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Assessing climatic risk in terms of water availability to the crops in drought prone tract of Bihar

ABDUS SATTAR* and S.A. KHAN[1]

Agrometeorology Division, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar-848 125

[1]Department of Agril. Meteorology & Physics, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal-741252

Email: sattar.met@gmail.com

ABSTRACT

An agroclimatic study was conducted to assess the climatic risks in fitting of rainfed crops based on weekly probabilistic values of Moisture Adequacy Index, (MAI) which is the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET). MAI was estimated at 50 and 75 per cent probability levels, compared to water demand of crops at different phases of growth and thereby to identify appropriate planting schedules for maize and rice based cropping systems in coarse, medium and fine textured soils in different districts under drought prone region (Zone IIIB) of Bihar. The AET was calculated by climatic water balance method using historical weather data. The results revealed that the crops grown in coarse textured soil had to endure greater water stress of different magnitudes at different phases of crop growth than those in medium and fine textured soils. During *kharif* season, maize could be successfully grown without water stress at any phases of growth across various districts and soils. Although adoption of crops during *rabi* season becomes risky, toria could be fitted in the cropping sequence for this drought prone region in fine textured soil. Results emanated from the study were of practical implication for field application and for breeding appropriate varieties matching with water availability period. The identification of water stress during different phenological phases of crops at varying risk levels could be useful for scheduling of irrigation.

Key words: Water balance, climatic risk, moisture adequacy index, crop planning

Rainfed agro-ecosystem plays a pivotal role in Indian agriculture (Venkateswarlu and Prasad, 2012). Fulfilling water demand of crops is one important aspect for achieving potential productivity under rainfed condition. As several risks are involved in rainfed agriculture, it is necessary to slice down the climatic risks in crop production to achieve desired crop yield. Hence, correct evaluation of water availability and also water stress during different phonological stages is an important pre-requisite for crop planning under rainfed condition. The assessment of agro climatic potential and climatic risk at micro level needs urgent attention for resource allocation and management of rainfed agricultural system more efficiently. The evaluation of climatic risks in fitting of crops, based on probabilities of water availability in terms of the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET), compared to demand of crops has been recognized as a rational approach of practical utility to identify appropriate crops under rainfed condition in a region (Ramana Rao *et al.,* 1979a). The ratio AET/PET which indicates the rate at which water is supplied to the crop compared to its demand has been considered as an index of water availability to crops grown under rained condition (Ramana Rao *et al.,* 1979a). Of all the agro climatic zones of Bihar, Zone IIIB, which comes under 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. In this paper, it has been attempted to assess climatic risks associated with rainfed crop production under water stressed environment and thereby to suggest suitable crops and cropping sequence in South Bihar Alluvial Plains (Zone IIIB) of Bihar for sustainable rainfed crop production based on moisture adequacy index.

MATERIALS AND METHODS

Climatic risks for fitting of rainfed crops during *kharif* and *rabi* seasons were assessed by employing the probabilistic values of AET/PET, *i.e.* index of moisture adequacy (I_{ma}), estimated at 50 and 75 per cent probability levels on weekly basis. The weekly values of I_{ma} was worked out through water balance method of Thornthwaite and Mather (1955) using historical weekly rainfall, normal weekly PET and available water holding capacity (AWC) of coarse, medium and fine textured soils (Table 1). PET was calculated using PET Calculator software (V 3.0) developed by Central Research Institute for Dryland Agriculture, ICAR, Hyderabad (Bapuji Rao *et al.,* 2011). Monthly PET data were converted into weekly total values by interpolation method as followed by Ramana Rao *et al.* (1979a). AWC of soil was estimated considering the layer wise soil textural classes up to one meter soil depth for each soil series. As reported by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Indian Council of Agricultural Research (ICAR), Nagpur, all soil series falling under three selected districts *viz.* Gaya, Jahanabad and Patna were considered to calculate the water holding capacity for coarse-, medium- and fine-textured soils of individual district following the procedure of Saxton and Rawls (2006). AWC per meter depth was calculated as the difference between field capacity and permanent wilting point.

