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Rainfall Probability and Tailoring Agriculture to Match it

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Variations in the timing and amount of precipitation are generally the key factors influencing agricultural production probabilities in semi-arid tropics. Methods for quantification of rainfall in 'agronomically relevant' terms could assist in agricultural development planning and transfer of technology. Several methods have been discussed and the utility of using rainfall probability estimates in relation to potential evapotranspiration is highlighted. An agroclimatic classification of semi-arid dry farming tracts of India using the moisture availability index has been presented. The use of water balance approach in providing reliable estimates of probabilities of water deficits by accounting for soil-moisture variations occurring at different phenological stages of crops over the growing season is illustrated with suitable examples.

Key Words: Rainfall probabilities, Potential evapotranspiration, Moisture availability index, Water balance, Dry farming tracts

Introduction

Plant growth in the tropics is influenced by a variety of physical factors including temperature, radiation, wind and humidity. In many cases, however, the intensity and duration of rains in relation to the soil and crop characteristics at a given location determine the success or failure of agriculture. Since the annual rainfall in the semi-arid tropics comes in a short period of 3-4 months during the year and since soil moisture storage is limited, the crops are under continuous stress in the dry season following the rainy season and intermittantly during the rainless periods even in the rainy season. Also the uniformly high temperatures and the relatively high evaporation during the rainy season place the crops under a high demand for water. Efforts have therefore been made to evaluate and screen "agronomically relevant" methodologies for quantifying rainfall distribution (timing, amount and duration) over the crop growing season.

Quantification of Moisture Adequacy

General average monthly, seasonal and annual rainfall based on long term weather records are used for assessing the precipitation characteristics and length of the humid season.

Methodologies suggested by several workers (Thornthwaite 1948, Troll 1965, and Cocheme & Franquin 1976) that involve comparisons between average rainfall and evapotranspiration can be used to arrive at conclusions regarding moisture availability to crops. Thornthwaite (1948) placed emphasis on the climatic factors that affect plant growth through the growing season. Moisture index relates the available rainfall to potential evapotranspiration. By assuming a level of soil-moisture storage, this method makes it possible to trace the availability of water for plants from month to month. The application of Thornthwaite's approach to the tropics offers some difficulties. The estimates of potential evapotranspiration were developed from the relationship between temperature and water losses from moist, vegetative surfaces in the USA. In the tropics where the frequency of dry seasons is more, Thornthwaite's estimates of potential evapotranspiration were found to underestimate water losses. Also maximum soil moisture storage values vary among the tropical soils; often the values exceed the threshold value of 100 mm assumed for the Thornthwaite's method.

Troll (1965) defined humid months as those in which mean rainfall exceeds potential evapotranspiration and delineated the tropics into different climates based on the length of the humid months. Virmani et al. (1978) showed that Troll's methodology adopted as per his procedure does not provide an agronomically relevant description of the semi-arid tropics and needs suitable modifications.

Based on the ratios of precipitation to potential evapotranspiration, Cocheme and Franquin (1967) defined the water availability period in the crop growing season. Apart from the rainfall, the available water in the root zone (i.e., sum of rainfall and soil moisture storage) was also compared with PE for different ranges of rainfall, PE ratios and crop water availability calendars were prepared for the seeding, emergence, growth and maturation stages.

In all the above methods the problems associated with large interannual variability have been recognised. World meteorological organisation in 1971 published frequency groups of rainfall based on 1931–1960 rainfall data.

Hargreaves (1971) developed a "moisture availability index" (MAI) which is a measure of the adequacy of precipitation in supplying crop water needs. MAI is a ratio of PD/PE where PE is the potential evapotranspiration. This approach involves the computation of dependable precipitation (PD) which requires calculation of specified probabilities. For most cases, he defined PD at the 75% probability level of the expected rainfall. Hargreaves hypothesised that semi-arid areas are regions suitable for the production of crops requiring a 3- to 4-month growing period.

Use of monthly averages to describe seasonal rainfall regimes is often not sufficiently accurate; at certain times in the crop growing season, the presence or absence of water is not critical, and indications of variability over shorter time periods are of great importance. Many agricultural operations revolve around the probability of receiving a suitable amount of rainfall. Farm scale operational planning often requires decision-making with respect to resources, manpower needs, available work days, cropping schemes and several other factors. A comprehensive idea regarding the probability of rainfall is essential in view of the economic implications of certain weather sensitive operations.

Robertson (1976) used dry and wet spells analysis by Markov Chain method for defining the rainfall distribution in the monsoonal Malaysian tropical areas. The India Meteorological Department has conducted extensive studies on the statistics of the rainfall distribution in the Indian sub-continent. It has been observed that incomplete gamma distribution fits the short-term rainfall observed in India (Mooley & Crutcher 1968). Sarker et al. (1978) carried out analysis for 87 dry farming locations to evaluate the expected amount of rainfall on weekly basis at several levels of probability.

