91.9 and 627.0 ± 91.6 mm for coarse, medium and fine textured soils respectively. Such information would be useful in agricultural planning such as water harvesting and provision of supplemental irrigation.

3.3. *LGP on the basis of moisture adequacy index (Im_a)*

The results on length of growing period (LGP) revealed that there was a wide variation in the length of rainfed crop growing period in various soils (Table 2 & Fig. 2) and across different blocks of the district (Fig. 3).

(*i*) *Coarse textured soil* : The earliest start of LGP occurred in 18 SMW (30 April - 6 May) in 2007, whereas the delayed start (27 SMW, 2-8 July) was observed in 1994. The earliest end of growing period happened in 39 SMW (24-30 September) in 2002 and the delayed end of LGP occurred in 47 SMW (19-25 November) in 2003. The total length of LGP calculated over the period between onset and cessation of LGP for individual years showed that the lowest LGP of 105 days was recorded in 1994 and the highest growing period of 197 days was observed in 2007. The mean LGP in coarse textured soils was calculated as 143 ± 19 days with a CV of 13.3%.

(*ii*) *Medium textured soil* : In this soil, the earliest onset of LGP was observed in 18 SMW (30 April - 6 May)

TABLE 1

Year wise rainfall (mm), water surplus (mm), actual evapotranspiration (mm) and water deficit (mm) during 1980-2012 in Darbhanga district

Year	Rainfall (mm)	Water surplus (mm)			AET (mm)			Water deficit (mm)		
		CT	MT	FT	CT	MT	FT	CT	MT	FT
1980	1268.3	600.2	529.3	495.3	670.6	758.2	781.2	691.5	603.9	580.9
1981	1785.3	1104.5	1030.8	996.5	680.8	755.4	789.7	681.3	606.7	572.4
1982	783.5	244.5	162.1	125	539.1	619.2	655.7	823	742.9	706.4
1983	1169.1	443.9	358.4	322.1	719.1	795.1	827.7	643	567	534.4
1984	1273.4	552.8	477.2	443.9	726.4	809.3	845.8	635.7	552.8	516.3
1985	1775.2	966.6	895.4	862.2	804.9	860.6	888	557.2	501.5	474.1
1986	1130.9	452.2	378.7	345.2	679.2	755.8	790.8	682.9	606.3	571.3
1987	1655.4	887	825.9	800	769.5	833.9	860.9	592.6	528.2	501.2
1988	1232.6	539.4	474.6	442.5	695.3	771.6	808.6	666.8	590.5	553.5
1989	1357.1	648.1	580.2	547.5	705.6	766.3	795.8	656.5	595.8	566.3
1990	920.3	299.4	220.4	184.8	623.8	706.7	743.8	738.3	655.4	618.3
1991	872.7	327.6	258.3	224	545.8	620.2	656.7	816.3	741.9	705.4
1992	651.9	100	37.9	6.2	550.7	610.3	641.8	811.4	751.8	720.3
1993	1229.9	522	446.4	412.2	708.8	785.4	818.4	653.3	576.7	543.7
1994	922.7	434	370	336.8	489.3	557.5	592.9	872.8	804.6	769.3
1995	856.4	285.8	207	177.6	565.5	630.8	654.1	796.6	731.4	708
1996	1092.7	549.7	461.6	423.9	546.9	641.1	680.7	815.2	721	681.4
1997	1402.9	814	735.9	700.1	584.5	664.3	701.8	777.6	697.8	660.3
1998	1403.7	725.4	646.8	611.3	682.2	755	787.6	679.9	607.1	574.5
1999	1414.7	776.3	684.3	645.8	636.6	721.6	757.7	725.5	640.5	604.4
2000	856.2	159.1	98.6	69.1	698.7	765.5	797.9	663.4	596.6	564.2
2001	1152.5	502.7	428.2	398.5	650	724.9	754.4	712.1	637.2	607.7
2002	864.2	314	238.6	203.6	552.3	643.9	686.8	809.8	718.2	675.3
2003	995.1	293.9	212.1	176	695.3	754.4	781.3	666.8	607.7	580.8
2004	1085.8	397	311.1	278.6	693.4	790	825.1	668.7	572.1	537
2005	524.2	48	0	0	477.1	537.3	550	885.1	824.8	812.1
2006	753.5	233.6	135.8	94.3	518.6	604.8	634.3	843.5	757.3	727.8
2007	1795.7	1044.9	974.6	944.4	748.7	810.2	836.6	613.4	551.9	525.5
2008	802.2	257.2	174.5	137.8	546.9	639.1	679.5	815.2	723	682.6
2009	663.4	244.8	168.3	132.1	418.9	498.9	536.6	943.2	863.2	825.5
2010	653.9	107.5	27.8	0.5	546.8	629.3	659.1	815.3	732.8	703
2011	1219.8	547.9	464.6	428.1	671.3	749.7	783.6	690.8	612.4	578.5
2012	1057.4	504.3	431.9	396.9	552	619.2	652.3	810.1	742.9	709.8
Mean	1109.8	482.7	407.5	374.6	627.1	702.6	735.1	735.0	659.5	627.0
SD(±)	340.7	273.6	273.5	272.3	94.0	91.9	91.6	94.0	91.9	91.6
CV (%)	30.7	56.7	67.1	72.7	15.0	13.1	12.5	12.8	13.9	14.6