The ratio AET/PET has been used as an index of crop water availability and for assessing the climatic risk associated with growing of rainfed crops in a region (Ramana Rao *et al.,* 1979a; Dey, 2008). The most important *kharif* and *rabi* crops grown under rainfed condition have been considered for this analysis in coarse, medium and fine textured soils over different districts in south Bihar alluvial plains. Rice and maize during *kharif* season, and toria, yellow sarson and lentil during *rabi* season have been considered for this study. The optimal requirements of AET/PET (bar) for different growth stages of transplanted rice, *kharif* maize, toria and lentil have been superimposed in the water availability diagrams in terms of AET/PET (line) estimated at 50 and 75 per cent probability levels. The optimum water requirements in terms of AET/PET for vegetative, reproductive and maturity stages of transplanted rice were considered as 1.0, 1.0 and 0.75, respectively (Doorenbos and Pruitt, 1977; Patel *et al.*, 1986). For rainfed crops such as *kharif* maize, toria, yellow sarson and lentil, the optimum water requirement values for seedling, vegetative, reproductive and maturity stages were taken as 0.33, 0.50, 0.75 and 0.33, respectively (Ramana Rao *et al.,* 1979a). Fitting of medium and short-duration varieties of rice in the cropping system has been considered. Different possible crop sequences under coarse-, medium- and fine-textured soils were considered and based on the risks in water availability, the best fit crop and the best fit crop sequence have been identified. Ideal transplanting time of rice crop was considered one week after that week when 200 mm rainfall was accumulated at 50 per cent probability level (Dey, 2008). The sowing of *kharif* maize was considered in a week when 20 mm rainfall in a week was recorded at 50 per cent probability level (Ramana Rao *et al.,* 1979a).

RESULTS AND DISCUSSION

Water availability risks for crops under coarse-textured soil

Water availability diagrams presented in Fig.1 revealed that *kharif* maize holds immense production potential in coarse textured soil since it faces no moisture stress at any growth phases. The available length of growing period (LGP) varied from 129 (±23) to 134 days ((±18) [Table 1], thereby indicating the possibility of adopting mono-cropping under rainfed condition in coarse textured soil. However, due to poor availability of AET/PET values during *rabi* season at both 50 and 75 probability levels, lentil/toria/yellow sarson could not be included in the crop sequence as rainfed crop. Short duration rice encounters water stress in all districts during *kharif* season. However, the level of moisture stress was found to be the highest in Jahanabad district (Fig. 1). The succeeding toria crop encounters various degrees of moisture stress at different growth phases, except at seedling stage. The reproductive stage of the crop was found to experience severe stress considering optimum moisture adequacy index. Patel *et al.* (1986) assessed agricultural drought at various growth phases of rainfed crops at Raipur based on AET/PET.

Water availability risks for crops under medium-textured soil

The moisture scenario becomes better under medium textured soil with availability of higher AE/PET values and longer growing period (Fig. 2 & Table 1). The LGP was found to vary from 157 (±28) to 169 (±26) days in this soil across three selected districts. The water availability diagram (Fig. 2) revealed that although *kharif* maize could perform well, succeeding *rabi* crops like lentil, yellow sarson and toria still had to endure varying level of moisture stress, with greater stress being experienced during reproductive phase. The minimum moisture requirement (AET/PET>0.33) of the succeeding *rabi* crops (lentil, yellow sarson and toria) was satisfied during reproductive phase in terms of AET/PET values at 50 per cent probability level. Considering short duration rice and toria sequence in medium textured soil, *kharif* rice in Jahanabad district faces greater moisture stress than Patna and Gaya districts (Fig. 2). The AET/PET requirements of toria for its all growing phases, except reproductive period, were nearly fulfilled at 50 per cent probability level and to a considerable degree at 75 per cent probability level. However at reproductive phase, water requirement was satisfied up to a level of 40 to 50 per cent at 50 per cent probability level. At 75 per cent probability level, the AET was satisfied above 25 percent of PET. Krishnan *et al.* (1980) defined moderate drought when AET/PET ratio was less than 0.50 and equals to or more than 0.25 (0.50>AET/PET≥0.25), severe drought when AET/PET ratio was less than 0.25 (AET/PET<0.25) and drought free growing period when AET/PET ratio was equals to or greater than 0.50 (AET/PET≥0.50).