Virmani et al. (1978) have used a combination approach by using the moisture availability concept of Hargreaves (1975) and the Markov chain probability concept of Robertson (1976). An analysis of weekly rainfall probabilities for Hyderabad region is shown as an example in figure 1. It is evident that Hyderabad has a fairly dependable commencement of rainy cropping season around week No. 25. This situation is amenable to dry seeding in the Vertisols in this region. It is also apparent from this analysis that mid season breaks in the continuity of the rainfall are likely to occur in 4 to 6 years of a 10-year period, on an average. Obviously one would not select a crop cultivar that would be in an active phase of development during this period. Either a sole short-duration crop (which completes most of its life cycle prior to the break in the rainfall) or a long-duration base crop with a short duration intercrop would be best suited for the Hyderabad environment under dryland conditions. Depending on the soil conditions, one could select even determinate or drought-sensitive crops. The wet/wet probabilities of rainfall show that in about 4 out of 10 years, rainfall has a tendency to continue after the normal date of recession. Crops that are sensitive to aberration in weather at maturity should not be selected, particularly in the Vertisols.

It is evident that the analytical approach used above has the advantage of determining the relative moisture adequacies in the rainy and rainless periods. It could also be used for comparison of different locations in terms of dependability of rainfall; such a quantification of the moisture environment based on short-term

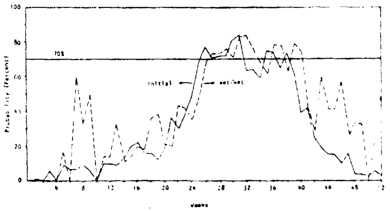

Figure 1 Probabilities of Rainfall (R/PE ≥ 0.33) at Hyderabad (1901–1970 data)

periods can be particularly effective in explaining differences in agricultural climate and crop yield potentialities. It could assist in identifying isoclimes and for the transfer to different climates of farming systems technology (Virmani 1980).

Classification of Dry Farming Tracts of India

Sarker and Biswas (1980) have carried out a detailed agroclimatic classification of the dry farming tracts of India using the MAI concept developed by Hargreaves (1975). They have defined an 'optimum moisture availability index' (OMAI) which is the ratio of assured rainfall at the 50% probability level to the potential evapotranspiration of the same period. It was found that for the purpose of classification, use of weekly MAI at the 50% probability level is equivalent to using biweekly MAI at 60% probability, both in duration and in accumulated rainfall during the period when MAI is more than 0.3. Using the computed OMAI values for weekly periods between 4 June-21 October, dry farming tracts of India have been classified into 4 zones to characterise the relative crop potentialities of each zone (figure 2).

Use of Water Balance Approach

The rainfall probabilities give only an idea of the environmental moisture adequacy for crop growth and could be used as a basis for a comparative study of the agricultural potentialities of locations with similar soils. However, soils of the semi-arid tropics show a great diversity in texture, structure, type of clay, organic matter content and depth. Also it should be remembered that among other things, the precipitation actually entering the soil depends upon the type, surface conditions, and moisture status of the soil. Holmes (1961) showed that in the case of sandy soils, the low moisture holding capacity and the low colloid content permit a rapid removal of much of the soil moisture. The depletion rate remains at a high level almost to the wilting point. For a heavy clay soil on the other hand, the moisture cannot be removed rapidly.

It is possible to calculate the water balance for a given region for any given crop from actual rainfall, evapotranspiration, and soil moisture characteristics over a series of years. This approach provides a reliable estimate of probabilities of water deficits by accounting for soil moisture variations occurring at different phenological stages of crops over the growing season. The use of computers for fast and accurate calculation of water balance using various simulation models has made this task relatively easy. Water balance results find useful application in the determination of the length of the growing season and the optimum sowing date; maximum water availability can be matched for optimal use of available resources. A primary advantage of such an analytical technique is not only that it allows a critical evaluation of the present cropping patterns and projections for new introductions, but also that it would substantially reduce the time and effort required for the selection of suitable varieties and cropping patterns through a process of elimination.

Binswanger et al. (1980) quantified the risk to reliability of rainy and post-rainy season cropping for three typical locations situated in somewhat similar soil-ecological zone of semi-arid India using water balance approaches.

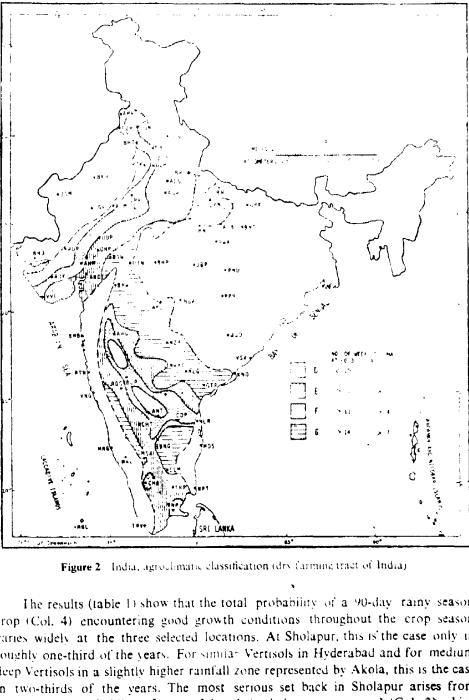

Figure 2 India, agroclimatic classification (dry farming tract of India)

The results (table 1) show that the total probability of a 90-day rainy season crop (Col. 4) encountering good growth conditions throughout the crop season varies widely at the three selected locations. At Sholapur, this is the case only in roughly one-third of the years. For similar Vertisols in Hyderabad and for medium deep Vertisols in a slightly higher rainfall zone represented by Akola, this is the case in two-thirds of the years. The most serious set back in Sholapur arises from a much lower probability of successful and timely 'crop emergence' (Col. 2) which is probable in only two-thirds of the years. However, all subsequent conditional probabilities also show that the crop is at a higher risk in Sholapur than in other two areas every growth stage even after it has completed earlier growth successfully.