in 2007 and the latest in 27 SMW (2-8 July) during the year 1994. The earliest end of LGP was recorded as 43 SMW (22-28 October) during 2002 and 2005. The delayed termination of growing period was recorded in 6 SMW (5-11 February) in 1995. The mean LGP calculated over the period of 33 years (1980-2012) was calculated as 180 ± 30 days with a CV of almost 17%. The highest duration of LGP (245 days) was observed in 1995 and the lowest of 133 days in 2005.

(*iii*) *Fine textured soil*: The earliest and latest start of LGP was like that of coarse and medium textured soils. However, the earliest termination of LGP took place in 45 SMW (5-11 November) in 2002, whereas the latest end of growing period was recorded as 7 SMW (12-18 February) in 1985 & 1995. The mean length of growing period calculated for this soil was 209 ± 36 days with a CV of 17.2%.

(*iv*) *Block level variability* : In Darbhanga block, mean length of growing periods calculated were 130, 166 and 183 days for coarse, medium and fine textured soils respectively. In Hayaghat block, the mean LGPs for coarse, medium and fine textured soils were 143, 182 and 207 days respectively. The values of mean LGP in Jale block were 130, 172 and 198 days for coarse, medium and fine textured soils respectively. When LGP in coarse textured soil across these blocks was considered, the highest duration (143 days) was recorded in Hayaghat block and almost similar value was observed for other two blocks. For medium textured soil, the highest LGP (182 days) was observed in Hayghat block and the lowest of 166 days in Darbhanga block. In case of fine textured soil, the highest LGP was calculated as 207 days in Hayaghat block and the lowest of 186 days in Darbhanga block. However, when all soil textures were considered together, Darbhanga, Hayaghat and Jale blocks

TABLE 2

Length of growing period (days) based on moisture adequacy index (Im_a) in Darbhanga district

Year	Coarse textured soil			Medium textured soil			Fine textured soil		
	Start (week)	End (week)	LGP (days)	Start (week)	End (week)	LGP (days)	Start (week)	End (week)	LGP (days)
1980	22	42	147	22	48	189	22	49	196
1981	23	44	154	23	46	168	23	48	182
1982	24	45	154	24	46	161	24	52	203
1983	24	43	140	24	49	182	19	50	224
1984	22	42	147	19	47	203	19	4	266
1985	23	45	161	19	2	252	19	7	287
1986	24	45	154	24	1	210	24	5	238
1987	23	44	154	22	50	203	22	2	231
1988	22	41	140	22	45	168	22	48	189
1989	21	43	161	21	49	203	21	1	231
1990	25	43	133	25	47	161	25	3	217
1991	24	41	126	24	45	154	24	47	168
1992	26	43	126	26	47	154	26	49	168
1993	21	42	154	21	46	182	21	49	203
1994	27	41	105	27	45	133	27	47	147
1995	24	40	119	24	6	245	24	7	252
1996	23	43	147	23	48	182	23	3	231
1997	22	41	140	22	45	168	22	51	210
1998	25	45	147	25	49	175	25	52	196
1999	24	45	154	24	52	203	24	5	238
2000	21	44	168	21	49	203	21	1	231
2001	25	43	133	25	49	175	25	5	231
2002	22	39	126	22	43	154	22	45	168
2003	23	47	175	23	52	210	23	6	252
2004	21	43	161	21	47	189	21	51	217
2005	25	40	112	25	43	133	25	43	133
2006	26	43	126	26	47	154	23	51	203
2007	18	45	196	18	51	238	18	4	273
2008	24	43	140	24	47	168	24	50	189
2009	26	42	119	26	46	147	26	49	168
2010	25	42	126	25	45	147	25	47	161
2011	25	42	126	25	47	161	25	2	210
2012	25	44	140	25	49	175	25	52	196
Mean			143			180			209
SD (±)			19			30			36
CV (%)			13.3			16.7			17.2

recorded an average LGP of 161, 177 and 167 days respectively indicating significant variability across different blocks. This calls for micro level crop management practices for proactive monsoon management and developing contingency crop planning to suit different rainfall patterns under changing climatic condition as suggested by Swaminathan (2005).