Table 1: Names of rain gauge stations, rainfall data availability, average water holding capacity of soils along with average annual rainfall, potential evapotranspiration (PET) and length of growing period

Districts	Rain-gauge Stations	Data availability (years)	Available water holding capacity (mm per m depth of soil)			Average annual rainfall (mm)	Annual PET (mm)	Length of growing period (days) based on moisture adequacy index (I_{ma})			
			CT	MT	FT			SA	CT	MT	FT
Gaya	Gaya, Atri Sherghati	1959-2013	58	132	165	997.0	1685.8	Mean	128.7	157.2	178.9
								S.D. ±	23.1	27.8	35.6
								C.V. (%)	17.9	17.7	19.9
Jahanabad	Jahanabad, Makdampur, Kako	1984-2013	64	143	170	891.8	1508.0	Mean	129.7	168.0	184.6
								S.D. ±	15.9	27.1	31.3
								C.V. (%)	12.2	16.1	17.0
Patna	Barh, Paliganj, Patna Sadar	1964-2012	65	139	172	1032.3	1487.8	Mean	134.1	168.8	190.1
								S. D. ±	17.8	26.0	31.0
								C.V.(%)	13.3	15.4	16.3

CT: coarse textured soil, MT: medium textured soil, FT: fine textured soil

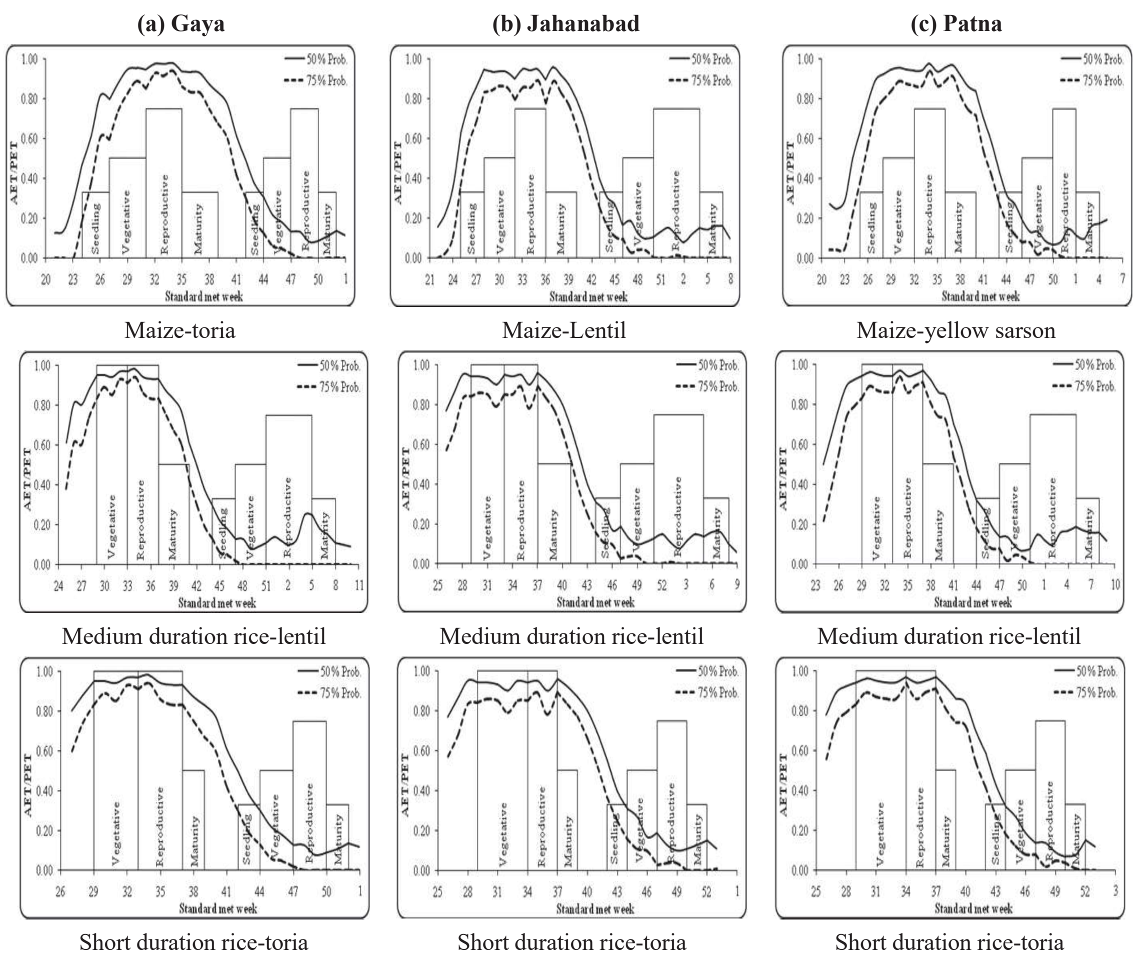

Fig. 1: Risks in crop water availability based on AET/PET during *kharif* and *rabi* seasons in (a) Gaya (b) Jahanabad and (c) Patna districts under coarse-textured soil