Table 1 *Reliability of a 90-day rainy season crop on Vertisols of three areas* (Probability expressed as % years) (After Binswanger et al. 1980)*

Local soil	*Annual rainfall mm*	*Probability of emergence before July 15*	*Probability of seedling survival*	*Probability of good growing conditions throughout*	*Probability of adequate soil moisture for post-rainy season sorghum*	
					After rainy season crop	*After rainy season fallow*
Sholapur—Deep Vertisols	742	65	49	33	60	80
Hyderabad—Deep Vertisols	761	85	76	62	50	82
Akola—Medium deep Vertisols	840	92	80	66	N.A	N.A

*Available water holding capacity of deep Vertisols is assumed at 230 mm and of medium deep Vertisols at 120 mm.

N.A., Not applicable. The water holding capacity is far too low to meet post-rainy season sorghum water needs.

A 33% probability of a favourable soil moisture regime is too low a basis for encouraging rainy season cropping on a normal annual basis. The loss of seed and cultivation expenses in some years and the low returns in other years should almost certainly reduce average profits of any crop to zero or result in losses.

The probabilities of adequate soil moisture for a post-rainy season crop after rainy season fallow (Col. 6) are about 80% at Sholapur, this level of probability exceeds that for good growth conditions for rainy season crop in Hyderabad or Akola (Col. 4). However, if a rainy season crop is taken in Sholapur, the chances of success of the post-rainy season crop on the residual profile moisture are reduced significantly (20%). Not only would consistant rainy season cropping often be unprofitable; it would also probably endanger the probability of success of the more important and relatively stable post-rainy season crop.

Conclusions

The quantification of the rainfall through probabilities and crop available water in the soil over the growing period, when compared with the crop water needs, could yield useful information for evaluating the suitability of crops in a given soil-climate environment. The agroclimatic techniques give an integrated index of rainfall, soil and evapotranspiration. Since it quantifies the crop-growing period and its characteristics in terms of water stress or sufficiency periods, the selection of crop combinations for any specific location becomes feasible. It also permits identification of ecologically similar isoclimes, thus facilitating the transfer of appropriate farming systems technology.

References

Binswanger H P, Virmani S M and Kampen J 1980 Farming systems components for selected areas in India: Evidence from ICRISAT. Research Bulletin-2. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A P India, 40 pp.

Cocheme J and Franquin P 1967 An agroclimatological survey of a semi-arid area in Africa south of the Sahara. Technical Note No. 86, World Meteorological Organization

Hargreaves G H 1971 Precipitation dependability and potential for agricultural production in northeast Brazil. Publication No. 74-D-159, EMBRAPA and Utah State University (USB) 123 pp

———1975 Water requirements manual for irrigated crops and rainfed agriculture. Publication No. 75-D 158, EMBRAPA and Utah State University (USA), 40 pp

Holmes R M 1961 Estimation of soil moisture content using evaporation data, in *Proceedings Hydrology symposium No. 2, Evaporation*, (Toronto : Department of Northern Affairs and National resources, Water Resources Branch)

Mooley D A and Crutcher H L 1968 An application of gamma distribution function to Indian rainfall. ESSA Technical Report EDS 5, U S Department of Commerce, Environmental Data Service, Silver Spring, Md. 47 pp

Robertson G W 1976 Dry and wet spells. UNDP/FAO, Tun Razak Agricultural Research Center Sungh : Tekam, Malaysia, Project Field Report; *Agrometeorology*; **A-6**

Sarker R P, Biswas B C and Khambete N N 1978 Probability analysis of short period rainfall in dry farming tract in India. Scientific Report 78/9. India Meteorological Department, Poona 40 pp

—— and —— 1980 Agroclimatic classification for assessment of crop potential and its application to dry farming tracts of India. Paper presented at Consultants' Meeting on Climate Classification, held at the International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A P India, pp 89-107

Thornthwaite C W 1948 An approach towards a rational classification of climate; *Geographical Review* **38** 55 94

Troll C 1965 Seasonal Climates of the earth; in *World Maps of Climatology* ed. E Rodenwalt and H Jusatz (Berlin : Springer-Verlag) pp 28

Virmani S M 1980 Climatic approach to transfer of farming systems technology in the semi-arid tropics; in *Proceedings of the International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer*, 28 August-1 September 1979, Patancheru, A P India pp. 93-101

———, Sivakumar M V K and Reddy S J 1978 Rainfall probability estimates for selected locations of semi-arid India. Research Report No. 1, ICRISAT, Patancheru, India. 127 pp