3.4. *Variability in LGP and profile soil moisture*

The variability of LGP in coarse, medium and fine textured soils in Darbhanga district revealed that growing period is showing decreasing trend in all types of soils in the district (Fig. 2). The rate of decrease in coarse textured soil was almost a day per year during the study period. The lowest decrease was recorded in fine textured soil perhaps due to higher organic matter content and higher fine pores. The variation in average soil moisture content per meter soil depth in coarse, medium and fine textured soils indicated that during *rabi* season, crop growth in coarse textured soil under rainfed condition was not feasible due to poor status of soil moisture regime (Fig. 4) However, in medium and fine textured soils, there was possibility of having good soil moisture per meter soil depth during *rabi* season indicating possibility of growing rainfed *rabi* crops successfully in these soils.

3.5. *Soil moisture content vis-à-vis AWHC and rainfall*

The March of weekly soil moisture content as a function of available water holding capacity and rainfall has been illustrated in Fig. 5, which revealed that in coarse textured soil, water availability in terms of greater than 50% AWHC prevailing during the period

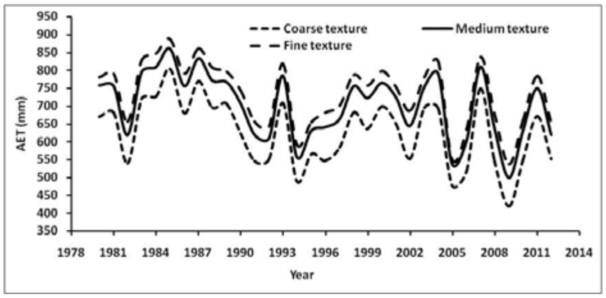


Fig. 1. Actual evapotranspiration (AET) from coarse, medium and fine textured soils in Darbhanga district

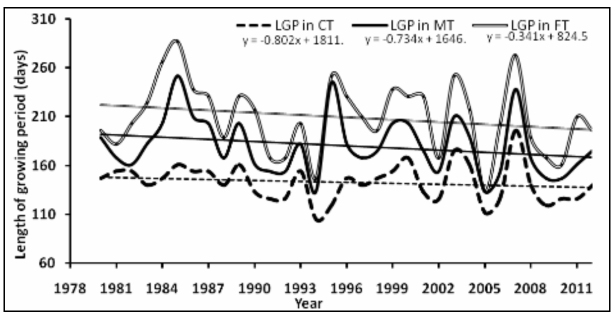
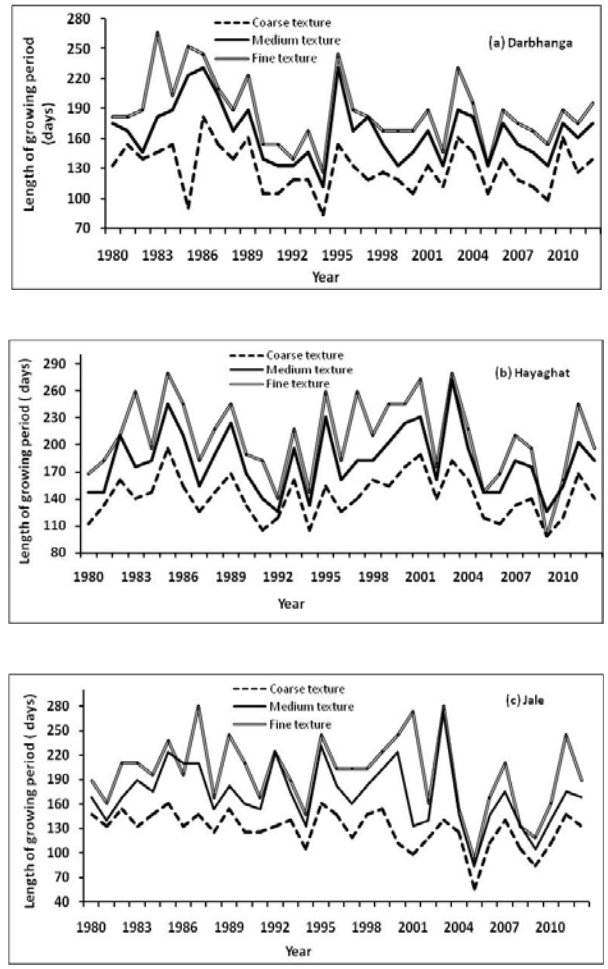