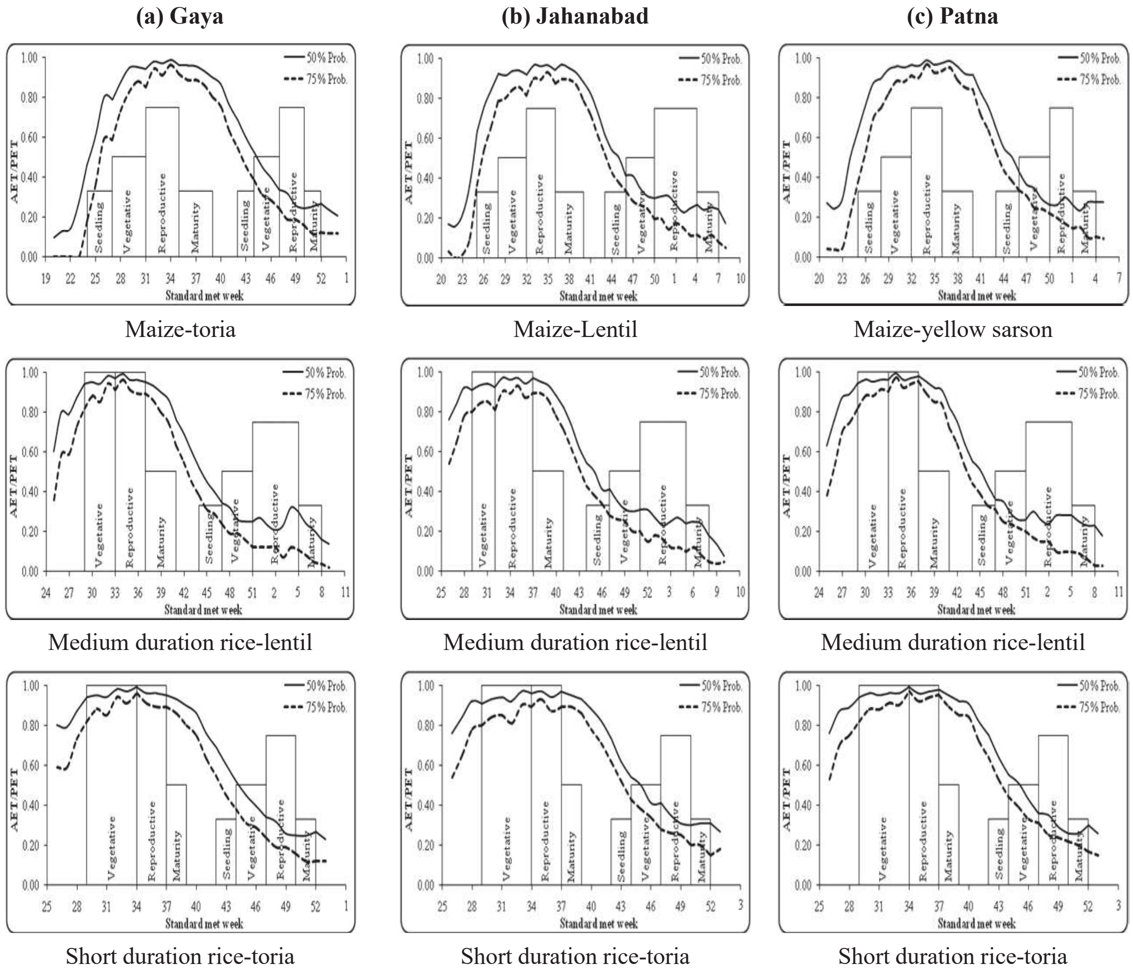

Fig. 2: Risks in crop water availability based on AET/PET during *kharif* and *rabi* seasons in (a) Gaya (b) Jahanabad and (c) Patna districts under medium-textured soil

Water availability risks for crops under fine-textured soil

The prospect of growing maize crop in *kharif* season followed by lentil/toria/yellow sarson in *rabi* season was observed to be brighter in this type of soil with availability of higher amount of moisture during different growth phases of crops. The LGP in this soil ranged from 179(±36) to 190(±31) days [Table 1]. The water requirement for different growth phases (except reproductive phase) of the succeeding *rabi* crop was available up to a satisfactory level at 50 per cent probability level and to a large extent at 75 per cent probability level (Fig.3). At reproductive phase of *rabi* crop, about 50 per cent of water requirement was met at 50 per cent probability level. Short duration rice in this soil too experiences water stress to a large extent at vegetative phase. However, during reproductive phase, the degree of water stress becomes narrower when compared to optimum crop water requirement (AET/PET=1.00). Although, water stress was still persisting in fine textured soil during reproductive period, toria could be fitted well in the crop sequence. Moreover, with the longest LGP available in this soil, longer duration *rabi* crops (lentil and yellow sarson) other than toria could be fitted in the cropping sequence with provision one irrigation during reproductive phase. Hence, short duration rice/maize and toria appears to be the promising crop sequence under rainfed condition in this zone. However, it would be a better option to grow maize in place of rice, considering lower AET/PET values in this dry agro climatic zone.

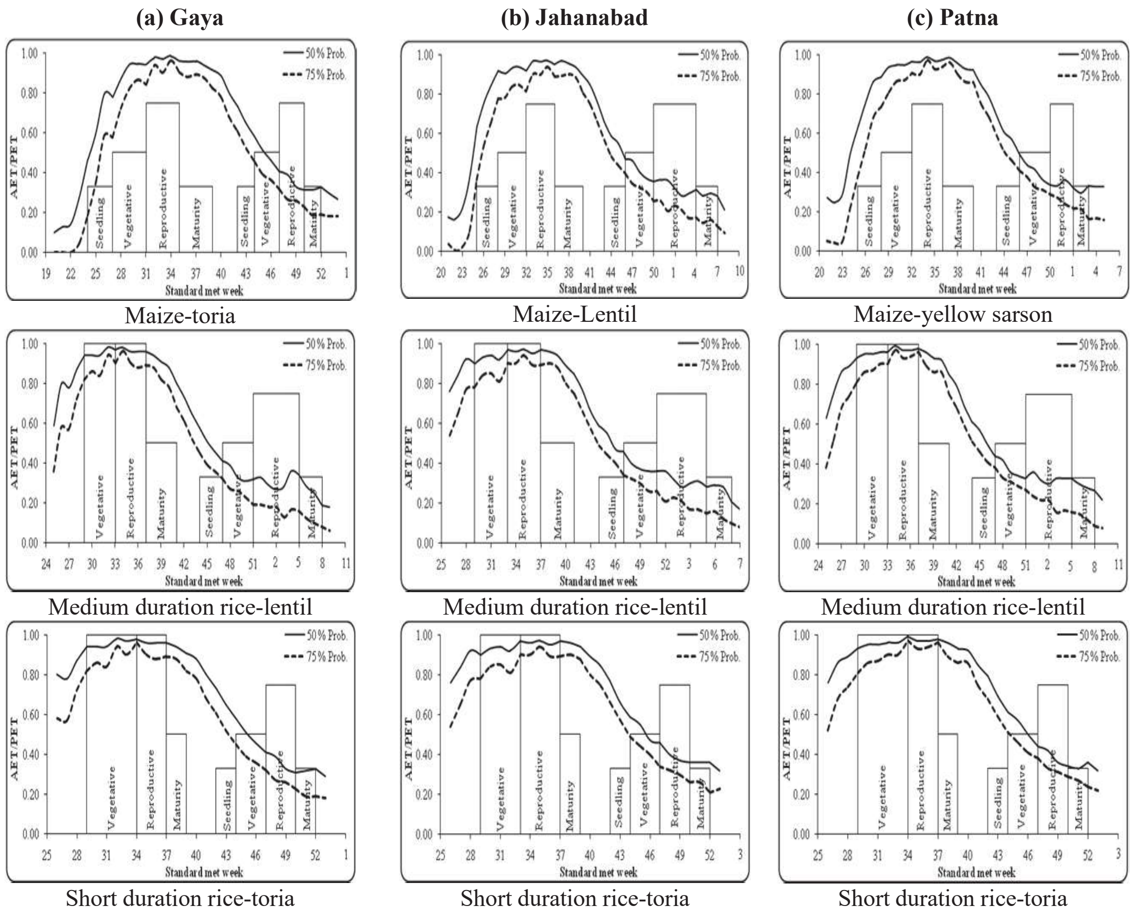

Fig. 3: Risks in crop water availability based on AET/PET during *kharif* and *rabi* seasons in (a) Gaya (b) Jahanabad and (c) Patna districts under fine-textured soil

Climatic risk vs. crop prospect

Lentil and yellow sarson undergo water stress in all the soils under study. Lentil, yellow sarson and toria confront with severe drought in coarse-textured soil and moderate drought when grown in medium- and fine-textured soils at different risk levels *viz*. 50 and 75 percent levels. In coarse textured soil, except maize during *kharif* season, all other crops had to face moisture stress. As all the growth phases of maize undergo drought free period (AET/PET ratio $\geq$0.50), maize appears to be the most suitable *kharif* crop under rainfed condition. The seedling stage of toria crop also escaped water stress in medium and fine textured soils at both 50 and 75 per cent probability levels. However, subsequent toria crop was found to experience water stress during vegetative, reproductive and maturity phases with the maximum stress being observed during reproductive stage. Toria could be fitted successfully in the cropping sequence in fine textured soil. For *rabi* crops, the maximum water stress was observed during reproductive phase. Lentil/yellow sarson could be successfully grown with provision of one (reproductive phase) or two (vegetative and reproductive phases) irrigations in medium and fine textured soils. Ramana Rao *et al.* (1979b) estimated the probabilities of AET/PET ratio for identifying suitable *kharif* and *rabi* crops for different soils of the Gulbarga region of Karnataka. With increase in duration of previous *kharif* crops, the effective growing period for subsequent *rabi* crops was shortened and they were subjected to drought of greater intensity and periodicity. Hence, farmers should grow crop varieties according to length of water availability periods in their areas, which would help produce at potential rate and reduce the chances of crop failure due to moisture stress, leading to agricultural sustainability and food security in the vulnerable rainfed agro-ecosystem.

CONCLUSIONS

The risks assessed through water availability diagrams provide a clear picture of water availability vis-a-vis water need of crops under the drought prone region of Bihar. Accordingly, crops and crop sequences based on water availability could be prioritized in order to avoid critical water stress on crop growth. The potential yield of maize could be achieved with good agronomic practices during *kharif* season under rainfed condition instead of rice. In this dry zone (Zone IIIB), toria could be successfully grown in fine textured soil, which is the dominant soil of the region. The study would be useful in scheduling irrigation at different growth phases of crops most vulnerable to water stress.

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