Fig. 2. Variability in LGP in coarse textured (CT), medium textured (MT) and fine textured (FT) soils in Darbhanga district

from 29-44 SMW (16 July-4 November) could be useful for potential productivity evaluation under rainfed condition. The total weekly rainfall during the corresponding period was 667.1 mm. In case of medium textured soil, the water availability period in terms of soil moisture greater than 50 % of AWHC prevailed during 27-44 SMW (2 July - 4 November), with total rainfall receipt of 818.5 mm. When fine textured soil was considered, it was observed that water availability period with soil moisture ≥ 50% of AWHC was found to occur from 27 to 45 SMW (2 July - 11 November) with the receipt of 820 mm rainfall during this period. As the rainfall increased, the length of growing period was found to be extended. Similar variation was also noticed when AWHC values were found to differ due to difference in soil texture. The fine textured soil exhibited the longest water availability period followed by medium and coarse textured soils. Thus, it was evident that quantum of moisture storage in soil profile and its subsequent availability for crop production are dependent upon soil texture and rainfall pattern. Such information on soil moisture availability as influenced by rainfall and AWHC values of soils could help the planners for selection of suitable crops and cropping sequences through efficient utilization of such natural resources for sustainable rainfed crop production.



Figs. 3(a-c). Variability in length of growing period in (a) Darbhanga, (b) Hayaghat and (c) Jale blocks of Darbhanga district

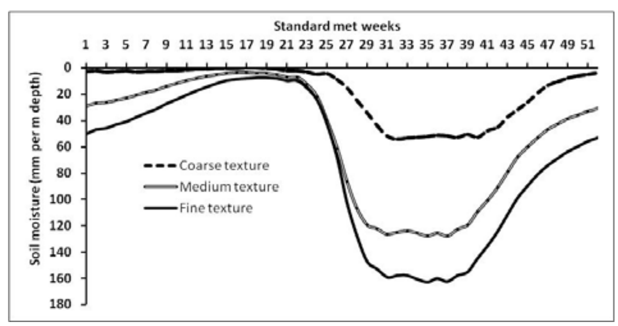


Fig. 4. Variation in average soil moisture per meter depth in coarse, medium and fine textured soils in Darbhanga district

3.6. *Moisture availability index*

According to Hargreaves' moisture availability index (MAI), water availability periods in Darbhanga district at 50 and 75% probability with MAI ≥ 0.34 (moderately deficient period) was found to occur from 23 to 40 SMW

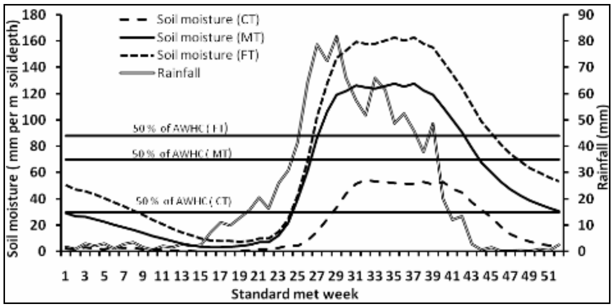


Fig. 5. Soil moisture content as a function of available water holding capacity (AWHC) of soil and rainfall in coarse textured (CT), medium textured (MT) and fine textured (FT) soils in Darbhanga district

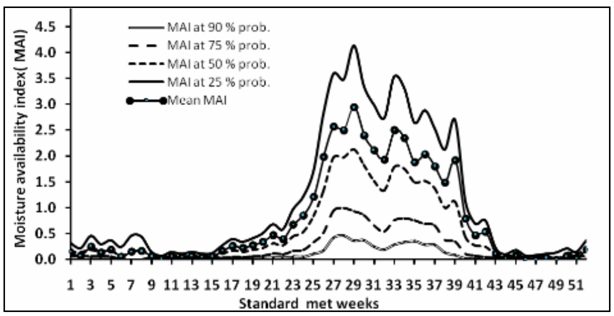


Fig. 6. Moisture availability indices at different probability levels in Darbhanga district

(4 June - 7 October) and from 26 to 38 SMW (25 June - 23 September), respectively (Fig. 6). MAI $\geq$0.75 prevailed during 23 to 42 (4 June - 21 October), 28 to 39 (9 July - 30 September) and 27 to 35 SMW (2 July - 2 September) at 25, 50 and 75% probability levels, respectively Water availability period with adequate moisture (MAI $\geq$ 1.00) at 50% probability level prevailed during 26 to 39 SMW (25 June-30 September). However at 75% probability, period with adequate moisture was not available, although weeks with values of MAI close to 1.00 were observed. If an MAI of 1.00 in a week is considered as sowing week, sowing/transplanting of rice could be undertaken in 26 SMW (25 June-1 July) at 50% probability level.

3.7. *Crop planning*

Length of growing periods estimated for coarse, medium and fine textured soils through water balance approach could be of immense help for crop planning under rainfed condition because of its utility in selection of crops or a variety under a crop in accordance with the duration of water availability period. The results indicated that adoption of double cropping under rainfed condition could be feasible in fine textured soil. Mono cropping with rice or maize in coarse textured soil, and inter and mixed cropping in medium textured soil are suggested in the district. Emphasis should be given for selection of appropriate short duration varieties for making the sequential cropping during *kharif* and *rabi* seasons more successful. As compared to pigeon pea as sole crop, upland rice and maize are of shorter duration in *kharif* season and the choice of improved short duration varieties of the subsequent crops in the *rabi* season is required to ensure the successful sequential cropping. However, pigeon pea is a potential component crop of the intercropping systems (Singh *et al.*, 1981). Short duration varieties of *rabi* oil seeds and pulses could be grown in medium and fine textured soils with greater success after the harvest of *kharif* crops. Selection of crops should be in conformity with the water holding capacity of soil. Drought caused lesser reduction in yield of *kharif* season crops on loamy soil than on sandy soil. Of the cropping sequences tested maize followed by wheat gave higher yield under rainfed condition (Verma *et al.*, 1978). Bhatia *et al.* (1980) observed that residual effects of soil moisture storage of different *kharif* crops at the times of their harvest differed from one another significantly and influenced the yield of subsequent *rabi* crops more significantly because of better moisture conservation. Intercropping pigeon pea sown in 50 cm rows with one row of maize or turmeric followed by green gram in the summer season with supplemental irrigation has been proved to be remunerative practice. Experiment conducted at ICRISAT, Hyderabad indicated that intercropping combinations have a potential for better use of moisture when compared with sole cropping due to complementary rooting pattern (ICRISAT, 1980). For effective soil and water resource utilization leading to increased and sustainable productivity evaluation, the following cropping systems are suggested.

(*i*) For using LGP of 180-209 days in medium and fine textured soils in medium and low lands, growing of medium duration rice varieties (*Rajendra Bhagwati, Rajendra Suwasni, Prabhat, Rajshree*) during 26 to 41 SMW (25 June - 14 October) followed by wheat/lentil/ mustard with provision of two irrigations at crown root initiation stage of wheat and flowering stage of wheat, lentil and mustard is suggested.

(*ii*) In case of LGP of 180-209 days in medium and fine textured soils in upland, pigeon pea + maize as intercropping sown during 5-15 June followed by green gram during 11-20 SMW (12 March - 20 May) with provision for pre-sowing irrigation and one irrigation at flowering phase is suggested. In place of maize, the cultivation of turmeric can be more remunerative component in the cropping system.

(*iii*) For utilization of LGP of 143-180 days in coarse and medium textured soils, growing of short duration rice varieties (*Prabhat, Dhanlaxmi, Richhariya, Saroj*) during

27-39 SMW (2 July- 30 September) followed by rapeseed and mustard during 42 to 5 SMW (15 October - 4 February) period is recommended for up and medium lands with provision of one irrigation at flowering stage of the crop.

(*iv*) To ensure efficient utilization of LGP of 180-209 days in lowland, the cultivation of low land rice (*Rajendra sweta, Santosh, Rajshree, Rajendra Mansuri, Satyam, Kishori*) during 26-46 SMW (25 June-18 November) followed by wheat/ late mustard (*Rajendra anukul, Rajendra suflam, Rajendra rai pichheti*) during 48-12 SMW (26 November-25 March) is recommended with provision of two supplemental irrigations at crown root initiation stage of wheat and flowering stage of mustard and wheat.

4. Conclusions

There was a wide variation in the length of rainfed crop growing period in various soils and across different blocks of the district. Accordingly efficient cropping pattern, crops and variety under a crop should be selected by matching with LGP for various soils in the district for achieving higher production under rainfed condition. When the MAI value of 1.00 in a week is considered, sowing/transplanting of rice could be undertaken in 26 SMW (25 June - 1 July) at 50% probability level. The results presented in the paper suggest that evaluation of agroclimatic resources at micro level is vital to ensure sustainable and profitable crop production. In order to make efficient use of residual soil moisture left in the profile after late harvesting of lowland rice, relay cropping needs to be introduced as a second crop for overcoming the problem of land preparation and taking advantage of high amount of residual soil moisture for germination and seedling establishment.

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